AD-A063 283 AIR FORCE HUMAN RESOURCES LAB BROOKS AFB TEX F/G 5/9

ADVANCED SIMULATOR FOR PILOT TRAINING (ASPT): AERIAL REFUELING --ETC(U)

SEP 78 E G MONROE, K I MEHRER, R L ENGEL

UNCLASSIFIED AFHRL-TR-78-51 NL

1 OF 1

AD
A063283

END
DATE
FILMED
3--79
DDC

(14) AFHRL-TR-78-51

LEVEL II

AIR FORCE HUMAN RESOURCES LABORATORY

(6) ADVANCED SIMULATOR FOR PILOT TRAINING (ASPT): AERIAL REFUELING VISUAL SIMULATION–ENGINEERING DEVELOPMENT.

By

(10) Eric G. Monroe,
Kent I. Mehrer, Capt, USAF
Richard L. Engel, Capt, USAF
Samuel Hannan, Maj, USAF

FLYING TRAINING DIVISION
Williams Air Force Base, Arizona 85224

James McHugh

Systems Engineering Laboratories
Williams Air Force Base, Arizona 85224

George Turnage

General Electric Company
Williams Air Force Base, Arizona 85224

David R. Lee

Singer Company-Link Division
Williams Air Force Base, Arizona 85224

(12) 42 p.

(11) Sep[redacted]978

(9) Final Report, [redacted] Sep[redacted]977 – Feb[redacted]978,

(16) 1123 (17) 10

Approved for public release; distribution unlimited.

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235

404 415

NOTICE

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.

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

EDWARD E. EDDOWES, Technical Advisor
Flying Training Division

RONALD W. TERRY, Colonel, USAF
Commander

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFHRL-TR-78-51	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* ADVANCED SIMULATOR FOR PILOT TRAINING (ASPT): AERIAL REFUELING VISUAL SIMULATION–ENGINEERING DEVELOPMENT		5. TYPE OF REPORT & PERIOD COVERED Final September 1977 – February 1978 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Eric G. Monroe, Kent I. Mehrer, Richard L. Engel, Samuel Hannan, James McHugh, George Turnage, David R. Lee		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Flying Training Division Air Force Human Resources Laboratory Williams AFB, Arizona 85224		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62703F 11231014
11. CONTROLLING OFFICE NAME AND ADDRESS HQ Air Force Human Resources Laboratory (AFSC) Brooks Air Force Base, Texas 78235		12. REPORT DATE September 1978 13. NUMBER OF PAGES 44
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)*

Advanced Simulator for Pilot Training (ASPT)
aerial refueling simulation
computer image generation (CIG)
environmental data base
flight simulation
graphics display
visual simulation

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This report documents the engineering modifications made to the Advanced Simulator for Pilot Training (ASPT) to expand its capability to include aerial refueling simulation. These modifications include the generation of a number of KC-135 tanker models (in various levels of image detail), refueling boom, and director lights. The existing variable/slewable field-of-view program was modified to generate multiple window configurations. The on-line programs were amended to provide boom dynamics, operational director lights, and tanker flow field effects. Performance measurement techniques and a dynamic graphics display were programmed to provide an adequate means of assessing and monitoring pilot performance.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

PREFACE

The development effort for the Advanced Simulator for Pilot Training (ASPT) Aerial Refueling Visual Simulation was conducted by the Flying Training Division of the Air Force Human Resources Laboratory for the Simulator System Program Office, ASD/SD24. The inhouse development effort was conducted under project 1123, USAF Flying Training Development; task 1123-10, Simulator Engineering Support. Mr. James F. Smith was the Project Monitor and Mr. Warren E. Richeson, the Task Scientist. The ASPT was procured under project 1192 Advanced Simulator for Undergraduate Pilot Training.

Appreciation is extended to Capt Dick Jeffreys, ASD/SD24B; Mr. Bill Kelly, General Electric Company; Mr. Jack Maynard, Singer/Link; Mr. Bob Miller, Systems Engineering Laboratory (SEL); Maj Jay Paulsen, AFHRL/FT; Mr. Robb Rife, AFHRL/FT; and Mr. Lynn Thompson, SEL; for the time and effort they devoted to this project.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

List of Illustrations (*Continued*)

LIST OF TABLES

ADVANCED SIMULATOR FOR PILOT TRAINING (ASPT):
AERIAL REFUELING VISUAL
SIMULATION–ENGINEERING DEVELOPMENT

I. INTRODUCTION

Background

On 18 October 1976, the Aeronautical Systems Division, Simulator System Program Office (ASD/SD24) requested the Flying Training Division of the Air Force Human Resources Laboratory (AFHRL/FT) to conduct an aerial refueling simulation study utilizing the Advanced Simulator for Pilot Training (ASPT). Command requirements for new simulators were becoming more full–mission oriented as more and more tasks were expected to be taught and practiced in simulators. Operational training requirements for forthcoming simulators included the receiver aerial refueling task. ASD was responsible for providing Air Force commands with this capability in the most cost effective manner; hence, the study requirement. It was felt that the inherent flexibility of the ASPT could best provide the numerous experimental conditions required for analysis of the behavioral impact on pilot performance of such variables as field of view (FOV), tanker image detail, and day/night systems.

Numerous coordination and planning meetings among ASD/SD24, Tactical Air Command (TAC), Strategic Air Command (SAC), and AFHRL/FT personnel were held during the following 12 months. These meetings resulted in identification of several ASPT engineering modifications which would be necessary to support the research plan. Once these requirements were specified, work commenced on the engineering design and development. Special computer image generation data base models of a KC-135 tanker in various levels of image detail were developed, as were special data base hoods to be utilized in the three-window FOV displays by the A-7/F-4 and FB-111 subject pilots. The one-window displays for the A-10 and B-52 subject pilots were generated with minor modifications to the normal variable/slewable FOV programs. A dynamic boom and the functional director lights were modeled, and software programs were written to simulate boom dynamic operations and to make the director lights operational. The ASPT T-37 handling qualities were slightly altered for each of the two pilot groups (SAC and TAC) to facilitate transition from their operational aircraft to the simulator. Finally, performance measurement programs were developed to assess pilot performance of the aerial refueling maneuvers.

Purpose

This report documents the engineering design and development of features providing an aerial refueling capability to the ASPT system.

II. ASPT SYSTEM CONFIGURATION

General System Description

1. Kinesthetic Simulation

The ASPT system (Figure 1) consists of a T-37 and A-10 simulator cockpits each mounted on a synergistic motion base having six degrees of freedom. Each platform is driven by six hydraulic actuators having 1.52 m travel and providing the following displacements:

Lateral	±1.22 m	Roll	±22°
Longitudinal	+1.24 m, −1.22 m	Yaw	±32°
Vertical	+0.97 m, −0.76 m	Pitch	+30°, −20°

The magnitude of these excursions providing onset cues with subsequent washout is as follows:

Lateral	±0.6g	Roll	$\pm 50^\circ/sec^2$
Longitudinal	±0.6g	Yaw	$\pm 50^\circ/sec^2$
Vertical	±0.8g	Pitch	$\pm 50^\circ/sec^2$

Sustained cues are provided by a g-seat consisting of 31 independently driven pneumatic cells located in the back seatpan and in the thigh panels. In addition, a seat belt provides tension by means of a small actuator.

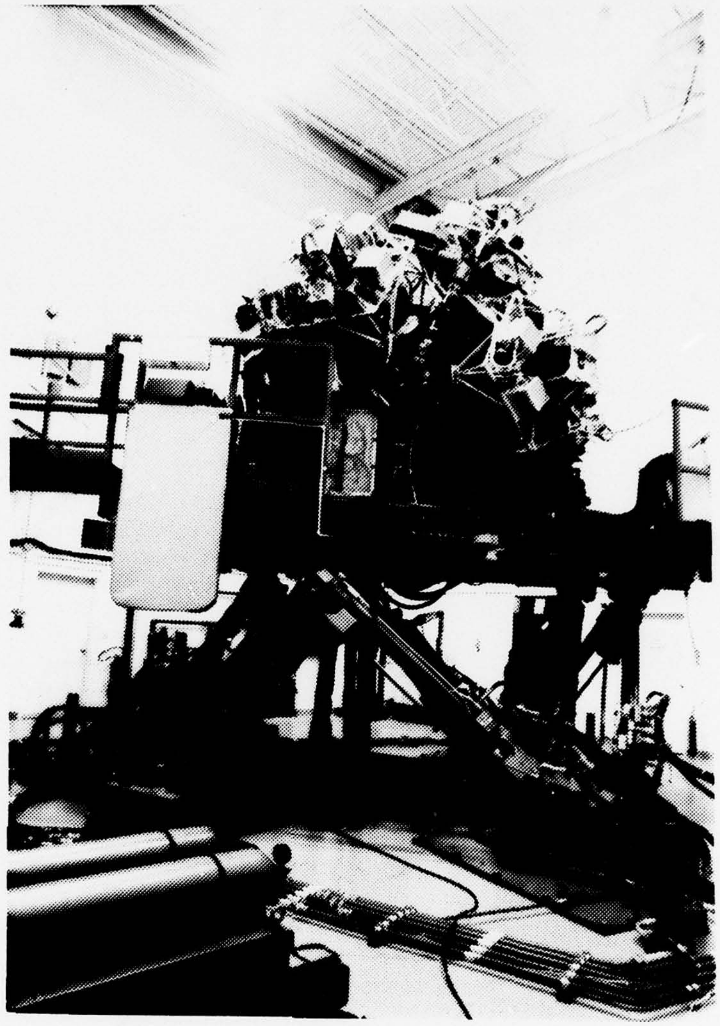

Figure 1. **ASPT.**

2. Visual Simulation

a. Computer image generation (CIG). CIG is a technique that takes a visual environment, which is defined as a three-dimensional math model and which is stored as numerical data in computer memory, and computes a two-dimensional model of a perspective image to be projected on the display plane. Inherent advantages of this technique are (a) unrestricted viewpoint, position, and attitude, (b) any field of view or window configuration, (c) unlimited number of visual environments can be readily constructed, modified, and amended, and (d) large gaming areas.

b. Variable/slewable FOV. A special feature of the ASPT visual system is its ability to restrict the display FOV to any desired size or window configuration via the CIG system. The chosen FOV may also be moved in real time throughout the wide angle, wraparound display in conjunction with the pilot's head motion. This is accomplished by means of an infrared helmet sensing device which determines the helmet attitude and relays this information to the CIG system.

c. Display system. Each cockpit is surrounded by a dodecahedronal structure (Figure 2) supporting seven 36-inch monochrome cathode ray tubes (CRTs). Each CRT has 1,023 scan lines with 1,000 elements per line and utilizes a highly efficient, green-tinted phosphor. It operates at 30 frames per second and provides 600 foot-lamberts of peak highlight brightness with a 7 arc minute line pair resolution. The CRTs are viewed through seven pentagonal Pancake Windows with in-line collimating optics which are mosaicked to provide a continuous FOV of approximately 300 degrees horizontal by 150 degrees vertical. The passage of the desired image through the various polarizers, filters, and beam splitters results in a one-percent transmission efficiency providing a virtual image with 6 foot-lamberts of peak highlight brightness.

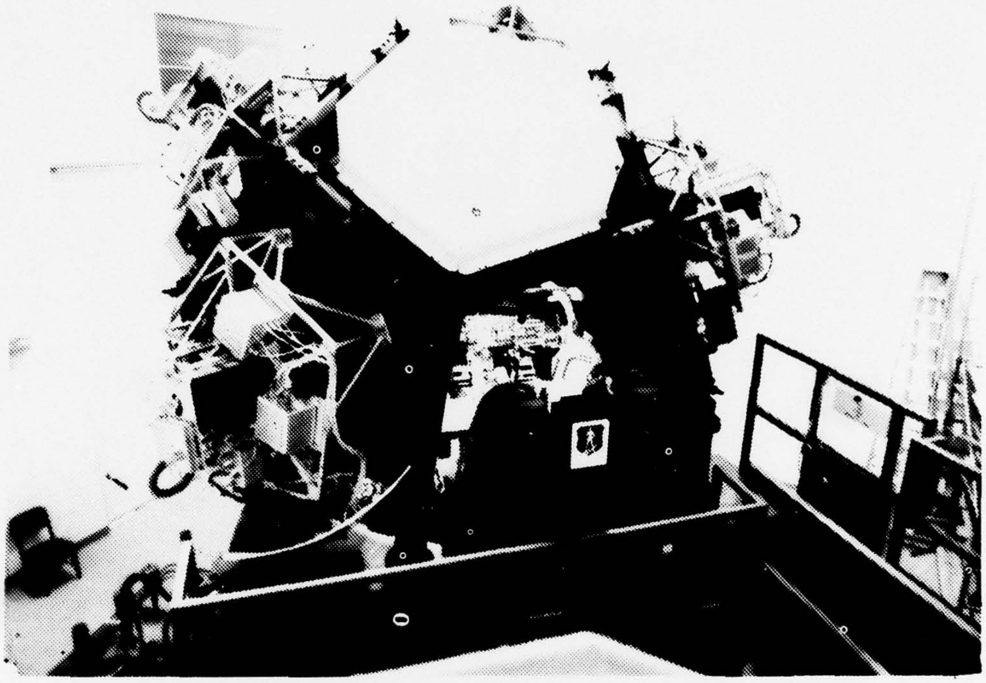

Figure 2. **Cockpit display.**

3. Auditory Simulation

a. Aircraft sound synthesizer. Aural simulation of aircraft sounds is provided by an oscillator which responds to digital-to-analog (D/A) signals. Since the D/A signals are software dependent, it is possible to build a frequency profile to simulate the desired aural cues. In ASPT, this feature is used to produce sound effects for engine noise, tire squeal on touchdown, cannon fire, flak, and bomb bursts.

b. Cognitronics multiplexed speechmaker. The speechmaker system permits the computer to respond to various user programmable conditional statements in audio form via the cockpit headset. The heart of the system is an audio drum. The system vocabulary is listed in Appendix A. The drum consists of film cylinders mounted one above another with information (words) in each cylinder recorded on 32 data tracks. The film utilizes the variable area type of recording which modulates a thin beam of light. This process produces sound in a manner similar to the way in which sound tracks on motion picture films generate audio. The rotation rate of the cylinder allows for an output of up to 100 words per minute.

4. Advanced Instructor/Operator Station

Control and monitoring of the simulator missions are maintained at the ASPT Advanced Instructor/Operator Station. This station contains a complete replication of all the simulator cockpit instruments and indicators, and all the controls, displays, recorders, lights, and other equipment necessary to set up, control, and monitor the simulated mission. In addition to these capabilities provided by conventional instructor/operator stations, the advanced station provides (a) rapid initialization, (b) freeze, (c) record/playback, (d) closed circuit TV cockpit observation, (e) two console TV monitors slaved to the cockpit display windows, and (f) two seven color programmable alphanumeric CRT displays.

The ASPT Advanced Instructor/Operator Station can be observed in Figure 3.

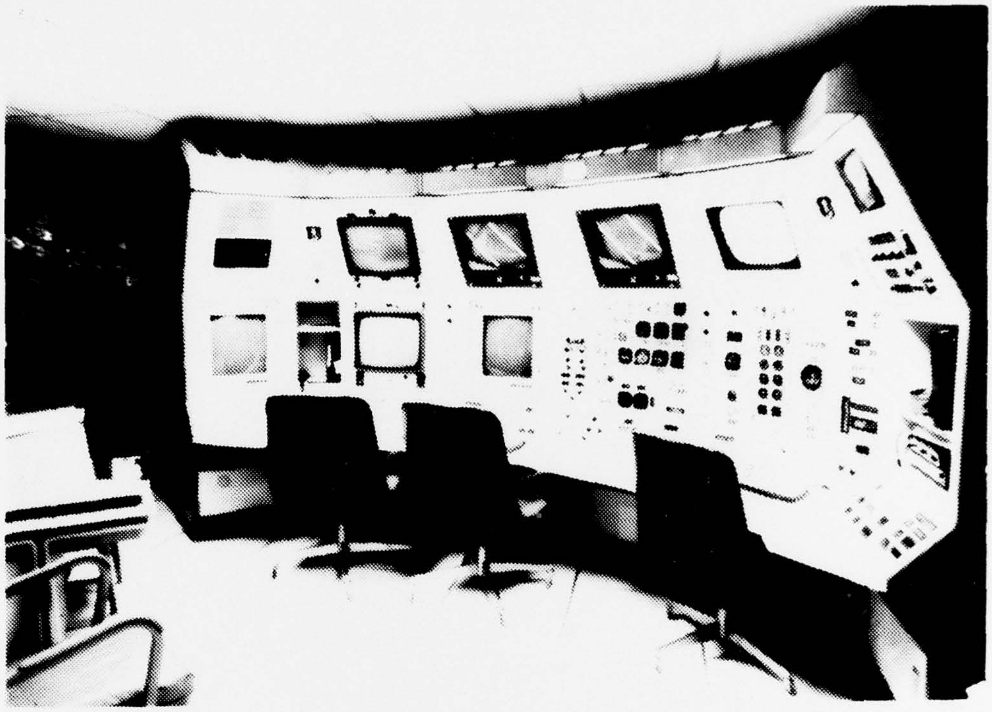

Figure 3. **Advanced instructor/operator station.**

Aerial Refueling Modifications

1. Environmental Data Base

a. Overall design. The data base developed for this project consists of three aerial refueling tankers (with operational director lights and refueling booms), four different FOV hoods, and an airfield. The tankers include a high detail, KC-135 model; a low detail, austere day model; and a simple night model. The FOVs include two three-window hoods duplicating the FB-111 and A-7/F-4 aircraft simulator FOVs and two single-window hoods duplicating the A-10 and B-52 aircraft simulator FOVs. The use of the ASPT CIG visual system allowed considerable flexibility in duplicating the various test FOVs and window configurations under consideration. The airfield used is Davis-Monthan AFB as modeled for a previous research project.

Three separate and distinct environmental data bases have been created. The first consists of the KC-135, day austere and night tankers, and the A-7/F-4 and variable window hoods. The variable hood is adjusted for either the A-10 or B-52 single window configurations. The second data base has the same three tankers, variable hood, and three-window FB-111 hood. The third consists of Davis-Monthan AFB, KC-135 tanker, A-7/F-4, FB-111, and variable hoods. Any environment can be loaded, and the system console operator can select any combination of tankers and hoods; e.g., KC-135 tanker with FB-111 hood.

These data bases are summarized in Table 1. A model summary giving model acronyms, environment location, size, software address, and description for each environment is given in Appendix B. The various

Table 1. **Aerial Refueling Configurations – Data Base**

	ARF #1 Trainer III Files G & E			
100%	Complex Tanker	Variable Hood	LOD1	Day
90%	Complex Tanker	A-7/F-4 Hood	LOD1	Day
75%	Austere Tanker	Variable Hood	LOD2	Day
50%	Austere Tanker	A-7/F-4 Hood	LOD2	Day
25%	Night Tanker	Variable Hood	LOD3	Night
10%	Night Tanker	A-7/F-4 Hood	LOD3	Night
Sense SW. CPU-A 0, 11, & 12 CPU-B None				
	ARF #2 Trainer III Files G & D			
100%	Complex Tanker	Variable Hood	LOD1	Day
90%	Complex Tanker	FB-111 Hood	LOD1	Day
75%	Austere Tanker	Variable Hood	LOD2	Day
50%	Austere Tanker	F-111 Hood	LOD2	Day
25%	Night Tanker	Variable Hood	LOD3	Night
10%	Night Tanker	FB-111 Hood	LOD3	Night
Sense SW. CPU-A 0, 11, & 12 CPU-B None				
	ARF #3 Trainer III Files H & C			
100%	DM AFB	Variable Hood		Day
90%	DM AFB	A-7/F-4 Hood		Day
75%	DM AFB	FB-111 Hood		Day
50%	Complex Tanker	Variable Hood	LOD1	Day
25%	Complex Tanker	A-7/F-4 Hood	LOD1	Day
10%	Complex Tanker	FB-111 Hood	LOD1	Day
Sense SW. CPU-A 0, 11, & 12 CPU-B None				

window hoods are shown in Figure 4, and their dimensions are given in Table 2. In addition, a list of the number of model partitions, objects, faces, edges, and vertices for each tanker and hood is given in Table 3.

Davis-Monthan AFB and vicinity (approximately 1,200 square miles) are modeled with the touchdown point on runway 30 at the CIG environment coordinate system origin.

The refueling tankers are fixed in space at 15,000 feet above mean sea level heading due east in a straight-and-level attitude. An adjustment was made to the receiver aircraft's visual velocity so that the tanker appears to be flying at 200 knots.

b. Refueling tankers

Complex KC-135 tanker. This complex day model was converted from another CIG system into the ASPT CIG format. The conversion resulted in a 1,000-edge model, excluding the director lights. In order to implement operational director lights on the underside of the fuselage, it was necessary (because the number of objects per model is limited) to partition the main fuselage into separate models (Figure 5). This procedure, of course, increases the number of model edges. After a number of test flights, additional markings (visual cues) were added to the model's underside, again creating additional edges. The final KC-135 model with director lights had 1,127 edges. The final KC-135 complex tanker model did not fully use the edge capacity of the ASPT system. An additional study to determine the impact of tanker model edge density should be conducted.

Figures 6 through 13 are photographs taken at the ASPT CIG Maintenance Console CRT showing various pilot viewpoints of the complex tanker. Figure 9 shows the tanker in refueling position. Note the director lights are on center indicating to the receiver aircraft pilot that he is in the refueling envelope. The pilot actually sees more of the tanker than shown here because the FOV spans several display channels,

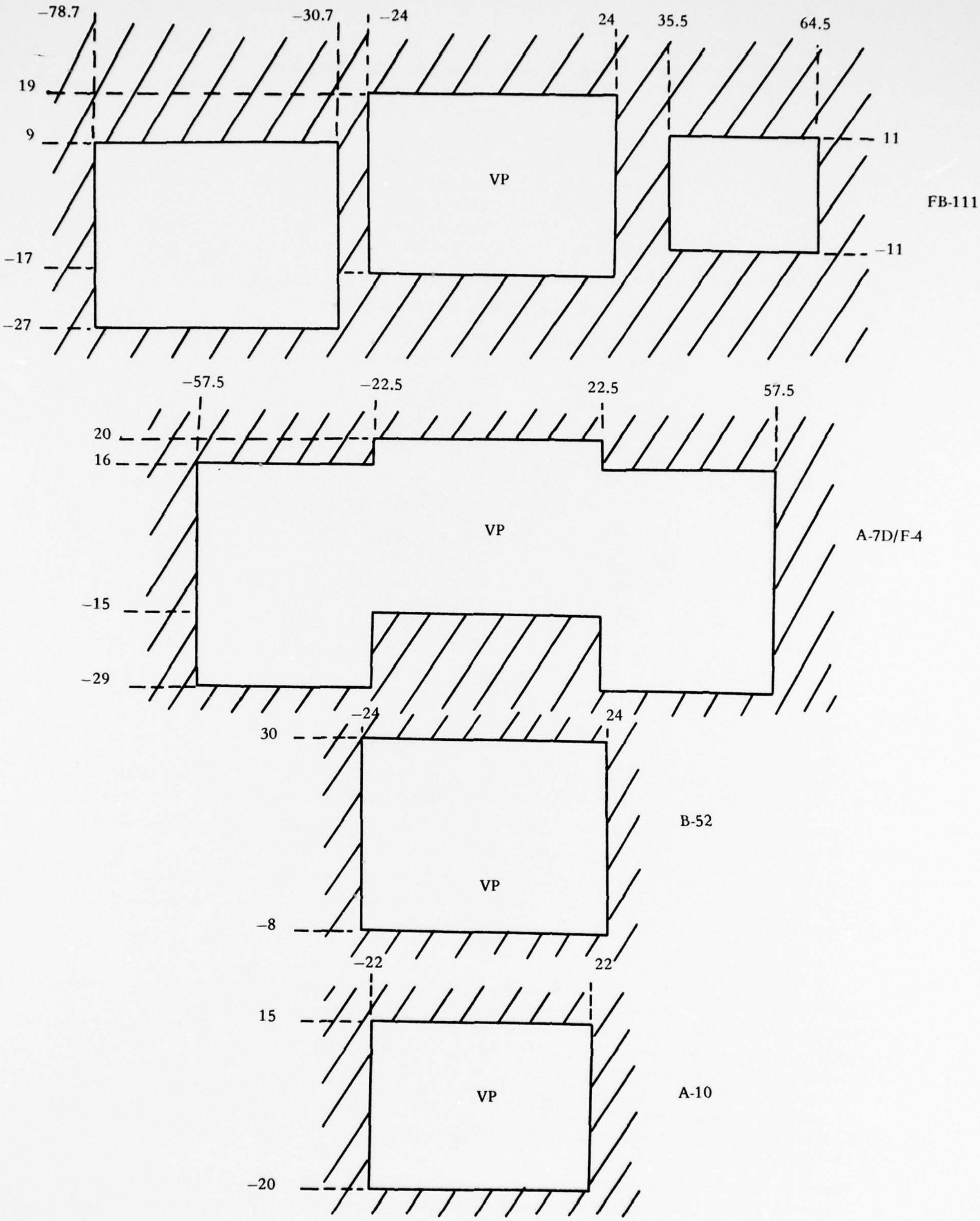

Figure 4. **Aerial refueling FOVs.**

Table 2. **Field of View Specifications**

FB-111A Three Window – Off Axis	
Pilot Front	$\pm 24^0$ H; $+19^0$, -17^0 V
Pilot Left	-78.7^0, -30.7^0 H; $+9^0$; -27^0 V
Pilot Right	$+35.5^0$, $+64.5^0$ H; $\pm 11^0$ V
A-7D/F-4E Three Window – On Axis	
Pilot Front	$\pm 22.5^0$ H; $+20^0$, -15^0 V
Pilot Left	-22.5^0, -57.5^0 H; $+16^0$, -29^0 V
Pilot Right	$+22.5^0$, $+57.5^0$ H, $+16^0$, -29^0 V
B-52 One Window – Off Axis	
	$\pm 24^0$ H -8^0, $+30^0$ V
A-10 One Window – On Axis	
	$\pm 22^0$ H -20^0, $+15^0$ V,

Table 3. **Aerial Refueling Models**

Name	Models	Objects	Faces	Edges	Vertices
Complex Tanker (KC-135)	10	73	561	1,127	666
Austere Day Tanker	5	20	99	213	138
Austere Night Tanker	8	23	107	241	164
A-7/F-4 FOV Hood	1	12	72	118	64
FB-111 FOV Hood	1	10	100	162	75

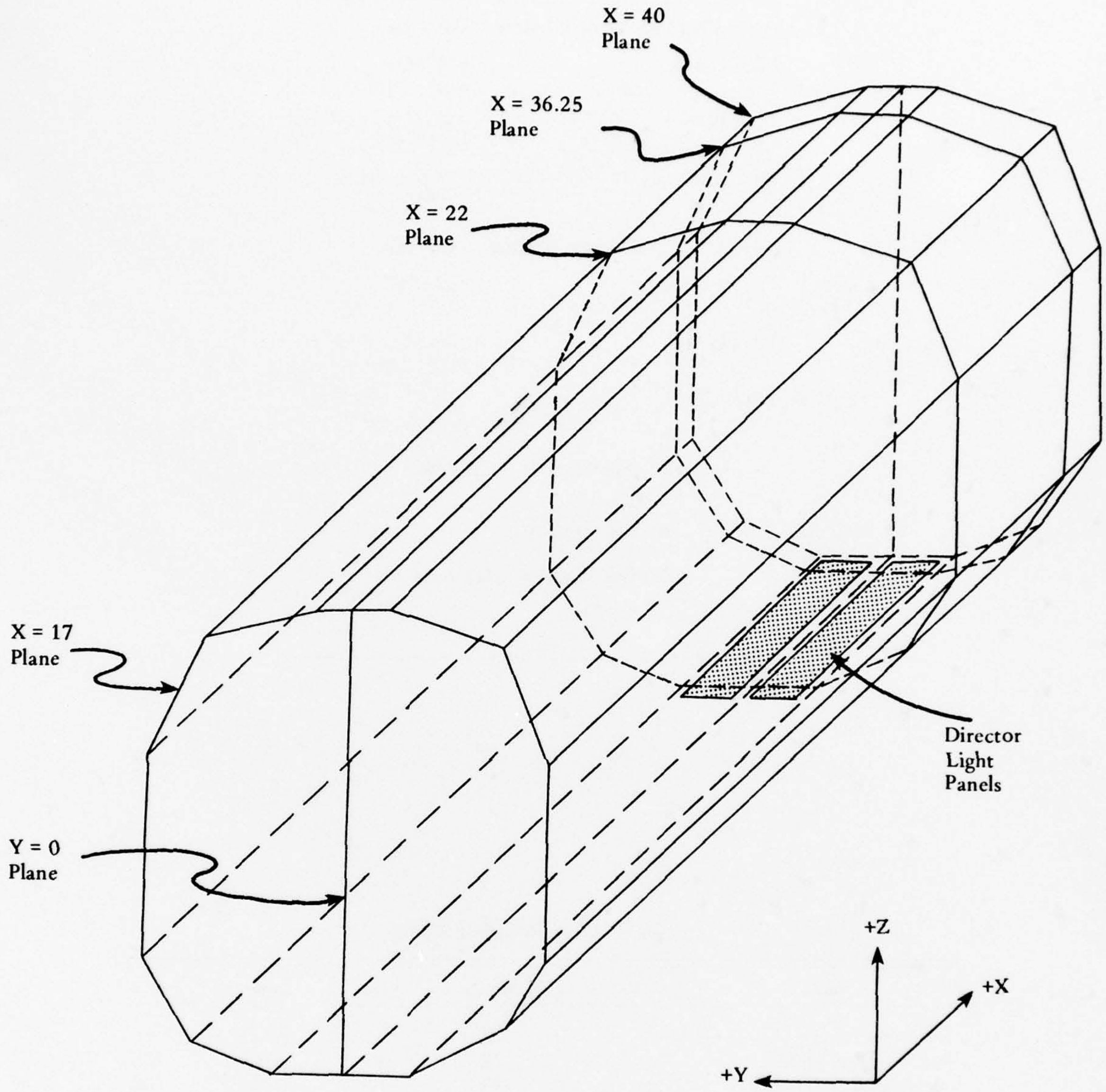

Figure 5. **KC-135 main fuselage (partitioned for director lights).**

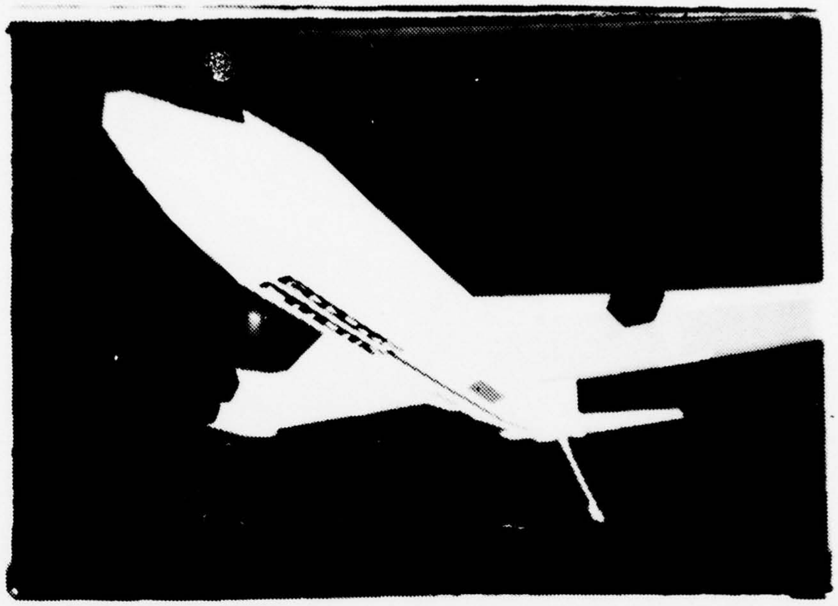

Figure 6. **Complex KC-135 tanker—front view.**

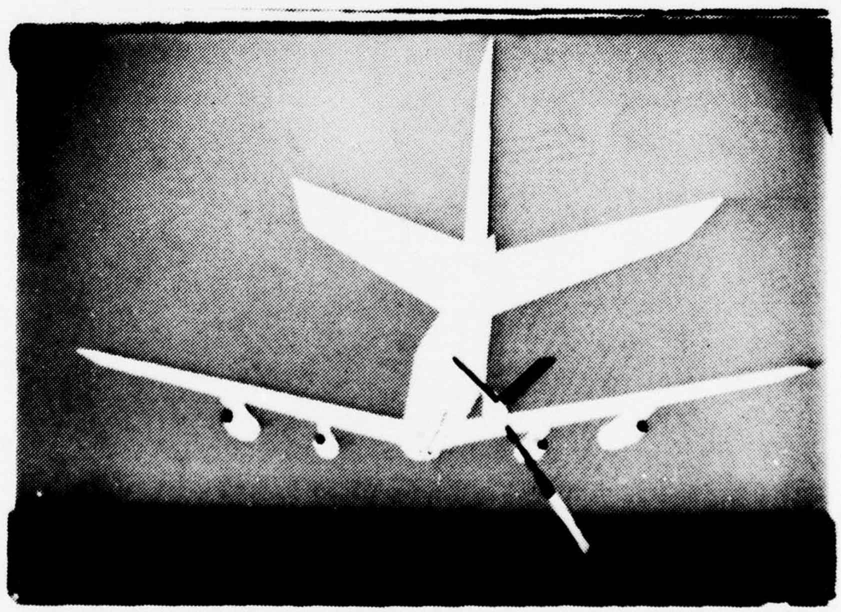

Figure 7. **Complex KC-135 tanker—rear view.**

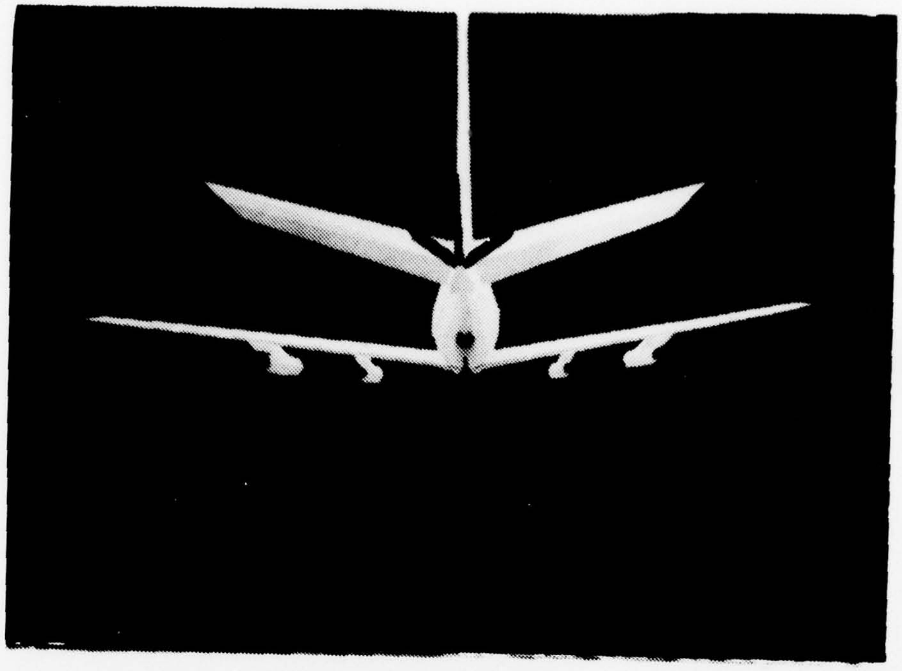

Figure 8. Complex tanker–refueling approach.

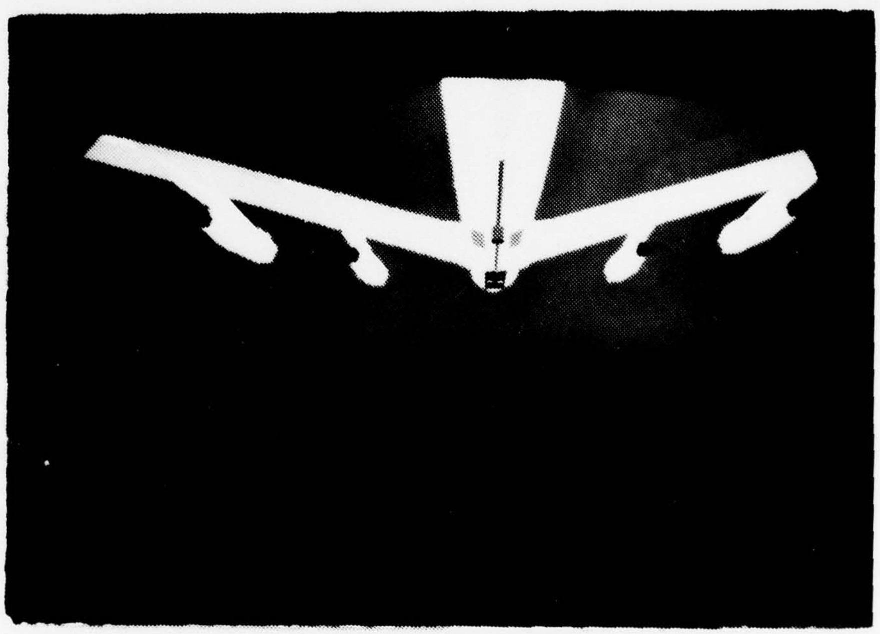

Figure 9. Complex tanker–refueling position.

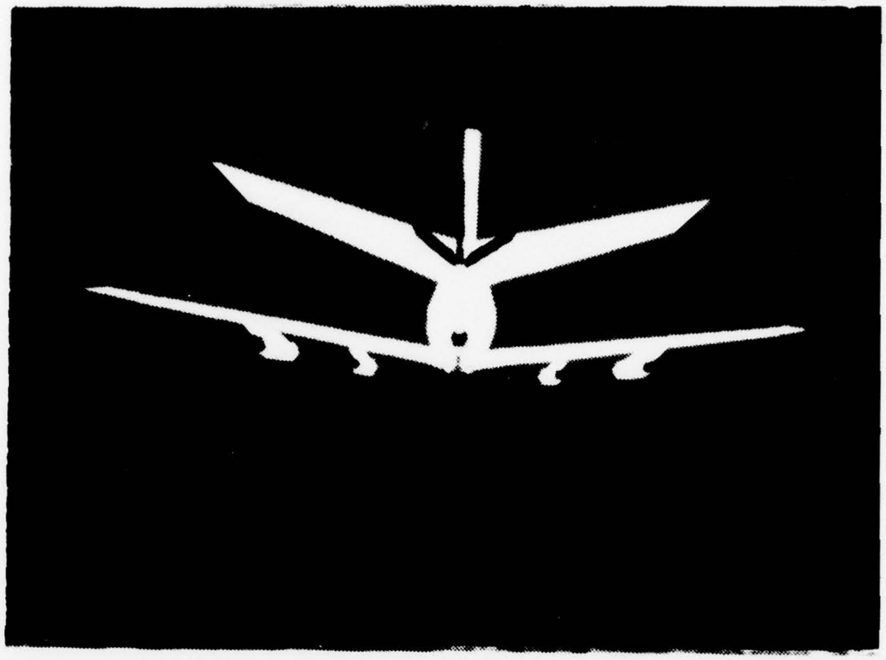

Figure 10. **Complex tanker and A-7/F-4 FOV.**

Figure 11. **Complex tanker and FB-111 FOV.**

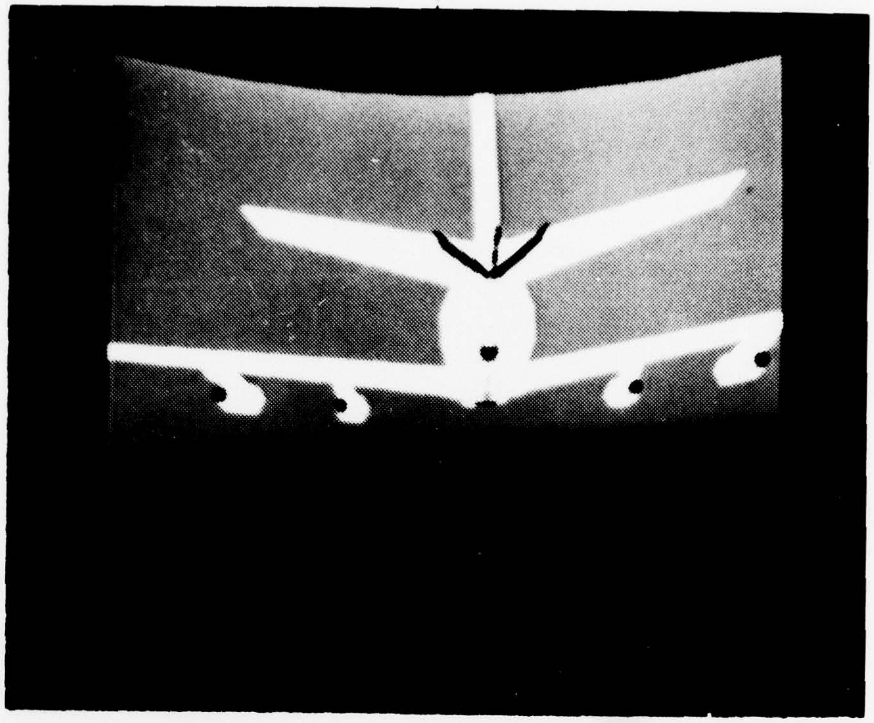

Figure 12. Complex tanker and B-52 FOV.

Figure 13. Complex tanker and A-10 FOV.

while the maintenance console CRT shows only one channel of the ASPT seven-channel display. Figures 10 through 13 give the four FOVs; i.e., A-7/F-4, FB-111, B-52, and A-10. The rounded borders are the console CRT boundaries.

Day austere tanker. This tanker was modeled from a photograph (Figure 14) provided by the Simulator System Program Office, ASD/SD24. The resulting model looked almost identical to this photo and consisted of the desired 85 edges; however, during initial refueling trials, it was found necessary to add more detail to the model resulting in a final edge count of 213 edges.

Figures 15 through 20 are photographs of the austere day model, showing various receiver pilot viewpoints with differing window/hood configurations. Figure 16 shows receiver in refueling position.

Night austere tanker. This night tanker is identical to the day austere model except for the wing and stabilizer gray shades and wing, tail, and boom lights. The addition of the lights increased the edge count to 241. Figures 21 and 22 give two viewpoints of this model; i.e., with and without the B-52 window hood.

c. Refueling booms

The booms are moving models hinged at the fuselage. The boom attitude is controlled by the basic simulator software. The boom's length is fixed at mid-extension which would place the nozzle tip at the refueling envelop center (Figure 23). The KC-135 tanker boom has 148 edges; the austere model booms have nine edges. These booms can be seen in photograph Figures 7 and 17.

d. Director lights

Originally, the director lights were modeled to the scale of the real aircraft (Figure 24). However, because of their resolution resulting from the shallow receiver pilot viewing angle (Figure 25), it was necessary to enlarge the lights. Use of enlarged director lights did not affect pilot acceptability of the KC-135 tanker model. The directional letters F (forward), A (aft), D (down), and U (up) were removed, since they were distracting and their incorporation was not found necessary to the mission.

The director lights are illuminated, depending on the position of the receiver aircraft's refueling receptacle relative to the refueling envelope center. The receiver director lights illumination profile is shown in Figure 26. When the receiver receptacle is positioned near the center of the refueling envelope, the director lights equal signs (captain's bars) are illuminated. If the receiver receptacle drifts off center, the equal sign lights extinguish and the correction indicator lights (come forward (F), go aft (A), come up (U), go down (D)) illuminate as necessary. The position of the refueling receptacle relative to the ASPT eyepoint for the various simulated receiver aircraft is given in Table 4.

e. Airfield

As was mentioned previously, the takeoff and landing airfield is a model of Davis-Monthan AFB and its surrounding environment. Study requirements included takeoffs and landings with the various cockpit FOV configurations. Figures 27 through 32 show airstrip approach with and without restricted FOVs.

2. Variable/Slewable Display Window Configuration

The Aerial Refueling Study required the generation of several simulator cockpit window configuration displays with various sized FOVs. Four different sized FOV displays were generated, with two displays being single-window and two displays being three-window FOVs.

The ASPT system has a capability called the Variable/Slewable Field of View feature which permits the user to generate any size single window FOV display (from ±2° up to ±120° azimuth; +80°, −60° elevation) by interactively inputting the size of the desired display via CRT terminal and keyboard. This feature also allows the FOV display to be slewed throughout the ASPT wide-angle FOV display in conjunction with the pilot's head movement. This is accomplished through inputs from a helmet sensing device which utilizes infrared beams and sensors to calculate the helmet attitude.

Minor software modifications were made to this feature to permit the FOV display fixed (frozen) by operator command once it was moved to an optimum location by the pilot.

The A-10 and the B-52 simulator cockpit single window configuration displays were generated using the standard ASPT Field of View Program. The three window FOV displays, (the A-7/F-4 and the FB-111

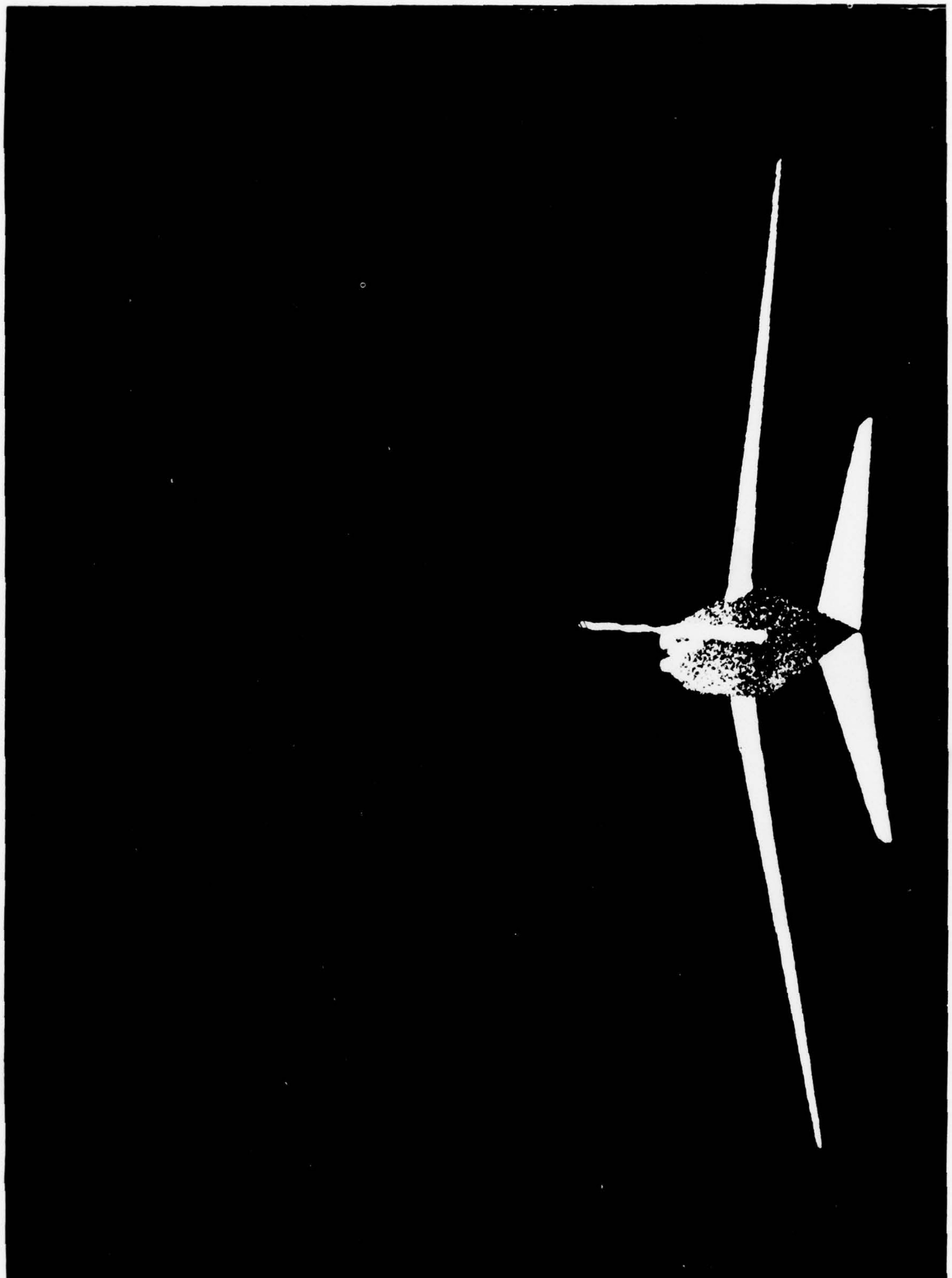

Figure 14. **ASD/SD24 austere model.**

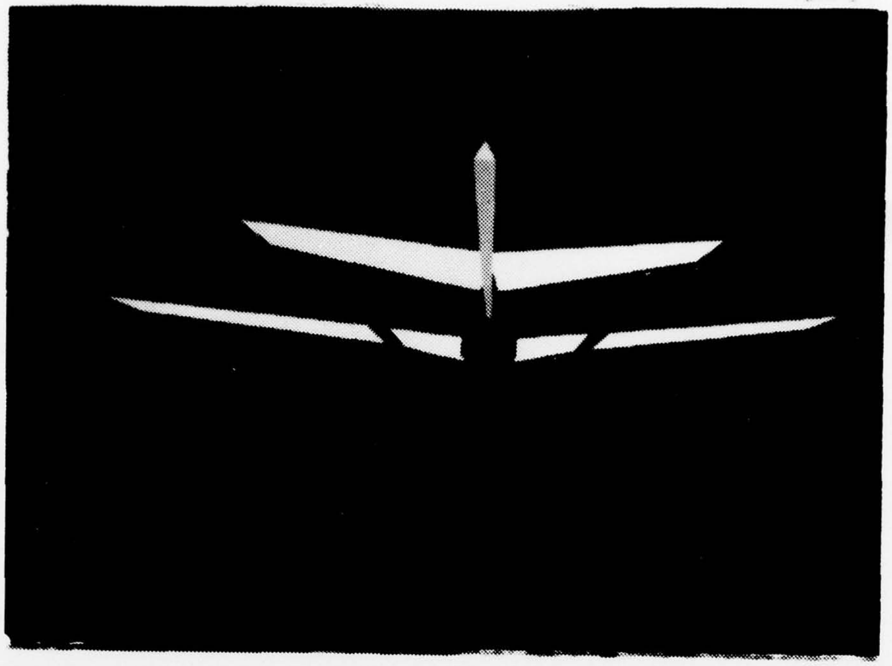

Figure 15. Day austere tanker.

Figure 16. Day austere tanker–refueling position.

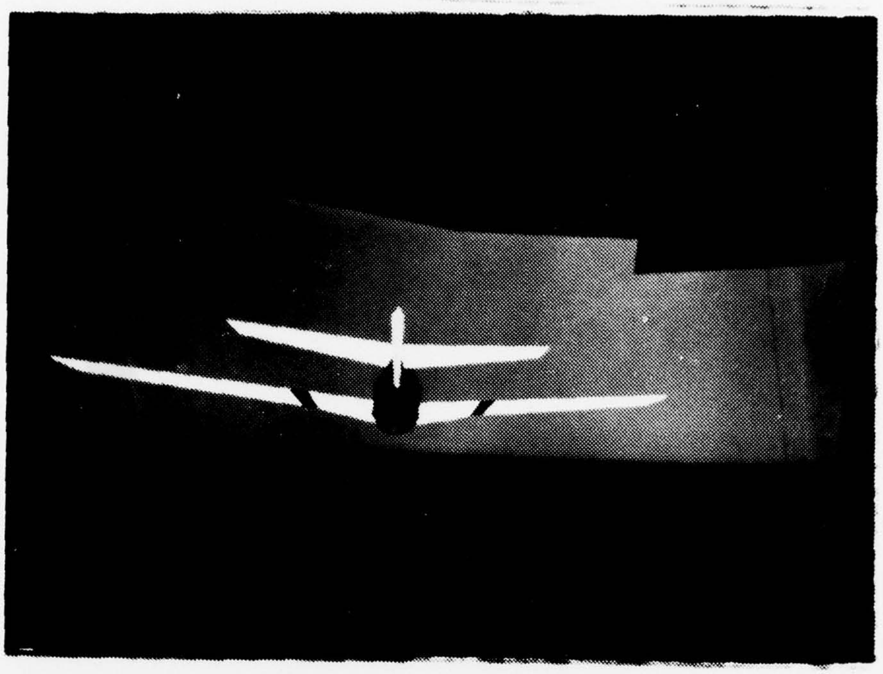

Figure 17. **Day austere tanker and A-7/F-4 FOV.**

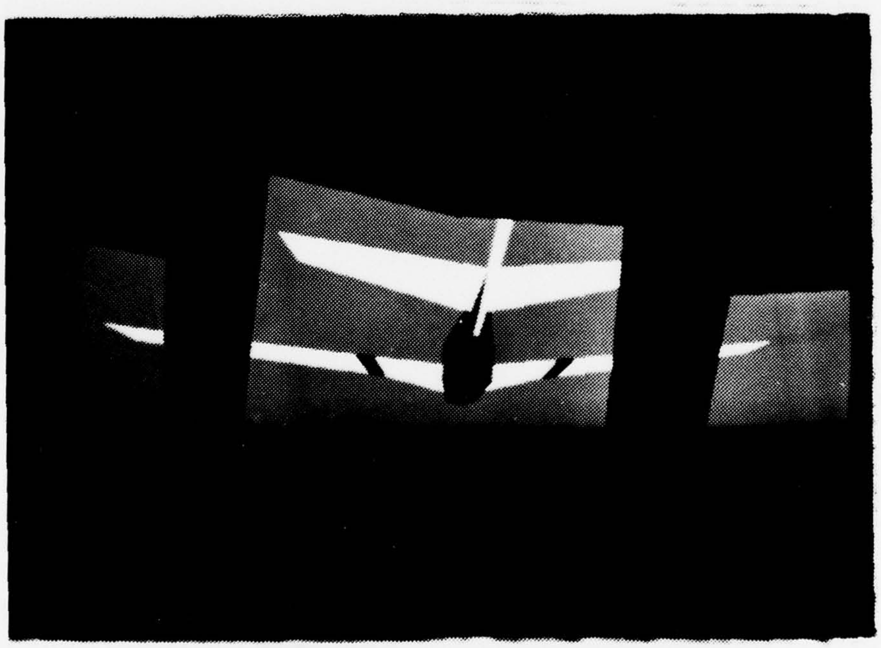

Figure 18. **Day austere tanker and FB-111 FOV.**

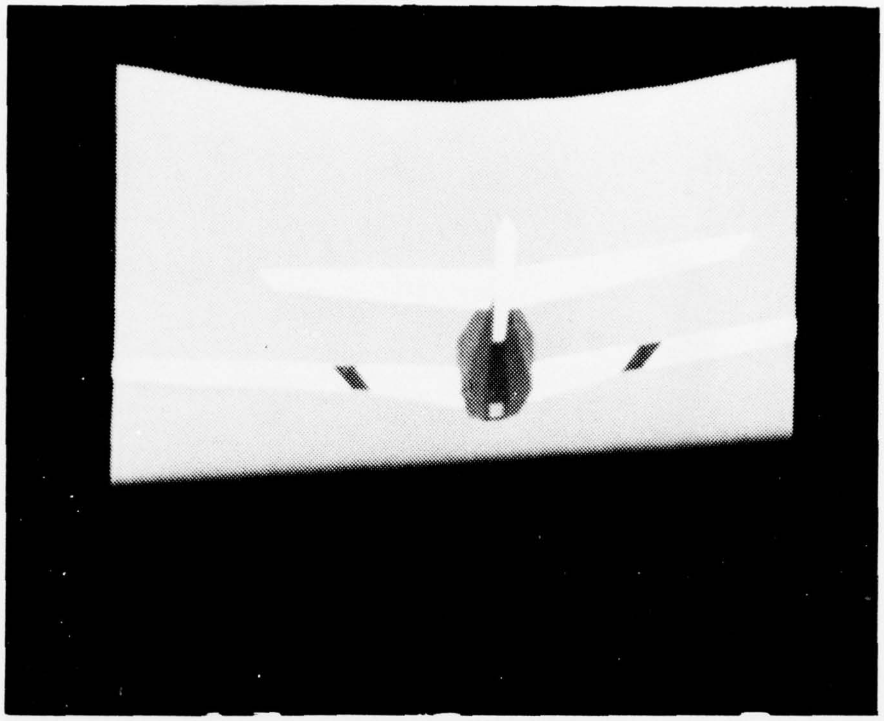

Figure 19. Day austere tanker and B-52 FOV.

Figure 20. Day austere tanker and A-10 FOV.

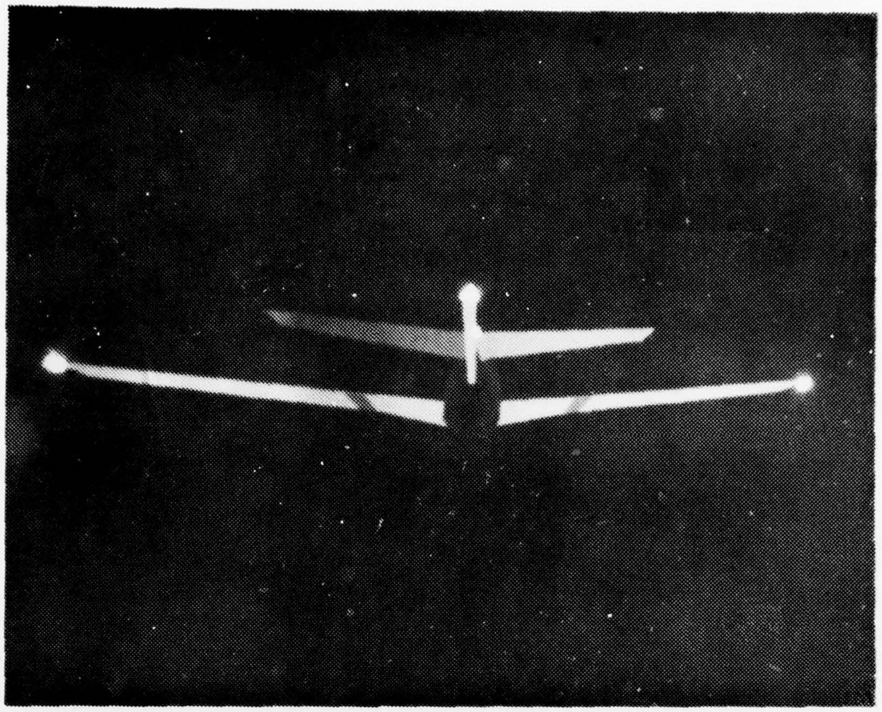

Figure 21. Night austere tanker.

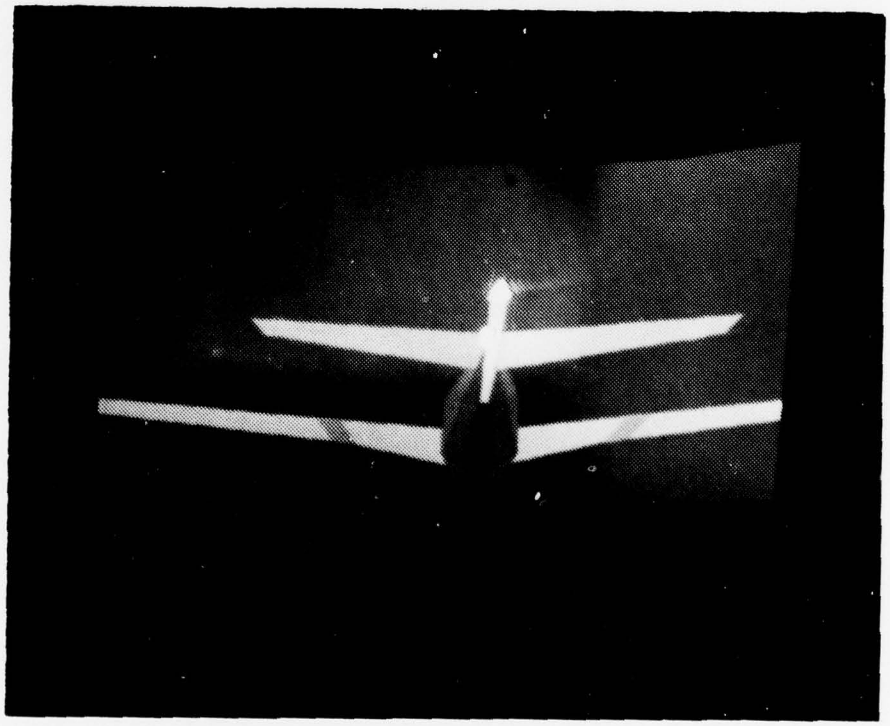

Figure 22. Night tanker and B-52 FOV.

BOOM ENVELOPE LIMITS

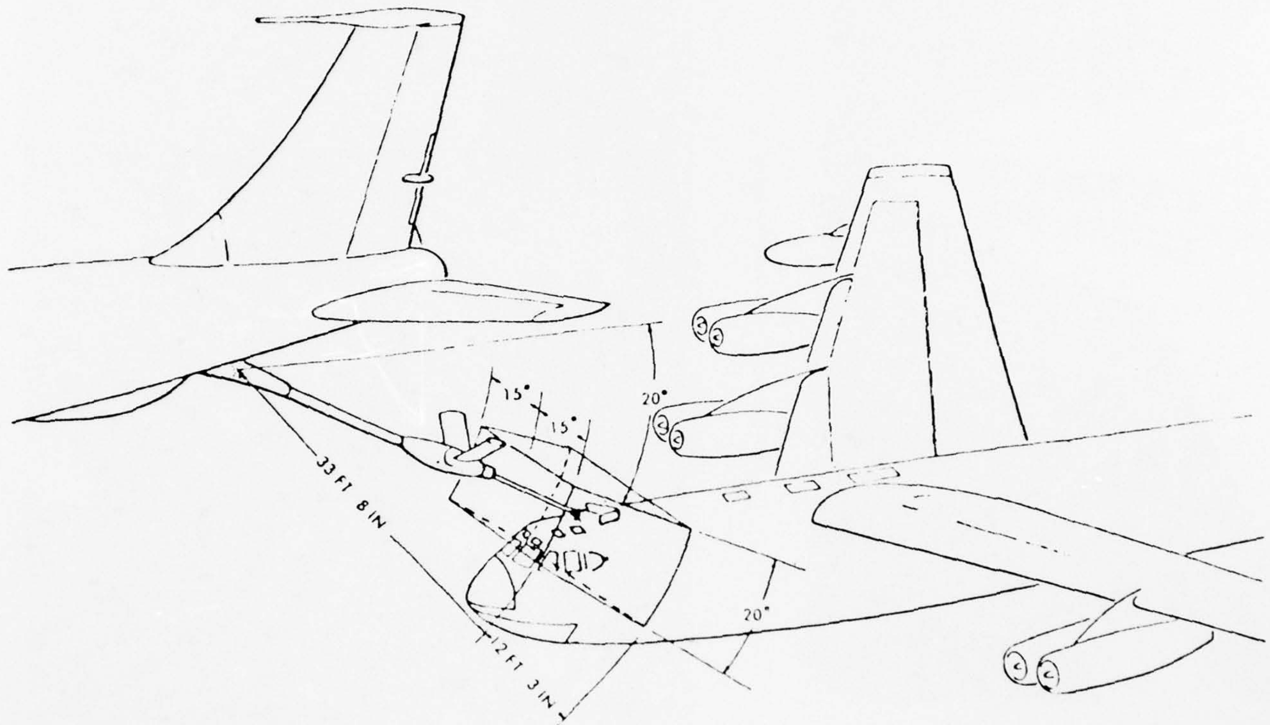

Figure 23. **Boom envelop limits.**

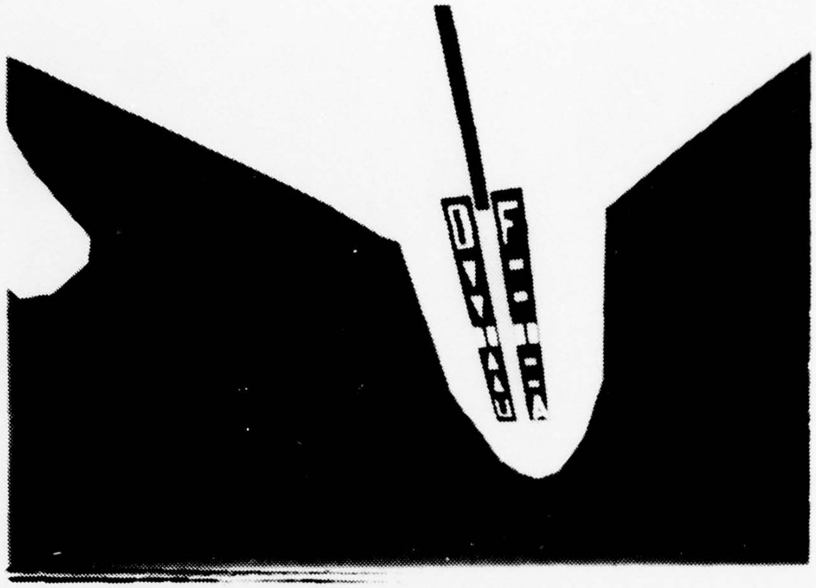

Figure 24. KC-135 director lights.

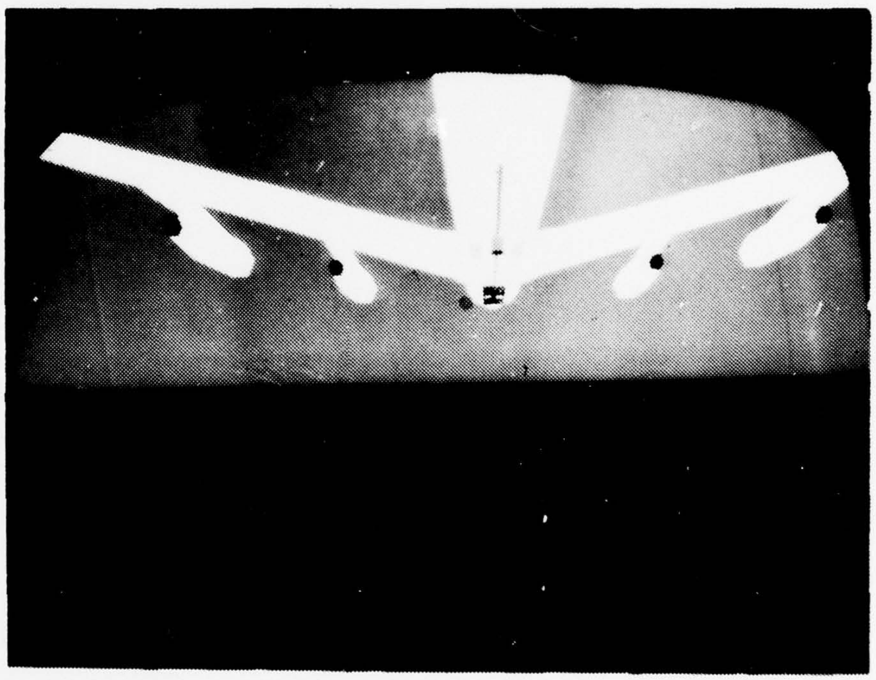

Figure 25. KC-135 director lights viewing angle.

RECEIVER DIRECTOR LIGHTS
ILLUMINATION PROFILE

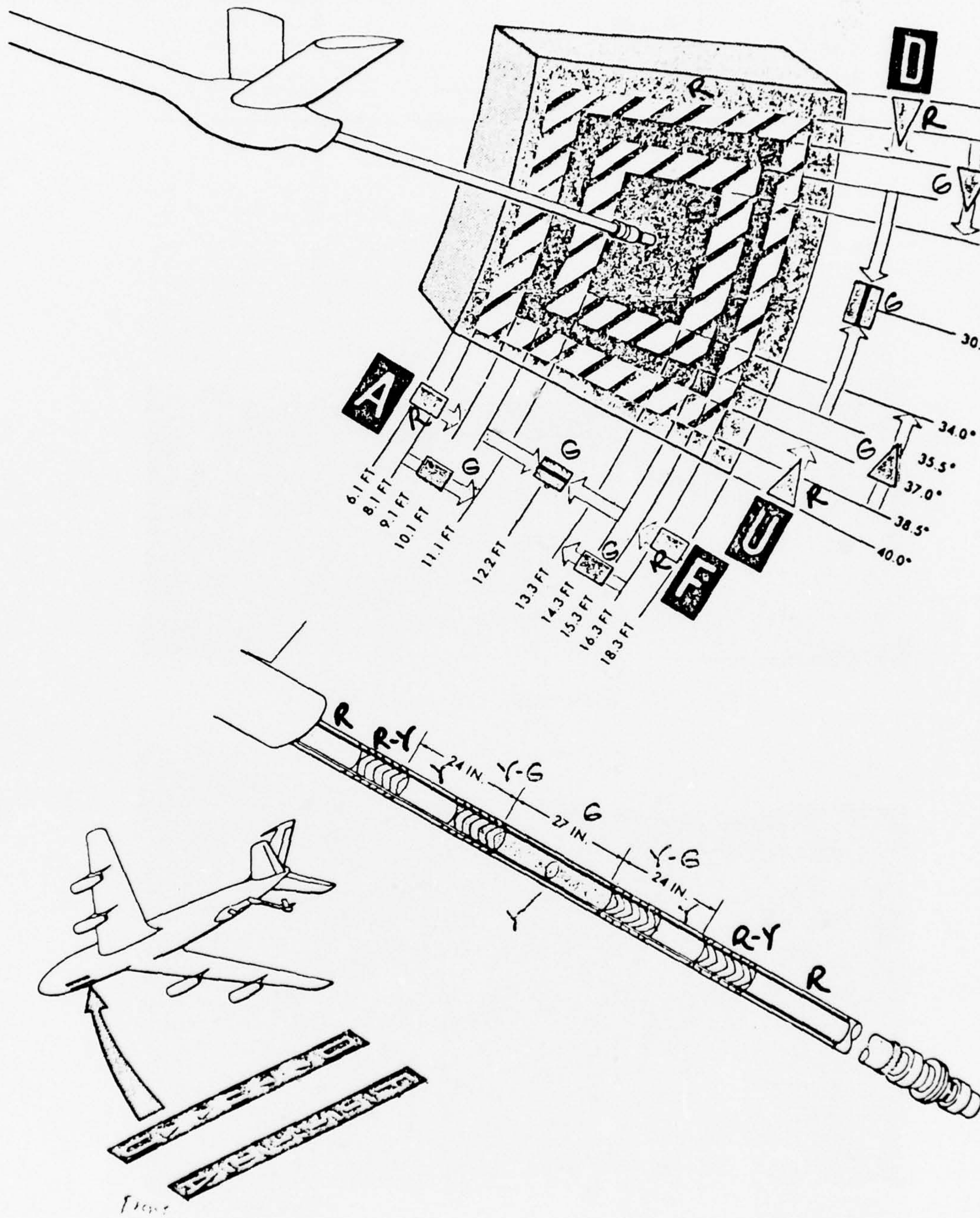

Figure 26. **Receiver director lights illumination profile.**

Table 4. **Receiver Receptacle Deviation from ASPT Cockpit Eyepoint**

Aircraft	Fore/AFT	Right/Left	Up/Down
B-52	2.03 m aft	0.48 m right	0.74 m up
F-4	4.23 m aft	–	0.44 m up
FB-111	4.34 m aft	–	0.22 m down
A-10	0.93 m fore	–	0.94 m down
A-7	2.90 m aft	–	0.23 m up

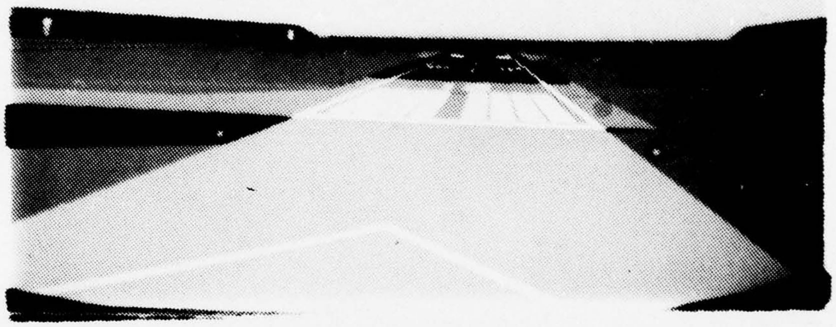

Figure 27. **Davis-Monthan AFB–runway 12.**

Figure 28. **Davis-Monthan AFB–runway 30.**

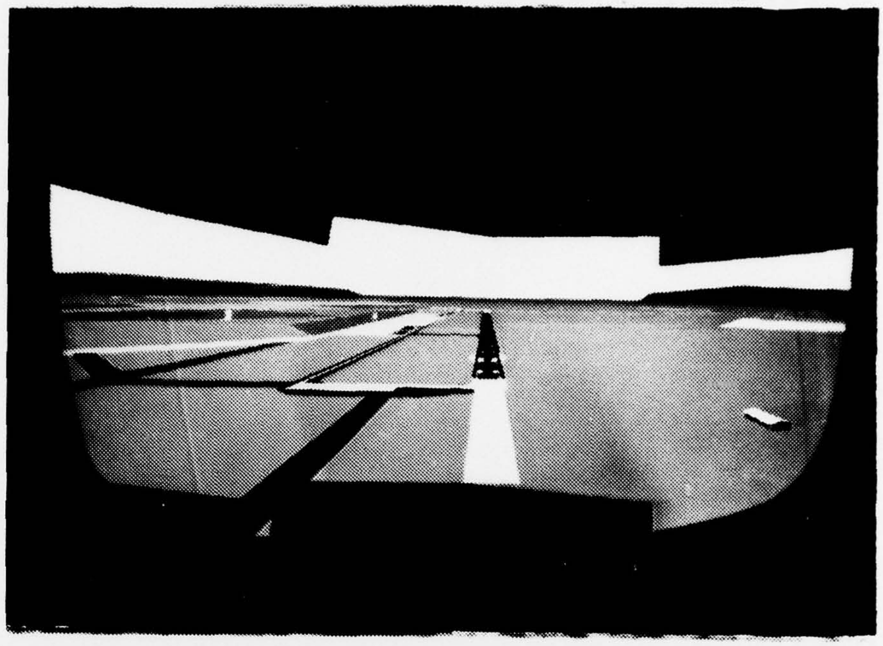

Figure 29. **Davis-Monthan AFB and A-7/F-4 FOV.**

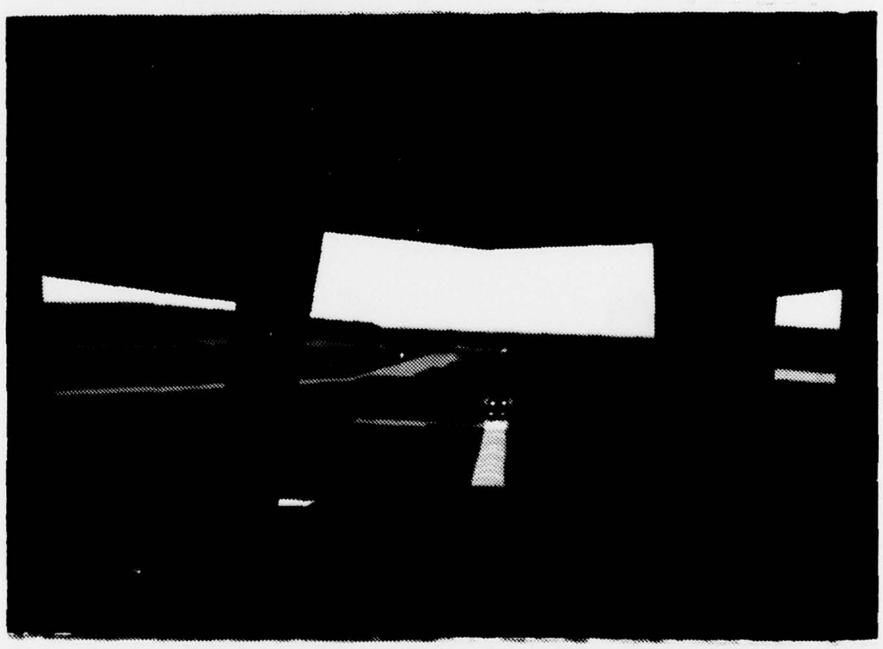

Figure 30. **Davis-Monthan AFB and FB-111 FOV.**

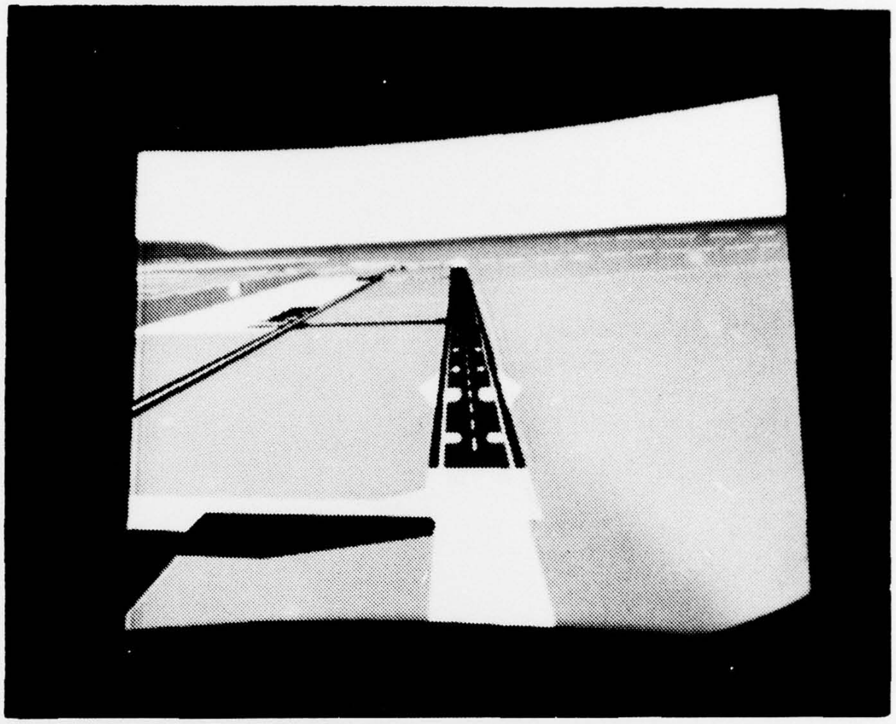

Figure 31. Davis-Monthan AFB and B-52 FOV.

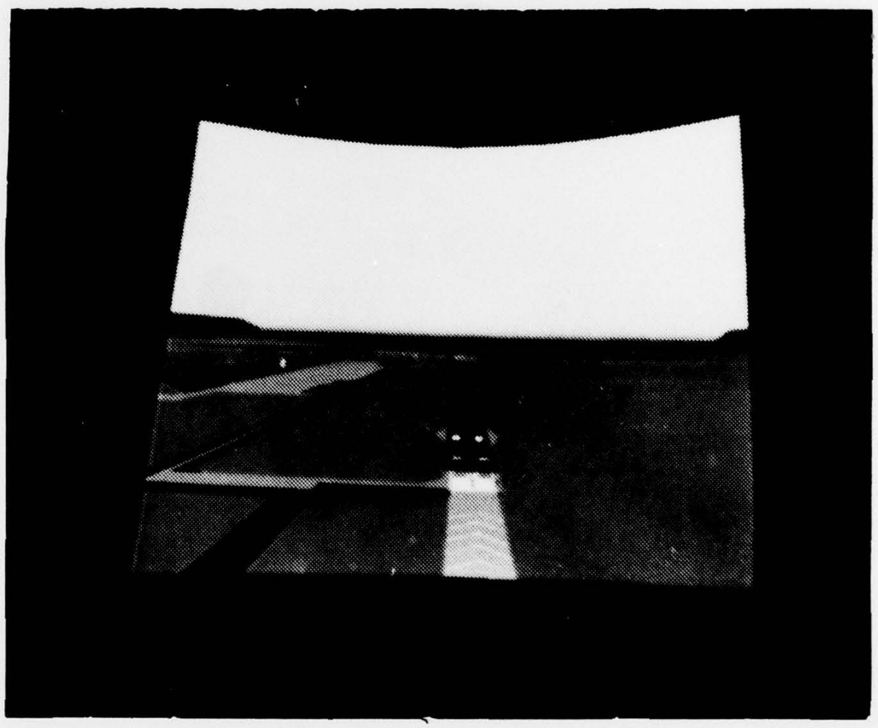

Figure 32. Davis-Monthan AFB and A-10 FOV.

displays) required various ASPT on-line software modifications and the generation of two special masks (hoods) to restrict the FOV displays.

3. Boom Dynamics

The boom dynamics program receives the requested position and requested rate of the boom coordinates from the operator logic program. The boom dynamics program simulates the response of the physical operator/boom system, assuming a skilled boom operator.

The reaction time based on the operator's perception and physical movements, as well as the reaction time of the boom system, are figured into the model.

4. Flow Field Effects

Changes in the aerodynamic coefficients due to the KC-135 flow field are calculated by this program. Only the near field (refueling envelope), wings-level condition is modeled. The relative roll variation is assumed negligible, and the near field to far field dependency is assumed to be linear. The coefficients are given as a function of lateral displacement of aircraft center-of-gravity locations at different values of vertical displacement. The flight coefficients are non-dimensional and consequently require only slight adjustment, depending on the type of aircraft which is being simulated as trailing the KC-135. In the case of this study, the flow field coefficients (lift, pitch, and roll) were refined, using multiplication factors displayed on the CRT screen.

These flow field coefficients are simply added to the respective aero dynamic coefficients.

5. Receiver Aircraft Handling Qualities

To complete the primary research objective, the basic refueling task had to be accomplished in an efficient and timely manner. To facilitate accomplishment of this basic task, handling qualities of the T-37 simulator were adjusted to emulate two broad categories of receiver aircraft. For pilots with tactical aircraft experience, a general "fighter" configuration was established, and for strategic bomber crews, a "bomber" configuration was developed. Both configurations were variants of the basic T-37 simulator math model. As originally developed, this model contained several factors, or multipliers, for adjusting the influence of numerous stability and control derivatives and general aircraft parameters. For the aerial refueling study, this capability was increased by adding factors for the basic drag coefficient, net thrust, and engine response (i.e., accelerating and decelerating). Flight test maneuvers were utilized to determine what value each factor should have. These manuevers included a control harmony investigation, level accelerations, and standard stability and control step and doublet control inputs.

Common to both configurations was a requirement to adjust the engine response. Evaluations of T-37 engine response by pilots of varied background indicated a need to increase the engine response. This was especially critical as the slow acceleration and deceleration of the T-37 centrifugal flow engines, compounded with limited visual cues for fore and aft movement, frustrated pilot attempts to control movement along the aircraft longitudinal axis. Engine response was increased by factor adjustments to the engine RPM/throttle-position time constant in the thrust module. Based on these changes, the engine acceleration time from idle to military was changed from 11 to 5 seconds. Visual perception of motion along the aircraft longitudinal axis remained a problem. An additional study should be conducted to determine which tanker model characteristics provide the pilot the best cues for movement along the longitudinal axis.

Additional changes for the fighter configuration included an increase in the pitch sensitivity and pitch damping. This was done to increase the pitch response and yet maintain good damping. The combination of pitch sensitivity and damping typified a fighter aircraft with operable stability augmentation equipment. The total thrust, gross weight, and drag were also adjusted to provide faster aircraft acceleration and deceleration. Attempts were made in early tests to also increase the roll sensitivity, but these adjustments tended to result in moderate to severe lateral pilot-induced oscillation when combined with limited FOVs. Since the basic T-37 simulator was sensitive in roll, a further increase in the lateral control for the fighter configuration was not deemed appropriate. Similarly, degradation of roll performance could mask test results caused by the limited FOVs; therefore, the basic T-37 roll configuration was judged the best compromise.

To simulate the more massive characteristics of bomber-type aircraft, simulator responses about all three axes were degraded in varying levels. Additional adjustments were made to lateral-directional derivatives to increase the tendency for cross-coupling. To control horizontal acceleration and deceleration of the bomber configuration, total thrust, gross weight, and drag were also changed. To evaluate these changes, B-52 qualified test pilots from the 6513th Test Operations Squadron at Edwards AFB flew the simulator with the changed simulator factors. These flights occurred after the subject pilots had completed their test sorties. Qualitative comments by the test pilots indicated that, while improvements had been made from the baseline T-37 configuration, they had not been optimized and additional improvements were possible with further refinements to simulator constants. The lack of optimization is not considered to have affected the test results. (See Appendix D.)

Additional handling quality engineering development should be done to evaluate changes associated with the tanker bow-wave and receiver weight changes during refueling.

A summary of changes to T-37 aircraft parameters and stability and control derivative is contained in Table 5.

Table 5. **Simulator Factors**

Simulator Factor	Trainer	Bomber	Fighter
Basic Drag	1.0	1.7	2.1
Net Thrust	1.0	1.4	1.7
Engine Response – Accel	1.0	3.75	3.75
Engine Response – Decel	1.0	7.5	7.5
Pitch Due to Elevator	1.0	0.6	1.2
Pitch Due to Pitch Rate	1.0	1.4	1.3
Roll Due to Aileron	1.0	0.5	1.0
Roll Due to Sideslip	1.0	1.5	1.0
Yaw Due to Rudder	1.0	0.8	1.0
Yaw Due to Aileron	1.0	1.4	1.0
Downwash – Lift	0.3	0.3	0.3
Downwash – Pitch Moment	0.3	0.3	0.3
Downwash – Roll Moment	1.2	1.2	1.2
Gross Weight	6,300	7,500	6,000

6. Cockpit Configuration

The simulator cockpit utilized for the Aerial Refueling Study was that of a T-37B jet trainer aircraft including canopy bow and windscreen center support. All instruments and indicators were operational. Although the T-37 aircraft does not have an aerial refueling capability, no additional special instruments or indicators peculiar to the aerial refueling task were added to the simulator cockpit. The simulator cockpit configuration may be observed in Figure 33.

7. Aural Cues

In addition to the visual simulation of the director lights, auditory simulation of the boom operator was given via verbal directions to the receiver aircraft pilot by the console operator. This was accomplished

Figure 33. **T-37 simulator cockpit.**

utilizing the alphanumeric graphics display which provided real-time fore/aft, right/left, and up/down magnitudes to achieve contact. Upon contact, the ASPT computerized voice would respond "ON" and "OFF" upon disconnect. Other simulated auditory cues include the engine whine and tire squeal upon touchdown.

8. Performance Measurement

As part of the Aerial Refueling Study, a performance measurement task was developed using the preprogramming system on ASPT. The task was part of the study phase which evaluated performance from pre-contact to contact, plus a predetermined amount of contact time. If a disconnect occurred after contact, the time to re-contact was recorded.

The scoring profile was as follows: After initialization at pre-contact and unfreezing, measurement consisted of deviations in horizontal and vertical about a line from pre-contact (3.05 m low and 15.24 m aft of the desired contact point) to contact. Along with this, the time from unfreeze to contact was recorded.

Once contact occurred, measurement was performed on three axes about the desired ideal contact position. Two of the axes were as from pre-contact to contact, horizontal and vertical. The other axis was that of the boom. This measurement continued for 1½ minutes of contact time on fighter-type aircraft and three minutes on contact time on bomber-type aircraft. If during this period a disconnect occurred, the number and the time of the disconnect were recorded. Scoring did not take place while attempting to reconnect after the initial contact occurred. After the desired contact time expired, a "Break Clear" command terminated scoring and ended the task.

In order to get an idea of pilot workload, two smoothness profiles were collected. Each profile consisted of selected aileron, elevator, rudder, stick, and throttle positions, forces, rates, and accelerations including the root mean square of certain values. The two profiles were from pre-contact to contact and from contact to "Break Clear" command (including all disconnect time). These data were subsequently stored on the disc utilizing the ASPT student data system.

As part of the measurement, the following tolerances were used:

Pre-contact to contact:

Horizontal	±6.10 m
Vertical	±3.05 m

Contact:

Horizontal	±3.72 m
Vertical	±1.43 m
Boom Extension	±0.95 m

NOTE: The contact limits approximate the Green to Green/Yellow to Yellow area of the boom extension (Figure 26).

To assist the console operators, a new graphic display (Figure 34) was developed at the advanced console of ASPT. The display consisted of a top and side view of the aircraft and boom. In addition, when pre-contact was reached, the term "PRE-CONTACT" would flash on the display. When contact occurred, a circle would appear and flash twice. If a disconnect happened, an "X" would appear over the circle and flash twice; and when reconnect occurred, the "X" would disappear and the circle would flash twice. In addition, contact and current disconnect times were displayed. The graphic display of boom position and receiver aircraft assisted operators/pilots during training and research studies of the air refueling task.

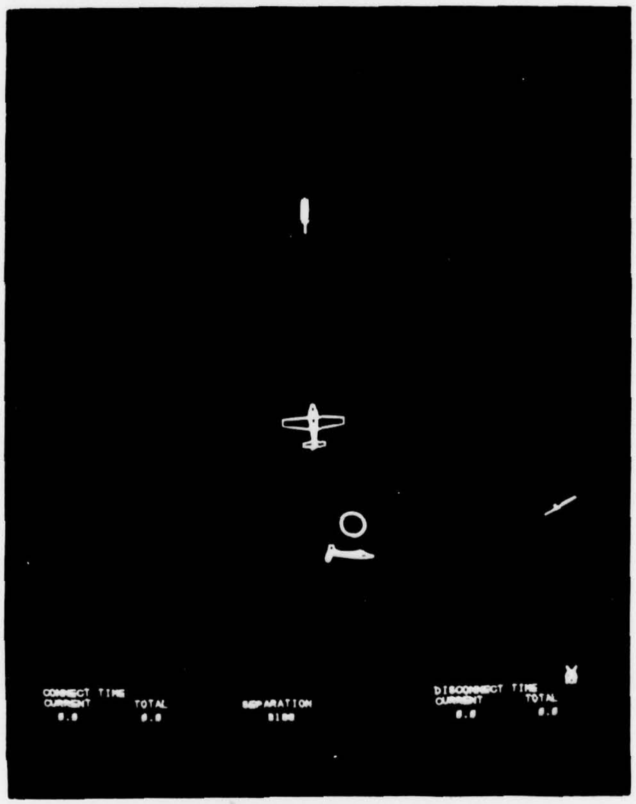

Figure 34. **Boom/receiver aircraft graphics display.**

In addition to the graphic display, three alphanumeric CRT displays were created: the first was used for development of the program to control the boom as an operator would, the second was a display to control and set the various values used during the study, and the last was a display to show the scoring results in real time.

The Boom Operator display (Figure 35) was designed for developing and debugging the program controlling the boom. Included on the display were flags for the various conditions and status of the boom. Additionally, input and output values to the program were available to ensure all aspects of the system were functioning.

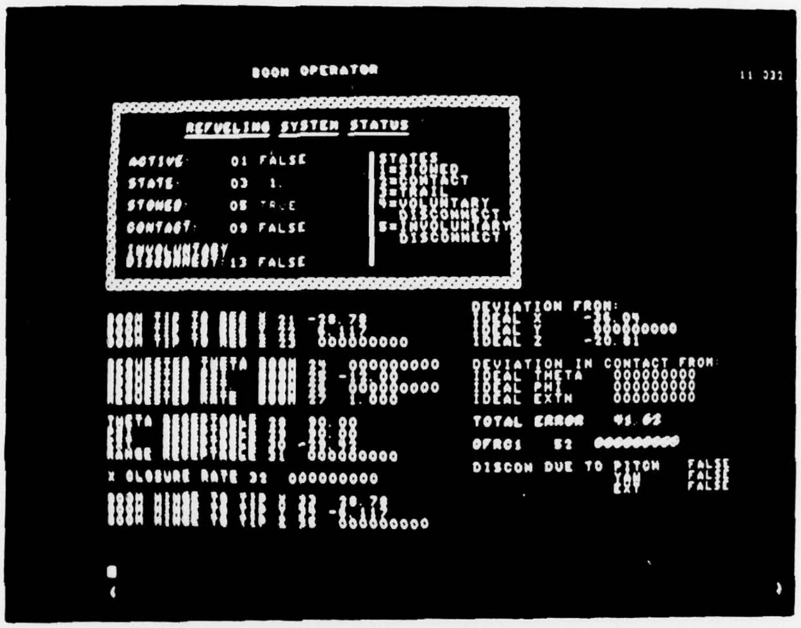

Figure 35. **Boom Operator display.**

The Aerial Refueling Control Page display (Figure 36) was used by the operators during the study for many functions. These functions include flags for the particular aircraft type being flown to ensure the airspeed adjustment is on, and a flag to show, when attached, the deviations from the desired boom position and the reasons for any involuntary disconnects. Also, as needed by each different type of aircraft, this display included controls for setting receiver aircraft receptacle offset from the pilot's eye viewpoint, FOV controls for sizes of the visual window displays, adjustment of FOV position, and boom refueling system status.

The last display generated was the Active Maneuver display (Figure 37) used during performance measurement as each pilot flew the mission for evaluation. This display, updated in real time, showed the percentage of time the pilot was within the prescribed tolerance bands for horizontal and vertical deviations while flying pre-contact to contact and for horizontal, vertical, and boom in and out deviations while attached to the tanker. Also displayed were times for pre-contact to contact, attached, and the disconnect time for the current disconnect, if any.

In addition to the above displays, the initial condition index was modified to list the conditions set up for the Aerial Refueling Study.

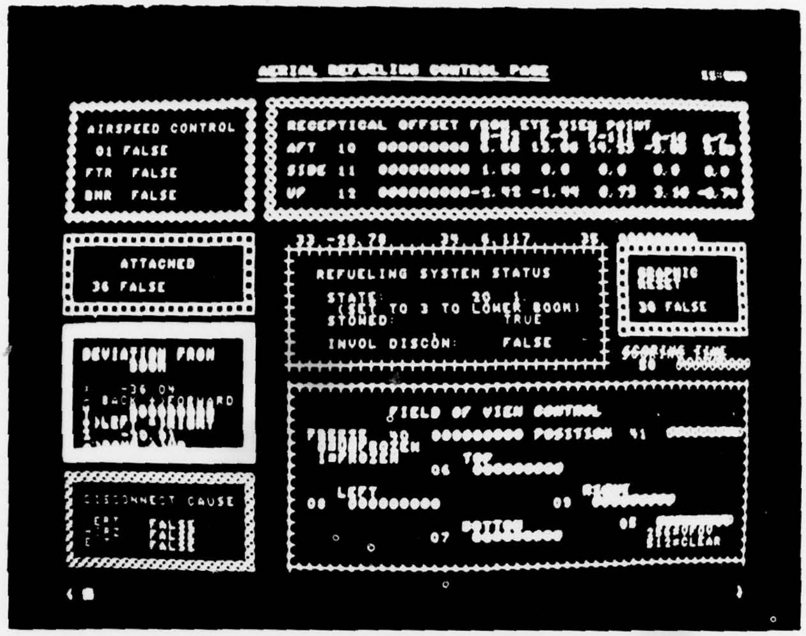

Figure 36. Aerial refueling control page.

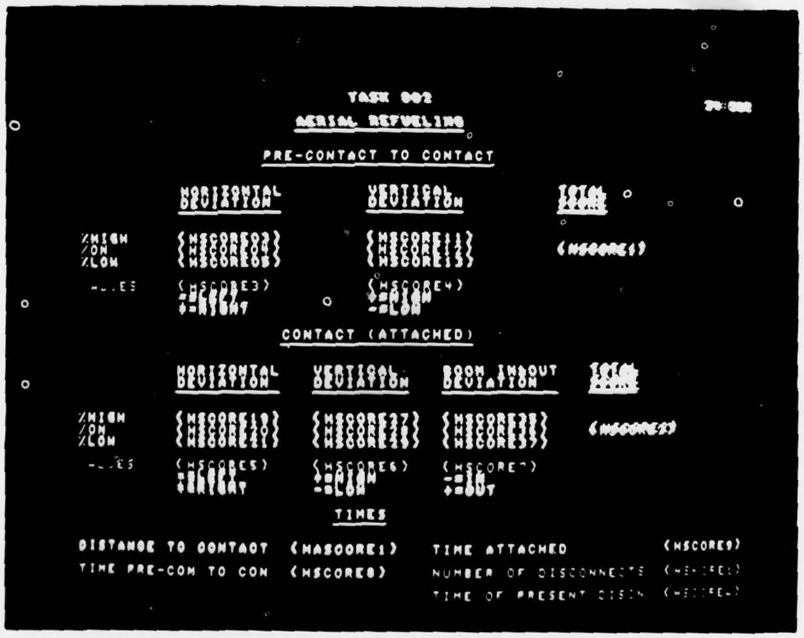

Figure 37. Active Maneuver display.

Conclusions

The use of the ASPT CIG visual system allowed considerable flexibility in duplicating the various test fields of view and window configurations under consideration.

Use of enlarged director lights did not affect pilot acceptance of the KC-135 tanker model.

Visual perception of motion along the longitudinal aircraft axis remained a problem.

Qualitative comments from B-52 test pilots indicated the adjusted T-37 handling qualities were an improvement from the baseline but not optimized. The lack of optimization is not considered to have affected test results.

The graphic display of boom position and receiver aircraft assisted operators/pilots during training and research studies of the aerial refueling task.

Recommendations

The final KC-135 complex tanker model did not fully use the edge capacity of the ASPT system. An additional study to determine the impact of tanker model edge density should be conducted.

An additional study should be conducted to determine what tanker model characteristics provide the pilot the best cues for movement along the longitudinal axis.

Additional handling quality engineering development should be done to evaluate changes associated with the tanker bow-wave and receiver change in weight during refueling.

In consideration of the knowledge gained from this project, the opportunity exists to apply this information and thereby, obtain a further refinement of the ASPT Aerial Refueling capability. It is, therefore, recommended that a second phase of this project be initiated to investigate the impact of the system refinements on pilot performance relative to the issues of FOV and tanker model visual cue requirements.

APPENDIX A: SPEECHMAKER VOCABULARY

AIM
ABORT
ABRUPT
AFT
ABOVE
ATC
AILERON
AIR
ALTIMETER
ALTITUDE
ANGLE
APPROACH
ARE
AROUND
AS
AT
ATTITUDE
BACK
BANK
BARWIDTH
BASE
BELOW
BOUND
BRAKE
BUFFET
CALL
CHANGE
CHANNEL
CHECK
CLEAR
CLOSED
CLEARANCE
CLIMB
CONTROL
COORDINATE
CORRECT
COURSE
CRAB
CRAFT
CROSS
DEGREES
DESCEND
DME
DOWN
DEFLECTION
DEPARTURE
DRIFT
DO

EIGHT
ELEVATE
EMERGENCY
ENGINE
ENTER
ER
FAILURE
FEET
FIELD
FINAL
FIVE
FIX
FLAPS
FLARE
FLOW
FOUR
FREQUENCY
FROM
FUEL
G
GCA
GEAR
GLIDEPATH
GO
GOOD
HALF
HEADING
HIGH
HINGE
HOLD
HORIZON
HUNDRED
IDLE
INCREASE
IN
ING
INITIAL
INTERCEPT
IDENTIFY
INVERTED
INSTRUMENTS
NOSE
NOW
NINER
OF
PROCEDURE
PULL
RADIAL

RAISE
SIX
SMALL
SPEED
SPIN
TOWER
TRAFFIC
TRI
TRIM
KNOTS
LAND
LEAD
LINE
LEFT
LEVEL
LONG
LOOSE
LIST
LIGHTS
LOW
MAIN
MAINTAIN
MAXIMUM
MILES
MINIMUM
MISSED
OFF
ON
ONE
OUT
OVER
OXYGEN
PASS
PATTERN
PENETRATE
PERCENT
PERFORM
PITCH
PLAN
POINT
POOR
POWER
PRESSURE
RATE
RECOVERY
REDUCE
REFERENCE
RELAX

REQUEST
RIGHT
ROLL
ROTATE
RPM
RUDDER
RUNWAY
SAFE
SET
SEVEN
SHOOT
SINGLE
STALL
STANDARD
START
STEEP
STICK
STOP
TAKE
TEN
TECH ORDER
THE
THOUSAND
THREE
THROTTLE
THROUGH
TIGHT
TIME
TION
TURN
TWO
UHF
UN
UNDER
UNTIL
UP
USE
VOR
WILL
WIND
WING
YOU
ZERO
SHORT
2025 Hz

Name	X Miles	Y Miles	Radius	Stripe	Description
BAR2	0.11	-0.13	848	6M105	DM Barrier Marker
BARM	-1.47	1.47	848	6M104	DM Barrier Marker
BLDA	-1.56	1.73	252	6M104	DM Northwest Bldg
BLDC	-1.68	1.43	521	6M104	DM Southwest Bldg
CHV2	-1.54	1.54	4596	6M104	DM Rnwy Chevron
CHVS	0.17	-0.19	4596	6M105	DM Rnwy Chevron
DAPA	-0.48	1.47	39588	6M104	DM Rnwy Apron
DHNG	-1.89	1.68	379	6M104	DM West Hangar
DMBA	1.18	0.48	111533	40M17	DM Base Gnd Texture
DMBR	1.09	1.94	36960	6M105	DM Base Gnd Texture
DMDV	5.03	-0.80	83185	40M17	DM Drag Strip & Vale R
DMEM	23.64	-2.25	19999	40M17	DM East Mountain
DMFW	-2.63	0.44	800000	40M17	DM Freeway
DMGC	-1.09	10.25	19096	6M104	DM Golf Course
DMGT	-0.72	0.00	800000	40M16	DM Gnd Texture
DMHY	-0.63	0.91	23684	6M104	DM Fuel Hydrants
DMNH	-5.83	-0.27	122825	40M16	DM Nogales Hwy
DMNM	8.25	23.64	19999	40M17	DM North Mountain
DMNW	0.95	6.53	316073	40M17	DM North Wash
DMOR	-1.26	1.92	800000	40M16	DM Old Runways
DMPK	-0.65	2.29	9277	6M104	DM B-52 Park
DMPW	2.97	2.69	254028	40M17	DM Pantano Wash
DMRB	-0.63	0.74	55528	40M16	DM Runway Base
DMRR	-1.71	1.09	800000	40M16	DM Railroad
DMS5	2.93	-1.52	10690	6M105	DM Site 5
DMSL	0.02	1.60	13623	6M105	DM School
DMSM	2.91	-31.96	19999	40M17	DM South Mountain
DMSS	-1.52	9.18	10733	6M104	DM Shopping & Skyline
DMTG	-1.52	0.11	21328	6M104	DM Tucson Gas
DMTI	-3.75	-2.42	48153	6M104	DM Tucson Intnl
DMTK	0.51	0.34	4903	6M105	DM Storage Tanks
DMTU	-2.25	4.55	237639	40M16	DM Tucson Texture
DMWM	-16.04	-0.65	19999	40M16	DM West Mountain
DRMA	-0.67	0.67	54563	40M16	DM Rnwy Markings
DRMB	-0.67	0.67	54563	40M16	DM Rnwy Markings
DRMC	-1.28	1.28	12307	6M104	DM Rnwy Markings
DROA	-0.63	0.74	53646	40M16	DM Runway Cutouts
DTXA	-1.16	1.64	8944	6M104	DM West Taxiways
A7F4	-0.02	0.00	28284	40M16	A-7/F-4 FOV Hood
AMB1	0.00	0.00	2828	40M17	KC-135 Nose Fuselage
AMB2	0.00	0.00	2828	40M17	KD-135 Main Fuselage
AMB3	-0.02	0.00	2828	40M16	KC-135 Left Wing
AMB4	-0.02	-0.02	2828	40M16	KC-135 Right Wing
AMB5	-0.02	0.00	2828	40M16	KC-135 Rear Fuselage
AMB6	-0.02	0.00	2828	40M16	KC-135 Tail Section
AMBA	0.00	0.00	2828	40M17	KC-135 Dir. Lt. Lf. Fuse.
AMBB	0.00	-0.02	2828	40M17	KC-135 Dir. Lt. Rt. Fuse.
AMBC	0.00	0.00	2828	40M17	KC-135 Dir Lt. Front Fuse.
LTLF	-0.02	0.00	2828	40M16	Night Lt. Lf. Wing
LTRT	-0.02	-0.02	2828	40M16	Night Lt. Rt. Wing
SLFS	-0.02	-0.02	2828	40M16	Austere Lf. Stabilizer

Name	X Miles	Y Miles	Radius	Stripe	Description
SNFS	–0.02	–0.02	2828	40M16	Night Lf. Stabilizer
SNLF	–0.02	0.00	2828	40M16	Night Lf. Fuselage
SNRF	0.00	–0.02	2828	40M17	Night Rt. Fuselage
SNTS	–0.02	0.00	2828	40M16	Night Rt. Stabilizer
SRTS	–0.02	0.00	2828	40M16	Austere Rt. Stabilizer
STLF	–0.02	0.00	2828	40M16	Austere Lf. Fuselage
STRF	0.00	–0.02	2828	40M17	Austere Rt. Fuselage
TLLT	–0.02	0.00	2828	40M16	Night Lt. Tail

APPENDIX C: DETAILED VARIABLE/SLEWABLE DISPLAY WINDOW CONFIGURATION SOFTWARE MODIFICATIONS

The following paragraphs describe the software modifications required to process the special three-window FOVs. Refer to Figure 4 for the four FOV sizes.

Helmet Sensor Freeze/Unfreeze Function (CPU-A)

Two data pool variables in the CPU-C and CPU-A common memory are used for the freeze/unfreeze capability. CPU-A memory address 1B7EO contains the control flag (zero means unfreeze, non-zero indicates freeze) and address 1B7E4 contains the latest pitch and yaw data received from the helmet sensor device prior to the freeze command. This function is used to allow the displayed FOV to move with the pilot's helmet movement and to be frozen at any location within the ASPT Visual System display constraints. This feature was used with all four FOV displays.

0	16	31
FREEZE CONTROL WORD	NON-AERO-FREEZE	
PITCH VALUE	YAW VALUE	

INTERFACE CONTROL WORDS FOR FIELD OF VIEW FREEZE/UNFREEZE FUNCTION

Hood Processing Modifications (CPU-B)

Two special hoods were constructed for the Aerial Refueling Study to limit the FOV. They are the A-7/F-4 and the FB-111 hoods. These hoods consist of three window fields of view each and were made to remain positioned relative to the cockpit's viewpoint and move with the cockpit's movement; however, if the helmet sensing device is being used, the hoods will move in conjunction with the helmet movement. The following paragraphs define the software modifications relative to the hood processing.

Special Hood Priority

The special hoods (A-7/F-4 and FB-111 FOVs) used were normal models read from the disc. The objects which have bit 24 set in their Active Object List (AOBJL) entries have priority over all other objects. When objects of this kind are active in the display, then no MODPLIST entry should be built for the models containing these objects or else priority problems will occur.

The AOBJL routine normally sets a bit of word 10 in the CPU3BOOK entry of a model if any of the model's objects are active, after which the MODPLIST routine builds model priority list entries for all models having their respective bit of word in the CPU2BOOK entry set. The AOBJL routine was modified to prevent the relevant bit from being set for models with special objects to prevent the priority problem.

PAOL and AOBJL Control Table Modifications

CPU-B's "SHIP" routine was modified to look at the special hood model's control bits (Bits 27 and 28 of MODTAB+2W) and if they are set, then set bit 9 in each of the hoods' object entries into the PAOL (Potentially Active Object List) table. CPU-B's "BUILD" routine was modified to test bit 9 of each PAOL entry and if set, then set bit 24 in the AOBJL for this object. If bit 9 is not set, then continue normal processing. Also, if any object has bit 24 set in the AOBJL, then the control work named "FOVFLAG" must be a non-zero value so that the special hood dynamics will be used for all objects with bit 24 set in the AOBJL.

APPENDIX D: TEST PILOT EVALUATION OF ASPT AIR REFUELING PROCEDURES

Pilot Debriefing Summary

On 16 February 1978, Maj Hank Hoffman and Capt Tom Lebeau (6512th Test Squadron, Edwards AFB) conducted a qualitative evaluation of ASPT flying qualities and visual presentation for the Air Refueling Study.

The basic objective of the Air Refueling Study was to evaluate various fields of view during simulated air refueling training. To assist in accomplishing the air refueling task, the handling qualities of the T-37 simulator were adjusted to emulate two broad categories of aircraft: fighter and bomber. Both pilots observed that the adjusted handling qualities were an improvement upon the basic T-37, but were nowhere near optimized as a B-52 bomber. They provided valuable corrections to the handling qualities which allowed a truer representation of the bomber-type aircraft. As observed during the engineering development and data collection, the primary problem was an inability to control movement along the longitudinal (X) aircraft axis. This difficulty was caused by:

1. Poor simulation of bomber acceleration/deceleration.
2. Absence of definite visual cues for the tanker model.
3. Absence of sensual cues for fore and aft motion.

Based upon their observation, the handling qualities were adjusted to:

1. Degrade engine RPM deceleration.
2. Degrade engine thrust.

These changes resulted in making the simulator more "inertia" sensitive such that small changes in engine RPM did not result in such large changes in aircraft acceleration/deceleration. This tended to increase the pilot's ability to control position along the aircraft X axis and hence minimize fore and aft refueling disconnects.

The pilots also provided the following general observations:

1. The T-37 model is too roll sensitive with the visual lagging slightly behind the aircraft.
2. Future tanker models should include a lower UHF antenna simulation with a single reference line behind the antenna for fore and aft position cues.
3. The B-52 "hood" appeared larger than the actual aircraft and various hoods did not appear to increase the difficulty of the task.
4. There was not sufficient change in difficulty associated with the night and day models. The day model was as difficult as actual night refueling and the night model did not vary significantly.
5. There should be a math model of a drag increase as the pilot approaches from pre-contact to the contact position.
6. There should be an audible cue of the air passing by the canopy associated with proximity of the boom.
7. The rolling moment in downwash should be increased slightly.
8. Rough air can be an aid in training, and as student proficiency increases, rough air can be added to increase task loading. It is mandatory that students not be discouraged; student confidence must be maintained throughout training.
9. The director lights are a very valuable cue even for day refueling. Lack of resolution did make our lights somewhat difficult to see.
10. The night tanker should have the shading reversed with the wings a dark gray and only the lines representing the engine nacelles a light gray. Also, some background lights should be added along the director light panel.

☆U.S. GOVERNMENT PRINTING OFFICE: 1978-671-056/91