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AFHRL-TR-78-98

LEVEL II

AIR FORCE

HUMAN RESOURCES

AD A070231

PILOT PERFORMANCE IN SIMULATED AERIAL REFUELING AS A FUNCTION OF TANKER MODEL COMPLEXITY AND VISUAL DISPLAY FIELD-OF-VIEW

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May 1979
Final Report for Period October 1977 – February 1978

Approved for public release; distribution unlimited.

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This final report was submitted by Flying Training Division, Air Force Human Resources Laboratory, Williams Air Force Base, Arizona 85224, under project 1123, with HQ Air Force Human Resources Laboratory (AFSC), Brooks Air Force Base, Texas 78235. Mr. Robert Woodruff (FTR) was the Principal Investigator for the Laboratory.

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

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFHRL-TR-78-98
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): PILOT PERFORMANCE IN SIMULATED AERIAL REFUELING AS A FUNCTION OF TANKER MODEL COMPLEXITY AND VISUAL DISPLAY FIELD-OF-VIEW
5. TYPE OF REPORT & PERIOD COVERED: Final, October 1977 – February 1978
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): Robert R. Woodruff, Philip A. Irish, III, Thomas M. Longridge, Jr., Richard T. Jeffreys
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Flying Training Division, Air Force Human Resources Laboratory, Williams Air Force Base, Arizona 85224
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62205F, 11921014
11. CONTROLLING OFFICE NAME AND ADDRESS: HQ Air Force Human Resources Laboratory (AFSC), Brooks Air Force Base, Texas 78235
12. REPORT DATE: May 1979
13. NUMBER OF PAGES: 24
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited.
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
    - flight simulation
    - refueling
    - simulator
    - training
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This research was conducted in the Advanced Simulator for Pilot Training (ASPT) to determine Computer Image Generation (CIG) complexity and field-of-view (FOV) requirements for aerial refueling (AR). The adequacy of three detail levels and five FOVs was assessed. Aircraft simulated, in addition to the KC-135 tanker, were the A-10, F-4, B-52, and F/FB-111. Twelve experienced pilots (three per aircraft) served as subjects. Performance measures included elapsed time to criterion, number of disconnects and aircraft control profile. An assessment of FOV position employed for takeoff/landing versus AR was also made. A-10 and F-4 pilots found the visual FOV position employed for simulated takeoff/landing must be raised approximately 12 degrees to accomplish AR. B-52 and F-111 pilots found AR could be satisfactorily performed using the same FOV position employed for takeoff/landing. Performance measures clearly indicated that AR performance varies as a function of both FOV size and tanker detail

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Unclassified

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level. The larger the FOV, the better the performance. Similarly, the more detailed the tanker model, the better the performance.

PREFACE

This report covers research conducted by the Flying Training Division of the Air Force Human Resources Laboratory, Williams Air Force Base, Arizona between October 1977 and February 1978. The project was conducted at the request of the Simulator Systems Program Office, ASD/SD24, Wright-Patterson AFB, Ohio. It supports project 1123, Flying Training Development, Mr. James F. Smith, project scientist; task 112310, Simulator Engineering Support, Mr. Warren Richeson, task scientist; work unit 11231014, ASPT Refueling Modeling, Mr. Eric Monroe, principal investigator.

The authors appreciate the assistance in this effort of Mr. T. F. Sun, Capt James H. Keller, and Mr. Bryon Pierce, who performed the mechanics of data analysis, and of the pilots who acted as subjects: Maj Larry McMaster, Capt Dick Johnston, Capt George Davies, Capt Rich Amisano, Maj Pat Daly, Capt Dan Williams, Capt Tom Goyette, Capt Bill Beno, Capt Nick Nicolai, Maj Chuck Larson, Maj M. (Sonny) Norsworthy, and Capt Bill Schnittger.

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I. INTRODUCTION

Statement of the Problem

Major command requirements for new aircrew training devices (ATDs) are becoming more full-mission oriented as state-of-the-art simulation technology increases the prospects of being able to teach and rehearse many tasks that could previously be taught only in the aircraft. Aerial refueling (AR) is one such task. Requirements for AR simulation exist in the majority of the ATDs now being specified. Examples are ATDs for the B-52, C-5, A-10, EF-111A, F-4, F-15, F-16, and F/FB-111 aircraft. Several ATD visual system manufacturers have demonstrated AR simulations; however, the ability of these simulations to satisfy the Air Force AR training requirements in a cost-effective manner is unsubstantiated. Therefore, the Flying Training Division of the Air Force Human Resources Laboratory (AFHRL/FT) undertook this study to answer specific AR simulation questions. The study was requested by the Simulator System Program Office (SIMSPO), assigned to the Aeronautical Systems Division (ASD/SD24) of the Air Force Systems Command.

The requirement for an AR simulation study originated in October 1976. At that time, it appeared that night-only computer-image-generation (NOCIG) systems would be included on the A-10 Operational Flight Trainers (OFTs) being procured by the SIMSPO for the Tactical Air Command (TAC). It was hoped that the visual system on the A-10 OFT would be suitable for AR as well as normal transition training; however, the limited detail available in the NOCIG systems that had been demonstrated raised questions concerning the effectiveness of AR training using them. The SIMSPO proposed that AFHRL/FT evaluate the possibility of using the Advanced Simulator for Pilot Training (ASPT) to emulate a NOCIG visual system to determine the feasibility of AR training under these conditions.

After the SIMSPO study requirement was originally formulated, several simulator acquisition program contracts were awarded. The SIMSPO awarded contracts for A-10 and F-16 OFTs, both with single-window, single-channel CIG visual systems. The Simulator System Managers at Ogden Air Logistics Center awarded contracts for four-window, three-channel CIG visual systems to be installed on existing and future F/FB-111 simulators and for three-window, three-channel CIG visual systems to be installed on existing A-7D/F-4E simulators. The AR simulation capabilities were included in the specifications for all of these procurements. These procurements made the goal of determining whether AR training was feasible moot because there was no chance to influence these procurements. Therefore, the primary objective of the AR study was changed from determining whether AR training could be accomplished to determining the effects of tanker model level of detail on pilot performance in the context of the display systems being procured.

AFHRL/FT agreed to undertake the study, and through a series of meetings with SIMSPO, preliminary planning tasks were divided between the two organizations. SIMSPO provided the requirements, identified the experimental factors to be included, and identified the systems to be modeled. AFHRL/FT designed the experiment, modeled the various tanker configurations (levels of detail) and visual systems, developed the performance measurement system, and identified selection requirements for the pilots to be used in the study. Throughout 1977, several iterations of planning meetings and changing requirements and test plans occurred. In August 1977, AFHRL/FT and the SIMSPO finalized the experimental variables and solicited support from TAC and the Strategic Air Command (SAC). A demonstration of the AR simulations was held at AFHRL/FT on 24 January 1978, and data were collected from the subject TAC and SAC pilots during the weeks of 30 January and 6 February 1978, respectively.

Objectives

The primary objective of the study was to determine the effects of tanker model level of detail on the performance of pilots in the context of the display systems being procured. In addition, three secondary objectives were to answer the following questions.

1. Could AR tasks be accomplished with the restricted fields of view (FOV) of the four selected visual system configurations oriented on their respective simulators to optimize the visual scene for takeoff and landing tasks?

2. What would be the optimum locations of the FOVs for the AR task for the four configurations?

3. Could takeoff and landing be accomplished with the visual system FOVs positioned optimally for the AR tasks?

II. METHODOLOGY

SIMSPO Requirements

SIMSPO specified three types of variables to be examined in this project. The first variable was visual display FOV, with four FOVs being specified: one for each of the four types of visual systems being procured. These visual systems all have cathode ray tube (CRT) displays; the A-10 and B-52 visual systems have a single window (one CRT), and the F-4/A-7 visual systems have three windows. The F/FB-111 has four windows, but only three of these are seen by the pilot, and those three were modeled for this study. The configurations of these displays may be seen in Figure 1. Degrees indicated are relative to the pilot's eye position.

The second variable was the location of the FOV. The initial positions were specified by SIMSPO and correspond to actual locations in the simulators being procured. These locations are optimized for takeoff and landing.

The third variable of interest was the complexity of the image in the visual scene. Since the specified simulators will all have CIG visual systems, SIMSPO wanted some indication as to the minimum model definition (level of detail) that would be required to portray the tanker aircraft model. SIMSPO specified the approximate levels of complexity desired, and AFHRL/FT engineers developed three models using this guidance plus a photograph of a complex model from the General Electric (GE) 2B35 system built for the Navy. (More detailed explanation of this and other FT engineering efforts that supported this study may be found in Monroe, Mehrer, Engel, Hannan, McHugh, Turnage, and Lee (1978).)

Equipment

This study was conducted using ASPT. The ASPT visual display system consists of seven CRTs which present a wide-angle (150° vertical X 300° horizontal) collimated display to the pilot. The display may be electrically masked to produce FOVs of any size, shape, and location. The ASPT image generation computer has a capacity of 2500 edges. ASPT also includes a synergistic six-degrees-of-freedom motion system and a pneumatically driven g-seat. (A more detailed description of ASPT may be found in Gum, Albery, and Basinger (1975).)

Subjects

Twelve pilots, six from TAC and six from SAC, served as subjects for this study. TAC provided three F-4 pilots, one A-10 pilot, and two A-7 pilots. (The two A-7 pilots flew the A-10 configuration.) Two of the F-4 pilots had only recently returned to the cockpit, after not having flown for the previous 2 and 4 years respectively. The SAC subjects were all qualified in the B-52 or F/FB-111. One of the F/FB-111 pilots, however, had been an AR instructor during recent months and, consequently, did not have as much recent hands-on AR experience as did the others. Table 1 provides a summary of subject experience.

Approach

Aircraft simulation. The characteristics of the ASPT were different for each of the aircraft represented in this study. In particular, the FOV was altered to be the same as the aircraft simulator being procured, and the handling qualities of the aircraft were approximated. For fighter and F/FB-111

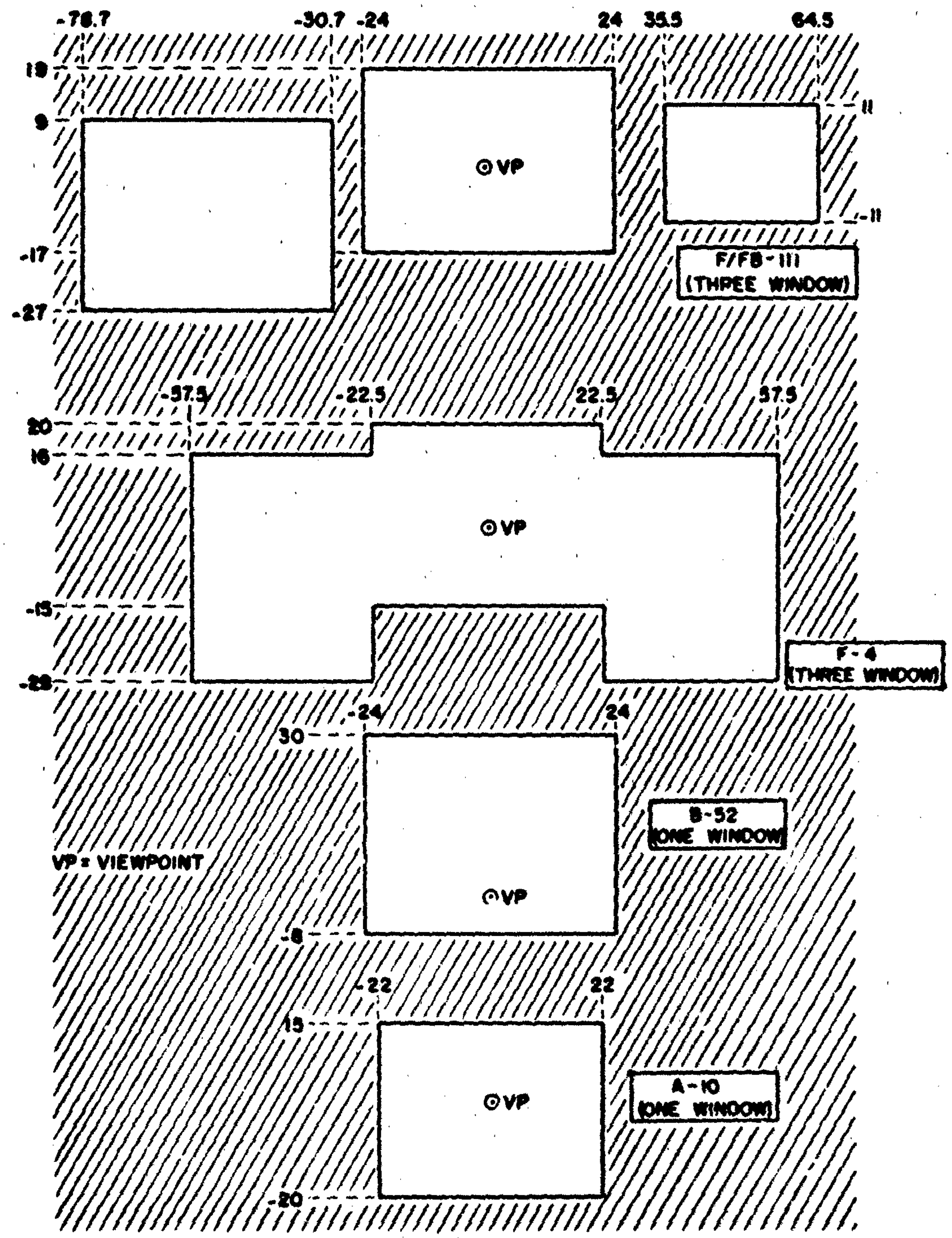

Figure 1. Aerial refueling display configuration.

Table 1. **Experience of Subjects**

Subjects	Years Rated	Pilot Hours		Refuelings		
		Total	Current Aircraft	Total	Current Aircraft	Last Year
F-4-1	10	2,300	2,100	200+	200+	2
F-4-2	13	3,690	1,240[a]	250+	250+	2
F-4-3	15	3,870	2,300[b]	600	600	2
A-10-1	9	2,100	150	52	2	2
A-10-2 (A-7)	6	1,400	1,200	100	100	2
A-10-3 (A-7)	6	1,750	700	24	24	4
B-52-1	8	3,055	1,600	200	200	15
B-52-2	11	4,920	4,800	600	600	35
B-52-3	8	3,220	1,800	200	200	25
F-111-1	11	3,400	700	100+	100+	25
F-111-2	12	3,565	625	500+	300	100
F-111-3	6	2,200	450	70	70	7[c]

[a]No Time 1973-1977 - 40 Hours in 1977-1978.
[b]No Time 1975-1977 - 50 Hours in 1977-1978.
[c]IP during 1977.

characteristics, the thrust and drag of the T-37 model were changed by adjusting the engine response time constant. (This resulted in near instantaneous response to throttle inputs.) For the B-52, in addition to changes in thrust and drag, aircraft gross weight was increased to change inertial response. A more detailed discussion of these changes may be found in Monroe *et al.* (1978).

The simulated refueling receptacle (which receives the tanker boom) was positioned to be in its correct location relative to the pilot's eye point. The receptacle for the A-10 was located on the nose, and for the other aircraft, it was located behind the cockpit either on or off the aircraft centerline. The cockpit configuration was not changed. Instrumentation, control arrangement, and location of canopy bows were those of a T-37. Each pilot flew only one simulated aircraft. Except for the A-7 pilots who flew the simulated A-10, the pilots flew the simulated aircraft they were experienced in. Each of the pilots flew the final AR task with both of the FOVs being procured by that pilot's command.

FOV location. In general, the approach planned to assess the FOV location was simply to have the subjects fly subjective evaluation sorties in ASPT. SIMSPO wished to have the evaluations begin at one of three specified rendezvous points (one-half mile behind, 1000 feet below the tanker, and on the tanker centerline or ± 10° horizontally). Each subject flew from one of the rendezvous points to the precontact position, stabilized, and then flew to the contact position. The function of the three rendezvous points was to determine the visibility of the tanker from a variety of positions. At contact the subject was required to remain on the boom for 1 minute. Each subject flew with the FOV located initially in the position specified by SIMSPO. The pilots were instructed to request a change in FOV location if, at any time between rendezvous and contact, they lost the visual cues they considered necessary to accomplish the task. If a pilot so requested, ASPT was immediately frozen, and the pilot was permitted to reposition the FOV using a helmet-mounted device (described in LeMaster and Longridge (1978)). The modified location was then recorded, ASPT was released, and the mission continued. In this way, the FOV size needed to accomplish a complete refueling mission from rendezvous to contact could be determined. The suitability of the adjusted FOVs for takeoff and landing was then evaluated.

Tanker Model Complexity. The three tanker models requested by the SIMSPO were described as (a) a complex day model, (b) an austere day model, and (c) an austere night model. AFHRL/FT engineers produced these three models with 1127, 213, and 241 computer edges, respectively. Although more edges were used in the night austere model than in the day austere model, the night model was more austere because its reduced contrast made the necessary visual cues more difficult to see. Figures 2 through 8 are wide-angle photographs taken inside the cockpit of the simulator used for this study. These photos show a selection of the three tanker models within the four FOVs from an approximate contact position behind the tanker. The camera was located at approximately the pilot's eye position. It appears that the ASPT T-37 canopy bow obscures a significant amount of the display; however, the pilots were able to move their heads within the 6-inch exit pupil radius of the display, and this, together with their binocular vision, eliminated most of the undesirable effects. The FOVs for the B-52 and F/FB-111 are shown in the position specified by SIMSPO, and the subjects found these locations satisfactory for AR. The subjects did not find the locations that SIMSPO specified for the A-10 or F-4 to be satisfactory for AR training. The locations shown in the photographs for those aircraft are not those specified by SIMSPO. The subjects were permitted to choose new locations which would enable them to perform AR successfully, and the figures show these selected locations. The effects of tanker model detail on pilot performance were evaluated using ASPT automatic performance measurement. Each subject performed a specified refueling task with each of the three models and each of the two FOVs being procured for that pilot's command. In addition, AR was performed using the ASPT full FOV (150° x 300°) and the three models. Subjects were randomly assigned order of conditions. A 3 by 3 repeated measures design was employed for each command. The task the subjects performed was simply to fly their aircraft from the precontact position to the contact position and to maintain contact for a specified time. Three minutes of tanker contact time was originally specified. Some subjects experienced excessive fatigue, however, in meeting this criterion in the F-4/A-10 configurations, and the required time was reduced to 1 1/2 minutes for the TAC pilots. The 3-minute requirement in the B-52/F/FB-111 configurations was met by the SAC subjects. Director lights on the tanker were operational throughout the task. The ASPT console operator simulated a tanker boom operator by giving standard instructions to the pilots. The subjects flew with the FOV optimally located for AR.

Figure 2. Full FOV/complex.

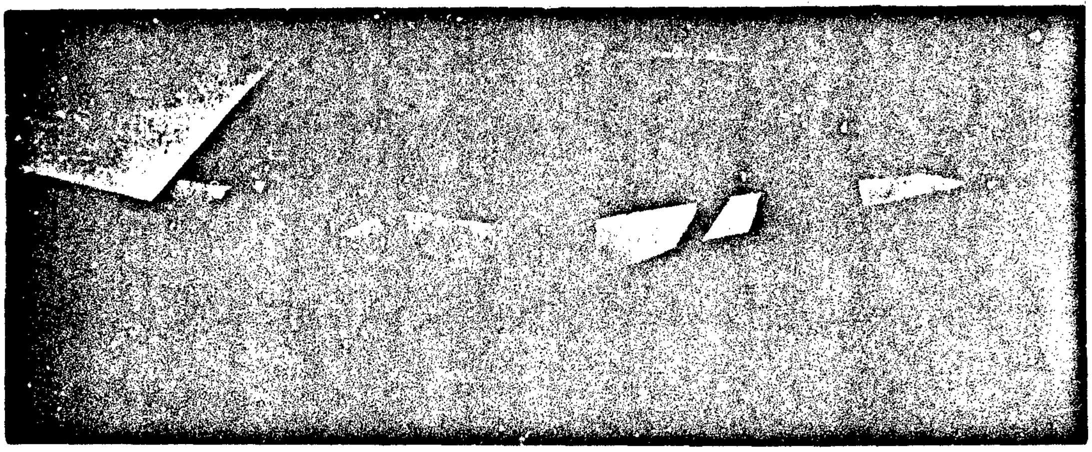

Figure 3. **Full FOV/day austere.**

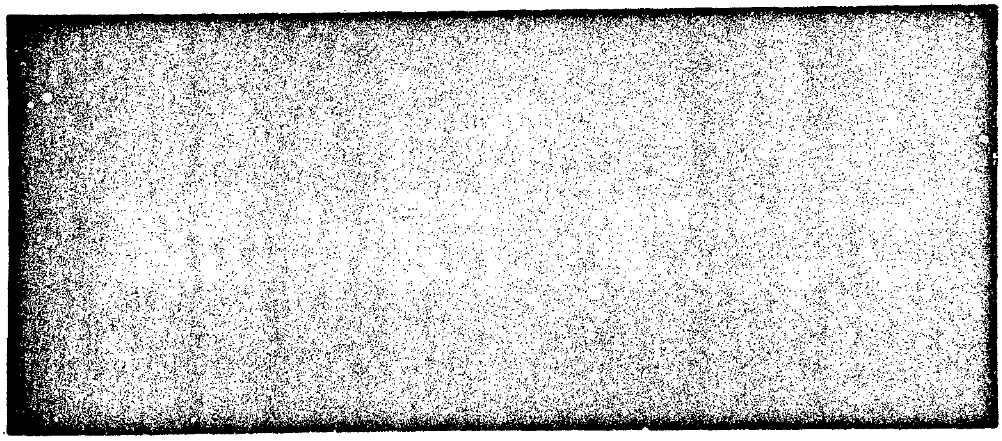

Figure 4. **Full FOV/austere night.**

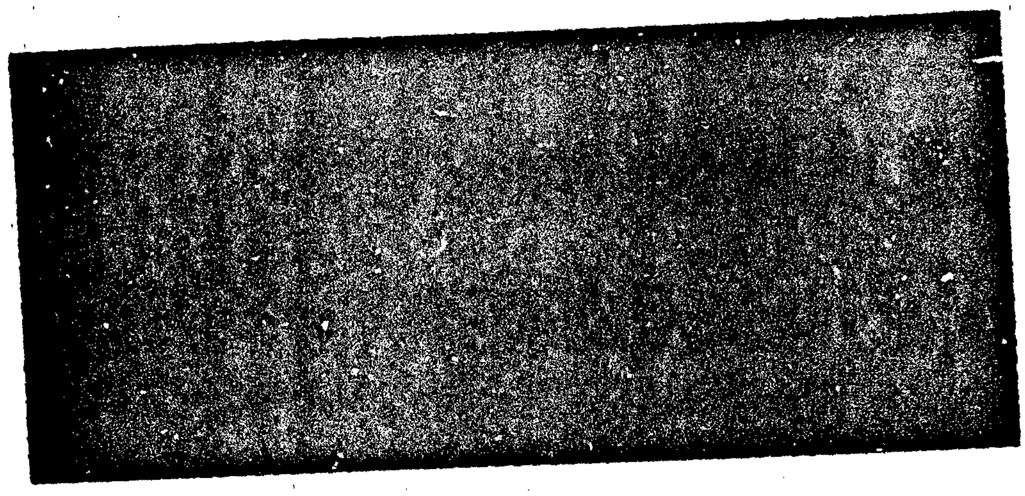

Figure 5. B-52 FOV/austere night.

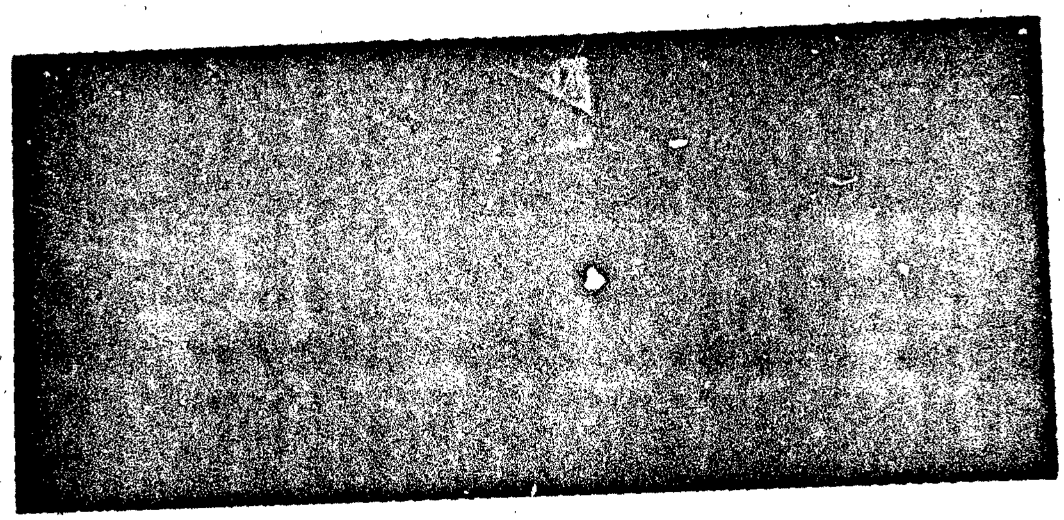

Figure 6. F-4 FOV/complex.

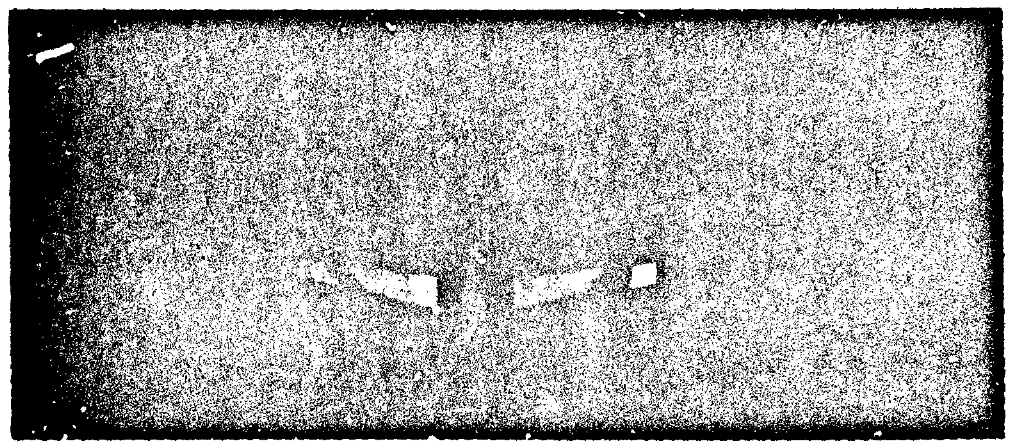

Figure 7. **A-10 FOV/austere day.**

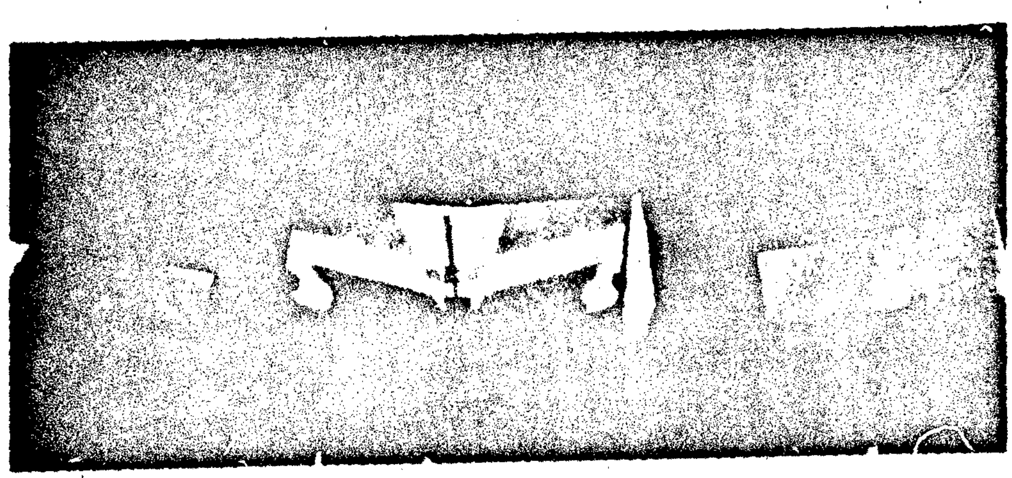

Figure 8. **F-111 FOV/complex.**

Performance Measures

Performance was measured automatically only during the final AR task. The measures taken were:

During contact, the amount of oscillation of the receiver aircraft receptacle around the center point of the acceptable boom movement envelope. A description of the automated procedure which performed this measure may be found in Monroe *et al.* (1978).

During contact, a variety of measures reflecting the smoothness of pilot aircraft control; included were aileron power, aileron RMS position, and aileron RMS movement.

The number of involuntary disconnects during the total hook-up (contact) time.

The time required to complete the task to criterion.

Specific Procedures

Each subject performed four ASPT sorties.

ASPT familiarization was done first. With the FOV in the position specified by SIMSPO, the subject flew from the precontact position behind the tanker to the contact position and maintained contact for 1 minute; this was done four times (two times with each of the two displays selected by that subject's command). Next the subject flew one takeoff and one landing using the display configuration for the aircraft being simulated. (At the request of SIMSPO, simulation of the F-4 and A-10 used the g-seat but not the motion platform; the B-52 and F/FB-111 simulations used platform motion but not the g-seat.)

Evaluation of the takeoff and landing display configuration for refueling followed familiarization.

1. ASPT was initialized at rendezvous point 1, 2, or 3 with the visual display FOV located according to SIMSPO specifications.

2. The subject then located the tanker and flew to the precontact position. Approaching precontact, the console operator acted as a boom operator to talk the subject into position.

3. When a console graphic display indicated "precontact," the console operator cleared the subject to proceed to contact. The console operator continued to act as a boom operator.

4. In the event that sufficient visual information was lost (e.g., the tanker left the FOV):

   a. The subject immediately asked the console operator to problem freeze the simulator.

   b. The subject was then asked about what necessary cues had been lost and his responses were noted.

   c. If the FOV needed to be moved, the subject requested the console operator to unfreeze it. The subject then moved the FOV to what he considered an optimum position and requested that the console operator again freeze the display.

   d. ASPT was then unfrozen and the test continued.

The purpose of the third sortie was to test the relocated FOV for takeoff and landing. The final AR FOV locations of all subjects from one major command were averaged, and the resulting AR mean FOV was evaluated for takeoff and landing as follows:

1. ASPT was initialized to the takeoff position on a simulated airfield, with the FOV located in the average AR position.

2. The subject then flew a takeoff.

3. ASPT was next initialized to a position for straight-in approach.

4. The subject flew the straight-in approach.

During the fourth sortie, subject performance was measured from the precontact position to the contact position, using two display configurations (for each major command), full FOV, and three levels of detail.

1. Each subject flew with both of the displays (for a particular command), plus an ASPT full-FOV condition, and with each level-of-detail condition.

2. Subjects were randomly assigned to experimental treatment.

3. ASPT was initialized at the precontact position.

4. The subject selected the FOV location for optimal performance.

5. Performance measures were activated and ASPT was released.

6. The subject flew to the contact position and maintained contact for a specified time; one trial for each treatment condition.

After the four sorties were completed by all subjects, they were debriefed.

III. RESULTS

Location of the FOV

The complex model was used to evaluate the adequacy of the three FOVs from the three rendezvous points. The model was visible from this point in all FOVs, except the A-10. It was necessary to raise the A-10 FOV to bring the tanker into view. The A-10 pilots chose to raise the FOV an average of 12.4 degrees. No change in lateral FOV location was necessary.

The location of the FOV for the B-52 and for the F/FB-111 at the precontact and contact positions was judged to be satisfactory. The pilots flying the F-4 and A-10 configurations, however, did move their FOVs vertically. The A-10 pilots moved the FOV vertically an average of +12.3 degrees (the similarity to the change made at rendezvous is coincidental), and then found that the 12.3 degree change interfered with their ability to takeoff and land in the simulator. The mean vertical change made by the F-4 pilots was +12.5 degrees, and this relocated FOV caused great difficulty in both takeoff and landing. The B-52 pilots also experienced difficulty, especially with takeoff. This may have been an artifact of the simulation; B-52 rotation on takeoff is only 1 degree, whereas the subjects found it necessary to rotate the ASPT from 6 to 11 degrees on takeoff.

Motion and g-seat

The SAC pilots felt the motion was realistic and a necessary part of the simulation. The TAC pilots' evaluation of the g-seat was neutral.

Pilot performance

Study 1 (A-10/F-4). Figures 9 and 10 graphically portray the mean elapsed time to criterion as a function of model and window configuration, respectively; the analysis of variance (ANOVA) is given in Table 2. Time required to complete the AR was a monotonically decreasing function of model complexity—as complexity increased, the mean time needed to complete 1.5 minutes of AR decreased significantly ($F = 5.14$, $p < .05$). Similarly, as window size increased, the mean time to criterion decreased ($F = 3.53$, $p < .10$). The interaction between model and window configuration was non-significant ($F = .86$, N.S.).

Figures 11 and 12 present the mean number of disconnects as a function of model and window, respectively; the ANOVA is given in Table 3. The results directly parallel those concerning elapsed time. As model complexity decreased, the mean number of disconnects increased significantly ($F = 12.36$, $p < .01$). As window size increased, the mean number of disconnects decreased significantly ($F = 4.15$, $p < .05$). The interaction between model and window configuration was again non-significant ($F = .56$, N.S.).

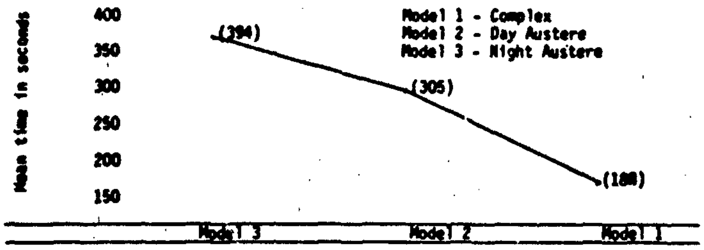

Figure 9. **Study 1 (A-10/F-4): Mean elapsed time to criterion as a function of model.**

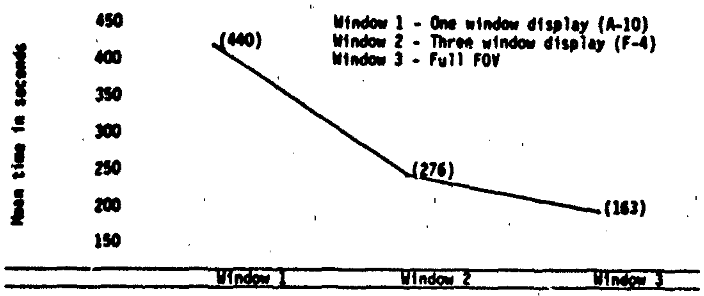

Figure 10. **Study 1 (A-10/F-4): Mean elapsed time to criterion as a function of window configuration.**

Table 2. **Study 1 ANOVA (A-10/F-4): Elapsed Seconds to Criterion**

Source	SS	df	MS	F
Model	418,576.63	2	209,288.32	5.14**
Window	697,720.35	2	348,860.17	3.53*
Subjects	1,643,318.01	5		
Model x Window	146,528.95	4	36,632.24	.86
Model x Subjects	407,578.39	10	40,757.84	
Window x Subjects	987,437.90	10	98,743.79	
Model x Window x Subjects	857,052.07	20	42,852.60	
Total	5,158,212.29	53		

$\bar{X}$ Model 1 = 180.07 $\bar{X}$ Model 2 = 305.08 $\bar{X}$ Model 3 = 394.75
$\bar{X}$ Window 1 = 440.26 $\bar{X}$ Window 2 = 276.18 $\bar{X}$ Window 3 = 163.43

Note. Model 1 – Complex.
Model 2 – Day austere.
Model 3 – Night austere.
Window 1 – One-window display (A-10).
Window 2 – Three-window display (F-4).
Window 3 – Full FOV.

$^*p < .10$.
$^{**}p < .05$.

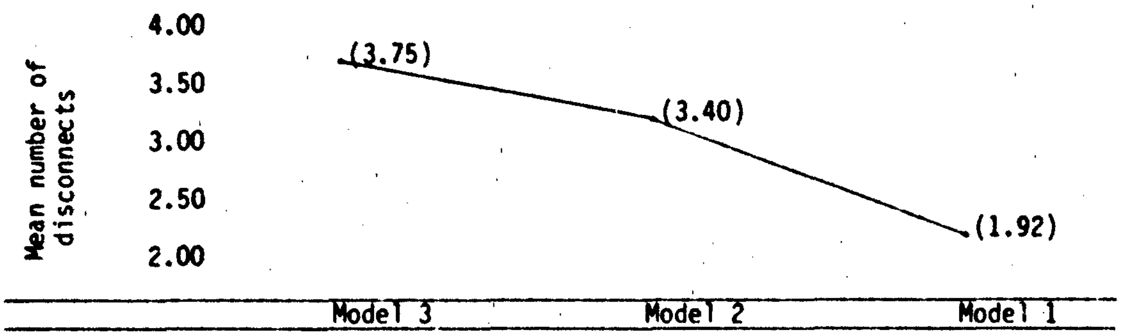

Figure 11. **Study 1 (A-10/F-4): Mean number of disconnects as a function of model.**

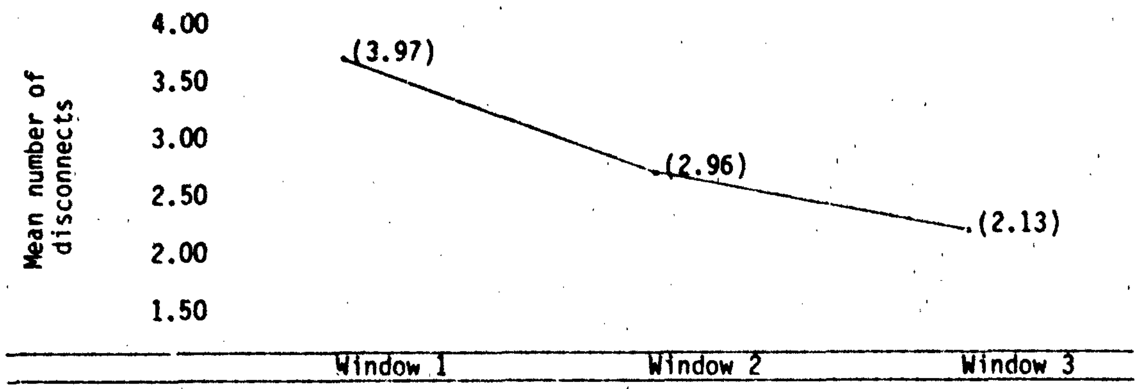

Figure 12. **Study 1 (A-10/F-4): Mean number of disconnects as a function of window configuration.**

Table 3. **Study 1 ANOVA (A-10/F-4): Number of Disconnects**

Source	SS	df	MS	F
Model	34.33	2	17.17	12.36**
Window	30.33	2	15.17	4.15*
Subjects	64.61	5		
Model x Window	12.33	4	3.08	.56
Model x Subjects	13.89	10	1.39	
Window x Subjects	36.56	10	3.66	
Model x Window x Subjects	110.78	20	5.54	
Total	302.83	53		

$\bar{X}$ Model 1 = 1.92 $\bar{X}$ Model 2 = 3.40 $\bar{X}$ Model 3 = 3.75
$\bar{X}$ Window 1 = 3.97 $\bar{X}$ Window 2 = 2.96 $\bar{X}$ Window 3 = 2.13

*$p < .05$.
**$p < .01$.

Study 2 (B-52/F/FB-111). The results in Study 2 are nearly identical to those in Study 1. Figures 13 and 14 graphically portray mean elapsed time to criterion as a function of model and window, respectively. *Table 4 presents the ANOVA.* Time increased significantly as model complexity decreased ($F = 12.99$, $p < .01$). Similarly, time decreased significantly as window size increased ($F = 9.88$, $p < .01$). *The interaction* between model and window was non-significant ($F = .80$, N.S.). Figures 15 and 16 present results with respect to mean number of disconnects; the ANOVA is given in Table 5. These results parallel those from Study 1.

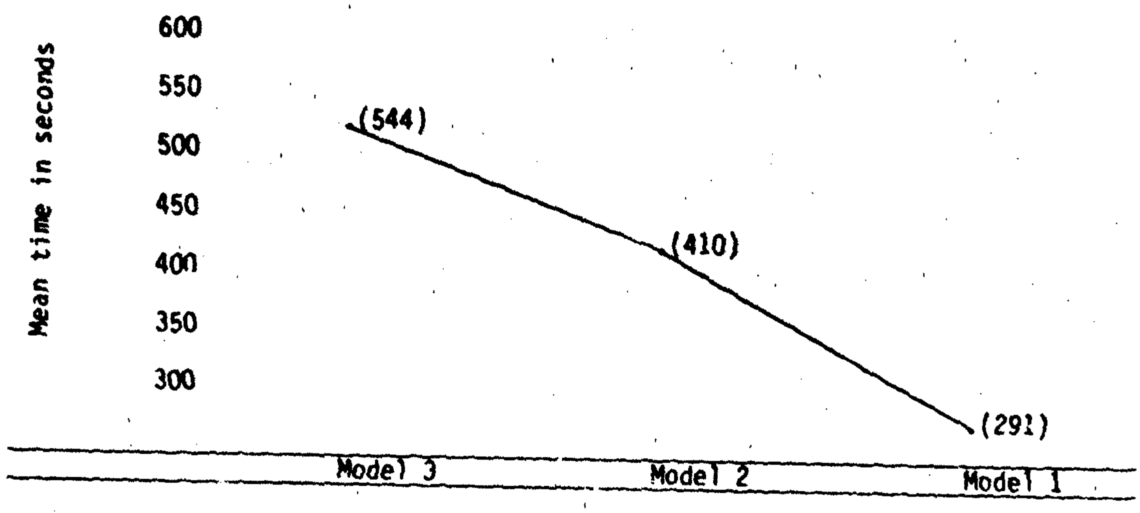

Figure 13. Study 2 (B-52/F/FB-111): Mean elapsed time to criterion as a function of model.

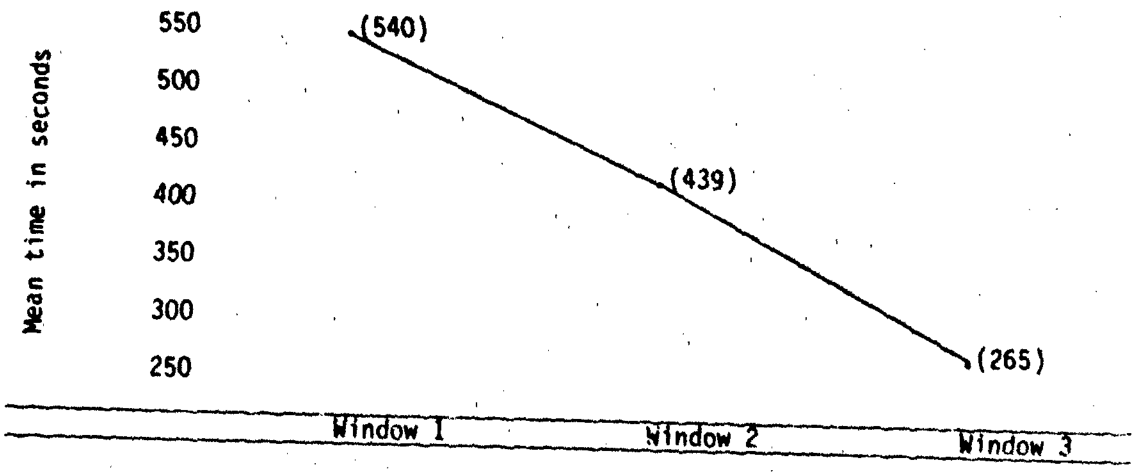

Figure 14. Study 2 (B-52/F/FB-111): Mean elapsed time to criterion as a function of window configuration.

Table 4. **Study 2 ANOVA (B-52/F/FB-111): Elapsed Seconds to Criterion**

Source	SS	df	MS	F
Model	581,805.72	2	290,902.86	12.99**
Window	694,587.93	2	347,293.97	9.88*
Subjects	737,048.70	5		
Model x Window	132,182.82	4	33,045.71	.80
Model x Subjects	223,987.63	10	22,398.76	
Window x Subjects	351,633.85	10	35,163.38	
Model x Window x Subjects	823,152.27	20	41,157.61	
Total	3,544,398.93	53		

$\bar{X}$ Model 1 = 290.53 $\bar{X}$ Model 2 = 409.60 $\bar{X}$ Model 3 = 544.61
$\bar{X}$ Window 1 = 539.91 $\bar{X}$ Window 2 = 439.42 $\bar{X}$ Window 3 = 265.37

*$p < .05$.
**$p < .01$.

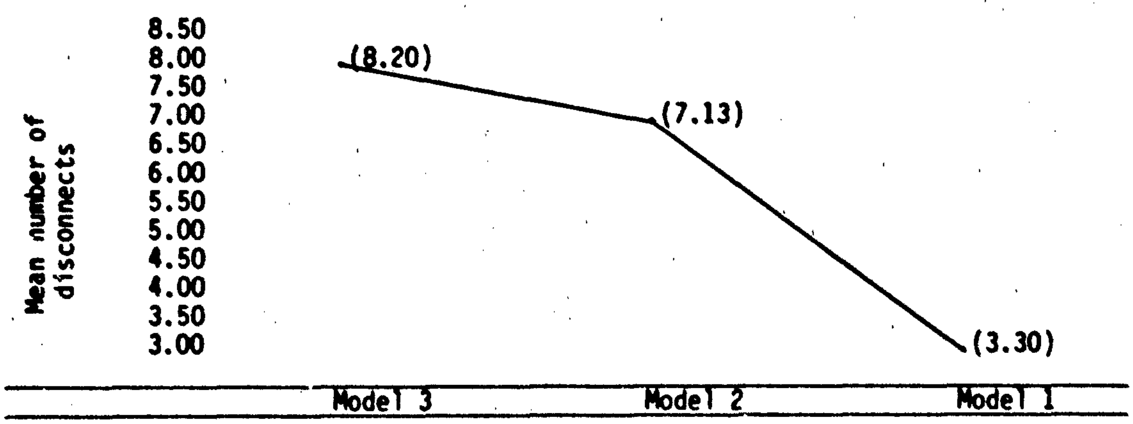

Figure 15. **Study 2 (B-52/F/FB-111): Mean number of disconnects as a function of model.**

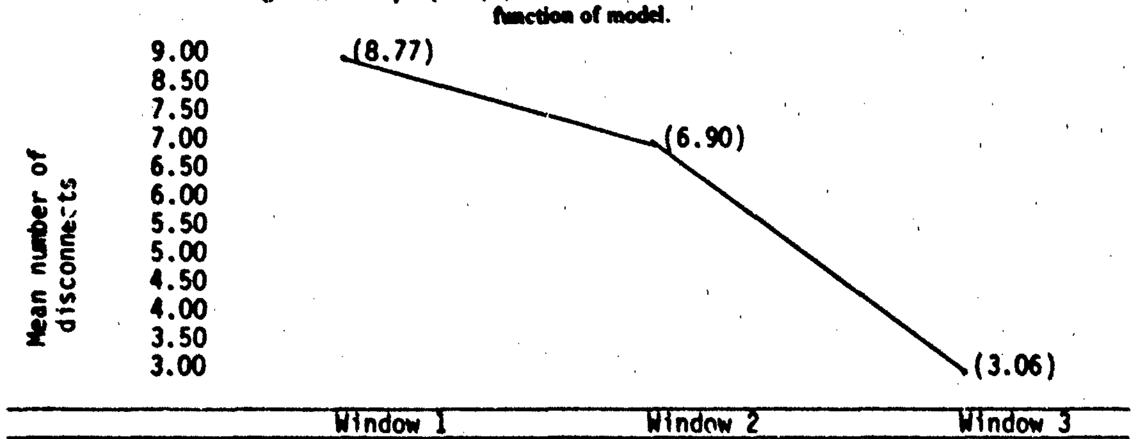

Figure 16. **Study 2 (B-52/F/FB-111): Mean number of disconnects as a function of window.**

Table 5. **Study 2 ANOVA (B52/F/FB-111): Number of Disconnects**

Source	SS	df	MS	F
Model	242.26	2	21.13	11.73*
Window	296.04	2	148.02	9.52*
Subjects	671.48	5		
Model x Window	39.41	4	9.85	.58
Model x Subjects	103.30	10	10.33	
Window x Subjects	155.52	10	15.16	
Model x Window x Subjects	338.37	20	16.92	
Total	1,846.37	53		

$\bar{X}$ Model 1 = 3.30	$\bar{X}$ Model 2 = 7.13	$\bar{X}$ Model 3 = 8.20
$\bar{X}$ Window 1 = 8.77	$\bar{X}$ Window 2 = 6.90	$\bar{X}$ Window 3 = 3.06

*$p < .01$.

It may be noted that the mean scores for both elapsed time and number of disconnects are higher for each data point in Study 2 than was the case in Study 1. That is, SAC subjects took more time to achieve criterion for each model and window, and they exhibited more disconnects for each such condition. This is due to the fact that SAC subjects were required to remain in contact for 3 minutes (twice as long as TAC) to achieve the criterion. For this reason, comparisons between Study 1 and Study 2 are not appropriate. Table 6 provides a summary of mean dependent variable scores as a function of condition for both Study 1 and Study 2.

Table 6. **Summary: Mean Dependent Variable Scores, Study 1 and Study 2**

Variable	Study 1 (TAC)	Study 2 (SAC)
	Elapsed Time to Criterion	
Complex model	180.07	290.53
Day austere model	305.08	409.60
Night austere model	394.75	544.61
Single window	440.26	539.91
Three window	276.18	439.42
Full FOV	163.43	265.37
	Number of Disconnects	
Complex model	1.92	3.30
Day austere model	3.40	7.13
Night austere model	3.75	8.20
Single window	3.97	8.77
Three window	2.96	6.90
Full FOV	2.13	3.06

Tables 7 and 8 present multiple ANOVAS (MANOVAS) on aircraft control as a function of model and FOV size for Studies 1 and 2, respectively. No variation in manner of aircraft control as a function of model was observed.

Table 7. **Study 1 (A-10/F-4): MANOVA on Aircraft Control Variables as a Function of Model Complexity and Window Configuration**

Source	Lambda-value	df	(df1, df2)	F-value
Block	.1645	1	(20,21)	5.331
Model	.2440	2	(40,42)	1.076
Window	.1143	2	(40,42)	2.056*
Model x Window	.1184	4	(80,85)	.765
Block x Model	.3295	2	(40,42)	.779
Block x Window	.2168	2	(40,42)	1.205

*p < .05.

Table 8. **Study 2 (B-52/F/FB-111): MANOVA on Aircraft Control Variables as a Function of Model Complexity and Window Configuration**

Source	Lambda-value	df	(df1, df2)	F-value
Block	.0153	1	(20,21)	67.655
Model	.2259	2	(40,42)	1.159
Window	.1619	2	(40,42)	1.559*
Model x Window	.1195	4	(80,85)	.8914
Block x Model	.4661	2	(40,42)	.9878
Block x Window	.1867	2	(40,42)	1.380

*p < .10.

FOV size did affect control variation, a smoother profile being exhibited with the full FOV. The latter difference was significant for Study 1 ($F = 2.06$, $p < .05$) and approached significance in Study 2 ($F = 1.56$, $p < .10$). Tables 9 and 10 present the ANOVA on receiver aircraft receptacle oscillation.

Table 9. **Study 1 (A-10/F-4): ANOVA on Receiver Aircraft Receptacle Oscillation**

Source	SS	df	MS	F-value
Block	33,269.574	1	33,269.5742	.3589
Model	411,489.55	2	205,744.7734	2.2196
Window	704,903.68	2	352,451.8398	3.8022*
Model x Window	147,839.49	4	36,959.8730	.3987
Block x Model	38,725.828	2	19,362.9141	.2089
Block x Window	94,118.121	2	47,059.0605	.5077
Error	3,707,824.7	40	92,695.6182	

*p < .05.

Table 10. **Study 2 (B-52/F/FB-111): ANOVA on Receiver Aircraft Receptacle Oscillation.**

Source	SS	df	MS	F-value
Block	148,628.63	1	148,628.6348	3.0595
Model	582,465.45	2	291,232.7227	5.9949*
Window	695,467.49	2	347,733.7461	7.1580*
Model x Window	132,226.90	4	33,056.7246	.0805
Block x Model	10,256.521	2	5,128.2607	.1056
Block x Window	36,309.531	2	18,154.8154	.3737
Error	1,943,192.4	4	48,579.8105	

*$p < .01$.

Overall oscillation as a function of model failed to reach significance in Study 1 ($F = 2.22$, $p = .12$) but was significant in Study 2 ($F = 6.00$, $p < .01$). Oscillation as a function of FOV was significant in both studies (Study 1, $F = 3.80$, $p < .05$; Study 2, $F = 7.16$, $p < .01$).

IV. DISCUSSION

The adequacy of the four visual FOVs specified by SIMSPO, as well as the full FOV, was evaluated in ASPT within the contexts of three flight task regimes: rendezvous, takeoff and landing, and aerial refueling.

At rendezvous, all subjects except those flying the A-10 configuration found that the tanker was visible from all three initialization points. The A-10 FOV did not extend upward far enough to permit visual contact. The A-10 and F-4 pilots felt that their visual FOVs must be elevated in order for them to see the tanker adequately to refuel. The B-52 and F/FB-111 pilots did not find this to be necessary, although the SIMSPO-specified F/FB-111 FOV position is essentially the same vertically as the F-4 FOV. Apparently the different requirements for FOV elevation resulted from differing refueling techniques between the commands. The SAC pilots reported that the B-52 and F/FB-111 FOVs permitted them to see everything they normally attend to during refueling. Cues used by SAC pilots, in addition to the director lights, include the relative positions of the UHF antenna and an adjacent row of rivets (sometimes painted yellow), the inboard engine nacelles, the trailing edge of the tanker wing where it joins the fuselage, and the gear doors. The motion of these latter items relative to the center cockpit window (B-52) or canopy bow (F/FB-111) enables pilots to judge the motion of their aircraft relative to the tanker. The TAC subjects expressed a need to see more of the tanker's underside and the boom. In addition to the director lights, A-10 pilots use the boom nozzle and the position reference markings on the boom, and they also use the inboard engines relative to the canopy bow. The F-4 pilots use the canopy bow of their aircraft relative to a variety of cues on the tanker. All pilots must develop their own particular refueling references because they do not all use the same sitting height. The A-7 receptacle is located behind the cockpit, and A-7 pilots use techniques similar to those of F-4 pilots. However, the two A-7 pilots used in the study had no difficulty adapting to the A-10 configuration and were able to perform competently almost immediately. It should be noted that the canopy bow used in this simulation may have caused the pilots some difficulty since the canopy bow is an important cue. The A-7, A-10, and F-4 pilots are accustomed to a symmetrical bow, whereas that of a T-37 is non-symmetrical from the pilot's point of view. Although the SAC subjects are accustomed to a non-symmetrical canopy bow, there were differences to which they had to adapt. Nevertheless this condition applied to the members of each major command equally, and the consistency of the results indicates that the purpose of the experiment was not compromised.

All subjects reported a great deal of difficulty in judging the relative motion between their aircraft and the tanker. The reason for this is not clear. It may have resulted from the necessity to rely on diminished and unfamiliar cues or perhaps from the lack of accurate depth cues (retinal disparity, convergence). For whatever reason, the subjects reported a strong dependence on the director lights because of their difficulty in judging relative motion. This comment accentuates the inadequacy of other cues since the subjects also had complaints about the director lights; for instance, they said they had difficulty reading the lights at their extremes because the limits of the lights were not clearly depicted. Subjects also reported that the position of the lights was difficult to judge because sometimes they "broke up" on the display raster lines especially, the "captain's bars" which indicate correct position. These complaints applied to all three model complexity levels.

The A-10 pilots were able to perform takeoff and landing with the FOV in an elevated position; however, they did this in spite of their visual handicaps: the elevated A-10 FOV is not suitable for training takeoff or landing. The F-4 pilots were not able to compensate adequately for an elevated FOV on takeoff or landing, perhaps because the lower boundary of the F-4 FOV is 5 degrees higher than that of the A-10. It may be concluded from these results that in order for the A-10 or F-4 simulators to be used effectively for refueling, as well as for ordinary transition training, the SIMSPO-specified FOV must be increased in size vertically about 12 degrees.

V. CONCLUSIONS

The results from the refueling task generally indicate that the three-window display was far superior to the single window, but not as effective as the full FOV. The complex model was better than the day austere model, which in turn was associated with better AR performance than the night austere model. FOV and model detail level are important variables in AR simulation, as is placement of tanker visual cues. In debriefing, the pilots reported that many of the visual cues they normally use to refuel were not present, even on the complex model employed in this research. The pilots therefore learned to utilize cues existing in the simulation, and when the model did not include as much detail (e.g., three-dimension engine nacelles) or when less of the tanker was visible in a smaller FOV, then performance deteriorated. The results indicate that the tanker detail level in the complex model is the minimum that should be employed for AR simulation. Care should be taken to construct the model with a better selection of frequently employed AR visual cues than that utilized in the present study. The results also suggest that the effectiveness of the one-window display for AR simulation training is limited, and that a single window cannot be used for training in both transition and AR for the TAC aircraft in this study. The results are consistent with those of LeMaster and Longridge, (1978), who found that accuracy in simulated air-to-surface bomb delivery degrades significantly as the size of the area of interest or field of view decreases.

In future refueling studies, the first consideration should be a careful examination of the detail that must be included in a tanker model to satisfy pilot cue requirements. A further study might examine the problem of depth perception and how to compensate for depth cues that are impossible to reproduce on a two-dimensional display. Finally, a transfer of training study could more clearly define the relative effectiveness of the AR simulation variables.

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 ☆U.S. GOVERNMENT PRINTING OFFICE: 1979-