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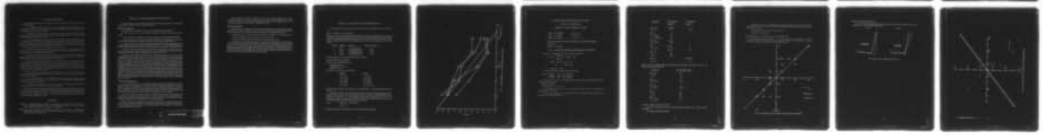

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EMULATION OF AN ADVANCED G-SEAT ON THE ADVANCED SIMULATOR FOR PILOT TRAINING

By

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Wright-Patterson Air Force Base, Ohio 45433

April 1978
Final Report for Period 20 December 1975 – 7 April 1977

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An in-house effort was initiated to investigate simple G-seat hardware configurations for the purpose of developing a low-cost approach to G-cuing simulation in flight trainers. The G-seat is a motion and force simulation device which replaces the aircraft seat in a flying training simulator; by virtue of its geometry and software drive, it imparts tactile cues to the seated pilot which are representative of the seat forces normally experienced in actual flight. The Air Force and Navy are procuring G-seats for both training and fighter simulators. These G-seats are research devices, and have up to 32 actuators distributed in the seat pan, backrest, and lap belt. These seats can be improved upon with respect to simpler geometry, fewer active components, and more effective drive algorithms. This report describes a research effort on the Air Force's Advanced Simulator for Pilot Training (ASPT) which

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culminated in the emulation of an advanced approach to G-seat simulation. The development of the software, the design of the advanced seat components, the implementation of the advanced design on the ASPT, and the results of the study are presented.

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SUMMARY

Problem

The objective of this study was to investigate simpler G-seat hardware configurations for the purpose of describing a low-cost approach to G-cuing for future flight simulators.

Approach

The approach to demonstrating a low-cost G-seat was (a) to develop an algorithm to drive a multi-celled G-seat such that groups of seat pan and backrest plates would be driven as a unit, (b) to simulate on an existing G-seat an advanced low-cost G-cuing system with fewer components and a simpler drive philosophy, and (c) to subjectively evaluate the modified seat using the researchers as subjects.

Results

An algorithm was developed to drive a multi-celled G-seat such that simpler seat geometries could be investigated. The algorithm was implemented and an advanced G-seat was simulated on the Advanced Simulator for Pilot Training (ASPT). The simulated seat embodied the principal components of an Advanced Low-Cost G-cuing System (ALCOGS) G-seat being developed by the Air Force Human Resources Laboratory (AFHRL), Advanced Systems Division at Wright-Patterson AFB, Ohio. The ALCOGS utilizes rubber seat cushion and backrest bladders overlaying passive thigh wedges and tuberosity blocks and metal seat pan and backrest plates. Four researches served roles as subjects throughout the study. The subjects were asked to estimate G levels and directions of cues based upon prior experience with the bladders and G-seat.

The simulated seat, simple in design, demonstrated a more integrated, continuous sensation of a seat structure than does the first generation ASPT-like seat. The advanced approach appears to provide more accurate G level direction perception than does the first generation seat. Contoured seat pan and backrest forms which were evaluated tended to increase the perceived sensation of area of contact. The evaluations provided the researchers with an early analysis of the ALCOGS.

Conclusions

An advanced G-cuing system has been simulated on the ASPT G-seat. The advanced seat represents a second generation development of G-cuing simulation hardware. The evaluations performed on the ASPT and described in this report demonstrated a simpler and more effective approach to G-seat simulation. The success of these evaluations lead the way for further G-seat simulation efforts.

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PREFACE

This study was initiated by the Advanced Systems Division, Air Force Human Resources Laboratory (AFHRL), Wright-Patterson AFB, Ohio, under project 6114, Simulation Techniques for Air Force Training, Mr. Don R. Gum Project Scientist, and task 611419, Motion and Force Simulation. The research was performed at the Advanced Systems Division and the Flying Training Division, AFHRL, with Mr. William B. Albery as principal investigator. Mr. Danny C. McGuire developed the software, described herein, and helped implement the research on the advanced simulator. The effort was conducted during the period from 20 December 1975 through 7 April 1977.

The authors wish to acknowledge the guidance and support of Mr. Gerald Kron, Singer Co. – Link Division, Binghamton, New York, who led the research described herein and whose trip reports serve as the basis for the conclusions reached; Mr. Jeffrey Kleinwaks, Singer-Link, who participated in the research at the Flying Training Division; Dr. Larry Young, MIT, whose background in human perception of motion and orientation was most beneficial to the study; Mr. Lynn Thompson, of the AFHRL Flying Training Division, whose overall knowledge of the Advanced Simulator for Pilot Training streamlined the research; and Ms. Cheryl Gilliland, who typed the draft report.

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EMULATION OF AN ADVANCED G-SEAT ON THE ADVANCED SIMULATOR FOR PILOT TRAINING

I. INTRODUCTION

The Air Force and Navy are currently pursuing flying training simulator programs for such tactical aircraft as the F–4E, F–4J, F–14, A–10, and F–16. What each of these programs has in common is that a G-seat is either being developed or planned for the simulator. The Navy is currently procuring eight (8) G-seats for the F–4J and F–14 simulators. The Air Force is currently on contract for procurement of sixteen (16) Link-built G-seat systems to be retrofitted into the F–4E trainers in this country and Europe. Six Air Force G-seats are currently in the field. These seats (Figure 1) are discussed in the literature (Kron, 1975) and in Appendix A.

The purpose of this report is to document G-seat research performed by the Advanced Systems (AS) Division of the Air Force Human Resources Laboratory, Wright-Patterson AFB, Ohio, on the Advanced Simulator for Pilot Training at Williams AFB, Arizona. The original Advanced Simulator for Pilot Training (ASPT) G-seat was modified to (a) investigate simpler G-seat geometries and drive schemes, and (b) simulate the principal elements of the Advanced Low Cost G-cuing System, or ALCOGS (Figure 2). It was anticipated that these studies on the versatile ASPT seat would give investigators insight into simpler hardware configurations and alternate G-cuing devices for the flying training environment. The studies described herein were conducted on the ASPT in October 1976 and January 1977.

II. SOFTWARE PREPARATION FOR G-SEAT CONFIGURATION RESEARCH

Objective and Approach

The objective of this study was to investigate simpler G-seat hardware configurations for the purpose of describing a low-cost approach to G-cuing for future flight simulators.

The approach to demonstrating a low-cost G-seat was (a) to develop an algorithm to drive a multi-celled G-seat such that groups of seat pan and backrest plates would be driven as a unit, (b) to simulate on an existing G-seat an advanced low-cost G-cuing system with fewer components and a simpler drive philosophy, and (c) to subjectively evaluate the modified seat using the researchers as subjects.

Initial preparation for this work was begun in December 1975. Based on reading and studying the literature (Kron, 1975), computer program listings, and manuals, a computer program was developed to "connect" (through software) selected groups of G-seat cells to act as a single unit. Thus a seat with fewer, larger cells could be simulated by these connections. For example, the present 16 small seat pan cells (Figure 1) may be used to simulate a four-large-cells device by "connecting" the four cells nearest each corner.

In order to make the program as flexible and useful as possible, it was desirable that the connection scheme be easily changed through a cathode ray tube (CRT) real-time keyboard without any need for software reprogramming. In addition, once a connection is made, the type of connection excursion calculation should also be variable (i.e., average, minimize, maximize, or deactivate cell excursions within the connections). The software logic (to satisfy these requirements) was developed at the Advanced Systems Division and used a connection input array of dimensions 8 by 16 (maximum of 8 connections; maximum of 16 cells within any connection) and method input array of 4 by 8 (any of 4 methods for the possible 8 connections).

Parameters to be input from the keyboard must be referenced in a section of the computer software called DATAPOOL. DATAPOOL is a common storage area reserved for program variables used by more

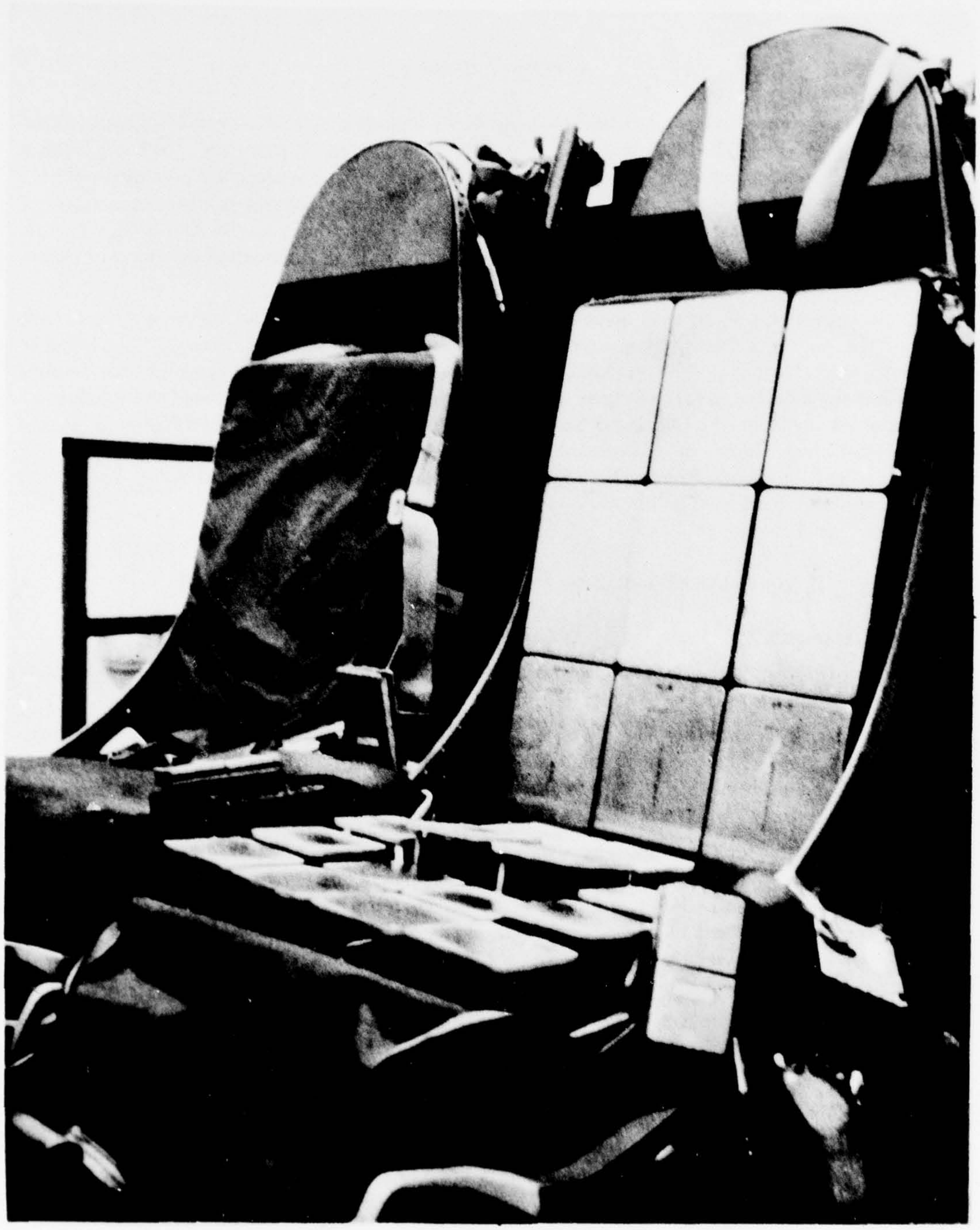

Figure 1. ASPT G-seat, uncovered.

Figure 2. **Advanced low-cost G-cuing system, ALCOGS** *(artist's concept).*

than one routine and/or those to be used in conjunction with the CRT capabilities. The variables need not be listed in the same order for each routine. Since DATAPOOL vacancy was scarce and the previous inputs would have required 160 words of computer core, the input scheme and consequently the entire logic flow had to be revised. The connection input scheme developed and tested successfully consisted of four numbers of four digits each. Each digit represents a cell and the value of the digit is the indication of within which connection the cell is located. A similar code was developed for the method inputs. The logic was tested on a Wang computer system before installation on ASPT, which is standard procedure for new software. This new input approach required additional software logic to break down the input codes, but reduced the DATAPOOL requirements from 160 to only 6. Only the seat pan was used, as it was assumed that the backrest cells could be similarly connected if necessary or desired.

Inputs

Cell connections are established through a 4-dimensional array named ASCNCODE. This input is composed of four numbers of four digits each (dimensions 1 to 4). Each number represents a row of cells, each digit represents a cell and the value of the digit indicates in which connection the cell is to be located.

The best way to visualize the input scheme is to (a) draw a sketch of the seat to be simulated, (b) superimpose the 16-cell seat, and (c) assign the same connection number to each cell which fits within a cell of the seat to be simulated. For example, a seat to be simulated is composed of 4 cells. Steps (1) through (3) are illustrated in Figure 3. Thus the inputs would be:

ASCNCODE (1) = 1122 (represents 1st row of cells)
ASCNCODE (2) = 1122 (represents 2nd row of cells)
ASCNCODE (3) = 3344 (represents 3rd row of cells)
ASCNCODE (4) = 3344 (represents 4th row of cells)

Another example, simulating a seat with translating plane, but stationary tuberosity cells (10, 11) is illustrated in Figure 3. Inputs become:

ASCNCODE (1) = 1111
ASCNCODE (2) = 1111
ASCNCODE (3) = 1221
ASCNCODE (4) = 1111

Once a connection of cells is made, there needs to be a method of calculating the desired excursion of all cells within the connection since each may have a different calculated command from the original program logic. In trying to develop all possibilities, it seemed most logical to average all calculated commands (from original program logic) and replace the commands with the average of all cells within the "connection." Additional options are deactivation (neutral 0.0 excursion command), maximization (all cells get the highest command within the connection) and minimization (lowest command for all cells within the connection).

Cell connection methods are established through a two-dimensional array named ASMECODE. This input is composed of two numbers of four digits each (dimensions 1 to 2). The first number represents the first four connections and the second number represents connections 5 through 8 (maximum of eight connections). The value of the digit indicates how the excursion of the cells within each connection is to be calculated (Table 1).

Table 1. **Cell Connection Code**

Value of Digit	Method of Calculation
0	No connection
1	Average excursions w/i connection
2	Deactivate excursions w/i connection
3	Minimize excursions w/i connection to that of least cell excursion
4	Maximize excursions w/i connection to that of greatest cell excursion

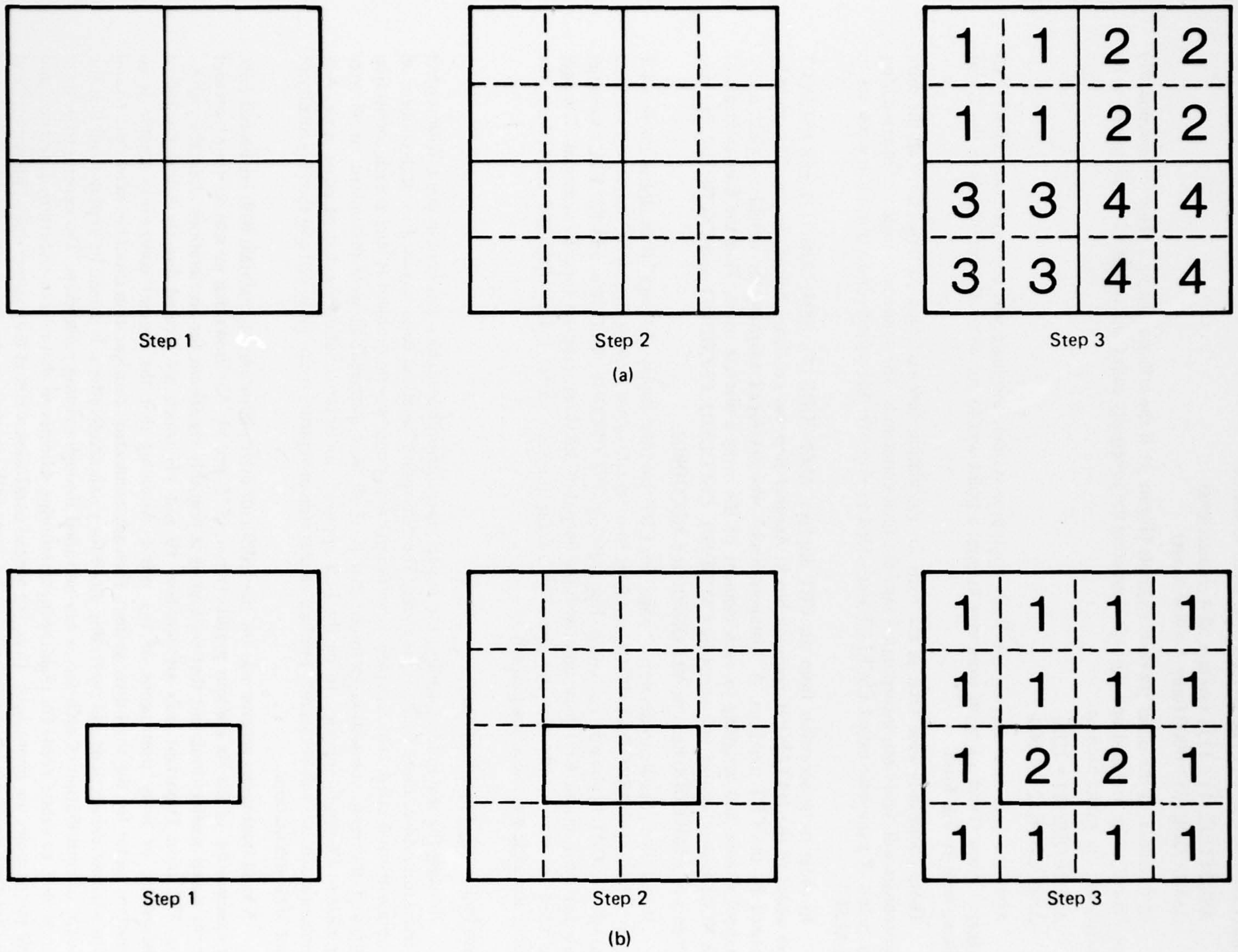

Figure 3. **ASPT G-seat cell connections.**

For example, in reference to the previous four-cell device example (Figure 3), if the four cells in each connection were desired to be averaged, the input would be:

ASMECODE (1) = 1111 (average all 4 connections)
ASMECODE (2) = 0000 (only 4 connections)

In reference to the other previous example (Figure 3), if the cells simulating a plane (connection #1) were desired to be averaged and the cells simulating the tuberosity cells (connection #2) were desired to be deactivated, the inputs become:

ASMECODE (1) = 1200
ASMECODE (2) = 0000

After the successful test on the Wang computer system, the logic was converted into FORTRAN language. From G-seat program computer listings, a point was found where the commands to the G-seat bellows were in final form.

These commands were used as the basis for calculating new excursion patterns, since all the drive philosophies will have been incorporated into the final commands. The connection logic was inserted after this point. A parameter called ESCELCT was added to skip over the added connection logic when set to ".FALSE.".

In order to be accessible from the CRT displays, ASCNCODE (4), ASMECODE (2), and ESCELCT were added to the DATAPOOL common block. Another step was necessary before the variables could be accessed by the CRT monitors. A "datapool deck" was developed assigning the variables a place in the datapool storage and assigning to each element of the array a discrete name. Thus the four elements of ASCNCODE also become referenced by CNCODE01, CNCODE02, CNCODE03, and CNCODE04. The two elements of ASMECODE become MECODE01 and MECODE02.

It was then possible to develop a "page" for CRT real-time display. A "page" is an alphanumeric CRT display of selected ASPT DATAPOOL variables from which values may be displayed, entered or changed through the CRT keyboard (Faconti & Epps, 1975). The CNCODE, MECODE, and ESCELCT variables were displayed on one CRT page along with the output of the G-seat program for cell excursions. The page was used to conveniently test the operation of the program. After a few trials and corrections, the connection logic was executing properly.

Drive Philosophy Considerations

In using the real-time capability, the impact upon drive philosophies was kept in mind. With respect to translation drive, there were no problems. The "maximize" method code was used for each connection to obtain the full effect. For seat plane orientation drives, there was no problem as long as each connection employed the same connection methods; that is, if all were averaged, all were maximized, or all were minimized. Averaging appeared to be the best approach for approximating the desired plane angle. Any connection scheme will necessarily produce greater step increments from cell to cell and thus the quality of plane angle orientation.

A valid contouring scheme was the most difficult drive philosophy to maintain with connected cells. An examination of the six contour profiles (Kron, 1975, pp. 54–55) shows that no seat contour is present for the x-axis accelerations, but that contouring is probably significant for accelerations along the y and z axes. The most important cells are numbers 10 and 11, which are located directly below the ischial tuberosities, or bony protrusions of the pelvis. Assuming that the present contouring scheme is an important factor for the total drive system, then any connection configuration should employ cells 10 and 11 in separate connections and preferably alone for y axis accelerations. It should be kept in mind that the amount of contribution of each factor can be varied through existing parameters. The experimenter must also be alert to subtle needs for maintaining contouring schemes so that relative excursion differences and drive philosophies are maintained. Thus, the general conclusion was that the existing drive philosophies and logic need not be affected if the connections are made with attention to the above considerations.

The development of this software has made it possible to use the ASPT seat to investigate simpler seat geometries. However, before simpler seat configuration research was begun, a need arose for a different type of seat simulation. The Advanced Systems Division began the development of an advanced G-seat in June 1976 and found the software described in this report to be most beneficial to the study of the advanced seat on the ASPT. The implementation of this software and the subsequent simulation of the advanced seat is the subject of Section III of this report.

III. ALCOGS CONFIGURATION SIMULATION ON ASPT

Background

In recent years simulation subsystems have become available and successfully used to reinforce the kinesthetic stimuli available from motion systems. It is thought that in addition to a reinforcing role these subsystems provide an enrichment of the sense of kinesthesis by adding their own unique complement of cues to the total cue aggregate. These subsystems have become known as the G-seat, G-suit, and seat shaker subsystems. In June 1976, the Air Force awarded a contract to the Singer Company Link Division to draw these three technologies together into one package called the Advanced Low-Cost G-cuing System (ALCOGS) while simultaneously designing to improve the performance of each subsystem at a reduced cost. Software drive analogies are to be reviewed and updated where possible by information developed since delivery of the first generation G-seat, G-suit, and shaker subsystems. The ALCOGS is to be installed as part of the AFHRL Advanced Systems Division Simulation and Training Advanced Research System (STARS) complex and used for continued research into G-cuing utility.

ALCOGS Seat Pan and Backrest Components

The ALCOGS (Figure 2) employs as seat subassembly items: (a) a hydraulically actuated seat pan cushion subassembly, (b) a hydraulically operated lap belt, (c) a hydraulically actuated backrest cushion subassembly, (d) pneumatic firmness cell pressure and area of contact devices for both seat pan and backrest cushion, (e) total seat frame buffet driven by a separate hydraulic actuator, (f) a pneumatically actuated G-suit, and (g) a passive shoulder harness.

In the case of positive G's or headwards (+Gz) vertical accelerations, the firmness bladder will deflate, thereby increasing the pressure on the buttocks, and particularly the ischial tuberosities, by lowering the subject onto the upper plane. For negative G's or footward accelerations the firmness bladder first will be inflated to the nominal 1G state, and then the upper plane will be translated up vertically to enhance the bladders's onset cue and alter the relative eye position. The roll and lateral cues will be similarly enhanced by selective inflation and deflation of the side-by-side cells.

It should be noted that the interaction of the dual-celled firmness bladder with the raised surfaces located outboard on the upper plane serves to cause these surfaces to contact the flesh of the seated subject's thigh in much the same manner the first generation G-seat active thigh panels (Figure 1) contact the thigh flesh area. According to the area of contact hypothesis, under increased G loads the firmness cells progressively deflate inducing an increase in the buttocks/seat area of contact. The first generation G-seat elevated its thigh panels under like conditions. Similarly for rightwards seat acceleration or roll right wing down, the left firmness bladder is progressively deflated causing increased buttocks/seat area of contact on the left side of the seat. Under similar conditions the first generation G-seat elevated its left thigh panel. The firmness cell approach appeared as if it could yield fairly strong pressure and area of contact stimuli and also displayed strong potential for providing a well integrated, continuous stimuli throughout the buttocks area.

The backrest cushion illustrated in Figure 2 will employ, like the seat pan, the upper/lower plane concept and display the basic capability of moving in three degrees of freedom: (a) tip, which causes the backrest cushion to be rotated about an axis which extends laterally across and in the plane of the backrest cushion; (b) tilt, which causes the backrest cushion to be rotated about an axis in the plane of the backrest cushion and perpendicular to the tip axis; and (c) surge, which causes the backrest cushion to translate in a direction normal to the nominal backrest cushion surface orientation.

In keeping with the belief that area-of-contact stimuli are very significant in the lower backrest during x-axis accelerations and are likely to become more important as seat recline increases in high-G aircraft and the backrest is made more responsive to z-axis acceleration, a radial drive element has been located in each of the lower corners of the back cushion upper plane. It is felt that active elements are needed here to provide the degree of area-of-contact change found beneficial in first-generation G-seat backrest contouring.

The backrest cushion will also employ a firmness bladder; however, it will contain only a single cell as opposed to the dual cell employed in the seat cushion. The backrest firmness bladder will overlay the upper plane and be used to generate pressure variation stimuli in the region of the center of the back. The operation of the backrest firmness cell will be similar to that of the seat pan firmness cells – under thrusting conditions, the cell will deflate so as to permit the pilot's back to be supported on the rigid backrest upper plane.

Need and Objectives for ALCOGS Configuration Simulation

A number of approaches to the problem of providing an ALCOGS have been considered. Many approaches can be rejected out of hand as oversimplifications of safety hazards. However, there are also many concepts compatible with the type of mechanization desired and possibly worthy of development even if they are only partial contributors to the overall G-cuing system.

The selection process was difficult in that each of the concepts has merit and some are not necessarily mutually exclusive with respect to others. In some cases, contending configurations show little difference in potential success.

Although evaluation of existing G-seats is by no means complete, experience reveals that G-seats provide cues by furnishing:

1. A differential pattern of pressures on the buttocks, thighs, and back corresponding to tilting the seat pan and seat back.

2. A variation in the amount of area of the buttocks providing support of the crewman's weight. This variation ranges from concentrating the crewman's weight on his ischial tuberosities, or diffusing his weight over the entire buttocks.

3. Perceived tightness of the seat belt.

The proposed ALCOGS design theoretically provides all these cues/sensations, is applicable to seats of various aircraft simulators, is elegant in its simplicity, and will provide low life cycle costs.

Thus, it was decided that an attempt to simulate the configuration and operation of the ALCOGS through modification of the ASPT G-seat would be appropriate. It was expected that the simulation would provide a preview into what can be expected from the ALCOGS, so that either the proposed ALCOGS design could be validated, or ineffective components identified, and alternatives suggested well in advance of hardware/software development.

Approach to ALCOGS Configuration Simulation

It was initially planned to perform the simulation using the software (discussed in the first half of this report) to connect appropriate cells. However, due to the unique nature of the ALCOGS (plane drive and firmness cells), it became apparent that an adequate simulation could not be performed by only connecting the cells. An alternative approach was developed which employed flat metal plates attached to the ASPT seat. The plates simulated the seat pan and backrest upper planes of the ALCOGS (Figure 2). Wood thigh wedges were attached to the plates to simulate the thigh wedge design of the ALCOGS (Figure 4). Two metal plates were made, one with a cutout to permit excursions of ASPT bellows which would represent active tuberosity elements. The other plate had no cutout and raised blocks were added under the tuberosity areas of increase pressure as the firmness cell deflated.

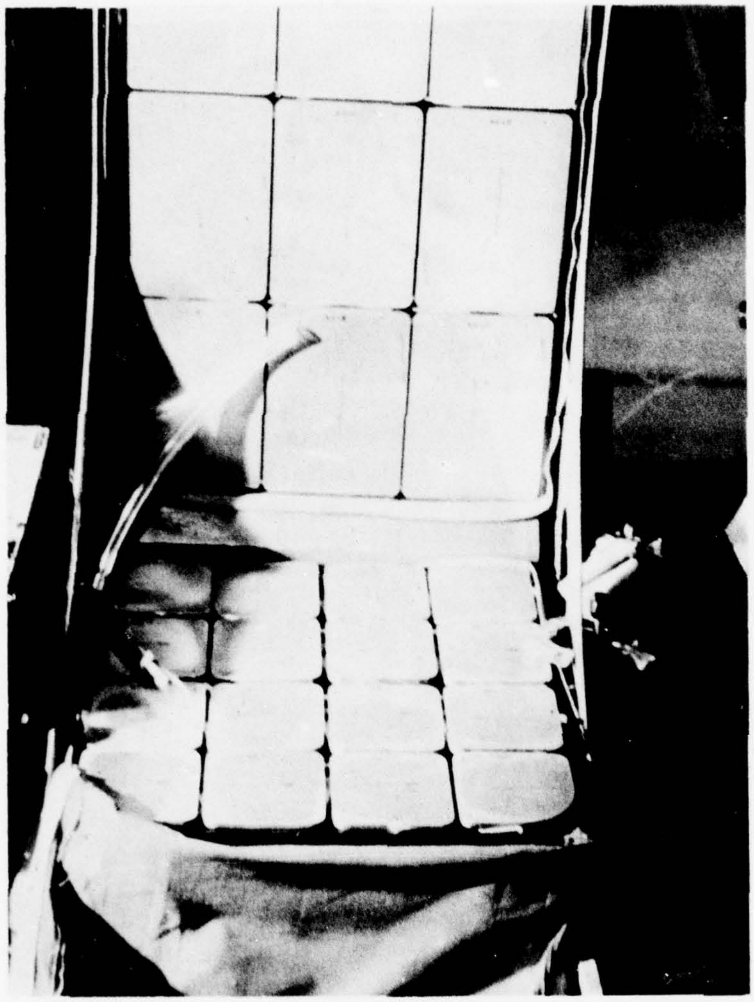

Figure 4. **Front view of exposed ASPT G-seat bellows.**

Firmness cells similar to the ALCOGS proposed firmness cells were provided by Singer-Link for use in the ALCOGS configurations simulation. The firmness cells were attached to the seat pan and backrest plates and lie over the thigh wedges (Figure 5). Thus, many of the major hardware components of the ALCOGS were simulated.

The firmness cells, however, are a relatively new concept with no analogous component in the ASPT G-seat. It was necessary to drive the firmness cell in a logical and valid manner in order to properly simulate the operation of the ALCOGS. Fortunately, since the metal plates were to be overlaid on the ASPT air bellows, the need for many of the ASPT bellows (and all of the ASPT thigh panel cells) was eliminated. The pneumatic hoses connected to the unused air bellows could thus be attached to the firmness cells for inflation or deflation control (Figure 5).

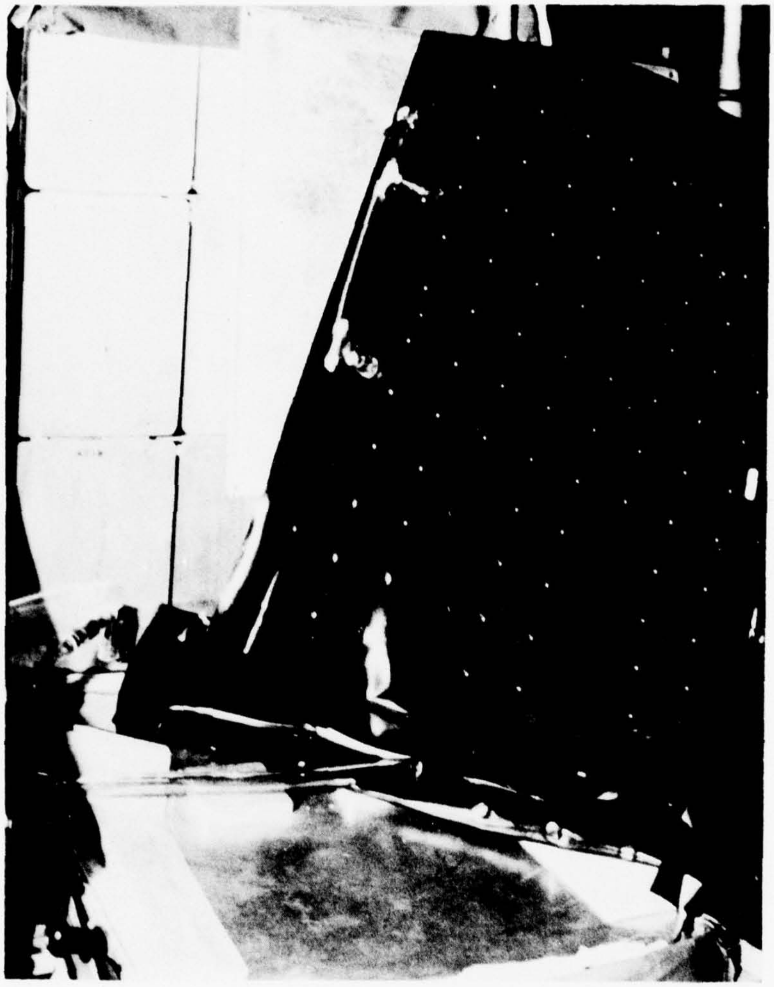

Figure 5. **ALCOGS simulation – metal plate taped over bellows with wooden thigh wedges, tuberosity blocks and firmness cell exposed.**

Software Development for Firmness Cell Control

Appropriate software was required in order to provide control of the inflation of the firmness cells in a logical manner coordinated with the other system components. As a new and unique device, the G-cuing capabilities of the firmness cell were unknown. It could be assumed, however, that the maximum pressure sensation would occur when the firmness cell was near total deflation (ischial tuberosities in full contact with the pressure blocks on the metal plates).

Conversely, the minimum pressure sensation would occur when the buttocks are raised off the metal plates by inflation of the firmness cells. Thus, a relationship between firmness cell inflation and sensed buttock pressure (G-cues) was established by the following methods with a series of subjects:

1. It was assumed that the relationship is continuous with no flexing (i.e., it can be approximated by an equation of second order).

2. The firmness cell was inflated until the subject's buttocks were just off the metal plates and no decrease in sensed pressure was produced by additional inflation (minimum buttock peak pressure).

3. The firmness cell was deflated until a maximum pressure was sensed by the subjects (maximum buttock peak pressure; maximum positive G-simulation).

4. Between these two points, the subject estimated the point midway between the maximum and minimum sensed buttock pressures.

5. A G-cue level was assigned to the maximum pressure sensation and a G-cue level to the minimum pressure sensation.

The general relationship expression is:

$$P = AG^2 + BG + C$$

where G = sensed pressure levels on buttocks (to become commanded G-cues from flight equations)

P = firmness cell inflation pressure corresponding to sensed pressures, G

A, B, C = coefficients determined by analysis of results from steps 1 through 5 above.

If the relationship is linear:

A = zero

B = slope of relationship plot

and C represents pressure required to maintain the normal 1G states as the zero (1G) plot intercept.

If the relationship is non-linear:

A and B are not easily discerned from plots, but may be calculated from a set of data from the previous steps 1 through 5.

C meaning is maintained as the 1G state pressure.

As previously mentioned, the thigh cells pneumatic lines were to be used for controlling firmness cell inflations. The ASPT thigh cells normally react to vertical, longitudinal, and lateral accelerations in a coordinated fashion. The drive philosophies for these excursions are similar to the overall drive philosophy of the firmness cells. Thus it was decided to use the existing software and commanded excursions to the thigh cells as the basic representation of the commanded G levels for the firmness cells. The lateral, rotational, and vertical components of the thigh cell commands would be applied to the seat firmness cells and the longitudinal component would be applied to the backrest. A pneumatic line, from the left thigh cells, was connected to the left firmness cell of the seat. A pneumatic line, from the right thigh cells, was connected to the right firmness cell of the seat. Another thigh cell (31) pneumatic line was used for driving the backrest firmness cell. It was anticipated that the thigh cell software commands would not be directly applicable to firmness cell operation. Therefore, attenuation factors on longitudinal and lateral components were added to the software.

Originally, it was believed that a bias factor on excursions would be appropriate, but subsequent analysis showed that it has no useful function that cannot be performed by the C term in the previous equations. It was deleted in future work to reduce confusion.

ASPT G-Seat Modification

At Williams AFB, Arizona in October 1976, the software was installed and the pressures (delivered to the ASPT G-seat thigh cells) were tested (Figure 6). It was decided to use the pneumatic line pressures of cell 31 as the backrest firmness cell drive, cell 27 pressures for the left half of the seat firmness cell, and cell 29 pressures for the right half of the seat firmness cell. The metal plates fit the seat and backrest well with

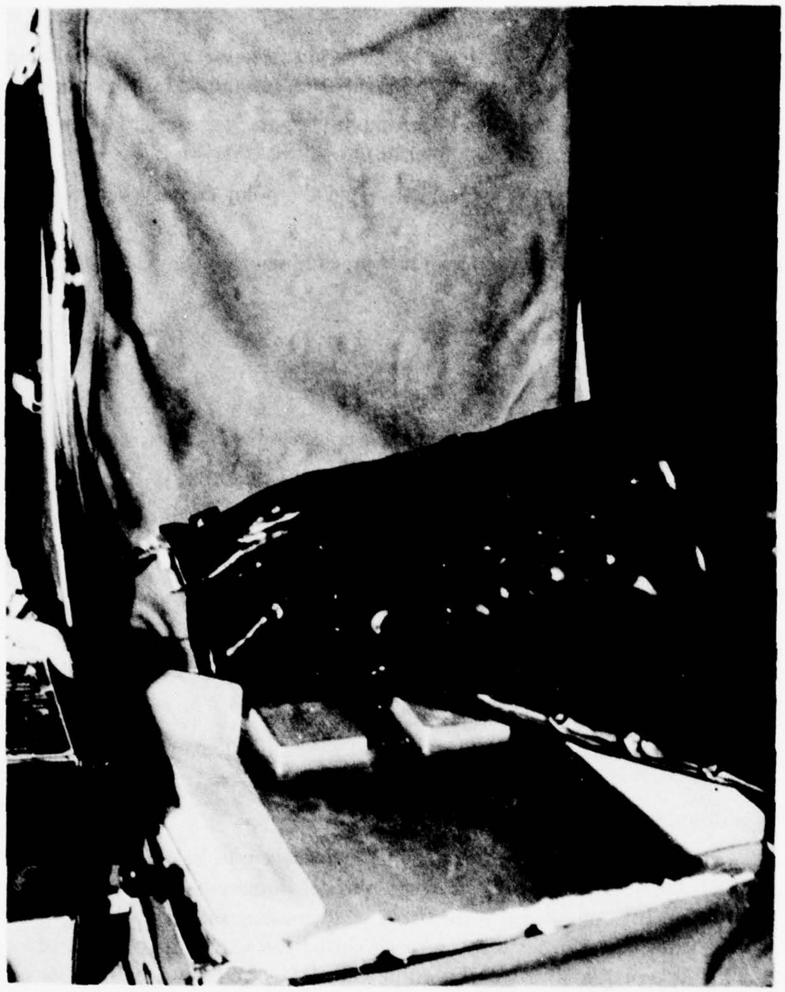

Figure 6. **ALCOGS simulation — seat pan and backrest metal plates and firmness cells.**

the exception that the corners of the seat plates had to be trimmed to avoid any possiblity of tearing the seat's covering material. CRT real-time monitor pages were developed in order to have all needed and convenient parameters displayed and changeable on one or two pages labeled "ALCOGS CONFIGURATION SIMULATION."

It was decided to "gate down" the pressures of the thigh cells so that a 1G level would command a pressure of 1.75 psi. This value had been determined as that needed to maintain slight ischial tuberosity contact with the metal plates from previous firmness cell experimentation at Singer Link and confirmed at AFHRL/ASM, Wright-Patterson AFB (see Appendix B). By adjusting the CONOFLOW valves to 1.75 psi at a normal 1G state, the need for the C term value in the previous equations was eliminated. It was now only necessary to determine the A and/or B coefficients of the relationship between sensed buttock pressures from the firmness cells and thigh cell excursion commands (related directly to G-cue commands). The pressures delivered by the pneumatic lines ranged from 0 to maximum G-cue (corresponding to minimum thigh cell excursion and minimum firmness cell inflation) to 1.75 at the normal 1G state.

The metal plates, thigh wedges, and firmness cells were installed over the ASPT G-seat mosaic cells. A software program change was made to permit G-seat software to be "detached" from dynamic flight inputs such that rotational parameters and specific constant G levels could be input for the x, y, and z axes without "flying" ASPT.

Static Evaluations

The firmness cell cuing capabilities were tested with various subjects using only the firmness cell cues by deactivating the seat and backrest drives (see Appendix B). After being given examples of maximum G, minimum G and other G levels, the subjects were able to distinguish quite well the random G levels input. G level inputs were varied in the x, y, and z axes at first separately and then in combinations of unknown magnitude to the subjects. The directions, sensations, and magnitudes of accelerations seemed correct. The results implied that as a result of gating down the CONOFLOW pressures to 1.75 psi at 1G, the relationship between sensed buttock pressures and thigh cell excursion commands was approximately a straight line with slope of 1 (B = 1, A = 0; a linear relationship). This result also confirmed preliminary testing at Wright-Patterson AFB, OH.

Tests were then repeated with seat and backrest planes active with equally successful results. However, a bias factor was added to backrest firmness cell operation to lower the 1G straight-and-level backrest pressure from 1.75 psi (to approximately 1.25). This biasing seemed to minimize or eliminate a problem of conflicting stimuli (contouring vs. pressure) caused by the overpressurization. It was later discovered that the bias factor would also decrease the range of the firmness cell responses, but in this case it was not to a significant degree.

Drive Philosophy Research

During the testing, a question had arisen as to the propriety of the backrest movement in response to accelerations along the x axis (same drive philosophy as used in the first generation G-seat under thrusting conditions; backrest pivots forward about a lateral line positioned slightly above the top of the backrest). In response, a set of baseline data (Appendix B) was taken with the backrest plane drive unaltered. The data consisted of estimating x-axis acceleration magnitudes and directions when input by an experimenter. A repeat of the tests was made with the backrest plane drive reversed and amplified such that, upon thrusting, the upper part of the backrest tilted aft. The data (Appendix B) confirmed the validity of the baseline (original) drive.

Using the baseline drive with respect to backrest plane directional movement, data (estimations of direction and G magnitude) were taken in baseline amplitude (gain) and double the baseline gain conditions (Appendix B). Again, a return to the baseline gain configuration was made based upon subjective comments.

Dynamic Evaluations

A 15-minute demonstration flight was recorded to compare the first generation ASPT G-seat (cockpit B) to the modified seat (cockpit A). The demo flight exercised the aircraft at high G and rotational rates in all axes, including braking, thrusting, rolling, yawing, negative and high +G maneuvers. The demo was replayed for subjective evaluation with subjects first experiencing the first generation (ASPT) G-seat, then the modified (ALCOGS) seat. Full visual simulation was provided but platform motion was off during these evaluations. The drive configurations were not identical for ALCOGS and ASPT for two reasons:

1. The ALCOGS modified seat employed roll velocity as a drive source; the ASPT seat uses roll acceleration.

2. The computer demo configuration seemed to be overwriting a z axis control parameter affecting (minimizing) the seat pan plane response to z accelerations on the modified seat. This was a permanent change to the software and it was not modified for the demo. Subjective comparisons were recorded and comments related to the above configurations were summarized.

Results and Recommendations

Having experienced the maximum accelerations to which the ALCOGS seat simulation is scaled, subjects are able to report G-level direction accurately nearly 100% of the time. G-level magnitudes with the modified seat are estimated quite well even in multicomponent acceleration conditions.

Pressure sensation on the ALCOGS seat in localized areas is very strong and perhaps too strong. Conversely, area of contact changes are subjectively too limited. A trade off of the increased pressure for an increased area of contact concept was recommended. The first step in this direction was a height reduction or elimination of the passive tuberosity blocks such that only a flat plane remained. The next step was the consideration of a contoured seat pan. In the case of the backrest, consideration was given to a concave plane with the center of the concavity located about one or two inches above the pilot's belt line.

Although not unanimously voiced, a number of subjects felt that the passive raised ramp thigh panels did not provide the magnitude of cue desired and in many cases could barely be felt at all. The thigh ramps (Figure 5) used in this study rise to 3/4-inch height at the outboard edges and the tuberosity blocks were 1/4-inch in height leaving only a 1/2-inch differential. The subjective feeling is that tuberosity blocks tend to hold the body up off the seat pan upper plane and this likely tends to diminish the perception of the presence of the thigh ramps. Elimination of the tuberosity blocks should, therefore, also help to eliminate the thigh ramp problem. However, thigh ramps with outboard elevation in the 1.25- to 1.5-inch region should be tested and will probably be required.

The active thigh panels of the first generation G-seat are definitely perceived and, although there is some argument among the subjects as to whether this is a valid replication of the sensation in the actual aircraft, there appears to be agreement that the thigh panel activity aids in cuing and perception of aircraft acceleration magnitude and direction. The single flight rated subject who experienced both the ASPT and modified seat opined strongly for more outer thigh stimuli than that provided by the modified seat.

It appears to be important to insure that the firmness bladders position the subject (under 1G straight and level conditions) such that the ischial tuberosities and spinal regions are in close proximity to the rigid plane under the firmness bladder. If not, a very confusing cue occurs during the initial phase of firmness bladder exhaust where skeletal structure settles to the plane. The present concept, although not fool-proof, calls for a subject weight bias to automatically make this adjustment from one subject to another.

The differences between CONOFLOW response in pressurization vs. exhaust cycles was detected by most subjects particularly in firmness bladder drive. The CONOFLOW performed above expectations in linearly adjusting pressure in a difficult region (0 – 1 psi). The ability to exhaust lightly loaded areas (upright backrest) was better than expected. Nevertheless, these are unsatisfactory in firmness cell utilization since exhaust to subatmospheric conditions is a necessity.

Only one of the two air inlet passages to each of the seat pan firmness bladder compartments were utilized. Only two of the scheduled four inlets were used in the backrest bladder. At least one subject noted low-pass type response as air "crept into" the bladders. It will probably be necessary to add two additional inlets to each of the seat pan compartments at the forward portion of the compartment. All inlets must be either manifolded into the upper plane underlayment or routed through metal tubing affixed to the underside of the upper plane.

There was not enough time to permit evaluation of all configurations as initially planned (such as active tuberosity drives), but additional research will be conducted after the existing data are analyzed and research needs are established.

Contoured Seat and Motion Consideration

The concept of contoured seat pan and backrest forms was investigated on the ASPT in January 1977. During this session, three specific interests were evaluated:

1. Evaluation of the interaction between the firmness bladder concept when employed in the presence of an active motion system.

2. Evaluation of the firmness bladder concept when the firmness bladder overlays a flat plane which does not contain passive, raised tuberosity blocks.

3. Evaluation of the firmness bladder concept when used with contoured underlayments (Figures 6, 7, & 8).

Several problems plagued this research but the results and conclusions of these evaluations are:

1. There appears to be either a neutral or positive (but not negative) interaction between the ASPT motion system/drive scheme and the firmness bladders (dependent upon which axis is in question).

2. The ALCOGS simulation research in October 1976 indicated excessive pressure sensation available with the 1/4-inch raised tuberosity blocks. This evaluation (January 1977) with no tuberosity blocks indicated that there was a lack of buttocks pressure sensation. The obvious conclusion is that perhaps a thin 1/16- by 1/8-inch block should be employed in the ALCOGS and evaluated before adopting a no-block policy.

3. The contoured seat pan (Figure 8) vastly increased the sensation of area of contact changes but the amount of contour should be less than that employed in this evaluation (or about 1 1/2- by 1 3/4-inches on the seat pan and 3/4-inch on the backrest). Pressure cues are nearly totally lost when such heavy contouring is employed. Continued research with the contoured seat pan and backrest (Figures 9 and 10) elements will be performed at AFHRL/AS with the ALCOGS.

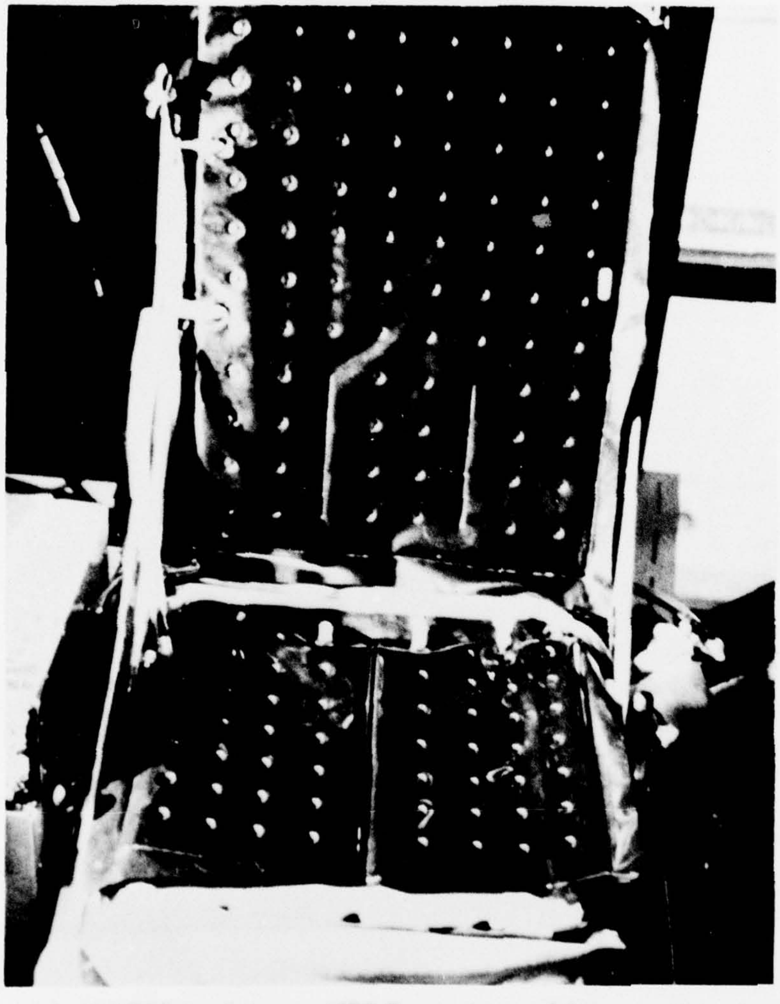

Figure 7. **ALCOGS simulation on ASPT G-seat; plates and firmness cells in place.**

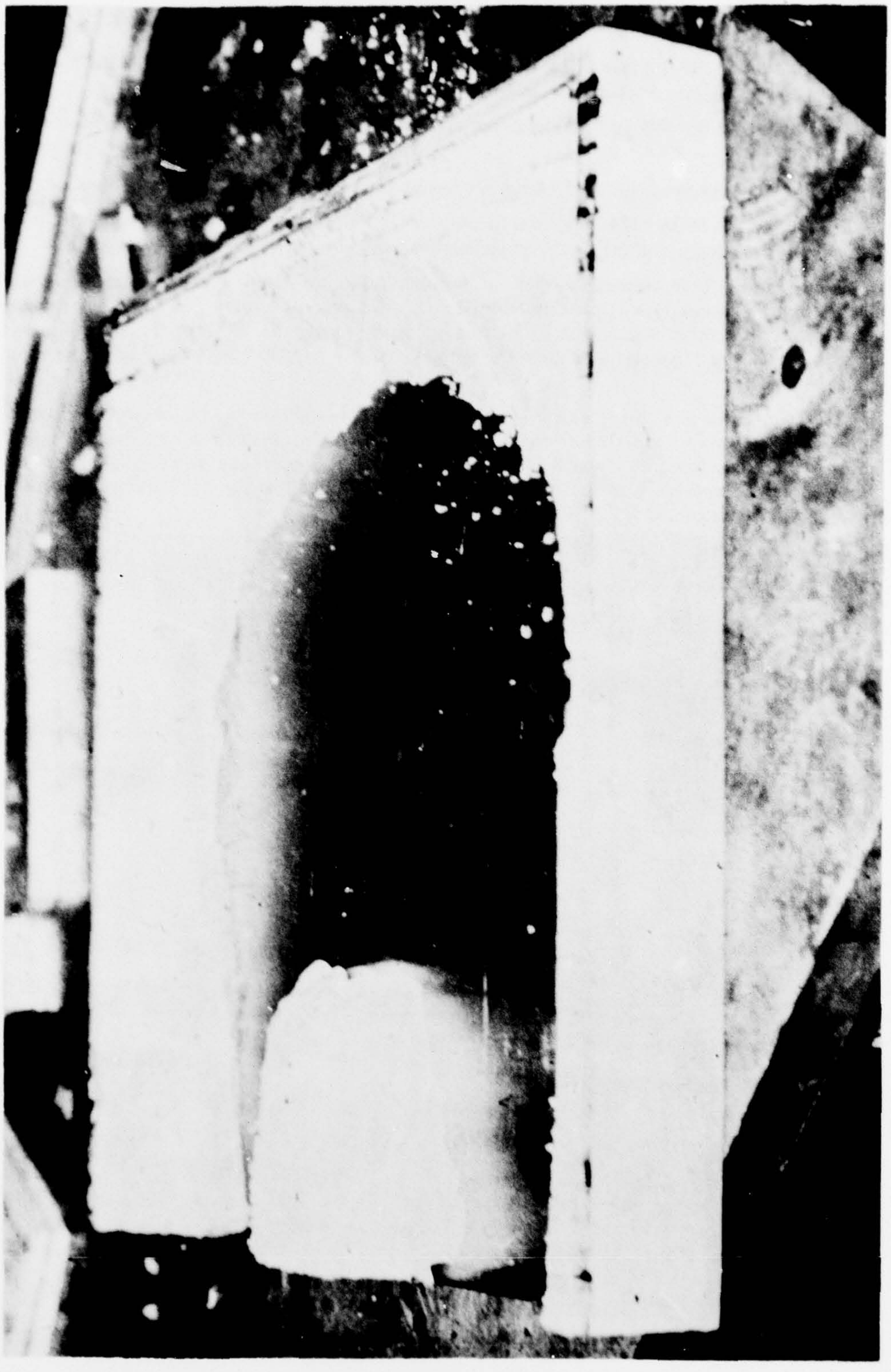

Figure 3. Contoured seat pan

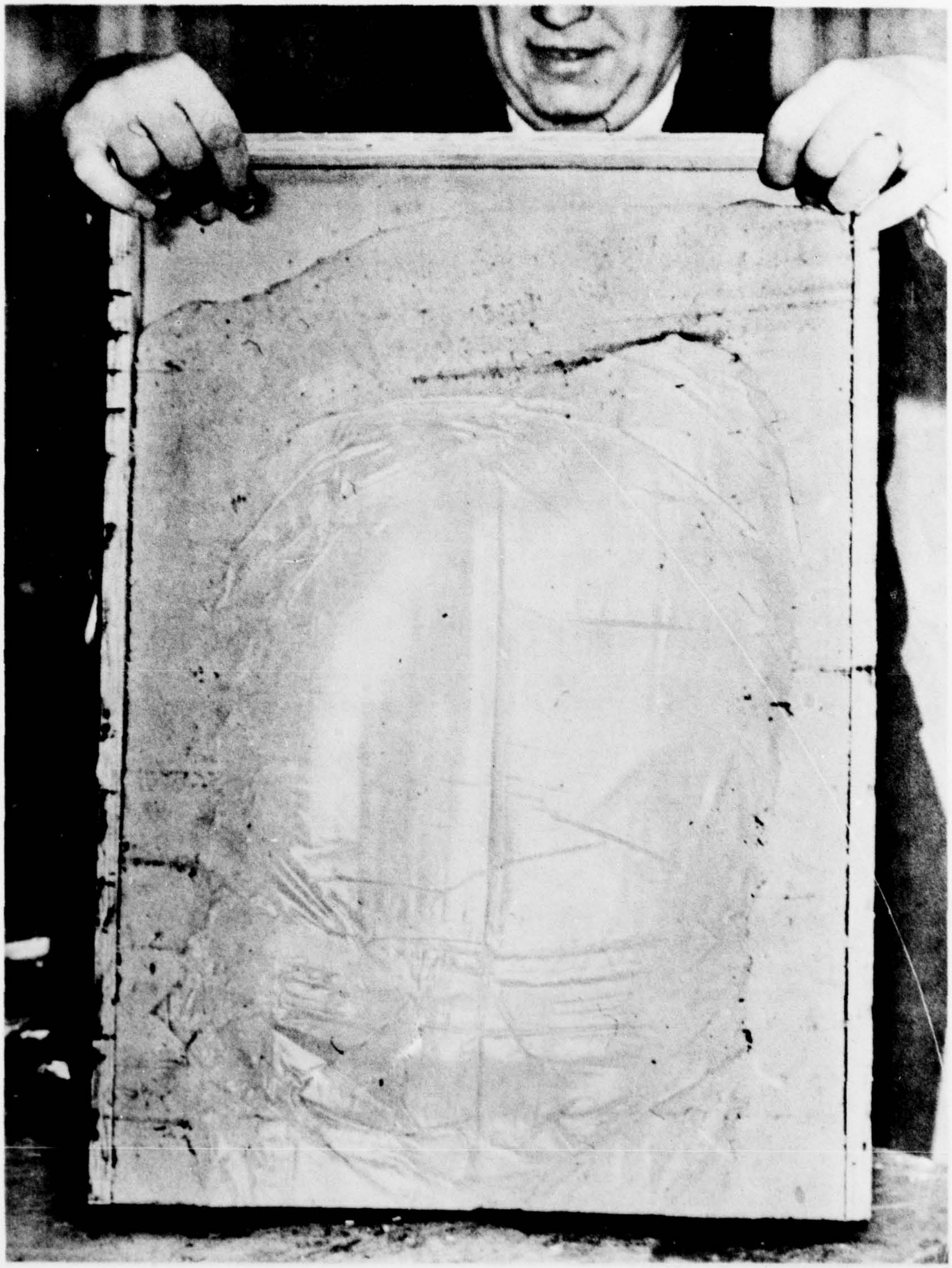

Figure 9. **Contoured backrest – plane view.**

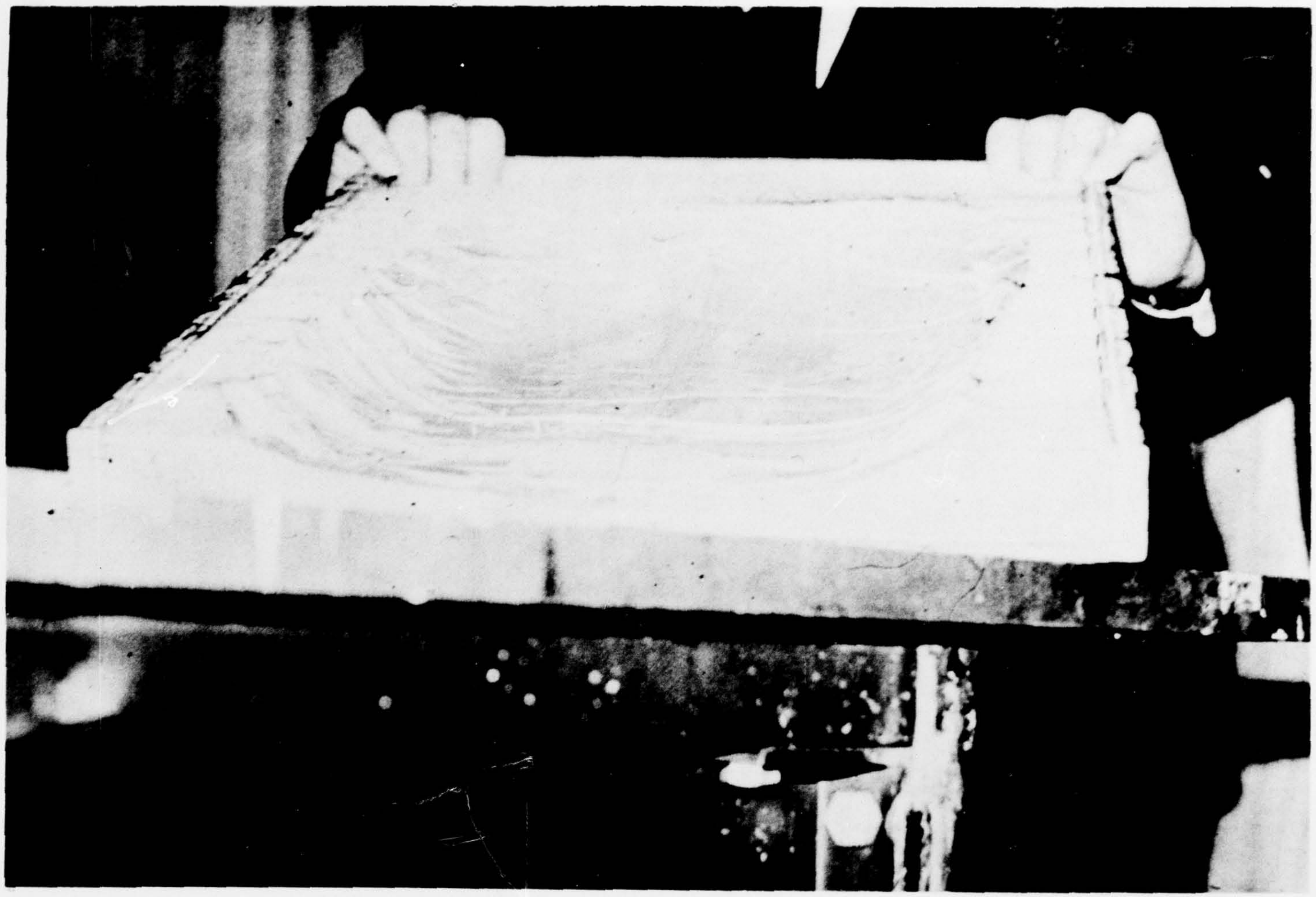

Figure 10. **Contoured backrest – oblique view.**

IV. SUMMARY AND CONCLUSIONS

G-seat configuration simulation on the ASPT has resulted in the following conclusions, as observed by the researchers/subjects:

1. The ALCOGS approach tends to provide a more integrated, continuous sensation of a seat structure than does the first generation, ASPT-type seat. The individualism of the drive components of the first generation G-seat seems to be perceptible.

2. There appears to be either a neutral or positive (but not negative) interaction between the ASPT motion system/drive scheme and the firmness bladders, dependent upon which axis is in question. This conclusion supports the utility of this concept.

3. The active thigh panels of the first generation seat are definitely perceived and although there is some argument among the subjects as to whether this is a valid replication of the sensation in the actual aircraft, there appears to be agreement that the thigh panel activity aids in cuing and perception of aircraft acceleration magnitude and direction. The passive thigh wedges rise to 3/4-inch height at the outboard edges and should, perhaps, be up to twice that height to be more effective.

4. Tuberosity blocks appear to be effective even if passive. However, it was found that 1/4-inch high blocks were too excessive and that no blocks provided a lack of sensation. Initial ALCOGS tuberosity blocks should rise to a medium range, perhaps 1/8-inch.

5. Having once experienced the maximum accelerations to which the ALCOGS seat simulation is scaled, subjects are able to report G-level direction accurately nearly 100% of the time. G-level magnitudes are estimated quite well even in multicomponent acceleration conditions.

6. Pressure sensation in localized areas is very strong and perhaps too strong. Conversely, area of contact changes are too limited. A trade off of the upper portion of the pressure-inducing capability to increased area of contact is definitely required. The first step in this direction is a height reduction of the passive tuberosity blocks. The next step is the consideration of a contoured seat pan upper plane. In the case of the backrest, consideration of a concave upper plane with the center of the concave located about 1 or 2 inches above belt line should be considered.

7. The contoured seat pan vastly increased the sensation of area of contact, but the amount of contour should be less than that employed in the evaluation. Pressure cues are nearly totally lost when such heavy contouring is employed.

8. Poor response performance of the CONOFLOW valves in pressurization vs. exhaust cycles was detected by most subjects, particularly in firmness bladder drive. It seems doubtful that CONOFLOWS will be satisfactory in firmness cell utilization.

9. Although the firmness cells alone provide a portion of the cuing complement, seat upper plane movement vastly improves the subjective impression of the simulation.

10. By virtue of these demonstrations, the principal investigator feels assured that proposed G-seats for future simulator programs (employing ALCOGS-like G-seats) could be simulated on the ASPT in much the same manner the ALCOGS was simulated. This simulation would allow the contractor the opportunity to set up a baseline configuration of his G-seat hardware and software and allow tactical aircraft pilots the opportunity to evaluate the proposed G-seat.

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Kron, G.J. *Advanced simulation in undergraduate pilot training: G-seat development.* AFHRL-TR-75-59(III), AD-A017 468. Wright-Patterson AFB, OH: Advanced Systems Division, Air Force Human Resources Laboratory, October 1975.

APPENDIX A: GENERAL DESCRIPTION OF THE ASPT G-SEAT

A general description of the ASPT G-seat and its drive philosophy is presented here. A more specific discussion (Kron, 1975) covers the entire G-seat development.

ASPT G-Seat Components

The existing G-seat in the ASPT is composed of the following basic elements (Figure 1):

1. *Seat Pan Cushion.* A 16- by 16-inch seat is formed by a mosaic of sixteen square metal air bellows.

2. *Backrest.* A 16 by 23-inch backrest is formed by a mosaic of nine rectangular metal air bellows.

3. *Thigh Cells.* On top of the seat pan in upholstered containers are two thigh panels, each composed of three plastic air cells. The cells are fabricated in such a way that their excursion strikes an arc.

4. *Lap Belt.* The lap belt is driven in extension and contraction. The seat is also equipped with a standard shoulder harness. Although this device is not actively driven, there is some coupling of the lap belt drive into the shoulder harness because the lap belt buckle also serves as a terminus for the shoulder straps.

5. *Upholstery.* The seat pan, backrest, and thigh cells are overlaid with a 0.5-inch-thick layer of closed cell foam padding. The seat is upholstered in canvas duck with side panels of elasticized material to permit cushion movement. Cushion zippers permit entry to the internal air cells.

A pneumatic control assembly provides individual pressure control of each one of the 31 drivable cushion-elements as well as the lap belt. The air cells and lap belt respond to G-seat software drive commands with pressure changes which are continuous in nature. The lap belt actuator, the six thigh panel air cells, nine backrest air cells, and sixteen seat pan air cells are all treated as excursion devices. The amount of excursion is controlled by the pressure of air delivered to the device. The desired pressure command is calculated by the G-seat software from flight model acceleration calculations (translational and rotational) transferred from the aircraft center of gravity to the pilot station axis. A fundamental premise in formulating the G-seat software is the concept that seat position is directly proportional to aircraft acceleration. In the normal 1G state, the seat is maintained at a neutral point which is formed when the air cells and lap belt are near the mid-points of their respective excursion ranges. In general, the seat should "fall away" from the areas of increased flesh pressure normally resulting from seat/subject acceleration. An exception to this rule is the contouring concept wherein localized areas of the back and buttocks are subjected to increased flesh pressure. The mosaic form of the seat permits the seat to fall away from general areas of increased flesh pressure, yet within that same area, locally increase flesh pressure by altering the shape of the G-seat.

ASPT G-Seat Drive Philosophies

The major software drive concepts are translation, plane orientation, and contouring. In seat translation, the elevation of a complete set of cells, either (or both) the seat pan, or the backrest set, is caused to translate in unison a uniform distance. In the case of the seat pan, the translation abides by the activity of the z-axis acceleration component. Positive (headward) acceleration produces decreased seat pan air cell elevation and negative (footward) acceleration produces an increase in seat pan elevation (simulates being lifted-out of the seat). The backrest cells are sensitive in a like manner to x-axis accelerations.

In seat plane orientation, the plane formed by a complete set of cells, either or both the seat pan set or backrest set, is caused to be reoriented. The key to the reorientation is the seat pan plane, which is driven so that it approximates an orientation normal to the total acceleration vector, including the gravity component. The plane of the backrest is driven in a complimentary manner.

Either or both the seat pan and backrest may be caused to assume a contoured shape which produces a flesh pressure redistribution thought to be compatible with body response to acceleration along any one axis or combination of axes. The degree of contouring is governed by the magnitude of the acceleration component along each of the seat axes.

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The thigh panel cell excursions respond to any or all of the lateral, longitudinal, and vertical acceleration components. For example, when the seat pan is caused to settle under headwards aircraft acceleration conditions, the arc struck by the thigh panels is caused to increase, bringing more of the seat into flesh contact and enhancing the feeling of "settling into the seat."

ASPT G-Seat Flexibility

The ASPT G-seat was designed to provide experimental flexibility as a general-purpose research model. Each of the basic G-seat drive concepts contain control parameters which may be easily altered by the experimenter. By way of example, these parameters provide the following latitude of control:

1. Permit each concept, on a per-axis basis, to be included or deleted from the overall drive scheme.
2. Permit the intensity of each concept, on a per-axis basis to be varied.
3. Permit the contouring schemes to be altered for acceleration along each axis.
4. Permit drive reversal within each concept on a per-axis basis. These and other control parameters are maintained in software files for ready retrieval. It is possible for the experimenter to alter the complete structure of the G-seat drive model in real-time without imposing long reinitialization delays upon his subject. An extensive CRT system allows the experimenter to access, monitor, and control software status. The CRT system possesses color capability and can present graphical displays, as well as alphanumeric data. Keyboard entry units, as well as display units, are located in both cockpits and at the advanced instructor station console, normally considered the base for the experimenter.

APPENDIX B: ALCOGS CONFIGURATION SIMULATION DATA

The following tests were performed on the modified G-seat. The actual data are given for each of the tests.

Test #1: ALCOGS Firmness Cell Calibration

The subject is seated on the deflated (0.5 psi) seat pan firmness cell without tuberosity blocks. The pressure at which the subject perceives being lifted just off the seat is determined and called the 1G state. A pressure of 0.5 psi is called the *maximum* G state. Starting at either of these two end points, the pressure in the bladder is changed. The subject then states what percentage of max Gs he is experiencing. (1G = 0%, max G = 100%)

Subj. No.	Subj. Wt.	Condition	Perceived 1G Pressure
1	175 lb.	1G Threshold Pressure	1.9 psi
2	185 lb.	1G Threshold Pressure	1.8 psi
3	215 lb.	1G Threshold Pressure	1.9 psi
4	178 lb.	1G Threshold Pressure	1.6 psi

Figure B1 summarizes the G estimation data gathered on 4 subjects.

Firmness Cell Pressure Data Summary

Backrest Firmness Cell with bias (Subj. 1)

Threshold – 0.8 psi
"Knee of Curve" – 0.2 psi
Saturation – 0.1 psi

Seat Pan Firmness Cell Pressure G Relationship

Right Side	Left Side
–1g = 1.7 psi	–1g = 1.75 psi
–2g = 1.2 psi	–2g = 1.3 psi
–3g = 0.7 psi	–3g = 0.8 psi
–4g = 0.25 psi	–4g = 0.4 psi
–5g = 0.1 psi	–5g = 0.2 psi
–6g = 0 psi	–6g = 0.1 –0.2 psi

Test #2: ALCOGS Firmness Cell, Thigh Wedges, Tuberosity Blocks – Calibration Data Summarized on Figure B2.

The subject was seated in the ASPT cockpit seat which was fitted with a backrest firmness cell, seat pan firmness cell, tuberosity blocks, and thigh wedges (Figure 7). The subject was taken through the various "G-levels" in the three axes, x, y, and z. Starting each time at the nominal state ($\ddot{X}=0$, $\ddot{Y}=0$, $\ddot{Z}=1$), the firmness cell pressures were changed and the subject conveyed what he thought the new state was, in terms of G's. A linear relationship between pressure and G's was assumed.

Limits:
$0 \leq \ddot{X} \leq .25$ (thrusting only)
$-.2 \leq \ddot{Y} \leq .2$
$-6 \leq \ddot{Z} \leq -1$

Tentative conclusions on four subjects' linearity on the dimpled firmness bladder:

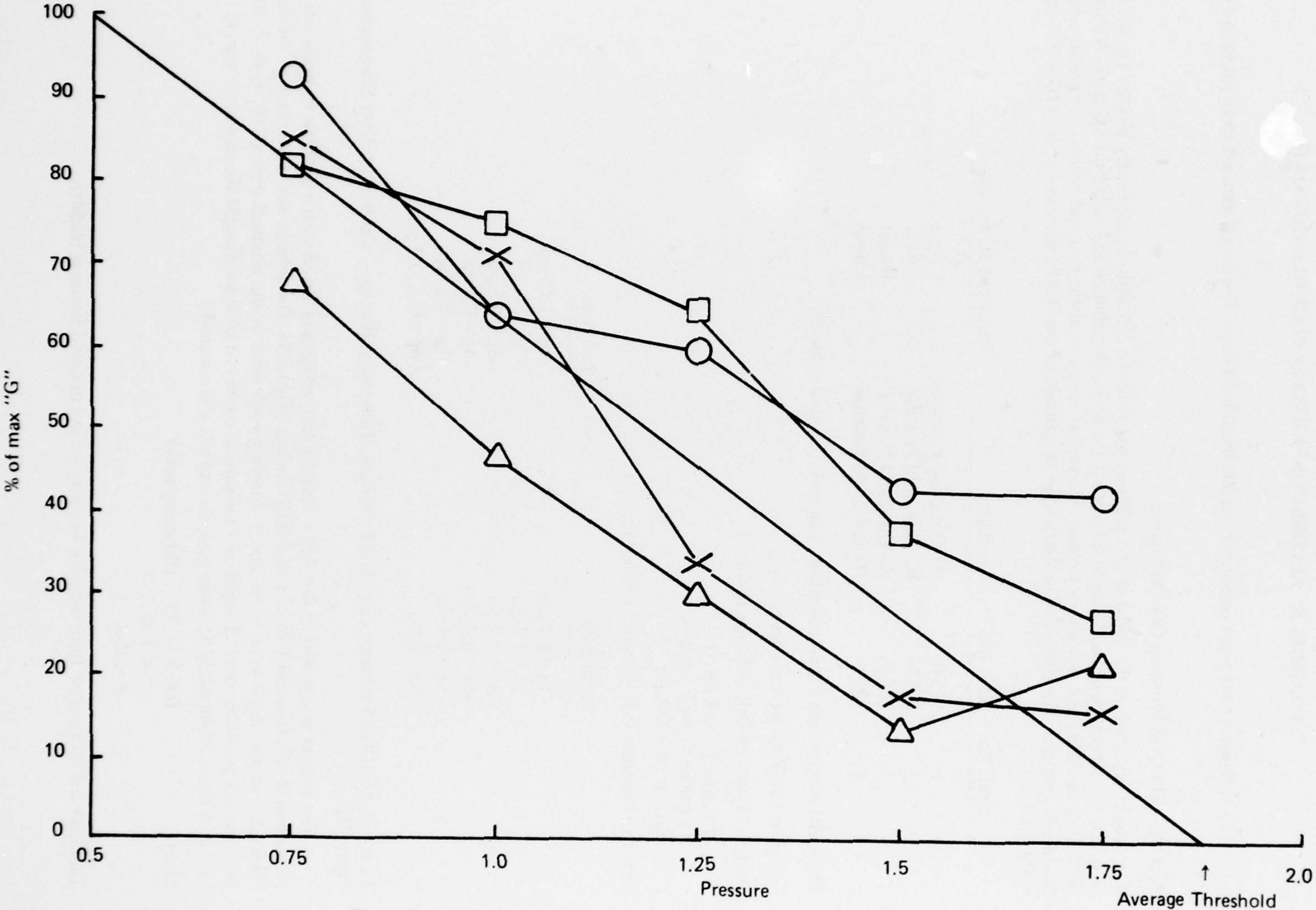


Figure B1. **Seat pan bladder "G" estimation through pressure variations.**

AVERAGE ERROR IN ESTIMATING Gs WITH BLADDER

AND ACTIVE PLANAR DRIVE

(SUMMARY OF RESULTS FROM TESTS 2 AND 3)

X AXIS – 19.2% ERROR	$0 \leq \ddot{X} \leq .25$
Y AXIS – 4.% ERROR	$-0.2 \leq \ddot{Y} \leq 0.2$
Z AXIS – 22.% ERROR	$1. \leq \ddot{Z} \leq 6.$

AFTER ADDITION OF BACKREST BLADDER BIAS, ERROR FROM SINGLE AXIS TEST

X AXIS – 7.7% ERROR

Figure B2. **Average error in estimating Gs with bladders and active planar drive.**

1. Ideal curve of subjective G's (% max) vs. pressure in psi would be:

$$G\ (\%\ \text{max}) = \frac{(100 - 0)}{P_{100} - P_o} (P - P_{100}) + 100$$

$$G = 100\left[1 - \frac{1}{1.4}(P - .5)\right] \quad \text{for } P_{100} = .5 \text{ psi}$$

$$P_o = 1.9 \text{ psi}$$

$$G = 100\,[1.36 - .71\,P]$$

2. Actual linear regression curves have a more shallow slope.

Approx. $G = 100\,[1 - .71\,(P - .5)]$ for subject 1
$G = 100\,[1.1 - .56\,(P - .5)]$ for subject 2
$G = 100\,[1 - .57\,(P - .5)]$ for subject 3

3. The actual curves have a second-order non-linearity, appearing more shallow at the higher pressures (lower subjective Gs).

Might fit equation by:

$G = 100\,[1 - a(P - .5) + b(P - .5)^2\,]$

4. The standard deviation of the % G at any one pressure is about 5% to 10% – and increases for higher pressures – lower % Gs.

5. There is some tendency for % G estimates to be higher for increasing pressures (lowering % Gs) than for decreasing pressures (hysteresis).

Actual (Gs)	Perceived (Gs)	Perceived (Gs)
	Subject 1	Subject 5
1) $\ddot{X} = +0.08$	"minimal"	0
$\ddot{Y} = 0$	0	$-.1$ (L)
$\ddot{Z} = -3$	-3	-2
2) $\ddot{X} = +.12$	0	
$\ddot{Y} = +.1$ (R)	+.14	
$\ddot{Z} = -1$ (normal)	2	
3) $\ddot{X} = +.12$	+.05	
$\ddot{Y} = +.1$ (R)	+.08	
$\ddot{Z} = -1$	-2.5	
4) $\ddot{X} = 0$	Unsure	.1
$\ddot{Y} = -.2$ (L)	$-.19$	$-.1$
$\ddot{Z} = -3$	Unsure	0
5) $\ddot{X} = +.2$	+.2	
$\ddot{Y} = 0$	+.05	
$\ddot{Z} = -6$	-5 1/2	
6) $\ddot{X} = +.15$		"a little $\ddot{x}$"
$\ddot{Y} = -.1$		$-.15$
$\ddot{Z} = 2.5$		2

Test # 3: Same as #2 with the addition of backrest and seatplane ASPT G-seat action. R = right, L = left (Results summarized on Figure B2)

Actual (Gs)	Perceived (Subj. 1) (Gs)
1) $\ddot{X} = 0.08$	.06
$\ddot{Y} = 0$	0
$\ddot{Z} = -3$	-4.5
2) $\ddot{X} = 0$	.07
$\ddot{Y} = -.2$ (L)	$-.18$
$\ddot{Z} = -3$	-1.5
3) $\ddot{X} = .12$	.1
$\ddot{Y} = .1$ (R)	.12 (R)
$\ddot{Z} = -1$	-2
4) $\ddot{X} = .2$	.15
$\ddot{Y} = 0$	.05
$\ddot{Z} = -6$	5 1/2
5) $\ddot{X} = .15$	.07
$\ddot{Y} = -.1$ (L)	$-.1$
$\ddot{Z} = -2.5$	3.5

Comments – Subject 1 (comments on test #3)

– On small excursions with roll, had trouble discriminating changes. (This is with seat plane operational)

– No rotational feelings from backplane.

- On backrest (x-axis acc.) .25G feeling right down spine to lower back solid against backrest; slow response felt from 0.0 to 0.07G with small positional change. Much quicker response and positional change noted from 0.07 to 0.12G.
- In nominal 1G state felt as if still on tuberosity blocks.
- Thigh panels not noticeable.

Test #4: Static Perception Test Results on the ALCOGS/ASPT G-Seat

Backrest firmness cell was biased. (Bias = −.3 in.); backrest plane was active. Starting at x = .125 (mid range), Gs were varied from that point. Subject gave his estimate of the new value. (G level always returned to .125 before inputting next value). These data plotted on Figure B3.

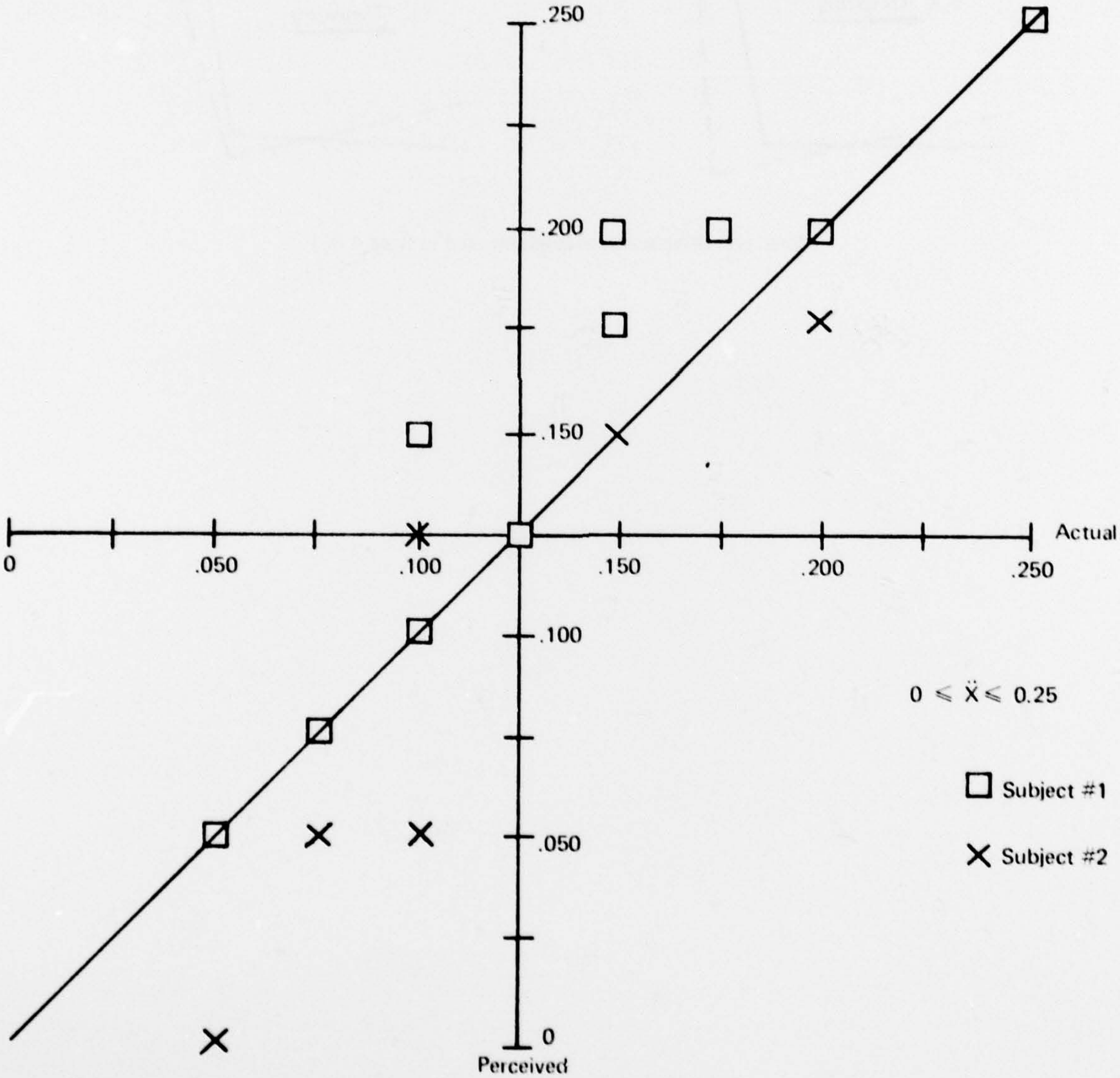
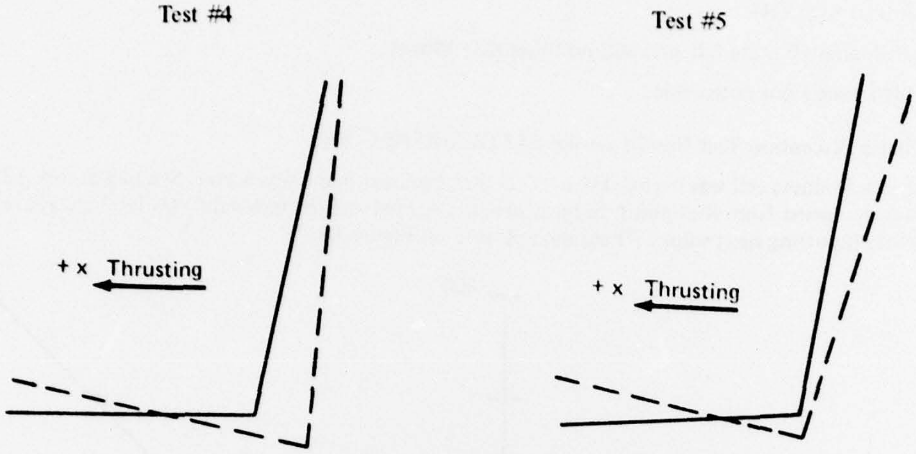


Figure B3. **Perception of X-axis acceleration using active backrest and bladder.**

Test #5: Alternate Backrest Drive Test

Same as #4, however backplane drive was changed to pivot from the bottom instead of the top. Starting point was x = .125 Data plotted on Figure B4.


Test #4

Test #5

Back rest drive schemes implemented in tests 4 & 5

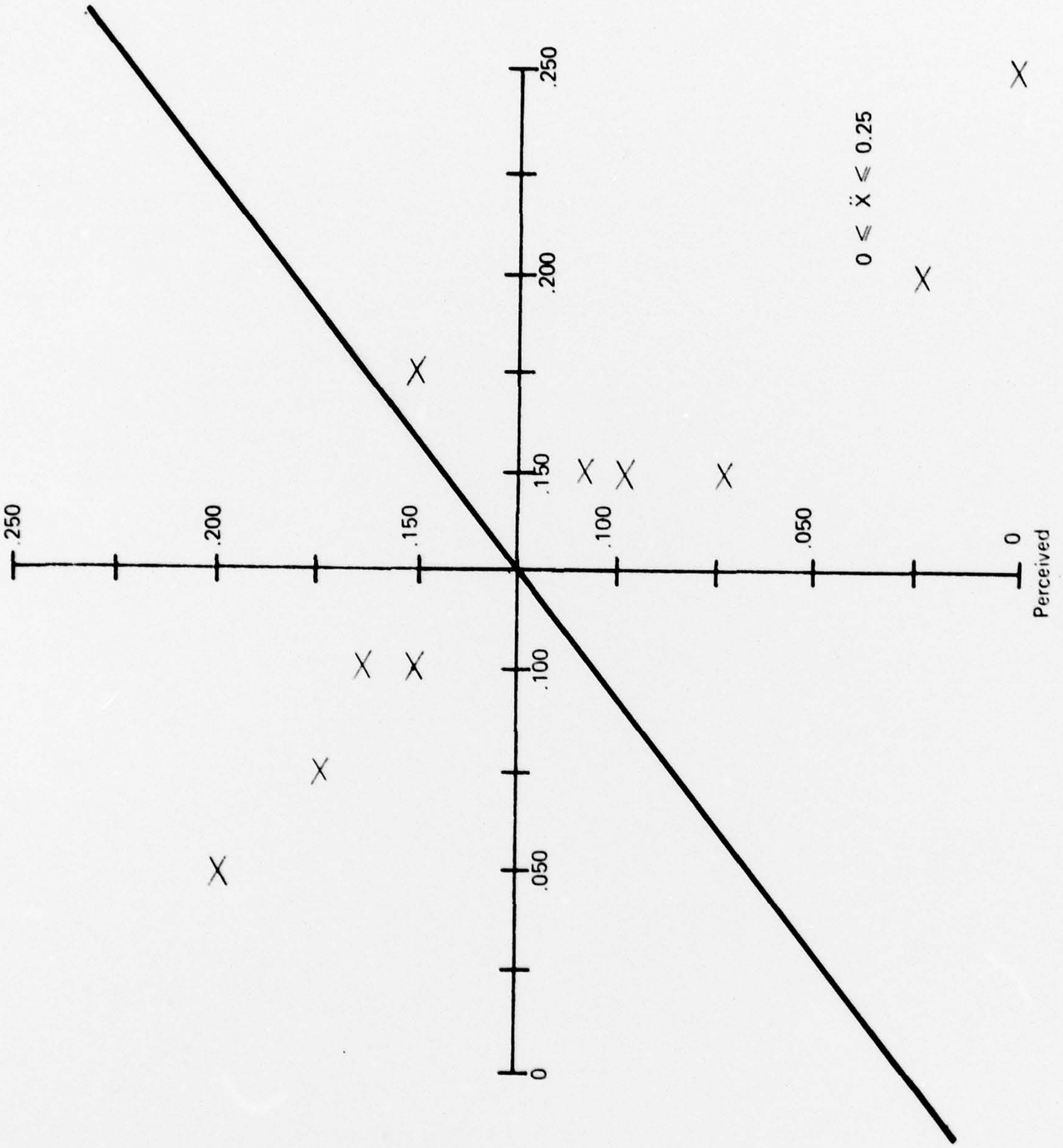


Figure B4. **Perception of X-axis acceleration with altered backrest drive.**

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