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SUBJECTIVE MOTION DISCRIMINATION IN THE SIMULATOR FOR AIR-TO-AIR COMBAT

By

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FLYING TRAINING DIVISION

Williams AFB, Arizona 85224

August 1978

Final Report for Period September 1975 – January 1976

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The primary objective of this study was to acquire subjective information on the ability of pilots to perceptually differentiate between selected conditions of motion cueing in the Simulator for Air-to-Air Combat (SAAC). A second objective was to prepare the initial framework for follow-on studies designed to determine the contributions of motion cueing to pilot performance and training in the SAAC. Four high experience F-4 pilots and four low experience F-4 pilots flew six contact maneuvers in the SAAC under eight experimental conditions of platform motion, G-seat, and G-suit. Subjective ratings were collected from the pilots on the effectiveness of the motion-cueing systems after the completion of each maneuver. The results indicated that the pilots could discriminate changes in G-suit performance via the ratings. However, no differences in the pilot ratings were elicited by changes in the G-seat or platform motion system operation.

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PREFACE

This effort was conducted by the Flying Training Division of the Air Force Human Resources Laboratory, Williams AFB, Arizona, and was supported by the 58th Tactical Fighter Training Wing, Luke AFB, Arizona. The project was completed under project 1123, United States Air Force Flying Training Developments; task 112303, the Exploitation of Simulation in Flying Training, and work unit 1123-03-09, evaluating the Training Effectiveness of the Simulator for Air-to-Air Combat (SAAC). Mr. James F. Smith was the project scientist, and Mr. James Brown was the task scientist. The report covers research performed between October 1975 and July 1976 in support of Tactical Air Command request for personnel research (RPR 73-19).

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SUBJECTIVE MOTION DISCRIMINATION IN THE SIMULATOR FOR AIR-TO-AIR COMBAT

I. INTRODUCTION

Of the many current issues in the field of aircraft simulation, one of the most widely debated lies within the area of motion cueing. A great deal of research pertaining to this topic has been directed toward ascertaining the benefits or detriments of having some form of motion cueing device installed on the aircraft simulator. These cueing devices take many forms, ranging from a hydraulic platform motion system to pneumatic G-seat and G-suit arrangements. They also vary widely in cost (approximately $625K for some six-degrees-of-freedom motion platforms to $125K for a simple G-seat system). Consequently, much attention has been focused on determining which system or combination of systems is most cost-effective in providing the required level of fidelity. This question is addressed in objectives 9 and 13 of the Follow-On Operational Test and Evaluation Plan of the Simulator for Air-to-Air Combat (SAAC) (See References). In response to this requirement, a research program was developed in September 1975 to investigate the effectiveness of the motion platform, G-seat, and G-suit systems presently used on the SAAC.

There are several psychological research methods commonly used in evaluating motion cueing as it affects a simulator's effectiveness. If the simulator is to be utilized as a trainer, the transfer of training (TOT) paradigm is often implemented; however, the TOT model provides only information about training environments and does not impart information on the underlying psychological processes at work during the training. Thus, this methodology provides only partial information on the effects of motion on pilot performance. For this reason, a multi-faceted approach was chosen for this research, comprised essentially of three separate strategies. The first step in this approach was to examine the pilot's abilities to discriminate various motion cueing devices installed on the SAAC. Along with this, substantive information would be gathered on the operations and maintenance of SAAC to allow more accurate future planning. Phase II was proposed as an investigation into the changes of both experienced and student pilot performance caused by alterations in the motion cueing devices as measured by an automated performance measurement system. This would allow refinement in the automated scoring algorithms as well as provide detailed documentation on the interactive effects of the motion cueing systems on pilot performance. The third step would be an investigation into the effects of those variables deemed of interest from the results of Phases I and II on the training of students and the resultant transfer data. In this manner, comprehensive *information would* be gathered on all relevant aspects of the motion simulation question.

Background

The main purpose of motion cueing devices (e.g., motion platforms and centrifugal arms) is currently thought to provide onset (alerting) information and briefly directional and magnitudinal information to the pilot. The latter type of cueing is short-lived due to hardware excursion and acceleration limits, among other constraints.

G-seats and other pneumatically driven devices provide more sustained cueing and as well as cues of higher frequencies. The cues are presented by an orderly inflation and deflation of air bladders placed within the seat backrest, seat pan, and thigh panels, thereby shifting the weight and position of the pilot.

The pneumatic G-suit works in much the same manner. Air bladders within the strap-on suit inflate and deflate about the pilot's waist, thighs, and shins according to the positive or negative g-loading being simulated in the vehicle. Again, the cues presented are normally sustained longer than those of the motion platform.

At this point, it would seem necessary to clarify the use of the word "cue," which in the past, has come to take on many meanings. For the purpose of this project, the "cue" will be defined as *"objectively identifiable* information which has a purposive nature." It is not within the scope of this report to enter into a lengthy discussion on the origin, classification, and synthesis of the various and sundry cues being generated in piloted flight. For an indepth review of these topics, consult Matheny, Lowes, and Raker (1971) or Staples (1970).

The main thrust of research into the motion issue has been the investigation of cockpit motion platforms. This is not a reflection on the utility or desirability of G-seat or G-suit systems, but rather is due to a relative scarcity in the number of these systems for use on advanced research devices. Most of the motion research investigating the need for and the effectiveness of platform motion has been equivocal. Many studies have investigated the performance of pilots of various experience levels on piloting tasks under conditions of no-motion, full six-degrees-of-freedom (DOF) motion, and assorted levels of degraded motion (Borlace, 1967; Brown, Johnson, & Mungall, 1960; Demaree, Norman, & Matheny, 1965; Huddleston, 1966; Waters, Grunzke, Irish, & Fuller, 1976). Research investigating G-seat/G-suit systems in aircraft simulators has been quite limited. One report, however, concluded that pilot training was improved when "G-seat forces" were provided in conjunction with motion cueing (Taylor & Gerber, 1969). A recent study (Waters et al., 1976) found that the G-seat was particularly beneficial to pilot performance in those maneuvers that were largely pitch sensitive. When motion and G-seat were used in combination, performance was significantly improved relative to when motion and G-seat were non-functional, again in pitch sensitive tasks.

Many research projects have also been involved with studying the perceptual sensitivity of pilots under various conditions of simulator motion. Those which have investigated this area have determined that workload is a significant factor in the detection of motion cues (Conrad & Schmidt, 1971). In this study, it was found that the greater the workload an individual faces, the more restricted his attention to motion cueing becomes. When attention must be paid to other tasks, the individual's motion detection ability declines. Attitudes also play a large role in the detection and discrimination of motion cues. Johnson and Williams (1971) reported that an individual's confidence in the visual environment dramatically affected his motion perception. Other studies have also shown that the ability to discriminate motion cues is dependent on the accompanying visual environment. This motion-visual interaction has been documented on occasion over the years (e.g., Young, 1971; Young & Henn, 1974). One report found that by varying the angular velocity of a moving visual stimulus, stationary subjects reported perceived body tilts up to and including 40° from vertical (Dichgans, Held, Young, & Brandt, 1972).

Additionally, some individuals feel that the addition of a helmet and mask may improve a pilot's ability to discriminate motion cues because of the physics involved. The hypothesis rests on the theory that adding a 2- to 3-pound weight would increase the forces acting at the pilot's head when the simulator platform and G-seat bellows are in motion. If this is indeed what occurs, then under conditions involving platform or G-seat motion, when the subject pilot is wearing this equipment, he should be able to more clearly discriminate whether he is experiencing motion.

The major problems, therefore, are threefold. The measurement of a pilot's motion discrimination ability is dependent not only on the strength of the motion cues but also on the workload he experiences and the specific visual display he is presented.

Study Rationale

For the purposes of this study, it was decided that the SAAC eight-channel visual display be kept constant in all aspects throughout the course of the study. It was also decided that the subject pilot's attention be manipulated such that a variety of tasks (encompassing many difficulty levels) would be performed without the knowledge of the true intent of the experiment. This method would hopefully alleviate the Hawthorne effect and permit more accurate measurements of the pilot's ability to detect and discriminate the motion cues being presented.

To achieve this, an evaluation form was constructed which included an equal number of distractor questions intended to keep the subject pilot from focusing on the motion issue. In this study, 16 questions were generated, of which eight dealt with the issue of primary concern. Six of the questions were directed towards qualities of the visual display, two were concerned with certain aspects of the aural signals, and three dealt with the incidence of psychophysiological effects (Appendix A).

Objectives

The primary objective of this study was to acquire subjective information on the ability of pilots to perceptually differentiate between selected conditions of motion cueing in the SAAC.

A second objective was to prepare the initial framework for follow-on studies designed to determine the contributions of motion cueing to performance and to training in the SAAC.

II. METHOD

Design

The design chosen for use in this study was a split-plot factorial (Kirk, 1968). The three SAAC system independent variables (motion, G-seat, and G-suit) had two levels each: operational and not operational, and thus eight unique treatment combinations (2^3) were constructed. Two groups of subjects participated in this study, group membership being determined by the amount of flying time acquired in the F-4. Each subject flew six representative maneuvers under each treatment condition which was presented in an independently random order. Thus, each subject flew a total of 48 maneuvers.

Apparatus

This study was conducted using the SAAC located at Luke AFB, Arizona. An abbreviated description of the device is available in "General SAAC Description" (author unknown) which is included here as Appendix B.

Subjects

Eight subjects were used in this study and were assigned to one of two groups, based on their experience level in the F-4. The four high experience level subjects ranged from 970 to 1400 F-4 flight hours, while the four low experience level subjects ranged from 110 to 290 F-4 flight hours.

Independent Variables

The variables selected for manipulation in this study and the experimental levels were:

Motion Platform	G-seat	G-suit
1. Off	1. Off	1. .1 lb/g
2. Full 6 DOF	2. On	2. .75 lb/g

The motion platform system when functional employed all six degrees of freedom: roll, pitch, heave, yaw, sway and surge, including gravity alignment. When off, the motion platform was initially raised to an extended position and then frozen.

The G-seat when functional was inflated, and the G-seat program was operative. When the G-seat was not operational, it remained inflated, but the program was not utilized. During both conditions, the buffet drive remained functional. Thus, the experimental levels of G-seat evaluated the standard operation of the G-seat as opposed to virtual random movement supplied by the buffet program.

Under those conditions demanding a functional G-suit, the suit was inflated at .75 pound per g (lb/g). When not operative, the G-suit was inflated at .1 lb/g which is considerably below that of normal operation. The rationale for establishing the G-suit at .1 lb/g and not zero was to attempt to preclude the device from lying uninflated in the subject's lap, an easily discernible situation.

Dependent Variables

The dependent variables used in this study were ratings and yes/no responses. The rating scale was an adaptation of the Kelly-Waag scale used in Phase I of the SAAC Operational Test and Evaluation (OT&E) (1). The scale consisted of a seven-point continuum of cue magnitude and was intended to measure the similarity or disparity of cues in the simulator as compared to those in the aircraft. It was also designed to indicate the direction of any perceived dissimilarity. An anchor point with three gradation levels on either side of this midpoint was considered to provide adequate discrimination levels for the subjects (Appendix C).

Of the eight questions pertinent to this research, four were evaluated with the use of this scale:

1. How would you rate the control feel of the simulator during this maneuver?
2. How would you rate the cues provided by the G-seat?
3. How would you evaluate the G-suit cues?
4. How would you rate the motion platform's cueing?

The remaining four questions were answered by checking yes or no. Those questions were:

1. Did you experience any stability problems in any of the three axes?
2. Did you experience any nausea during this maneuver?
3. Did this maneuver subject you to any headaches or eyestrain?
4. Were you at any time during this task disoriented or suffering from any form of vertigo?

Maneuvers

The six contact maneuvers flown in this study were chosen as being representative of the types of tasks and task difficulties encountered in F-4 Reinforcement Training Unit (RTU) upgrade crew training. The formation regime was represented by a fighting wing maneuver. The barrel roll attack was included to represent basic fighter maneuvering. A sequential attack was chosen to represent air combat maneuvering. A time-limited free engagement was included as a comprehensive task involving many of the former tasks. Finally, an aileron roll and a loop were chosen to represent transition phase airwork. Although no single maneuver isolated any one specific g onset rate or direction of g force, it was felt that collectively the maneuvers adequately sampled the performance regime of both the aircraft and the simulator.

Procedures

Each individual was given an overall familiarization with the SAAC and with the emergency procedures and the specific procedures for data collection. The subjects, however, were not made aware of the actual intent of the study, but were told that this research was intended to investigate their performance as measured by the computer under various simulator configurations. (See Briefing Guide included as Appendix D.) Special emphasis was placed on the possibility that the visual displays would be changed. Use of the rating scale was thoroughly briefed to each individual. All of the questions included in the evaluation form were reviewed by a researcher and the pilot prior to the first data collection mission.

Mission Profiles

For each mission, two subjects flew simultaneously, each cockpit being configured differently. Each subject was permitted approximately 5 minutes at the beginning of each mission for warm-up. After the warm-up, the simulator was initialized for a fighting wing. Each subject spent 2 to 3 minutes flying lead and the same amount of time flying the wing position. After this activity was completed, the simulator was frozen, and the subjective evaluations of the two pilots were reported independently to the researchers at the console. The next maneuver, a barrel roll attack, was then initialized. In this maneuver, each subject flew as a target for approximately 2 to 3 minutes and as the attacker for the same length of time. Again, at completion, the evaluations were reported. The third maneuver, a sequential attack, lasted approximately 5 minutes. In this maneuver, the target was flown by the console operator. A 5-minute free hassle was flown as the fourth experimental maneuver. The aileron roll and the loop were flown as the fifth and sixth maneuvers, respectively, and lasted 1 to 2 minutes each. The average total mission length ranged from 35 to 45 minutes.

Data Analysis

Those questions requiring rating responses were analyzed via a split-plot factorial analysis of variance. The original raw ratings were transformed using a Z-score transformation. This data transformation was accomplished by calculating each specific rating's distance from the individual's mean rating and was expressed in standard deviations. The rationale for this transformation was that each individual entered the research project with a personal bias toward simulation. The Z transformation allowed this individual bias to be removed statistically. A parametric omnibus test was selected following an analysis of the sample data characteristics. A total of six analyses of variance (ANOVAs) were computed, one for each maneuver. Several *a priori* orthogonal contrasts were hypothesized and computed where overall significance was reached. The questions regarding psychophysiological effects and control stability requiring yes/no responses were analyzed by recording the frequency of incidence for each and applying a chi-square test of independence.

A correlational matrix was computed for the four questions answered with ratings in an attempt to determine the inter-relationships of the responses.

Correlational matrices among the four questions were also calculated, in order to inspect for individual differences in rating schemes.

Finally, reliabilities for each dependent measure were computed.

III. RESULTS AND DISCUSSION

It was discovered upon initial analysis of the data that the variance of the responses was quite small, making investigative analysis and interpretation difficult and speculative. A plethora of reasons might have accounted for this. An inadequacy in the discriminability of the measurement scale or an inability of pilots to differentiate the treatment conditions may have resulted in such small variability. Nevertheless, consistent, significant treatment effects were evidenced on the G-suit ratings across five of the six maneuvers studied. The exception was the aileron roll, a relatively low g, low difficulty maneuver. The remaining maneuvers, fighting wing, barrel roll attack, sequential, free hassle, and loop all incorporate high-g loading at one time or another during completion of the maneuver and it is reasonable to expect that recognition would be fairly easy during these maneuvers and not during the aileron roll. Table 1 shows the significant effects for the G-suit ratings, and Figures 1–6 show by maneuver the individual treatment combination cell means. In these figures, the abscissa is used to present the experimental treatment combinations. The letters G,G, and M correspond to the presence of the G-Seat, G-Suit, and Motion systems, respectively. Absent letters represent non-functional systems in the specific treatment. The t-tests provided in Table 2 show that the significant treatment effects were in fact due to the different conditions of the G-suit and not caused by the variation in motion and/or G-seat. On one maneuver, the free engagement, the G-suit/no G-suit contrast did not reach significance. One explanation is that in this maneuver the goal is to defeat the other pilot. Because of this competitiveness, the pilot directs more of his attention to the task at hand resulting in poorer discriminability. Group by treatment interactions reached significance in two of the six maneuvers (the fighting wing and the barrel roll attack) on the G-suit ratings. It was only on these maneuvers that group membership differentially affected the ratings. The direction of this interaction indicated that the experienced group of pilots were more sensitive to changes in the status of the G-suits and that their ratings of this cueing were much more varied.

Table 1. **F-Ratios for All Maneuvers**

Source	G-Seat	G-Suit	Motion	Control Feel
		Fighting Wing		
A	.767	.009	.747	.526
B	.525	4.170**	.996	1.221
AB	.898	2.385**	.866	.849
		Barrel Roll Attack		
A	.326	.03	1.215	.788
B	.292	5.740**	.863	.318
AB	.801	1.876**	1.020	.730
		Sequential		
A	.083	.124	.323	2.293
B	.458	3.158**	.254	1.020
AB	1.347	1.117	.263	.551
		Free Hassle		
A	.354	.048	.368	.082
B	.283	2.308**	.363	.938
AB	1.398	1.102	.690	.968
		Aileron Roll		
A	.068	.182	.0005	.047
B	.525	1.774	1.518	.209
AB	.505	.503	1.321	.716
		Loop		
A	.211	.169	.086	.996
B	.699	2.198*	.627	.260
AB	.849	1.249	.288	.678

Note. — A=Groups; B=Configuration Condition; AB=Group by Condition Interaction.
*$p < .05$.
**$p < .10$.

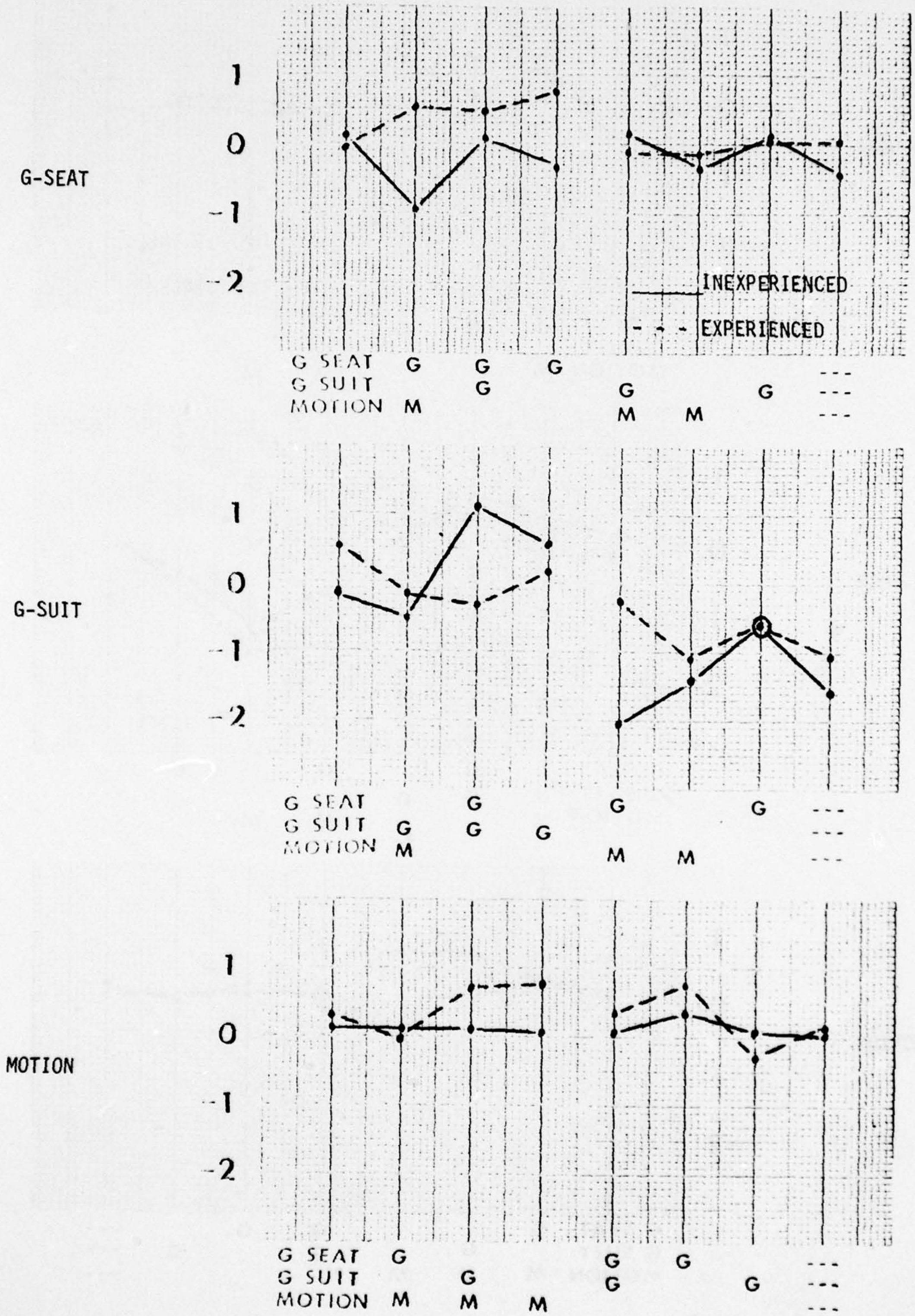

Figure 1. **Fighting wing mean deviation ratings.**

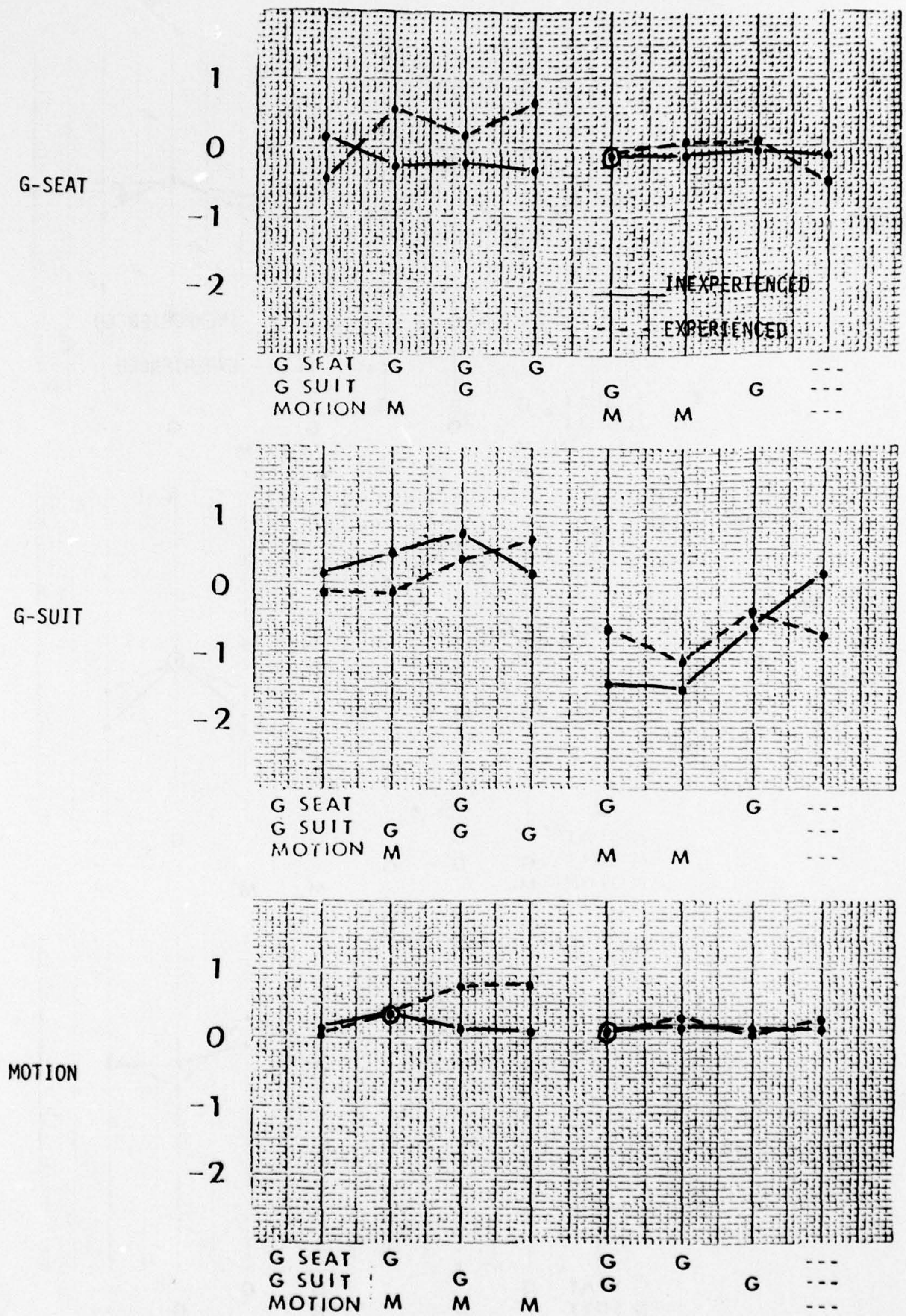

Figure 2. **Barrel roll attack mean deviation ratings.**

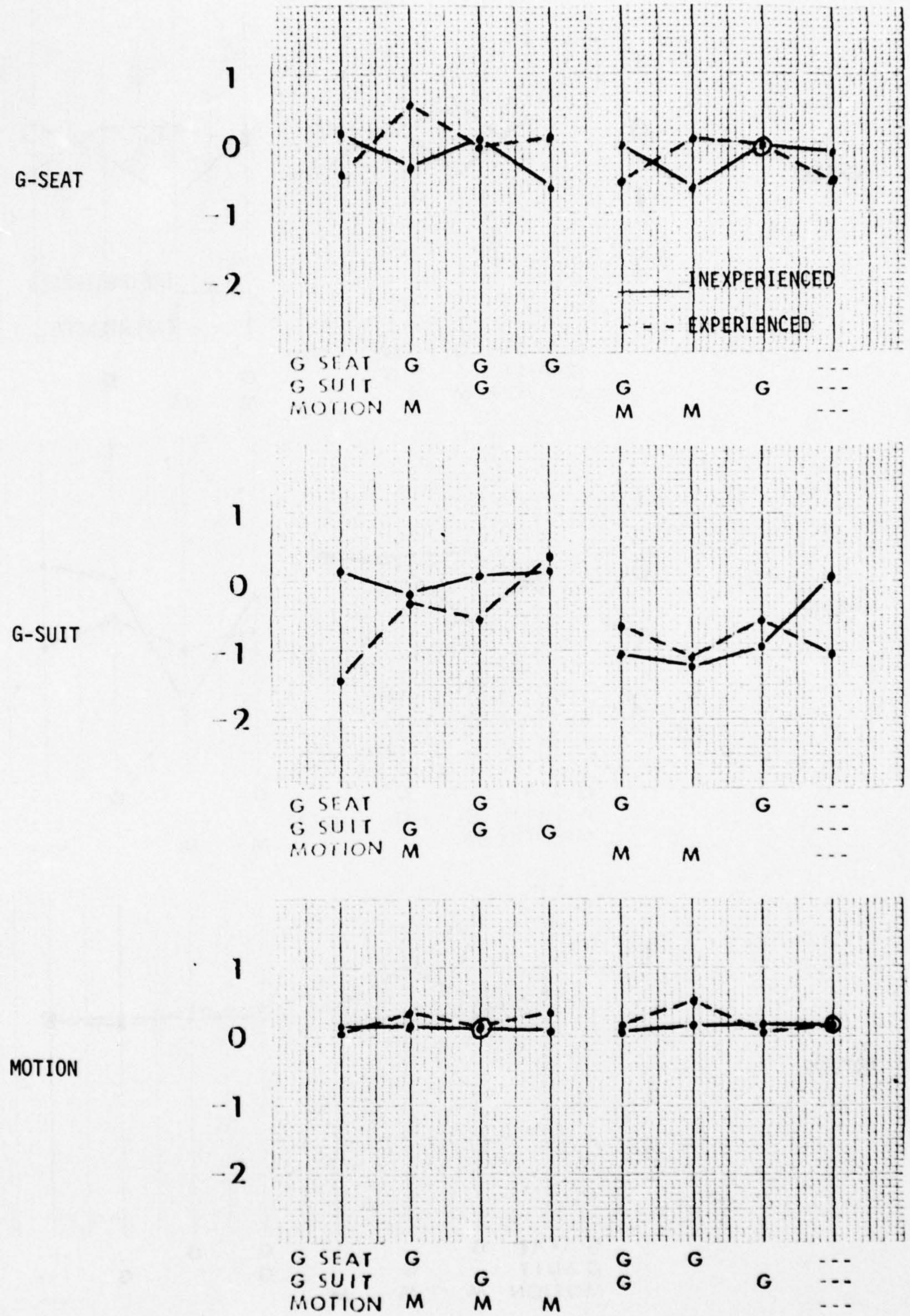

Figure 3. **Sequential attack mean deviation ratings.**

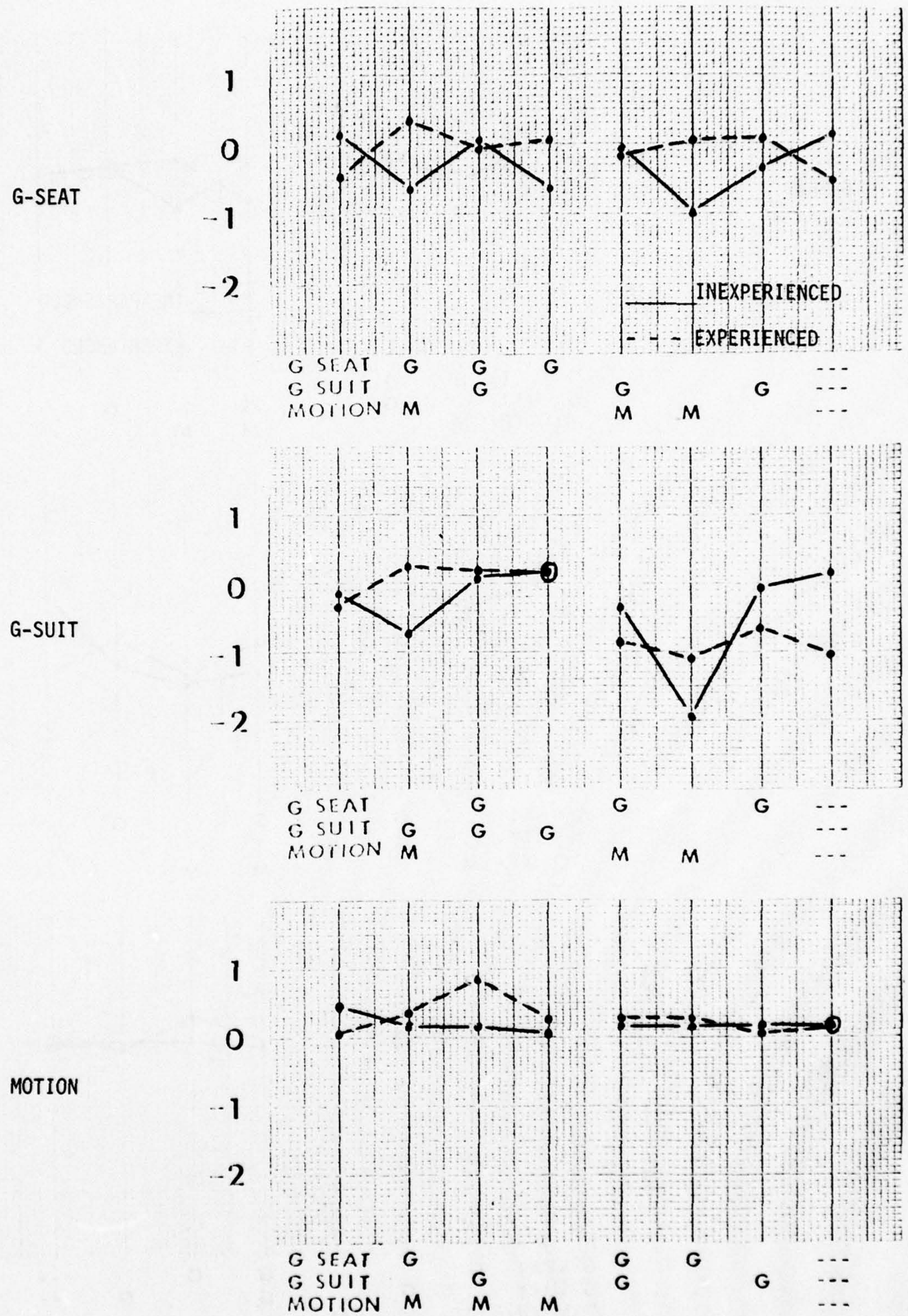

Figure 4. **Free engagement mean deviation ratings.**

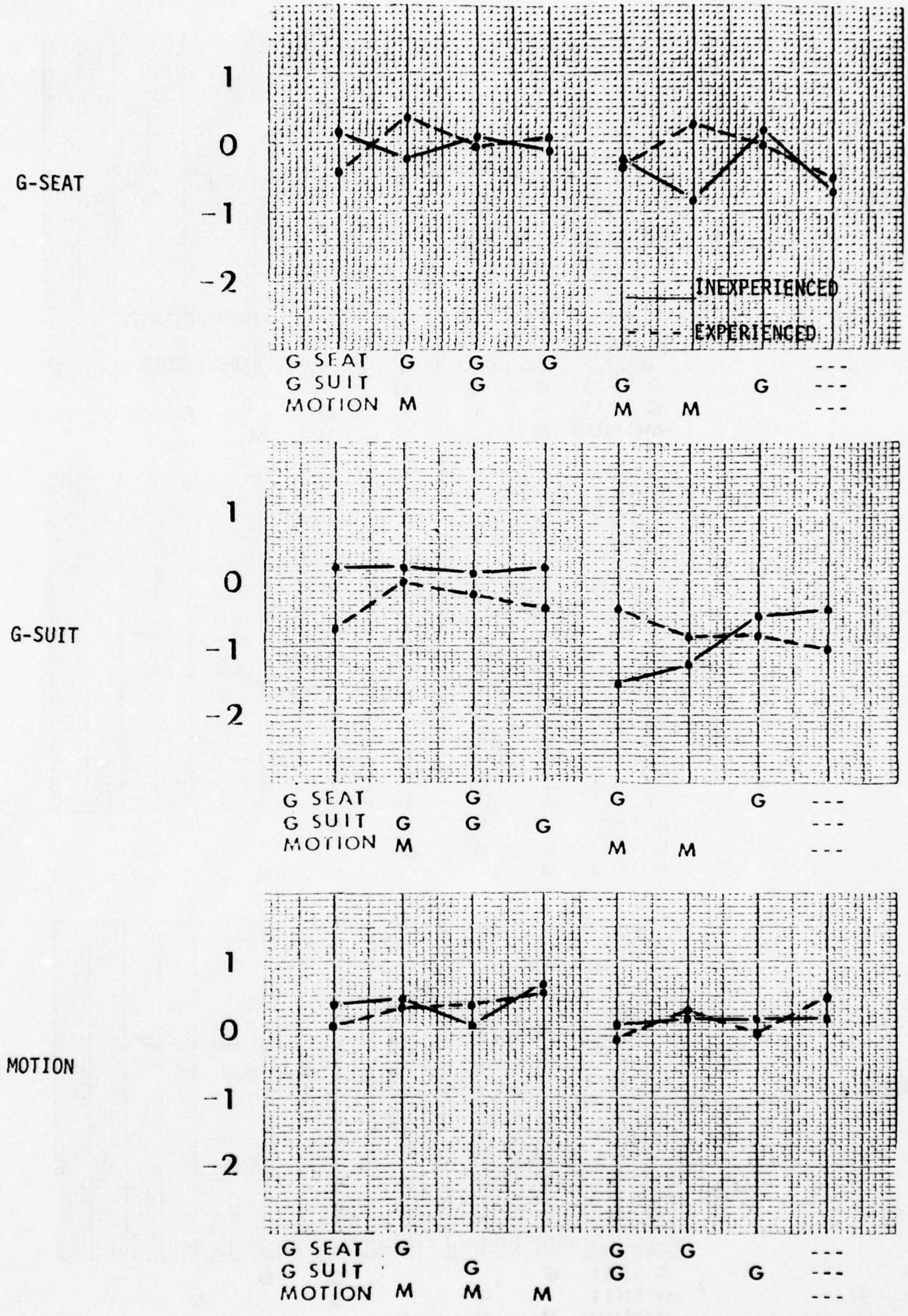

Figure 5. **Loop mean deviation ratings.**

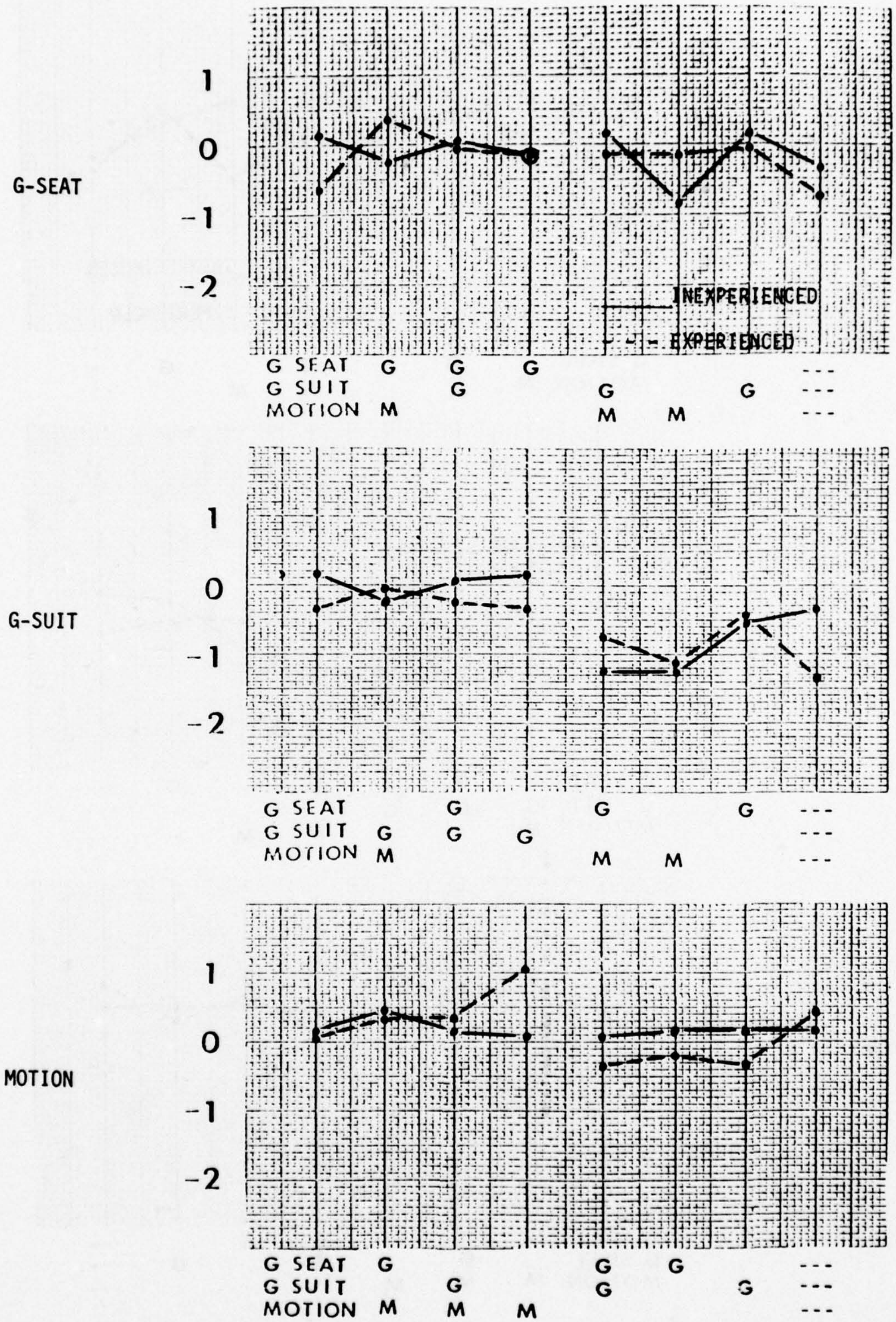

Figure 6. **Aileron roll mean deviation ratings.**

Table 2. **T-Tests on G-Suit Mean Deviation Ratings**

Fighting Wing		Barrel Roll Attack	
Mean G-Suit on (X_g) = .156	t=2.35**	X_g = .182	t=2.71***
Mean G-Suit off (X_{ng}) = –.915		X_{ng} = –.820	
Mean Motion on (X_m) = –.632	t=1.13	X_m = –.567	t=1.51
Mean Motion off (X_{nm}) = –.114		X_{nm} = –.007	
Mean G-Seat on (X_s) = –.288	t=.373	X_s = –.351	t=–.287
Mean G-Seat off (X_{ns}) = –.458		X_{ns} = –.287	
Sequential Attack		**Free Engagement**	
X_g = –.068	t=2.372**	X_g = –.113	t=.368
X_{ng} = –.805		X_{ng} = .284	
X_m = –.566	t=–.701	X_m = –.654	t=–.805
X_{nm} = –.308		X_{nm} = –.280	
X_s = –.463	t=–.144	X_s = –.352	t=.497
X_{ns} = –.410		X_{ns} = –.583	
Aileron Roll		**Loop**	
X_g = –.011	t=1.64	X_g = –.131	t=1.831*
X_{ng} = –.809		X_{ng} = –.882	
X_m = –.603	t=–.596	X_n = –.586	t=–.388
X_{nm} = –.317		X_{nm} = –.427	
X_s = –.416	t=.181	X_s = –.522	t=–.076
X_{ns} = –.504		X_{ns} = –.491	

df=242
*$p < .10$.
**$p < .05$.
***$p < .02$.

No significance was found in the data recorded on the control feel question. Table 3 depicts the treatment means. This was also reasonable as the control loading in each cockpit was constant throughout the course of the study.

No significance was found on the question regarding the fidelity of the motion platform cues. This was consistent across all maneuvers and all conditions and is illustrated in Table 1 and Figures 1 to 6. Group differences were also nonsignificant. Apparently, experience did not play a major role in the detection or discrimination of motion platform cueing in the simulator.

The G-seat ratings also did not reach significance across treatment conditions or maneuvers (Table 1 and Figures 1 to 6). Like the motion ratings, group experience did not play a significant role in the detection or discrimination of the G-seat cueing.

The nonsignificance of the motion and G-seat ratings may have been due to many reasons. The rating scale may have been insensitive to the changes in the motion platform and G-seat. The pilot's sensitivity either because of excessive task difficulty, visual display dominance, or ineffective cueing may have been lacking. Unfortunately, no clear answer was available.

The correlation matrices computed for the four questions regarding control feel, G-seat, G-suit, and motion platform for all maneuvers and all subjects are provided in Table 4. Significance was reached for the correlations of control feel and motion ($p < .10$), G-seat and G-suit ($p < .01$), and G-seat and motion ($p < .01$).

The finding that several dependent measures covaried significantly indicates nonindependence of the rating strategies of the pilots and has particularly important implications regarding the use of experimental pilot rating methodologies.

Correlation matrices were also calculated for each subject (Tables 5 through 12) to investigate possible individual differences in the method of employing the rating scales. Inspection of the tables would seem to confirm that this was the case.

Although not originally intended to be analyzed, the question regarding the incidence of psychophysiological effects (headaches, nausea, disorientation, etc.) was felt after data collection to be an interesting sidelight to the main thrust of this experiment. The frequencies of these effects were recorded for each treatment combination and were analyzed via a chi square test of independence. Interestingly, a significant difference was discovered in the number of times an effect was reported dependent upon the status of the platform motion system (see Table 13). As can be seen, more effects were reported under the motion condition.

Similarly, the control stability question was investigated after the fact. Significant differences were evidenced for the motion/no-motion condition comparison as shown in Table 14. More stability problems were reported under conditions of motion than under no-motion. This result is somewhat contradictory to the previous finding that the subjects could not discriminate the presence or absence of motion by way of rating the effectiveness of the motion cueing.

Intraclass correlation reliabilities were computed for each dependent measure to assess the amount of variability in the ratings. Table 15 shows that with the exception of the G-suit ratings, the measures demonstrated very poor reliability. (The negative reliability for motion was caused by a larger error variance than treatment variance.)

Post-Experimental Subjective Commentaries

After completion of all data sorties, the subjects were given a comprehensive debriefing. In the debriefing, all of the subjects were questioned as to their perceptions of the true intent of the study. Most of the subjects expressed a belief that the visual display was being manipulated. Six of the eight subjects were aware that the G-suit performance was being altered. None of the subjects expressed an awareness that the G-seat and motion platform were turned off and on. After being informed that this was indeed the case, several subjects expressed a great deal of surprise.

Table 3. **Control Feel Mean Deviation Ratings**

		Fighting Wing		Barrel Roll Attack		Sequential		Free Hassle		Aileron Roll		Loop
1. G-Seat												
G-Suit	I	1.03	I	1.22	I	1.22	I	.76	I	.99	I	.99
Motion	E	.69	E	.41	E	.23	E	.23	E	.125	E	.01
2. G-Seat	I	.62	I	.35	I	.805	I	–.015	I	.53	I	.26
Motion	E	.69	E	.26	E	–.085	E	.60	E	.07		
3. G-Suit	I	–.33	I	.11	I	–.071	I	.25	I	–.26	I	–.04
Motion	E	.52	E	.66	E	–.345	E	.51	E	.53	E	.46
4. Motion	I	.39	I	.199	I	.39	I	.44	I	.02	I	.39
	E	–.03	E	.23	E	.23	E	.36	E	.94	E	.09
5. G-Seat	I	.61	I	.29	I	.29	I	.29	I	.02	I	.29
G-Suit	E	.15	E	.50	E	.655	E	.48	E	.48	E	.48
6. G-Seat	I	.38	I	1.07	I	1.07	I	.75	I	.43	I	.43
	E	.23	E	.36	E	.64	E	.62	E	1.02	E	.61
7. G-Suit	I	.08	I	1.22	I	.76	I	1.40	I	.63	I	.94
	E	–.08	E	–.22	E	–.22	E	.06	E	.18	E	.33
8. None	I	.43	I	.43	I	.43	I	.11	I	.70	I	1.02
	E	.69	E	.165	E	–.03	E	–.26	E	–.17	E	.00

I = Inexperienced.
E = Experienced.

Table 4. **Correlation Matrix (Across All Subjects and Maneuvers)**

	Control Feel	G-Seat	G-Suit	Motion
Control Feel	1.0	.034	.001	.084*
G-Seat		1.0	.149***	.167***
G-Suit			1.0	.016
Motion				1.0

df=382
***p < .01.
**p < .05.
*p < .10.

Table 5. **Correlation Matrix Subject 1 (Experienced Pilot) Across All Maneuvers**

	Control Feel	G-Seat	G-Suit	Motion
Control Feel	1.0	.421***	–.086	.518***
G-Seat		1.0	–.021	.456***
G-Suit			1.0	.265*
Motion				1.0

df=46
***p < .01.
**p < .05.
*p < .10.

Table 6. **Correlation Matrix Subject 2 (Experienced Pilot) Across All Maneuvers**

	Control Feel	G-Seat	G-Suit	Motion
Control Feel	1.0	.064	.047	.179
G-Seat		1.0	.334**	.115
G-Suit			1.0	.119
Motion				1.0

df=46.
***p < .01.
**p < .05.
*p < .10.

Table 7. **Correlation Matrix Subject 3 (Inexperienced Pilot) Across All Maneuvers**

	Control Feel	G-Seat	G-Suit	Motion
Control Feel	1.0	.277*	.277*	.116
G-Seat		1.0	1.0***	.420***
G-Suit			1.0	.420***
Motion				1.0

df=46
***p < .01.
**p < .05.
*p < .10.

Table 8. **Correlation Matrix Subject 4 (Experienced Pilot) Across All Maneuvers**

	Control Feel	G-Seat	G-Suit	Motion
Control Feel	1.0	.206	–.088	.100
G-Seat		1.0	.164	–.332**
G-Suit			1.0	.286**
Motion				1.0

df=46
***p < .01.
**p < .05.
*p < .10.

Table 9. **Correlation Matrix Subject 5 (Inexperienced Pilot) Across All Maneuvers**

	Control Feel	G-Seat	G-Suit	Motion
Control Feel	1.0	–.213	–.328**	.255*
G-Seat		1.0	.233	.333**
G-Suit			1.0	–.040
Motion				1.0

df=46
***p < .01.
**p < .05.
*p < .10.

Table 10. **Correlation Matrix Subject 6 (Inexperienced Pilot) Across All Maneuvers**

	Control Feel	G-Seat	G-Suit	Motion
Control Feel	1.0	.439***	.536***	.318***
G-Seat		1.0	.743***	.248*
G-Suit			1.0	.184
Motion				1.0

df=46
***$p < .01$.
**$p < .05$.
*$p < .10$.

Table 11. **Correlation Matrix Subject 7 (Inexperienced Pilot) Across All Maneuvers**

	Control Feel	G-Seat	G-Suit	Motion
Control Feel	1.0	.226	–.240*	–.088
G-Seat		1.0	.070	–.213
G-Suit			1.0	.148
Motion				1.0

df=46
***$p < .01$.
**$p < .05$.
*$p < .10$.

Table 12. **Correlation Matrix Subject 8 (Experienced Pilot) Across All Maneuvers**

	Control Feel	G-Seat	G-Suit	Motion
Control Feel	1.0	.314*	.351**	.338**
G-Seat		1.0	.102	.251*
G-Suit			1.0	.052
Motion				1.0

df=46
***$p < .01$.
**$p < .05$.
*$p < .10$.

Table 13. **Psychophysiological Effect Frequencies Across All Maneuvers**

1 G-Seat	2 No G-Seat	3 Motion	4 No Motion	5 G-Suit	6 No G-Suit
5	9	12	2	9	5
$X_1^2 = 1.14$		$X_1^2 = 7.14$*		$X_1^2 = 1.14$	

*$p < .01$.

Table 14. **Control Stability Problem Frequencies Across All Maneuvers**

G-Seat G-Suit Motion	G-Seat Motion	G-Suit Motion	Motion	G-Seat G-Suit	G-Seat	G-Suit	—
13	11	14	15	8	9	10	7

$X_7^2 = 5.36$

G-Seat	No G-Seat	Motion	No Motion	G-Suit	No G-Suit
41	46	53	34	45	42
$X_1^2 = .44$		$X_1^2 = 3.68$*		$X_1^2 = .113$	

*p < .10

Table 15. **Dependent Measure Reliabilities Across All Subjects and Maneuvers**

	Control Feel	G-Seat	G-Suit	Motion
R_{xx}	.156	.122	.705	−.196

As a point of interest, four of the pilots were then placed back into the simulator and were questioned as to whether a specific device was operational or not. They were permitted to perform any maneuver/maneuvers they desired. The G-seat and G-suit conditions were correctly evaluated by all four subjects; however, the motion platform condition was incorrectly reported by three of the four, the specific treatment condition remaining constant for all four subjects. The condition was G-suit on, G-seat on, motion off. The implications are obvious. When aware that the G-seat, G-suit, and motion systems were being manipulated, the pilots easily detected the presence or absence of the G-seat and G-suit; however, even when aware that the motion status was changing, detection was difficult. It is reasonable to suspect that the domination of the visually induced motion cues was accountable.

Recommendations

The results of this study strongly suggest that alternative methods to the subjective pilot rating technique be employed when attempting to establish perceptual differences concerning motion-cueing devices in the simulator. One author succinctly stated an important aspect of the problem:

> In the laboratory, the subject's task is to detect motion. In the simulator, his task is to fly. The outputs of the kinesthetic sense do not under normal conditions reach awareness until attention is directed at them. Attention will not normally be directed to motion in the simulator. The problem is that any conventional technique of measuring thresholds involves the subject paying attention to the stimulus modality. Hence, if one conducts a conventional threshold experiment in a flight simulator, even in the presence of a realistic task, one has entirely altered the subject's task from that which one has most interest in. The act of measurement renders the situation unrealistic. In order to determine the threshold levels to motion which are in principle present during flight simulation, a procedure must be used which does not require the subject to attend to motion cues any more than he would do during normal operation of the simulator (Gundrey, 1976).

Although the study attempted to control the pilots' attention to motion cueing by the performance of realistic fight tasks and by the inclusion of irrelevant distractor questions and yet provide adequate attention in order to discriminate the differences in cueing, it would seem from the results that this did not occur; consequently, the seven-point rating scale did not provide the sensitivity required for an adequate evaluation of the pilot's discriminability. Indications demonstrative of this poor sensitivity included the very low reliabilities of the ratings, the small total variance of the ratings, as well as the apparent contradictions in the findings; i.e., although the ratings of the motion system's effectiveness were not significantly different across motion conditions, the incidence of control stability problems were.

The results of this study also place more importance upon Phase II of the proposed research program; i.e., the study of the changes in pilot performance in the simulator due to manipulation of the motion, G-seat, and G-suit systems. The Phase II effort as proposed would provide not only a method for unobtrusive observation of a pilot's control responses to various simulator configurations (an index of discriminability) but also allow for the validation of the measurement algorithms prior to subsequent transfer of training studies.

REFERENCES

Borlace, F. *Flight simulator motion, its enhancement and potential for flight crew training.* Proceedings of the third International Simulation and Training Conference, New York, April 1967.

Brown, F.P., Johnson, H.I., & Mungall, R.G. *Simulator motion effects on a pilot's ability to perform a precise longitudinal flying task.* NASA-TN-D-367, AD-236 265. May 1960.

Conrad, B., & Schmidt, S.F. *A study of techniques for calculating motion drive signals for flight simulators.* NASA Contractor Report CR-114345, July 1971.

Demaree, R.G., Norman, K.A., & Matheny, W.G. *An experimental program for relating transfer of training to pilot performance and degree of simulation.* NAVTRADEVCEN-TR-1388-1, June 1965.

Dichgans, J., Held, R., Young, D.R., & Brandt, T. Moving visual scenes, influence the apparent direction of gravity. *Science,* 15 December 1972, 178, 1217-1219.

Gundrey, J. *Man and motion cues.* Paper presented at the Royal Aviation Society Symposium of Flight Simulation. Farnsborough, Hants, 1976.

Huddleston, H.F. Cockpit motion requirements for flight simulation. *Royal Air Force Institute of Aviation Medicine.* February 1966, Farnborough, Hants.

Johnson, B.E., & Williams, A.C., Jr. Obedience to rotation-indicating visual displays as a function of confidence in the displays. *Aviation Research Monographs,* December 1971, **1**(3), 11–25.

Kirk, R.E. *Experimental design: Procedures for the behavioral sciences.* Belmont, California: Brooks/Cole Publishing Co., 1968.

Matheny, W.G., Lowes, A.L., & Raker, G. *An investigation of visual, aural motion and control movement cues.* Report NAVTRADEVCEN-69-C-0304-1. Life Sciences, Inc., Fort Worth, Texas, April 1971.

Staples, K.J. *Motion, visual, and aural cues in piloted flight simulation.* AGARD CP-79-70. Advisory Group for Aerospace Research and Development, Nevilly-SUR-Seine, France, 1970.

TAC Project 75A-0400. *Evaluation of the simulator for air-to-air combat (SAAC) follow-on test and evaluation report.* February 1976.

Taylor, R., & Gerber, A., et al. *Study to determine requirements for undergraduate pilot training research simulation system (UPTRSS).* AFHRL-TR-68-11, AD-858 640. Wright-Patterson AFB, OH: Training Research Division, Air Force Human Resources Laboratory, July 1969.

Waters, B.K., Grunzke, P.M., Irish, P.A., Fuller, J.H. *Preliminary investigation of motion, visual and g-seat effects in the advanced simulator for undergraduate pilot training (ASUPT).* Paper presented at the AIAA Visual and Motion Simulation Conference, Dayton, April 1976.

Young, L.R. *Developments in modeling visual-vestibular interactions.* AMRL-TR-71-14. Space Sciences Division, Whittaker Corporation for Aerospace Medical Research Laboratory, 1971.

Young, L.R., & Henn, V.S. Selective habituation of vestibuar nystagmus by visual simulation. *Acta Otolaryng,* 1974, 77, 159–166.

APPENDIX A: SAAC EVALUATION FORM

1. How would you rate the resolution of the visual system?

   1 2 3 4 5 6 7

2. Did you notice a change in visual display brightness during the maneuver?

   Yes No

3. Were there any discontinuities in the visual scene during the maneuver?

   Yes No

4. Was it difficult to ascertain the target aircraft's aspect?

   Yes No

5. How would you rate the presentation of the target model?

   1 2 3 4 5 6 7

6. Did you have the opportunity to experience the blackout/greyout feature?

   Yes No

7. Could you detect any changes in the intensity level of the sound?

   Yes No

8. Did the aural effects change in clarity during the maneuver?

   Yes No

9. How would you rate the control feel of the simulator during this maneuver?

   1 2 3 4 5 6 7

10. Did you experience any stability problems in any of the three axes?

    Yes No

11. How would you rate the cues provided by the G-seat?

    1 2 3 4 5 6 7

12. How would you evaluate the G-suit cues?

    1 2 3 4 5 6 7

13. How would you rate the motion platform's cueing?

    1 2 3 4 5 6 7

14. Did you experience any nausea during this maneuver?

    Yes No

15. Did this maneuver subject you to any headaches or eyestrain?

    Yes No

16. Were you at any time during this task disoriented or suffering from any form of vertigo?

    Yes No

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APPENDIX B: GENERAL SAAC DESCRIPTION – Author Unknown

Singer SPD is presently developing the Simulator for Air-to-Air Combat. The objectives of this simulator are to serve as:

1. A research tool for evaluation of fighter aircraft and tactical weapons used in air-to-air combat.
2. A simulator for developing and evaluating air-to-air combat techniques.
3. A low-risk training and maintenance of proficiency simulator for air-to-air combat.

SAAC is a two-aircraft simulator for air-to-air combat, developed primarily to be used by experienced combat pilots in the air-to-air combat environment. The simulator provides spatial infinity views of the other aircraft and synthetic ground terrain visual scenes to the cockpits. The simulator will provide realistic aircraft motion and G-cues derived from the six-degrees-of-freedom motion system, seat buffet and vibration, G-seat, G-suit, and visual G-blackout systems. The realism of these systems has been verified by qualified combat fighter pilots in evaluation reviews throughout the program.

The performance and scoring of the proficiency and their related armament are realistically monitored to accurately determine the validity of kills or misses. The scoring system will critique the pilot and aircraft weapon system based on the pilot pre-launch maneuvers and inflight behavior of the simulated weapons.

The missile flightpaths and cannon ballistic trajectories are determined in real time, and hit or miss calculations are influenced and determined by the maneuvers of the evasive pilot and his experience to avoid a kill situation. The SAAC Program can also develop foreign-type aircraft performance packages to more realistically present enemy type of energy maneuverability envelopes.

As the two pilots are engaged in a combat situation, experienced pilots working as instructors will be able to observe the overall combat situation development. The instructor pilots will be able to critique and assist the aircraft pilots in determining the errors and possible improvements to tactical situations. The situation as viewed by the operators is presented on a three-dimensional display showing the aircraft attitudes and flightpaths as well as the force altitude, angle-of-attack, and airspeed of the two aircraft. As the situation is developing, the operators can switch the display to an out-the-window view of what each pilot is seeing, to better evaluate and obtain full involvement in the mission.

At the instructor station, a display of what stores are available, selected, and fired is presented to the instructor to judge the effectiveness of their use and delivery by pilots. The combat engagement is recorded and significant occurrences can be marked by the instructors. At the end of the mission, the pilots and instructors can play back the mission either in total or only the unique areas of interest, to determine errors made by the combat pilots or the vulnerability of the simulated aircraft. During this debriefing phase, missile and cannon scoring printouts are available to clearly determine how the miss or kill occurred. The record/playback system can be run at half-speed or can be frozen and snapshots taken from a plotter-printer to show when and how the attacking aircraft obtained the advantage and position to make the kill or to show what maneuver the evasive aircraft performed to elude the kill. These record flights can be stored and performed as documented history for future evaluations.

The flexibility of the computational system allows for the ability to change the energy maneuverability of the two aircraft by experimenters. These changes are programmed and loaded into the computer complex in modules; e.g., fuel control surfaces or engine. These new aircraft characteristics can then be evaluated by the same pilots to determine if the aircraft can obtain an advantage. If these experiments prove valid on the simulator, they could be implemented into real aircraft design.

The present computer complex consists of three general purpose computers which control the motion, cockpit instrumentation, visual system and the elaborate air combat engagement displays system.

Some of the air-to-air training and evaluation capabilities of the SAAC include:

1. Two pilots in a one-on-one, head-to-head air combat engagement.

2. One pilot flying an attack against a predetermined evasive maneuvering enemy aircraft.

3. One pilot flying defensive wingman for a predetermined lead aircraft.

4. Two friendly aircraft start off in a spread format or search mode; when enemy aircraft is sighted, the lead aircraft and wingman switch over to a fighting wing position. In the fighting wing, the lead aircraft attacks the enemy aircraft while his wingman attempts to provide tight positional control on the lead aircraft and provide protective coverage.

SAAC Sub-Systems Descriptions

The SAAC realistically simulates the performance of two F-4E fighter aircraft engaged in one-on-one aerial combat, by performing an accurate real-time simulation of the forces, moments, accelerations, velocities, attitudes, flightpaths, system responses, and relative positions of the two aircraft in response to control actuations by the two pilots.

Flight Controls

The complete F-4E flight control system is provided in the two cockpits. The F-4E primary flight controls consist of the stabilator, rudder, ailerons, and spoilers. Secondary controls consist of the wing-mounted speed brakes.

Accessary Systems

Realistic simulation of the engines, fuel systems, electrical power, icing, pneumatic, oxygen, bleed air, cabin pressurization, canopy and seat ejection, anti-G and pressure suits, cockpit lighting, and the caution and warning systems are provided for each cockpit.

Radar and Fire Control Computer

The forward-looking radar system is simulated to assist in target location prior to visual identification. The system provides single air target location capability by displaying target range, elevation, and azimuth information. An automatic lock-on feature is provided at the operator's station for acquiring the target within 50 miles. After acquisition, an attack display will be presented on the command indicator, providing steering information corresponding to the operational envelope of the selected weapon.

Air Data Computer System

The simulated air data computer supplies corrected static pressure outputs to the altimeter, vertical velocity indicator, and the airspeed/Mach indicator. The computer also will supply electrical output signals to the fire control system for computing missile guidance.

Lead Computing Optical Sight

The lead-computing optical sight system (LCOSS) is simulated to provide correct lead angle generation for air combat operation with the visual system. The sight will function in the air-to-air mode and provide the pilot aircraft attitude and target information via reticle symbology.

Stores Management

Control and monitoring equipment is provided to simulate ejection or launch of air-to-air missiles and guns. The controls and indicators duplicate the operating characteristics and physical appearance of the aircraft equipment. Connection with other systems–i.e., flight equations and weapon systems–is provided as required for realistic weapon delivery operation. The aircraft weapon system attach points are simulated to provide loading effects to other system simulations. For example, each load has a specific gross weight, drag coefficient, and position which must be considered in the aerodynamic and weight and balance equations.

NAVCOM Systems

Operation of the ADI, HSI, radar altimeter, and standby compass is provided for in the individual aircraft simulations. The HSI is limited to compass directions only, since there is no TACAN simulation providing range, bearing, and deviations. The aircraft intercom provides communication between the pilots and the instructor station.

Aural Effects

The normal and abnormal sounds that are conspicuous in the cockpit during air-to-air combat missions are provided by means of a sound generator. The blending of various sounds is controlled by the simulator computer programs as a function of such parameters as engine speed, airspeed, armament firing, etc. Sounds which are simulated include airflow, engines, hydraulics, armament, and stall and buffet.

Motion Systems

Each cockpit is mounted on a 60-inch-stroke, synergistic six-degrees-of-freedom motion system with improved shock limiting. Cockpit movement is based upon the computed six degrees of aircraft motion freedom and is correctly correlated with the motion of the simulated aircraft. All aircraft stability derivatives are accounted for in such a manner that aircraft movement in any degree of freedom will correctly influence movement along or about the axes of the motion system. The motion system will respond correctly to aircraft center of gravity or center of pressure movements, including fuel depletion, fuel dump, and various aerodynamic effects. The sensations of motion are representative of sensations experienced in the operational aircraft resulting from changes in the flightpath, such as banks, climbs, dives, acceleration/decleration, buffets, stalls, slips, and control-induced changes in the exterior configuration of the aircraft. The motion system software drive signal programs will satisfy four basic objectives:

1. Rotational acceleration simulation through platform re-orientation

2. Onset phase translational acceleration through platform translational movement.

3. Long-term acceleration simulation through subliminal platform reorientation to cause body-axis gravity projections to be interpreted as sustained external force acceleration

4. Position and velocity washout at subliminal acceleration levels.

Scoring Systems

A scoring system is provided for computation of missile and gunfire trajectories in order to determine pilot air-to-air combat competence. The real-time inflight missile trajectory computational algorithm employs the flight dynamics and maneuvering capabilities of the AIM-9 missiles. The AIM-7 missile simulation involves a point (A) to (B) solution when all fire control conditions are satisfied. The gunfire trajectory equations will determine probability of kill based on the two aircraft's maneuvers, spatial positions, and firing condition of the weapon systems. Scoring readout information is displayed at the operator's station and/or by line printer. A critique of interceptor and target pilot performance is provided by the line printer on command from the operator's station. This information consists of launch or firing conditions (range, target, and interceptor velocity, lead angles, etc.) and information pertinent to hit or miss conditions, such as miss distance and angle. The design includes the sophistication needed to inform the instructor of the cause of a miss, such as excessive forces at launch, gun fired while out of effective range, successful evasive maneuver by target, afterburner, and sun position.

G-Seat

Sustained g simulation will be provided by a G-seat in each cockpit. The general simulation philosophy employed by this system is to present sustained acceleration and small motion onset cues as defined by the simulated aircraft equations of motion. G-seat simulation is accomplished by inflatable cushions which provide the somatic sensations experienced by the pilot's buttocks, thighs, and back during high-g maneuvers.

G-Suit

Sustained acceleration effects are also simulated by activation of the G-suit systems in each cockpit. Pressure is supplied to the suit when the upward acceleration at the pilot's position, as computed in the equations of motion, exceeds 0.75g. The pressure will be linearly variable from 0.4 psi to a maximum of 15 psi, with a maximum rate of change of 2 psi/g. Any slope less than the maximum may be selected. The desired slope will be supplied by a pilot-operated adjustment. The maximum capability is 15-psi suit pressure, with relief valves near the suit connectors adjustable up to and including 15 psi.

High-G Blackout Cues

Perceived light level dimming as a function of high-g loading is provided as a high-g blackout cue. The most noticeable visual effect of high g loading is the entrance to an exit from the blackout condition. Normal relaxed subjects seated in an upright position experience a loss of peripheral vision at approximately the 4g level and complete blackout at the 4.5g to 5g level. These values are not absolute because the function is dependent not only on the g loading level, but also on the acceleration build-up rate (jerk) and the time integral of the acceleration profile.

The visual scene brightnesses are controlled by the D/A linkage and software program. This program will accept inputs of g-level, g-vector orientation, rate on onset, and duration and will respond by production of a commanded cockpit light level and visual scene brightness.

Buffet and Vibration Effects

The effects of aircraft seat buffet and vibration are simulated. Frequencies and amplitudes correspond to those experienced in the aircraft at any point within the operational flight envelope. Vibrations are generated by a mechanism mounted in the seat. The vibration system provides a frequency range of 3 to 20 Hertz, a peak velocity of 25 inches per second, and a maximum displacement of ± 1 inch. Amplitude response of the servo falls off in frequency so as to limit the maximum acceleration capability to 2g.

Visual System

The SAAC visual system consists of the following subsystems:

1. Aircraft Image Generator (AIG)
2. Synthetic Terrain Generator (STG)
3. Mosaics
4. Display System

The visual black-and-white display system for each cockpit displays terrain, horizon, sky, and sun image as well as the other aircraft with speed brakes and afterburner operation visible. These visual elements, along with the required gun and missile kill, and sun model glint effects, are presented by means of a three-axis gimbal system and aircraft model, high-resolution camera, synthetic ground and sky generator system, and a special effects generator, whose output will be viewed through eight pentagonal display windows. This display system provides the pilot with a near unlimited field of view. The inline infinity optics (Pancake Windows TM) are mounted so as to form eight faces of a dodecahedron. This arrangement essentially encloses the pilot and cockpit with displays. The center of the field of view is located at the pilot nominal eye position.

Technical capabilities in the visual area alone, which put the SAAC in a class by itself and beyond existing devices, are:

1. Large, wide angle visual display to operate on a motion system.
2. Wrap-around (unrestricted field of view) infinity-image display.
3. "Extremely high" resolution picture of other aircraft (up to 1 arc-minute) to perm operations at slant ranges from 300 feet to 30,000 feet.

4. A visual display of the ground which will provide a correct representation of all aircraft attitude and translational motions (e.g., position, velocity, altitude, and sink rate).

Because of the high-resolution image (1,200 scan lines per inch, compared with 525 for a home TV set), the target can be seen as far away as 3 miles. At 1 mile, the pilot can make out details such as direction, speed, attitude, and wing geometry.

Besides being a training tool, the simulator will be used to study the flight dynamics of aircraft–specifically, how to delay the onset of a stall and spin. New aerodynamic parameters involving direct lift and side force also will be investigated, and the simulator will be used to answer basic questions about simulation itself. For example, is simulation an effective research tool for studying air-to-air combat? How could it be improved for more realism?

APPENDIX C: CUE MAGNITUDE SCALE

1. *Extremely Less:* Cue is missing or magnitude is so small that it cannot be detected.
2. *Apparently Less:* Cue magnitude is apparently less when compared to the aircraft.
3. *Slightly Less:* Cue magnitude is slightly less when compared to the aircraft.
4. *Same:* Cue magnitude is the same as the aircraft.
5. *Slightly Greater:* Cue magnitude is slightly greater when compared to the aircraft.
6. *Apparently Greater:* Cue magnitude is apparently greater when compared to the aircraft.
7. *Extremely Greater:* Cue magnitude is extremely greater when compared to the aircraft.

APPENDIX D: SAAC CONFIGURATION EVALUATION BRIEFING OUTLINE

You are participating in an evaluation of various configurations of the Simulator for Air-to-Air Combat. During the course of the study, we will ask you to rate certain features of the simulator, such as the resolution and brightness of the visual system and the clarity and intensity of the sound system.

You will fly eight identical mission profiles in the SAAC, each lasting approximately 30 minutes. During the sorties, you will be requested to perform the following maneuvers:

1. Formation–Fighting Wing
2. BFM–Barrel Roll Attack
3. ACM–Sequential Attack
4. Free Hassle
5. Aileron Roll
6. Loop

Your performance on these maneuvers will be automatically recorded by the computer. At the completion of each maneuver, you will be asked to give your ratings on the various simulator features.

Necessary equipment for all sorties: Helmets and G-suits.

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