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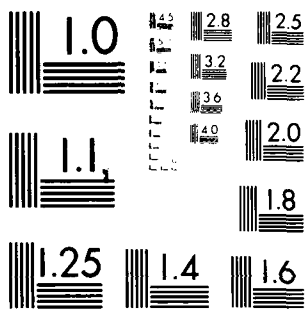

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AIR FORCE HUMAN RESOURCES LABORATORY

VISUAL SCENE SIMULATION REQUIREMENTS FOR C-5A/C-141B AERIAL REFUELING PART TASK TRAINER

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This report addresses the requirements of visual scene simulation for effective training in a ground-based air refueling part task trainer (ARPTT) to be used by Military Airlift Command (MAC) for C-5A and C-141B aircrew continuation training. Although effective training has been demonstrated in other ARPTTs for initial qualification pilots, it is unclear what this implies for continuation training. Given the reliance of the experienced pilot on a variety of tanker visual cues, any significant reduction in the fidelity of such cues in the simulated visual scene may result in reduced effectiveness of the device for skill maintenance. An analysis of the cues utilized in air refueling, based on responses from 283 pilots, suggests that an ARPTT will require a high degree of tanker image detail and a horizontal

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field of view (FOV) of sufficient size to include the tanker outboard engines and wing areas. Recommendations are made concerning minimum resolution, FOV, use of color, luminance level, contrast modulation, and design eyepoint for the ARPTT visual display.

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The Public Affairs Office has reviewed this paper, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This paper has been reviewed and is approved for publication.

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PREFACE

This research was performed to satisfy the requirements of Air Force Human Resources Laboratory Technical Planning Objective G03, the thrust of which is air combat tactics and training. The general objective of this thrust is to identify and demonstrate cost-effective training strategies and training equipment capabilities for use in developing and maintaining the combat effective of Air Force aircrew members.

VISUAL SCENE SIMULATION REQUIREMENTS
FOR C-5A/C-141B AERIAL REFUELING PART TASK TRAINER

1. INTRODUCTION

The growing global airlift mission requirements of the Military Airlift Command (MAC) have necessitated an increase in the number of transport aircraft capable of aerial refueling (AR). The training of aircrews in the initial acquisition of AR skill and in the maintenance of proficiency in AR, however, must be conducted in the face of limited tanker sortie availability, high fuel costs, and fleet airframe limits.

In order to meet the demands of increased aircrew AR training, MAC will procure several ground-based AR part-task trainers (ARPTTs) for the training of its C-5A and C-141B aircraft commanders. Maintenance of aircrew AR skill will be the major use of the devices. Estimates of the AR training hours that will be required to meet fleet readiness for C-5A and C-141B aircrews show that continuation training will require nearly four times as much device utilization time as is needed for initial AR skill acquisition (Military Airlift Command, 1978).

This report addresses the requirements of visual scene simulation for effective training in a ground-based ARPTT. The restriction of this report to the visual scene display characteristics reflects the importance of visual cue utilization in AR as well as the fact the device cost will be driven largely by the visual scene simulation requirements. The issue of simulator handling fidelity is also important in the specification of an ARPTT but is beyond the scope of this report. The recommendations in this report are made with the presumption that the highest possible fidelity between aircraft and simulator handling qualities will be provided in the ARPTT device.

2. APPROACH

In order to determine the required cues for the ARPTT visual display system to meet the needs of initial and continuation training, a detailed analysis of the AR task was conducted as well as a survey of training and human factors literature relevant to AR and site visits to simulator facilities currently involved in AR training. While it would have been highly desirable to conduct an empirical evaluation of the continuation training effectiveness of various ARPTT candidate configurations, equipment, time and cost constraints made this approach impracticable. The results of studies assessing the effectiveness of ARPTTs for initial AR qualification are included in this report.

3. AERIAL REFUELING

The essential task in AR is to fly close formation with another aircraft. The pilot must develop fine coordination between visual recognition/discrimination of cues on the tanker aircraft (KC-135 or KC-10) and attitude/thrust control of the receiving aircraft. The task is made more difficult due to significant aerodynamic interaction effects that occur when two large aircraft are in close vertical proximity. The downwash and wingtip vortices produced by the tanker aircraft may further increase the difficulty of the tasks, particularly for the receiver pilot initially qualifying in AR.

3.1 Initial Qualification and Continuation Training

Synthetic training devices have proved to be highly cost effective in training pilots in the initial skill acquisition phase of AR. At the Boeing Aerospace Company simulator facility, contracted training of C-5/C-141 pilots in AR resulted in the savings of one inflight AR training sortie per pilot (Sitterly, 1981). Success with ground-based AR simulators has also been found for initial qualification of B-52 aircrews in AR by the Strategic Air Command (SAC, 1980). The finding of positive transfer of ground-based AR training for initial qualification pilots should not be interpreted as being evidence that continuation training programs will meet with the same success utilizing these ARPTT systems. The training requirements for a pilot unfamiliar with AR differs significantly from those of a pilot who is already proficient in AR but may require periodic training to maintain skill proficiency. The novice pilot undergoing initial AR qualification must overcome the substantial apprehension associated with the need to acquire and maintain close contact with another large aircraft for periods as long as ten minutes. Secondly, stabilizing an aircraft the size of a C-5 or C-141 in a precontact position approximately 50 feet aft of the tanker requires the training of aircraft control skills of a higher level that those required for normal flight operations. Initially, qualifying students may require a substantial amount of training just to stabilize the receiver aircraft behind the tanker; the downwash created by the tanker can result in a pilot-induced roll oscillation which may lead to a severe wing-walk of the receiver aircraft. Experience with initial qualification of pilots using current ARPTT systems suggests that the principal utility of these devices has been in providing the pilots the opportunity to gain confidence in their ability to safely execute close formation flying with another large aircraft as well as in providing training in the initial development of control skills unique to AR.

In contrast to initial qualification training, continuation training will emphasize the maintenance of AR skill that has been refined over the course of repeated inflight AR sorties. Experienced AR pilots develop a reliance on a variety of tanker visual cues. In the absence of such cues, these pilots may experience difficulty in precontact stabilization, judging the closure rate to the contact position, and in maintaining contact with the tanker for sustained periods of time. Comments of AR qualified pilots who have "flown" current ground-based ARPTT systems suggest a wide range of opinion on the importance of certain visual cues needed to safely perform AR. Some pilots found that the horizontal field of view (FOV) of the current ARPTT systems was too restrictive and others required more realistic texturing of the fuselage on the displayed tanker image. While a consensus can be reached as to pilot opinion concerning the need for certain visual cues in AR, individual differences among pilots will undoubtedly affect the importance assigned to any given cue. The differences in cue utilization by pilots indicate that, while a consensus of pilot opinion can be a useful guide for the simulation of the visual scene in an ARPTT, any significant reduction in the fidelity between the simulated and inflight visual scene may result in reduced effectiveness of the device in the maintenance of skill proficiency for some pilots. Moreover, an ARPTT system intended to maintain skill proficiency of experienced pilots in lieu of inflight AR sorties must meet more stringent criteria of commonality with the inflight environment than a system designed only to familiarize a novice AR pilot with the task. It can be expected, therefore, that acceptance of the device as a substitute for inflight AR experience will be an important factor in the ultimate training effectiveness of the device.

3.2 Visual Cues in Aerial Refueling

In order to assure that a candidate ARPTT system for C-5/C-141 AR training provides sufficient scene content to fulfill the requirements for the maintenance of AR skill, it is necessary to provide a detailed analysis of the visual cues utilized by experienced AR pilots. Since it was not possible to conduct an experimental test of AR cue utilization, the analysis included data available through interviews and surveys conducted by the Air Force Human Resources Laboratory (AFHRL) and MAC. The following summary of cue utilization by experienced AR pilots is based on responses from a total of 283 aircrews. The major tanker cues utilized by pilots when refueling from a KC-135 are shown in Figure 1. Cues utilized for the KC-10 tanker refueling will not be discussed.

3.2.1 Daytime AR. For daytime AR, visual cues on the tanker are not critical until the receiver aircraft is within 500 feet aft of the tanker. At this point the receiver aircraft pilot should be able to align the boom nozzle and ruddevators with the nose of the tanker to form a "rifle-sight" view for directional stability. At 300 feet aft of the tanker the receiver pilot should be able to detect the color-coded director light system located on the tanker fuselage underbody forward of the leading edge wing root. The UHF antenna and the row of quick release fasteners (known as the "reference line" and painted white on some tankers) are clearly discernible 100 feet behind the tanker. The pilot uses the intersection of the UHF antenna and the reference line to judge vertical position relative to the tanker. In addition, tanker design lines on the main gear pod and wing roots are used for azimuth control at this distance.

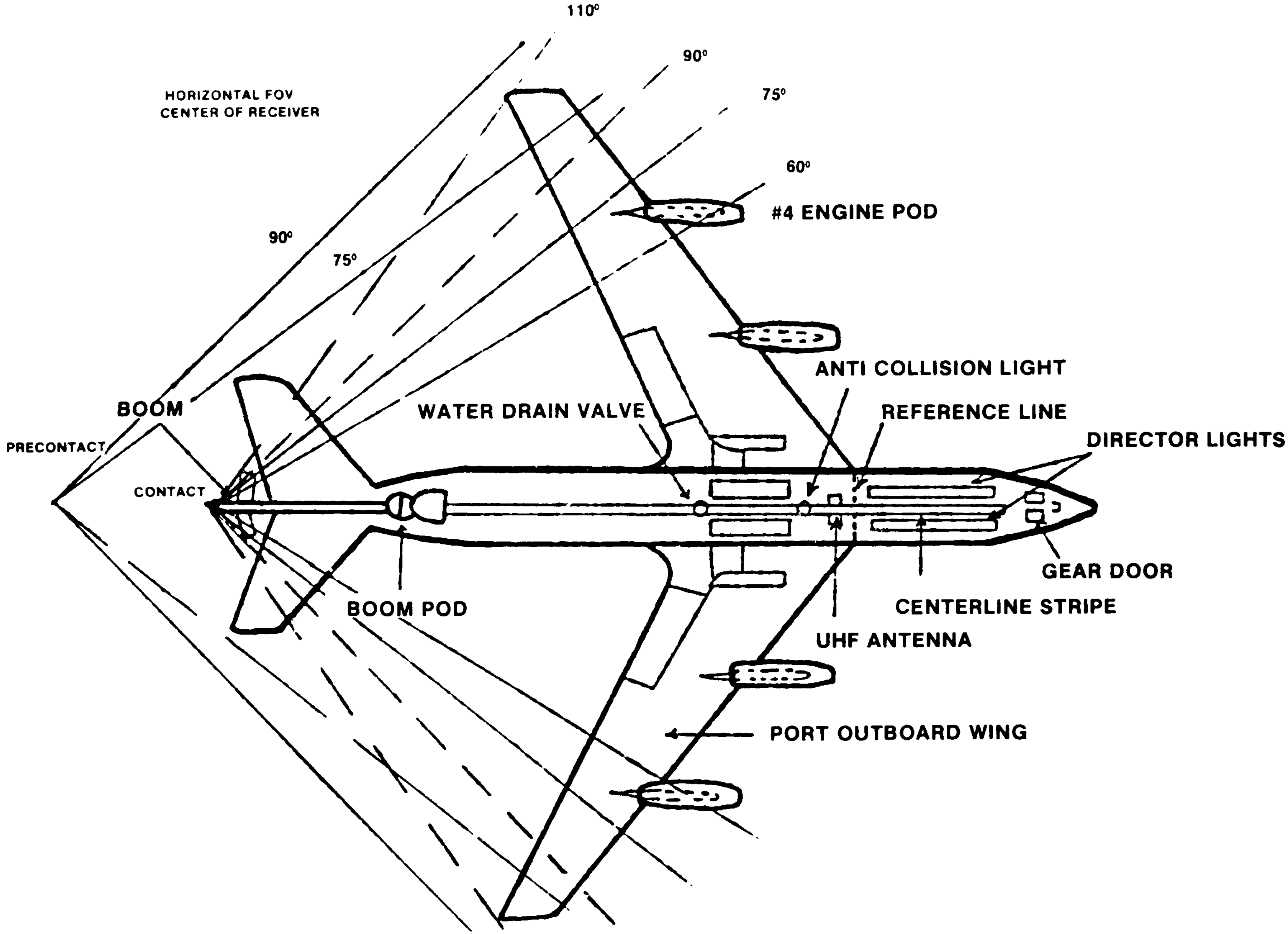

Figure 1. KC-135 TANKER PRIMARY AERIAL REFUELING CUES AND HORIZONTAL FIELDS OF VIEW FROM THE CENTER OF THE RECEIVER COCKPIT IN THE PRECONTACT AND CONTACT POSITION

At the pre-contact position approximately 50 feet aft and 10 to 15 feet below the tanker, roll information is provided by the tanker wingtips. Changes of 1^{o} to 1.5^{o} of tanker roll are discriminable at this distance and are utilized not only for roll stabilization of the receiving aircraft but also for tracking bank changes during tanker/receiver coordinated turns. Individual elements of the tanker flight director light system, as well as the boom operator window, will be clearly discriminable at pre-contact. Flight director lights are needed since the tanker boom operator may manually guide the receiving aircraft from the-pre-contact into the contact position using both radio communication and director lights.

The major cues used by the receiver pilot when contact is achieved with the tanker boom are listed in the order of importance to the receiver pilot:

1. The tanker outboard (No. 4) engine resting against the right edge of the pilot's forward windshield. The engine nacelle incident to the windshield post is used for fore/aft position control.

2. Flight director lights. The director light system on the KC-135 consists of two rows of lights located between the nose and main landing gear projecting downward at an angle of 30^{o} from the tanker's longitudinal axis. Seen from the receiving aircraft's perspective, the left row of lights provides vertical position information while the right row provides information for the correct fore-aft position of the receiver. For each row of lights, correct position is indicated by a green light and incorrect position by a red light.

3. Intersection of the UHF antenna with the tanker reference line. The pilot will attempt to maintain the UHF antenna perpendicular to the reference line for vertical position control.

4. Boom operators window and pod resting slightly below the top of the pilot's windshield.

5. The wing area outside of the No. 1 engine for pilot roll control and outside the No. 4 engine for instructor (co-pilot) roll control.

6. The yellow centerline stripe on the tanker fuselage is used for azimuth position control.

3.2.2 Nighttime AR. The major cues for AR during night refueling missions are the tanker illumination lights and the flight director lights. In order to establish the proper approach angle, the pilot of the receiver aircraft will use the boom nozzle lights incident with the tanker underbody lights that illuminate the outboard engines. The flight director lights will be used from the pre-contact through the contact stages of AR during nighttime AR.

4. RECOMMENDED VISUAL SCENE SIMULATION FOR AN ARPTT

The visual scene simulation for an ARPTT will require a high degree of tanker image detail and a horizontal FOV of sufficient size to include the tanker outboard engines and wing areas. Scene brightness, contrast and chromaticity will also impact the extent to which elements of the generated scene are visually discriminable at the appropriate range and in the correct perspective.

4.1 Display Resolution

The resolution requirements of a visual display are determined by the range at which critical elements of the visual scene are resolved by the retina of the human eye. The limiting resolution of photopic (daylight) vision is about 1 arc minute in the fovea centralis, an area having a radius of 1^{o} about the foveal (or central) axis. Resolution power of the eye drops rapidly for scene elements presented off this foveal area; nearly 80% of the eye's resolving power is lost at 10^{o} off the foveal axis.

The requirements for the resolution of the ARPTT visual display can be determined by computing the visual angle subtended by the critical cues (e.g., UHF antenna) used in AR. The analysis of visual cues used in AR revealed that the majority of these cues on the tanker underbody are at or forward of the wings. At the precontact stage of AR these elements would have a minimum angular subtense of approximately 3.8 arc minutes (horizontally and vertically). The exception to this estimate are the quick release fasteners on the reference line which could be artificially enlarged in display generations with very little loss of geometric perspective. Alternatively, the reference line may be depicted in the displayed image as a white stripe as it is on some tanker aircraft.

Resolution requirements beyond the area of the tanker fuselage are determined by the need to discern the vertical displacement of the wings. A 1^{o} roll change of the tanker will result in .7 to 1 foot displacement of the wing measured, respectively, at the outboard engine and at the wingtip. Viewed at a distance of 120 feet, this displacement will traverse a visual angle of from 20 to 29 arc minutes.

Horizontal resolution requirements beyond the tanker fuselage are determined by the need to discriminate the size of the disparity between the pilot's forward windshield strut and the tanker's No. 4 engine for fore-aft movement cueing. The precise angle of incidence for this cue depends upon the point of regard for the pilot which in turn depends on individual differences in the choice of seat position. Discrimination of a 1-foot change in distance between the two aircraft should be possible for a candidate visual display system. Movement of this magnitude will result in approximately 9 arc minutes of horizontal displacement of the outboard engine on the pilot's retinal image if the pilot views the engine at a distance of 120 feet.

The limiting resolution requirements for an ARPTT will therefore differ markedly for the display of scene elements at or within a few degrees of the longitudinal axis of the tanker when compared to the display of those elements further away fom the tanker fuselage. A limiting resolution of 3.8 arc minutes per line horizontally and vertically is indicated for displaying details such as the flight director lights and UHF antenna on the tanker underbody. In order to display sufficient wing displacement and the outboard engine/windshield strut angle of incidence, a limiting resolution of 9 arc minutes per line horizontally and 20 arc minutes per line vertically is indicated for the display of tanker features located in areas other than the tanker fuselage.

4.2 Display Field of View (FOV)

The FOV requirements for an ARPTT visual display are determined in the vertical axis by the pilot's need to see the tanker horizontal stabilizer at the precontact position. For the horizontal FOV requirement, the width of an ARPTT visual display is determined by the need to discern wing movement at or beyond the No. 4 engine position and the incidence of the No. 4 engine with pilot's forward windshield inboard strut at precontact.

A vertical FOV of 36° is clearly adequate for an ARPTT visual display. Possible ARPTT display horizontal FOVs are illustrated in Figure 1 at the approximate precontact and contact positions. The horizontal FOV of 48° has been found to be adequate for initial qualification in AR in studies conducted by SAC for B-52 aircrews. For the continuation training of experienced AR pilots, however, the only available evidence that FOV may affect training effectiveness of the ARPTT is found in a study conducted by Woodruff, Longridge, Irish, and Jeffreys (1979). This study examined the effects of various simulator FOVs on the ability of experienced AR pilots to achieve in a simulator a criterion performance of 3 minutes of continuous tanker contact. Reductions in horizontal FOV resulted in significantly reduced AR performance as measured by contact time and inadvertent disconnects. No measures of the effects of reduced FOV on the transfer of the simulator training to the aircraft were provided by this study. Although the study results do not provide conclusive evidence that reduction in the FOV for an ARPTT below that available in the aircraft will result in unacceptable training utility, the reduced FOV effects in this study indicate that experienced AR pilots use cues, in the aircraft, that require an ARPTT FOV of sufficient size to permit their inclusion. The task analysis of AR indicates that the major cues which would require a wider FOV than either the 48° horizontal of the B-52 ARPTT or the 60° horizontal of the Boeing ARPTT are the vertical displacement of the wing and the incidence of the No. 4 engine with the pilot's windshield strut at contact. The FOV from the pilot's position in a C-5A aircraft is presented in Figure 2. A minimum of 75° horizontal FOV would be required to provide the desired fore-aft cueing in the contact position and some of the wing area outside the No. 1 engine. A 90° horizontal FOV would provide

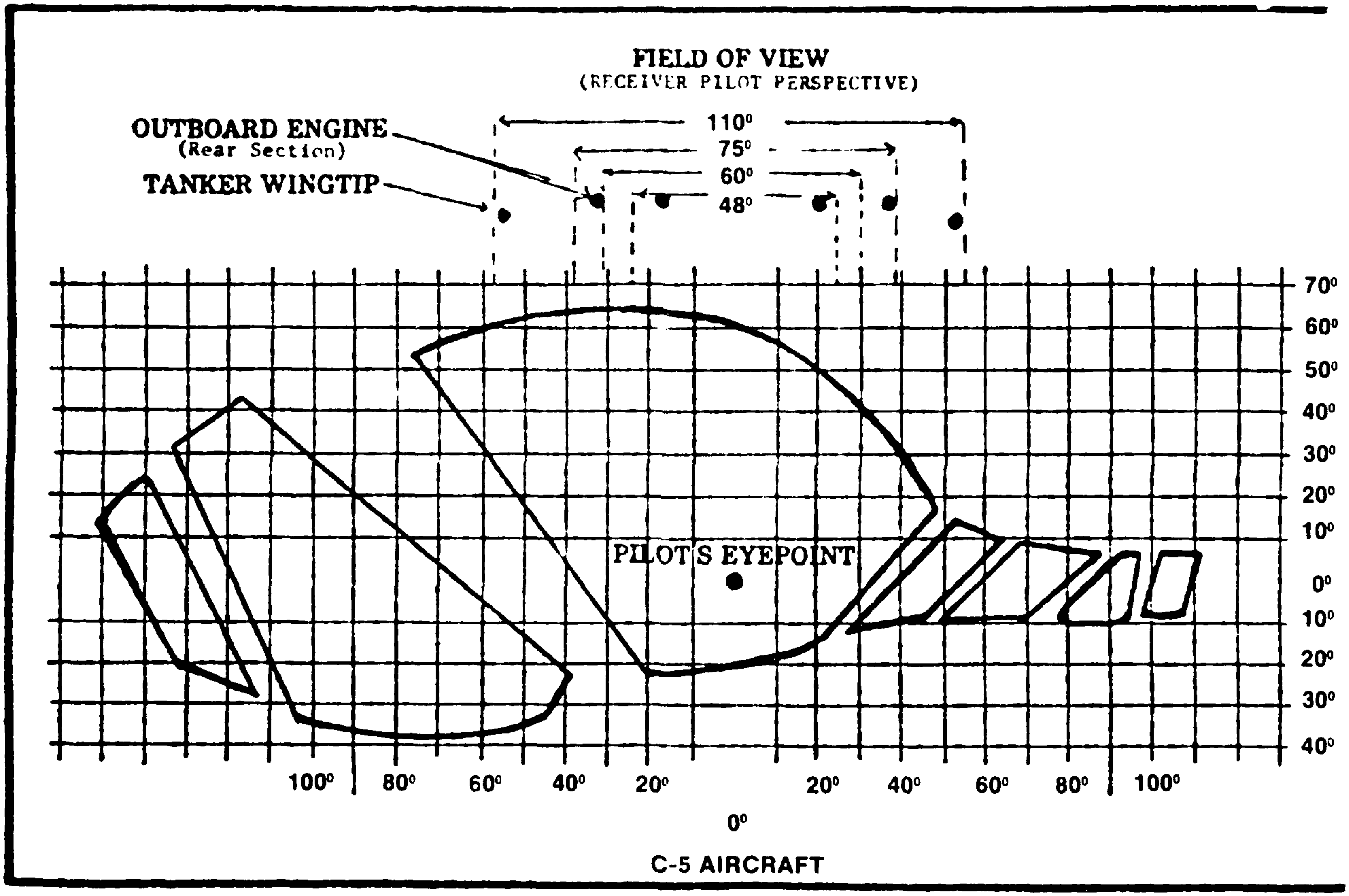

FIGURE 2. C-5 COCKPIT FIELD OF VIEW AND LOCATION OF TANKER ENGINES/WINGTIPS IN THE AERIAL REFUELING CONTACT POSITION

that color in dynamic visual scene simulation may be perceived by pilots as more realistic because it increases the range of luminance values available in the scene. This in turn will result in an appearance of increased texture and salience of scene elements. However, no formal test of the impact of scene chromaticity on AR training has been conducted. Color is recommended for the ARPTT visual scene for director light display and is considered a desirable option for the entire scene only if the inclusion of scene chromaticity does not result in a sacrifice either to scene resolution or to FOV.

4.4 Display Luminance Level

The visual scene simulated on an ARPTT visual display system must be of sufficient brightness to assure that the pilot-trainee's vision operates at a level corresponding to normal photopic conditions for daytime AR. Reducing the luminance level of the visual display below optimal range for photopic vision results in a reduction of the eye's contrast sensitivity. This reduction in sensitivity will impair the pilot's ability to discriminate the small tanker details provided by the display. In short, a high resolution display system may be rendered inadequate for the presentation of critical scene elements if the mean luminance level of the display is not sufficiently great. The minimal luminance level at which photopic vision predominates is approximately 6 foot-lamberts (ftL). This luminance level should be considered as a minimum for the average level of luminance of an ARPTT visual display to assure that projection of small details of the tanker will be perceived by the pilot for the daylight AR training requirements and provide the illusion of daylight missions (North Atlantic Treaty Organization, 1981). If color-coded information is provided in the display, a mean luminance level of 10 ftL is required for accurate color perception. As with the case of high resolution, the training value of the addition of chromaticity to the display may be defeated if the average display luminance level is insufficient.

4.5 Display Contrast Modulation

In addition to the importance of providing a sufficiently high mean luminance level in an ARPTT visual display, the dynamic range of luminance values provided by the display must meet or exceed the threshold sensitivity of the pilot's vision in order to assure that small details are discernible. It was noted earlier that contrast sensitivity of the eye will vary with the mean luminance level of the display. For a given level of luminance, the threshold contrast sensitivity of the eye will also vary as a function of the spatial frequency (in cycles per degree of visual angle) of luminance levels in the displayed image. In brief, the contrast of an image element to its background must increase as the resolution of the display increases in order to assure that the threshold contrast sensitivity of the eye is exceeded. Therefore a correspondingly greater modulation in display contrast is needed for the eye to detect the details provided by higher resolution displays (Farrel and Booth, 1975). A display system with a resolution of 3.8 arc minutes line requires a minimum luminance range of .20 ftL given an average luminance of 10ftL. A display with the same average luminance, but with a resolution of 9 arc minutes per line, requires a minimum luminance range of .12 ftL.

In order to provide the array of light patterns normally encountered in daylight scenes a monochrome visual display should provide 10 shades of gray, each successive shade of gray being greater by a factor of 2 units of luminance (North Atlantic Treaty Organization, 1981). Such a display would provide a contrast ratio of 32:1 for daylight views. The B-52 ARPTT by comparison has a contrast ratio of 25:1 and has provided adequate training in AR. A display contrast ratio of a minimum of 25:1 would appear to be required for a candidate ARPTT that would have a higher resolution (3.8 arc minutes vs 8 arc minutes in the B-52 ARPTT). A design goal of a 32:1 contrast ratio is desirable for enhancing scene realism.

nearly half of the wing trailing edge area between the outboard engine and the wingtip. Wingtips will be visible at contact with a 110° horizontal FOV ARPTT visual display system.

Certain cues used in aerial refueling may not be reflected in conventional task analysis, however. Increasing the horizontal FOV will, for example, present the pilot with increased opportunity to detect tanker wing movement in the visual periphery as the pilot attends to cues on the tanker fuselage. However, the peripheral roll cueing of the tanker provided by the wing movement is not a simple, linear function of the extent of the tanker wing that a simulator display could provide. First, visual acuity of the pilot degrades as a nonlinear function of distance from the fovea (center) of the eye. Secondly, the sensitivity of the pilot's visual periphery will be affected by the average brightness of the scene (Lamar, Hecht, Shlaer, and Hendley, 1947). Since the average brightness of current simulator visual displays is only a small fraction of that available in daylight scenes, the sensitivity of the pilot's peripheral vision in the simulator is not the same as it is in the inflight environment. It is clear that without a systematic experimental evaluation of various simulator display FOVs, a precise determination of the horizontal FOV required to provide tanker roll cue for the pilot's peripheral vision is not possible.

Field of view and image detail. Any discussion of display FOV must necessarily include the potential loss of image detail that may be sacrificed for an increase in display field of view. This issue is of particular relevance to aerial refueling since prior studies of aerial refueling simulation displays have repeatedly shown degradation of pilot performance with decreases in detail on the displayed tanker image (Sitterly, 1981; Woodruff, et al., 1979).

Practical experience with visual scene simulation for aerial refueling training devices emphasizes the problem of trading off image detail for a wider field of view. Sitterly (1981, p. 435) reports the following observation when an attempt was made to increase field of view at the expense of image detail:

> "Both the presently used 60°h FOV and a 120°H FOV have been used in the aerial refueling simulation at Boeing. Very early in the program the 120°h FOV was tested to determine if adequate cue resolution could be maintained with the wider field of view which incorporated the tanker wing tips. The wide field of view provides only about one-half the resolution of the tanker features used as refueling cues, and as might be expected, this loss in cue resolution was not an acceptable trade for the added roll cue afforded by being able to see the tanker wing tips."

There is, therefore, evidence of a substantial risk associated with trading off image detail for increased FOV in aerial refueling simulator displays. This fact must be considered a key element in determining FOV requirements for a candidate ARPTT visual display system.

4.3 Display Chromaticity

There is no research to indicate that color in visual scenes of flight simulators will significantly enhance training effectiveness. However, scene element color is clearly needed where it is normally associated with hazardous conditions, provides flight control information, or enables required target discrimination. Optical landing systems, such as the Visual Approach Slope Indicator (VASI) and Fresnel Lense Optical Landing System (FLOLS), are examples of scene elements that require chromaticity to provide flight control information. The director light system for AR also provides color-coded flight control information and should, therefore, be presented in color in an ARPTT visual display. Color for the visual display of features other than the director lights cannot be justified on this basis since the critical visual cues used for flight control purposes in AR are not color dependent.

Scene color, however, may have indirect effects on training by providing increased realism of the visual scene displayed and potentially increased pilot acceptance as a result. In an informal test of display chromaticity, Sitterly (1981) has found that the addition of color in the simulated AR scene enhanced the pilot's perceived realism of the scene. It is likely

4.6 Display Design Eyepoint

The display design eyepoint determines the calculations for image generation of the ARPTT visual scene perspective geometry. These calculations assure that the observer will perceive scene elements on a two-dimensional display as they would appear to the eye in the real, three-dimensional world. However, the ARPTT will require observation of the display by both the student pilot (in the left seat) and the instructor pilot (in the right seat) simultaneously. The solution to the problem of image projection for two observers in current ARPTT simulation has been either to provide for selective change in viewpoint of the scene (as in the B-52 ARPTT) or to fix the design eyepoint between the two pilots (as in the Boeing ARPTT). The former solution necessitates an improper scene perspective for the student pilot if the instructor selects the viewpoint for the right seat; the latter solution assures that neither pilot will be provided with the correct perspective. In neither case has this viewpoint problem been a significant obstacle in training pilots with no prior experience in AR. However, correct perspective projection of the tanker image to the pilot training for the purpose of AR proficiency maintenance would be warranted for the C-5A aircrews for whom the wide-body cockpit provides marked differences in viewpoint between the left and right seats.

As an instructional feature for AR training, correct, simultaneous projection of the display image to both instructor and student pilot (multiview display) would be a more desirable option than selective duo-view projection since the nature of AR instruction is one of continuous instructor feedback for attitude/thrust control adjustment. The selection of the right seat eyepoint by the instructor interrupts the continuity of the task as well as presenting the student with an incorrect perspective of tanker visual cues.

5. SUMMARY OF RECOMMENDED VISUAL SCENE SIMULATION REQUIREMENTS FOR THE C-5/C-141 ARPTT

A limiting resolution of 3.8 arc minutes per line vertically and horizontally for the central visual display area is required. For optimal viewing this central area should subtend an FOV of 15^o radius from the center of the display (Department of Defense, 1974). For the display area beyond 15^o radius from the display center, a limiting resolution of 9 arc minutes per line horizontally and 20 arc minutes per line vertically is recommended.

The total FOV for the ARPTT visual display should be a minimum of 36^o vertical. The horizontal FOV should be a minimum of 75^o. A 90^o FOV is a desirable option if it can be provided without loss of image resolution detail. A cost-savings solution to meeting the high resolution requirements for the central ($\pm$ 15^o) area of the display without sacrificing FOV would be a separate high resolution inset area. The high resolution area could be either fixed in the central display area or slaved to the tanker fuselage area. The latter option would permit a high detail display of critical tanker features throughout the AR mission. If a high resolution area-of-interest inset is selected, proper merging of the inset boundaries with the lower resolution display area is essential to minimize the potentially distracting boundary contrast and resolution differences.

Color in the ARPTT visual scene is required for the director light system on the tanker fuselage since this system provides color-coded flight control information to the pilot. A complete color display system is a desirable option only if it meets the minimum requirements of resolution and mean luminance level without sacrificing FOV.

In order to assure adequate perception of small tanker details and to provide the illusion of a daylight AR mission, a minimum of 6 ftL average luminance level is required for a monochrome display. If a color display is chosen, a minimum luminance level of 10 ftL is required to assure correct color perception by the pilot and instructor. A contrast ratio of a minimum of 25:1 for the display is required to assure adequate portrayal of tanker details in daylight AR training with a 32:1 contrast ratio as an optimal value.

The display design eyepoint should be that of the pilot's (left seat) to assure that tanker features will be viewed in the correct perspective. A desirable option would be to utilize a multiview display system that would provide the correct perspective to both the pilot and the instructor simultaneously. A selective duoview option is not recommended. The exit pupil for the design eyepoint should be a minimum of 15 cm in radius to permit pilot head movements without image distortion.

6. CONCLUDING REMARKS

The requirements recommended in this report for visual scene simulation in a C-5/C-141 ARPTT are based on user experience with currently operating ARPTT devices, published reports on flight visual scene simulation, and knowledge of the operating characteristics of the human visual system. In the absence of experimental evaluations of the training utility of a range of visual display specifications, the recommendations provided here favor the highest fidelity possible between the simulated visual scene of an ARPTT and the out-of-the-cockpit view of inflight AR missions. Moreover, the intended primary use of the ARPTT as a device for the maintenance of AR skill in experienced pilots necessitates consideration of pilot acceptance as a factor in design goals. The confidence of aircrews in the ground-based ARPTT as a substitute for the real aircraft mission can be expected to have an impact on the ultimate training utility of the device.

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