A UNIQUE SOLUTION FOR TRAINING AIR REFUELING TASKS IN AN OFT

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ABSTRACT

Upon initiating the recent procurement of a new OFT for a Navy tactical aircraft, NTSC was faced with a design problem: how to position the wide field-of-view day visual system in order to provide effective training for ground-referenced aircraft operations (takeoff, landing, enroute navigation, maneuvering flight, spin recovery) and also provide training in air refueling. The trainer's manufacturer developed a unique solution: install the trainee station cockpit on a separate buffet platform capable of operation at two different pitch attitudes, and mount the buffet platform on the motion base along with, but separate from, the visual system. Using this design, most flight training activities are conducted with both the motion base and the buffet platform oriented horizontally. For air refueling training, the buffet platform is pitched 10 degrees nose down while the motion base is pitched 10 degrees nose up, thereby repositioning the visual field-of-view along the cockpit centerline 10 degrees upward. Not only does this arrangement provide effective field-of-view coverage for all training tasks, but it substantially reduces the vibrational stress on the display components of the visual system by isolating them from the high-frequency vibration and buffet cues which are now applied only to the cockpit.

INTRODUCTION

In the development of simulation training devices, occasionally a new design concept emerges that appears to be a radical departure from traditional practice. On closer examination, one usually finds that the new concept is simply based on an extension or re-combination of existing features, and that it developed from a creative attempt to respond to new training concerns.

One new concept currently being employed on an operational flight trainer involves the use of whole-cockpit independent buffet and rotation combined with full six degree-of-freedom motion. The cockpit is rotated about the pitch axis in order to provide a different visual field-of-view (FOV) orientation for different portions of the training mission.

This concept originated as a solution for two concerns: visual FOV limitations, and the reliability of the visual system when subjected to vibrations and buffet. Both issues relate to the particular training mission of the EA-6B Operational Flight and Navigation Trainer (OF/NT), Device 2F143. The concept grew out of an approach previously used successfully on other training devices: the crew seat buffet system.

ORIGIN OF CONCEPT

Training Mission

The EA-6B is a four-place, twin-engine, jet-powered Electronic Countermeasures (ECM) aircraft manufactured by Grumman Aerospace Corporation. The primary mission of the EA-6B is to support strike aircraft and ground troop intelligence within a combat area. It is flown by Navy and Marine Corps pilots and is carrier-based. The crew consists of a pilot and an Electronic Countermeasures Officer (ECMO)/co-pilot seated side-by-side in the forward cockpit, and two additional ECMOs seated side-by-side in the aft cockpit. The aircraft has air refueling capability in the form of a refueling probe that extends upward from the forward cockpit (see Figure 1).

The purpose of the OF/NT is to provide training in the development of flight and navigation skills on the part of the pilot and ECMO/co-pilot. The trainer simulates only the forward cockpit of the EA-6B. The entire flight envelope and all field/carrier operations are simulated, including all normal and emergency procedures. This includes carrier/field take-off, departure stalls and spins, carrier marshall, point-to-point navigation (including low-level radar and visual navigation), aerial

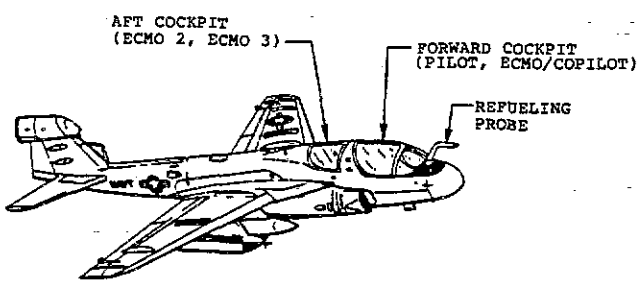

Figure 1. EA-6B AIRCRAFT

refueling enroute, carrier/field approach and landing, and section take-off and rendezvous.

The project team at the Naval Training Systems Center (NTSC) specified use of a wide-screen visual system on the OF/NT to support the take-off/landing and low-level navigation training tasks. Such visual systems consist of an image generator and a display system. The display system includes a collimating mirror that wraps around the front of the cockpit.

While the wide-screen visual systems available provide at least 180° FOV horizontally, they provide only about 40° FOV vertically. Thus, a major problem had to be solved: how to position the field of view vertically in order to provide adequate coverage for training the crew in carrier operations and navigation as well as air refueling. As shown in Figure 2, orienting the FOV 20° left of center and between +15° and -25° vertically provides the pilot with excellent coverage for conducting carrier operations, navigation, and formation flight. However, as shown in Figure 3, a +15° FOV does not provide adequate coverage to properly train air refueling. A +25° FOV would be desirable for this purpose, but to reposition the entire FOV to +25°/-15° would deprive the pilot of part of the view required for carrier operations. Clearly, some other more original solution was required.

<u>Requested Solution</u>

In order to resolve this problem, NTSC engineers settled upon the idea of tilting the vertical FOV about the pilot eyepoint. They specified that the visual system be installed such that the vertical FOV would be oriented +20°/-20° at 0° cockpit azimuth, and +15°/-25° at -90° azimuth relative to the pilot eyepoint. This would require mounting the entire visual structure on a 5° wedge around the cockpit (see Figure 4), and would result in the visual FOV appearing to the flight crew as a "frown". This solution provided a reasonable compromise to the question of visual FOV orientation, but it introduced some additional complexity in design of the trainer structure as well as other complications regarding maintenance of the visual system, due to the 5° tilt.

<u>Alternative Solution</u>

The trainer's manufacturer instead developed a new concept for solving the vertical FOV question that was based on the buffet seat design approach. The concept is as follows: mount the entire cockpit on a separate frame within the visual system so that it can be pitched 10° nose down during refueling training, and provide dynamic software-driven hydraulic control of the frame to make it a whole-cockpit buffet system that provides a vertical acceleration of $\pm$0.75G and a vertical displacement of $\pm$1.0 inch.

This concept provides a desirable FOV

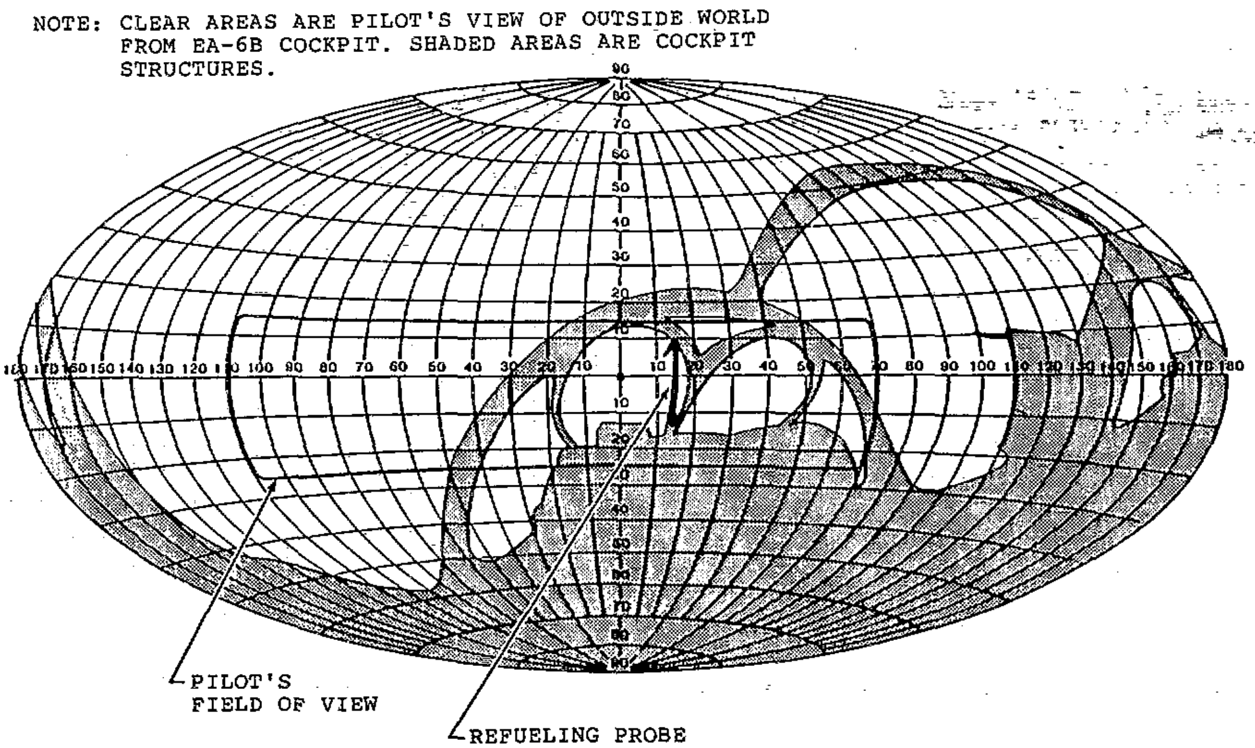

Figure 2.
EA-6B PILOT'S FIELD OF VIEW WITH WIDE-SCREEN VISUAL SYSTEM

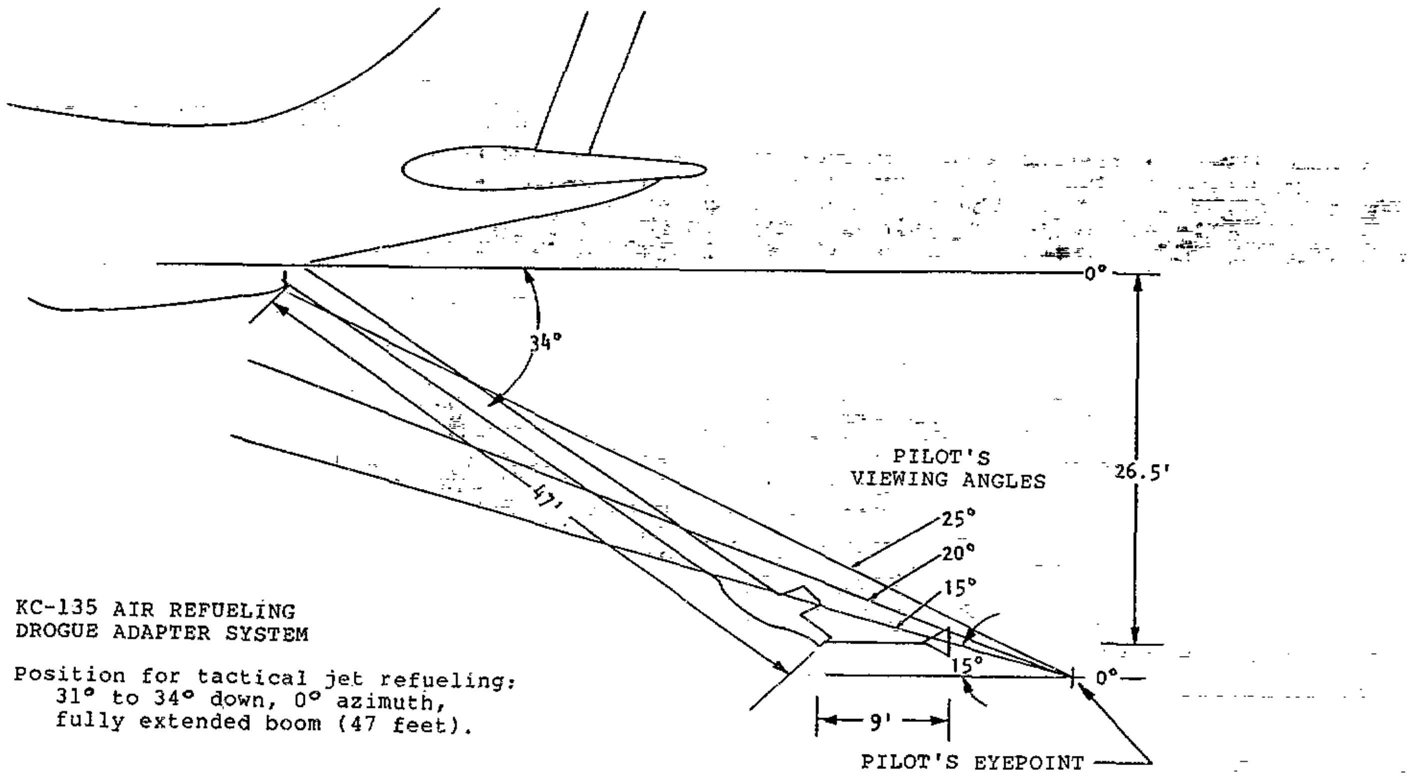

Figure 3. AIR REFUELING GEOMETRY FOR EA-6B RECEIVER AIRCRAFT

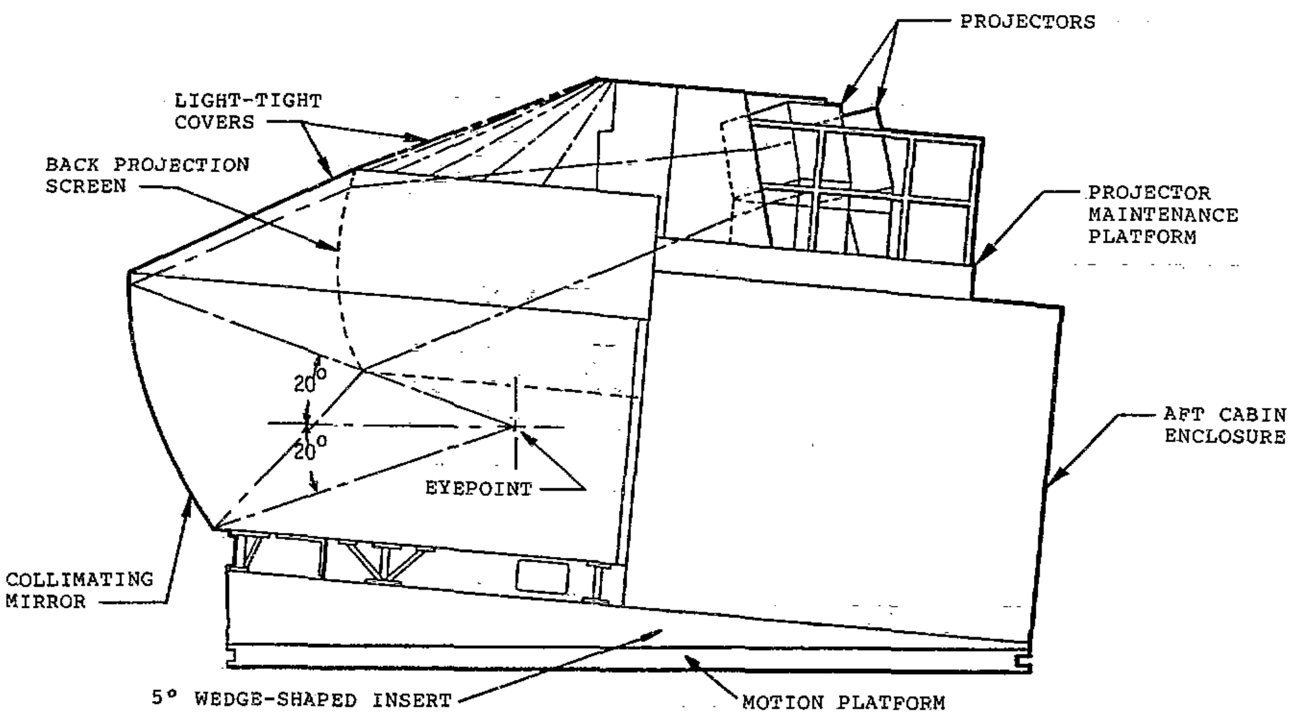

Figure 4. VISUAL SYSTEM INSTALLATION - COMPROMISE APPROACH

orientation for both normal flight and air refueling training, and also provides another primary benefit: improved visual system reliability. The improved visual reliability is the result of generating high-frequency vibrations (3 to 20 Hertz) only in the buffet platform, and limiting motion system operation to the frequency range of 0 to 5 Hertz. This design largely isolates the visual display system projectors from the high-frequency vibration and buffet cues, thereby increasing their life expectancy.

There is one performance limitation involved in using the cockpit buffet/rotation approach. In order to maintain proper orientation of the cockpit with respect to earth's gravity during refueling training, it is necessary to compensate for the 10° nose-down pitch of the cockpit relative to the motion frame by pitching the motion system's neutral orientation up 10° (see Figure 5). This reduces motion system excursion capability in all degrees of freedom during refueling training by a modest amount. Because of close proximity to the tanker during refueling, the pilot of the receiving aircraft attempts to limit his aircraft's motion, so having reduced motion excursion capability in the trainer during refueling is not a problem. The only exception occurs during the breakaway maneuver, but the user felt this would not constitute negative training because of the pilot's intense concentration on the view out the cockpit, which faithfully represents the maneuver.

SYSTEM PHYSICAL DESIGN

System Geometry

The primary factor influencing the entire design approach was that the trainees must be positioned within the visual system eyepoint volume at all times. Two modes of trainer operation were defined: normal flight mode, and refueling mode.

The eyepoint viewing volume of the visual system employed (Rediffusion's SPX500T with WIDE II display) measures 6 inches both vertically and longitudinally (fore/aft). To allow for trainee seat adjustability, the nominal design location of the pilot's eye has to be identical in both the normal flight and refueling modes and at the center of the viewing volume. This location must therefore also be the center of rotation of the entire buffet platform assembly when transitioning from one mode to the other (refer to Figure 5).

An important guideline used to determine the final system geometry was reduction of system complexity. This was accomplished by having a simple two-position actuator at the forward end of the platform, and a dynamically-controlled actuator at the aft end. The aft actuator is used in conjunction with the forward actuator to establish the basic cockpit orientation in each mode. The aft actuator alone provides the buffet cues.

These factors were used to establish

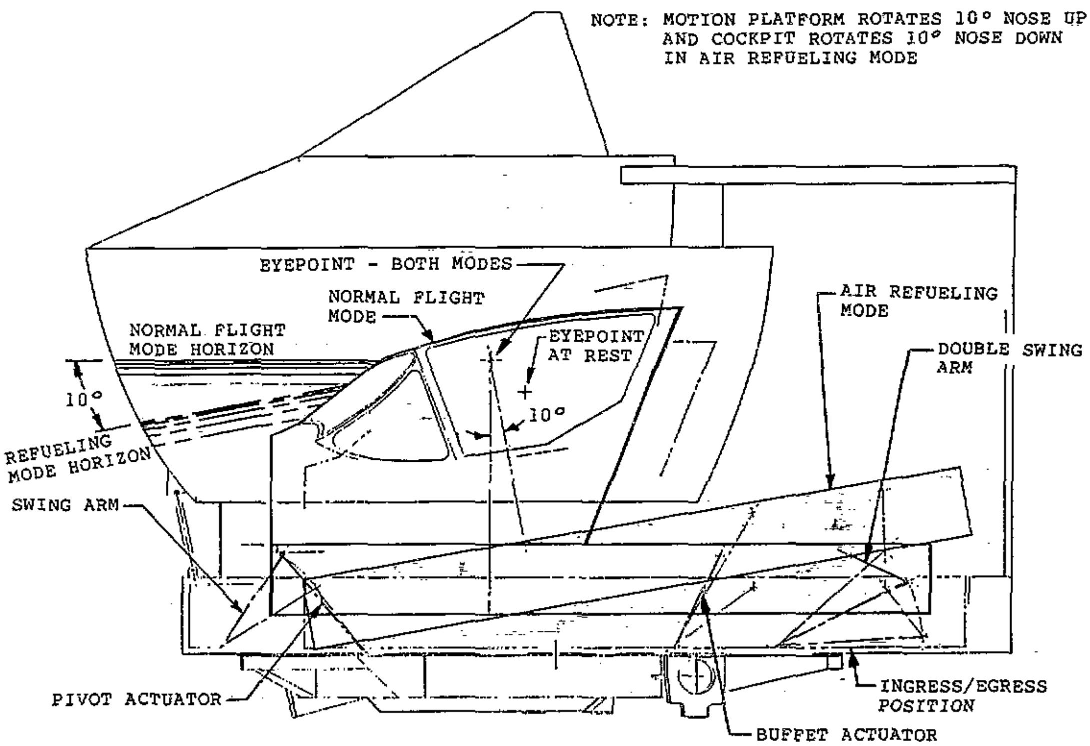

Figure 5. COCKPIT BUFFET SYSTEM CONCEPTUAL DESIGN

the three principal positions of the buffet frame: normal flight, refueling, at-rest (see Figure 6). As dictated by the geometry, the buffet platform must be raised 9.08 inches and moved forward 9.89 inches to reach the normal flight position from the rest position.

The principal elements of the WIDE II visual display system are shown in Figure 4. The aft cabin enclosure has a forward wall with an opening for the cockpit. The back projection screen is held above the cockpit by a support structure. Availability of clearance between the display system structures and the top of the cockpit assembly was verified for the worst-case situation, i.e., with both actuators fully extended.

Because of the proximity of the back projection screen support structure to the cockpit, the canopy cannot be opened in the normal clam-shell fashion. Therefore, the trainee seats are mounted on rails and slide in and out of the cockpit (forward/aft). The buffet frame has to be wide enough to support the cockpit and long enough to support the cockpit and the trainee seat rails. However, there are good reasons for keeping the size of the buffet frame as small as possible (reduce total mass and inertia, minimize interference with visual system attachment points, etc.). This was the initial design goal. However, when maintainability issues were investigated, the frame was designed to be wider than the cockpit to allow additional mounting space for electrical and hydraulic equipment in the frame, so that these items could be accessed by simply removing floor plates from the buffet platform adjacent to the cockpit. As a result, the buffet frame was finally sized to be 108 inches wide, 172.5 inches long, and 13.25 inches high.

Visual Installation

With the buffet system's geometry and size established, the next consideration was how to install the visual display system and buffet platform to accommodate trainee ingress/egress. For safety, the buffet system should be at rest during ingress/egress, but the cockpit floor level at rest is 9.08 inches lower than it is during normal flight training (refer to Figure 6). This presented a problem since the visual display system was already designed to be installed at the level of the cockpit floor when in the normal flight mode, not at the level of the cockpit floor when the buffet system is at rest.

The problem was resolved by designing a two-level visual support frame. It provides a mounting surface that is 9.08 inches above the cockpit at-rest floor level at the front and on both sides, and provides a floor surface aft of the buffet frame that matches the cockpit at-rest floor level. The visual manufacturer simply extended the rear wall of the aft cabin enclosure downward by 9.08 inches, and also lowered the aft cabin door by the same amount. The entire display system was then able to be mounted directly on the visual support frame without further modification.

With this design, there is only one uniform floor level in the trainee station during ingress/egress. Once the trainees have secured themselves in the cockpit seats and the trainer is initialized, the

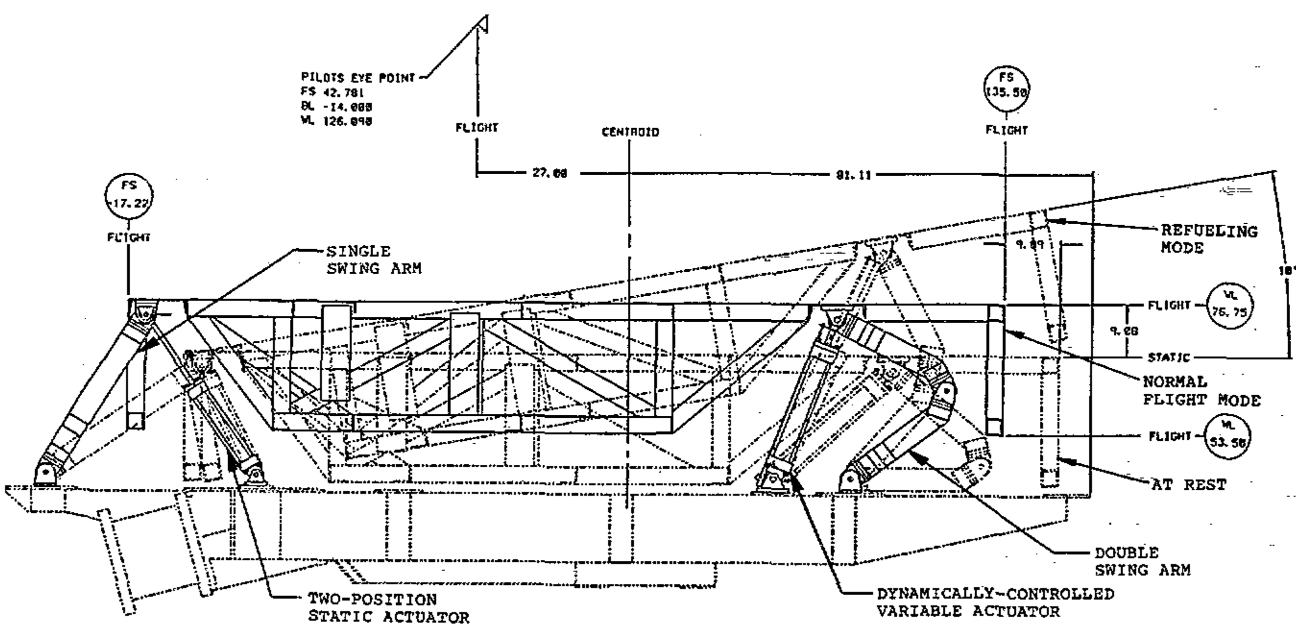

Figure 6. COCKPIT BUFFET FRAME DETAILED DESIGN

buffet platform moves upward and forward under instructor control to bring the trainees to the design eye position.

Motion/Buffet Interaction

In the original design concept, the buffet vibrations were intended to be limited to the vertical direction only. In developing the detailed design, it became apparent that this would not be possible without redesigning the motion system frame. Even by redesigning the frame, it would not be possible to achieve perfectly vertical orientation of the buffet actuator in both the normal flight and refueling modes because of the geometry (refer to Figure 6). A compromise was reached in which the existing motion frame design was preserved and the actuator mounted so that it forms a 21° angle with respect to vertical when in the normal flight mode, and a 35° angle with respect to vertical when in the refueling mode. This introduces a vibration component in the longitudinal direction, but the user felt this was not detrimental.

The design concept also includes the use of a position control loop with a very high frequency response to drive the buffet actuator. With this approach, motion system cues will be passed faithfully through the buffet platform to the trainees provided there is sufficient structural rigidity in the buffet frame and mounting hardware. Conversely, the inertial effects of controlled movement of the buffet system will be "felt" by the motion system. However, the effect will be negligible since the motion system includes acceleration control loops using ram pressure feedback.

Buffet Frame Rigidity

Considerable attention was paid to the issue of structural rigidity. The frame itself was designed to withstand the total G-loads from the combined motion and buffet cues. Attention was also focused on the method of buffet frame attachment.

The method chosen was to attach the buffet frame to the motion frame at the forward end by using a single swing arm assembly, and at the aft end by using a double swing arm assembly (refer to Figure 6). Each swing arm assembly consists of a cross-braced frame with a pair of thrust-resisting bearing assemblies attached on both edges. Since the bearing assemblies are thrust-resisting, they transmit lateral forces from the motion frame to the buffet frame and allow the swing arm assemblies to provide the needed rigidity for the buffet frame.

Light-Tight Seals

Since the buffet platform is free to move within the confines of the visual support frame, there are spaces all around it. These spaces have to be closed off in some way that will not interfere with the platform's movement, but will prevent leakage of ambient light from below the cockpit floor level into the visual enclosure. Light leakage would detract from the apparent visual image brightness.

Along the sides of the buffet frame, where the width of the space is constant, thick brushes were installed that keep the space filled in both normal flight and refueling mode. At the forward and aft ends of the buffet frame, however, a different solution had to be found because of the platform's range of movement. At these locations, a sheet of thick neoprene was installed between the buffet frame and the adjacent visual support frame with sufficient slack to accommodate the platform's movement.

SYSTEM OPERATION AND CONTROL

Hydraulic Control

Hydraulic control of the buffet system was designed to reposition the trainees during mode transitions at a safe, controlled rate. The forward actuator has two discrete operating positions and is solenoid-controlled via digital output from the trainer host computer. The aft actuator is servo-controlled via analog output.

Hydraulic pressure is supplied to both actuators through a three-way solenoid valve that requires electrical power for activation (see Figure 7). When

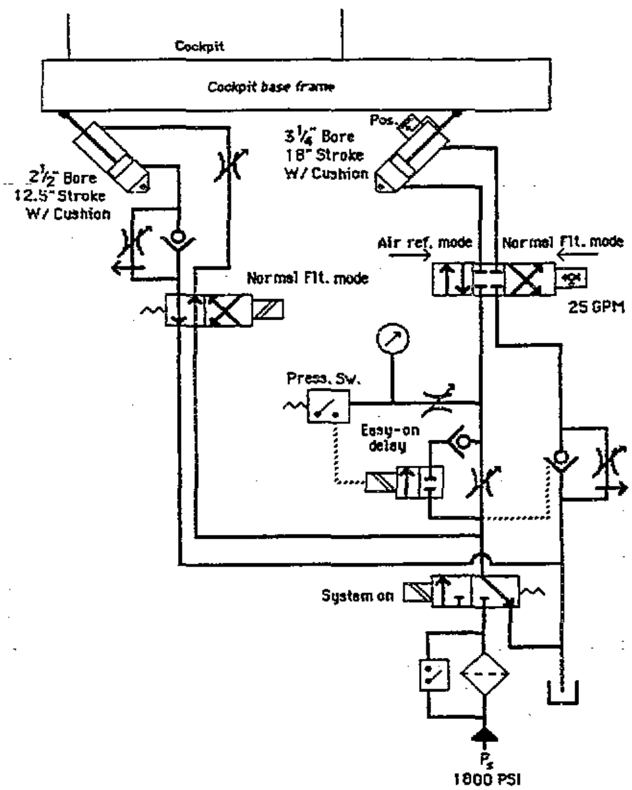

Figure 7.
COCKPIT BUFFET SYSTEM HYDRAULIC CONTROL SCHEMATIC DIAGRAM

it is energized, fluid is routed to both actuators. Input to the forward actuator is ported through a four-way solenoid valve to power either extension or retraction of the actuator. The return flow goes through a pressure compensated flow control valve for actuator velocity control, to provide a safe rate of movement during repositioning of the buffet platform. Input to the aft actuator is ported through a reduced flow circuit to the servo valve. When full pressure is sensed, a two-way solenoid valve is energized to provide a full flow path to the servo valve. A pilot-operated abort valve controlled by the system pressure opens to allow flow to the aft actuator from the servo valve. If hydraulic pressure is removed, the abort valve switches the aft actuator flow so that it returns through a pressure compensated flow control valve for actuator velocity control, to provide a safe rate of descent of the buffet platform.

Drive Signals

In order to produce the high-frequency vibration cues experienced by an aircraft in certain flight conditions, it is not sufficient to generate vibration signals solely as a result of motion software modeling. Software executing at 30 Hz will be able to produce frequencies no higher than 5 or 6 Hertz. To generate vibration frequencies up to 20 Hertz, drive signals are generated by the trainer's digital aural cue system. Since most low-frequency sounds experienced in an aircraft during flight are the result of mechanical vibration, this simulation approach can be viewed as reversing the real-world process: vibrations of the trainer cockpit are generated using audio recordings of the aircraft's vibrations.

The method used to generate buffet actuator drive signals is shown in Figure 8. Motion system vibration circuit cards are used to combine motion modeling vibrations computed by software (up to 5 Hertz) with the higher frequency vibrations produced by the aural cue system hardware. The resulting vibration signals are sent to a circuit card designed to drive the buffet actuator in the frequency range of 3 to 20 Hertz. The drive signals control the servo valve in a position feedback loop.

Instructor Control

The controls provided at the instructor's station to enable buffet system operation consist of **MOTION ON**, **MOTION OFF**, and **BUFFET ENABLE** pushbuttons. When the motion system is activated by the instructor (**MOTION ON**), the buffet platform is automatically erected to the normal flight position at a safe rate. However, it will not provide vibration cues or be capable of repositioning to the refueling orientation until the instructor

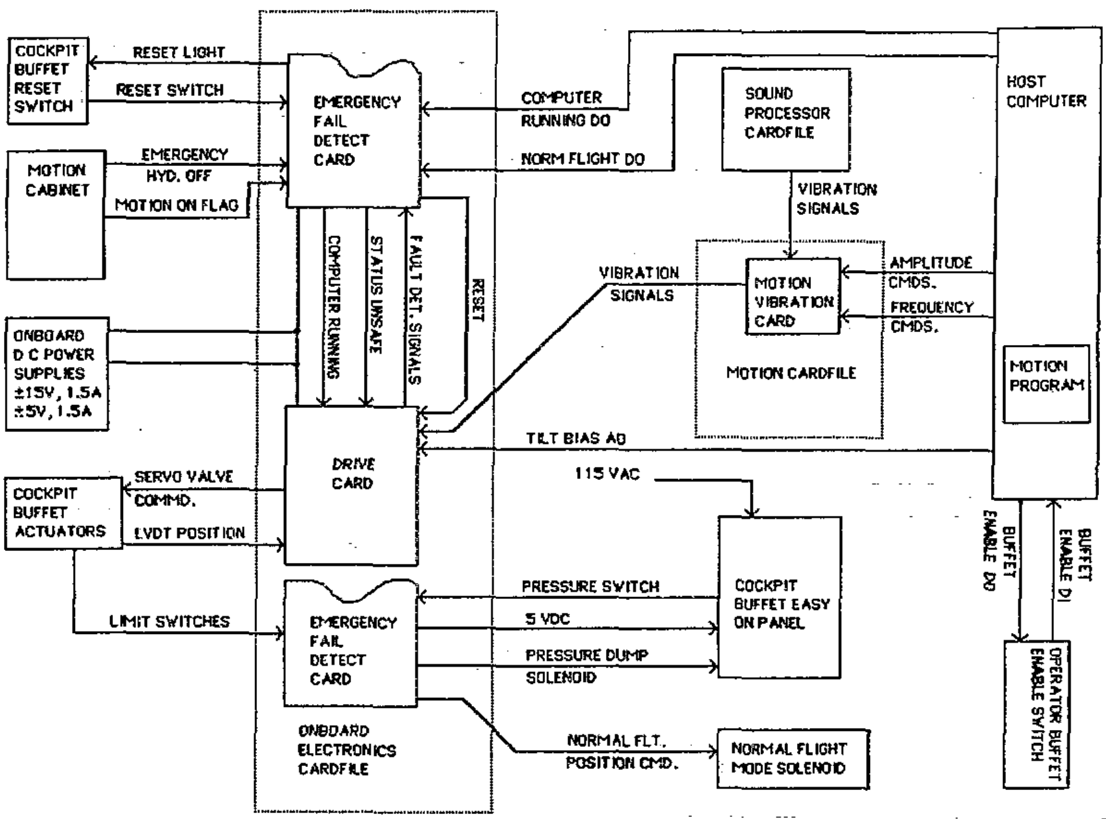

Figure 8.
COCKPIT BUFFET SYSTEM CONTROL SIGNAL BLOCK DIAGRAM

activates the *buffet system as well* (**BUFFET ENABLE**). Whenever the instructor deactivates the motion system (**MOTION OFF**), the buffet system is automatically deactivated and the buffet platform settles to the at-rest position at a safe rate.

The instructor causes the buffet platform to be repositioned for refueling mode simply by selecting an air refueling mission scenario. Selection of any other mission scenario automatically returns the buffet platform to the normal flight attitude.

Safety Features

Safety was a major consideration in the design of the cockpit buffet system. As previously described, several safety features were designed directly into the hydraulic control system. In addition, an emergency failure detection circuit was included in the electronic controls of the system. This circuit detects failures such as activation of either actuator's limit switches, an abort of the motion system, or failure of the computer system to cycle at the prescribed real-time rate. It also monitors the state of various safety interlocks and either enables or disables buffet system operation. For example, if the trainee station door is not closed and both crew seats are not securely latched in the forward position, the system will not operate. Any time system operation is disabled by this circuit, the buffet platform returns to the at-rest position at a safe rate.

Software Control

Most of the functions performed by the software have already been discussed: safety interlock validation, instructor control implementation, buffet platform orientation control and motion synchronization, and motion simulation in refueling mode employing a 10° pitch bias. One additional major function is performed by the software that enables the entire concept to work: the visual scene viewport is controlled by the host computer.

The viewport can be thought of as the "window" in space through which the visual scene data base is viewed by the trainee. Data base elements that can be "seen" by ray tracing from the eyepoint through the viewport are computationally transformed and mapped into two-dimensional image space by the visual system's real-time software. The contents of the image space are used by the visual system image generator to drive the projectors, producing the scene viewed by the trainees on the collimating mirror. The viewport geometry is defined by the visual system's field of view and by its orientation with respect to the reference horizon. (The reference horizon is the same as the visible horizon when the aircraft is flying straight and level.)

In normal flight mode, the reference horizon is 15° below the top of the FOV at all azimuth positions around the mirror (refer to Figures 2 and 5). In refueling mode, as seen from Figure 5, the reference horizon is 25° ($15^{\circ} + 10^{\circ}$) below the top of the FOV at 0° azimuth (straight ahead) while it is still only 15° below the top of the FOV at $\pm 90^{\circ}$ azimuth. Within the displayed image, then, the reference horizon during refueling mode looks like a "smile" when traced on the mirror, but looks flat to the trainees who are rotated downward 10° in the trainer with respect to the mirror.

In order to accomplish this *reorientation of the displayed image in* refueling mode, the viewport geometry used by the visual system software must be different from normal flight mode. Instead of the customary practice of using constants to define the viewport geometry in the visual system software, these values are calculated by the trainer host computer software and passed to the visual computer in real time, where they are used to generate the displayed image.

One important decision regarding software design was reached early. Rather than delving into the complexities of attempting to transition the motion system, the buffet platform, and the visual scene smoothly and simultaneously from one mode to the other during real-time training, the software has been designed to make the transition discretely during trainer freeze. Instructor attempts to unfreeze the trainer are inhibited until the transition is complete.

RELIABILITY/MAINTAINABILITY CONSIDERATIONS

Degraded Mode Operation

As soon as the system geometry was determined, it became clear that the trainer can not be used for any visually-referenced training unless the buffet system is operational. This is because the trainees are located approximately 6 inches below and 7 inches aft of the visual system eyepoint volume when seated in the cockpit with the buffet platform in the at-rest position. While the trainees can view a portion of the visual scene this way, this can not be considered proper training.

Consequently, a feature was added to the system design to provide degraded mode operation. The hydraulic control system can be operated by either the motion system pump (primary) or the control loading system pump (secondary). If the motion system pump is not available, the buffet platform can still be erected by the instructor to the normal flight position to conduct training. When using the secondary pump source, all training capabilities are available except that vibration cues are not provided, and it is not possible to enter the refueling mode.

Maintenance Access

Maintainability of the trainer was improved substantially by eliminating the approach of mounting the visual system on a 5° wedge. However, a small reduction from this general improvement occurred because of the reduced maintenance accessibility of components installed within the buffet frame. This is due to the large number of structural members in the buffet and visual support frames. The design minimizes these deleterious effects by arranging most of the elements requiring maintenance beneath removable floor panels in the buffet platform.

Visual Alignment

With the buffet platform in the at-rest position, it is not possible to place an instrument such as a theodolite within the visual system's eyepoint volume. Therefore, the buffet platform needs to be raised to the normal flight position in order to conduct visual system alignment.

To accommodate this, manual controls are provided on the buffet system's easy-on hydraulic control panel. This panel is mounted in the visual support frame where it is accessible to maintenance personnel. These controls bypass the computer drive signals and allow the buffet platform to be raised to the normal flight position so long as hydraulic pressure is available.

SUMMARY

The cockpit buffet/rotation system is presently in final performance evaluation, so it is premature to render an assessment of either the design approach or of its implementation, although initial results are encouraging. Performance data is being collected on the overall behavior of the motion and buffet systems in order to determine whether there are any unanticipated detrimental effects of using this design approach.

It is also premature to fully assess the added costs of employing this concept against its benefits. However, a few points can be made.

In addition to the primary benefits of visual FOV optimization and visual reliability enhancement, some secondary benefits were also realized by employing the whole-cockpit buffet system. Because of the relatively small mass of the buffet platform assembly and the high frequency response of the buffet actuator, it is possible to simulate a higher frequency portion of the vibration spectrum than by using just the motion system alone. Also, by buffeting the entire cockpit rather than just the trainee seats, a more realistic physical environment is created for the trainees.

A different sort of benefit was realized from the fact that the cockpit could be installed on the buffet frame and left on blocks on the shop floor until final assembly of the entire trainer. This made it much more convenient to install equipment and control loaders and perform wiring tasks than if it had been mounted directly on a frame atop the motion system. The teardown and site installation process is also made easier by having the cockpit on its own separate frame that is relatively small.

In designing the whole-cockpit buffet/rotation system, many minor complications had to be resolved before a workable design was achieved. None of these were individually significant, but their number was larger than anticipated. Many were only discovered serially as the design process unfolded, sometimes necessitating rework of already completed design details. However, it cost only about 2% of the contract value to incorporate this system into two trainers, including all non-recurring development efforts. This cost is insignificant when compared to that of a separate part-task trainer in which to conduct air refueling training, or the cost of performing refueling training in the air.

Unless major drawbacks to the use of the cockpit buffet and rotation approach become apparent during final testing, it seems to be a cost-effective solution for providing air refueling training in various types of OFTs, WSTs, etc. The approach is clearly best-suited to trainers employing wide-screen visual systems because the display system structure is not attached to the trainer cockpit, making the buffet platform design task relatively simple. However, there is no reason to conclude that this approach could not also be used on trainers having visual systems with discrete-channel CRT displays.

ABOUT THE AUTHOR

David J. Kramer is a Project Engineer with Reflectone, Inc. As such, he has been responsible for the design of all elements of various flight simulation training devices for military and commercial aircraft. His current assignments include an EA-6B WST and two EA-6B OF/NTs. He previously served as Project Engineer for a C-5A/C-141B Air Refueling Part-Task Trainer, and for Phase III B-747 and A-310 OFTs. He was formerly Computer Systems Group Leader. Prior to joining Reflectone in 1977, he developed real-time signal-processing systems for ComGeneral Corporation. Prior to obtaining his B.S. in Computer and Information Science from the Ohio State University in 1972, he was a mechanical designer for Systems Research Laboratories, Inc. He was a NATO Fellow in 1975, investigating large-scale simulation models. He currently serves as Industry Co-Chair of the Functional Requirements Subcommittee of the USAF MODSIM ISWG.