High Speed Research Flight Deck External Vision System Pilot Head Movement Evaluation Results

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FOREWORD

This report entitled "External Vision System Pilot Head Movement Evaluation Results" was created for the Phase II High Speed Research Program. It is being submitted in accordance with the Statement of Work of Contract NAS1-20220.

This report was prepared by the Industry Team led by the Boeing Commercial Airplane Group under contracts sponsored by the NASA Langley Research Center (LaRC). Russ Parrish of the Langley Research Center is the LaRC Flight Deck Technical Lead for this Task.

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1.0 Introduction and Background

The High Speed Civil Transport (HSCT) in order to permit a fixed-nose configuration, will not have forward facing windows on the flight deck. An External Vision System (XVS) will be used to provide at least equivalent functionality as flight decks with forward windows. One of the components of such a system will be high-resolution wide field of view displays (one in front of each pilot). Because these will be displays and not transparencies, they will not provide the flight crewmembers with the ability to expand the external field of view by moving their eye closer to the display surface. This raises a number of questions concerning a pilot's need to expand the external field of view for critical flight tasks.

In the initial efforts of the XVS program, performance requirements were defined with respect to flight and ground operations. These requirements are based on the operational criteria for flying in the specified airspace (e.g., accept ATC vectors or perform curved approaches and achieve a stabilized flight path on centerline and glideslope at least 2600 feet from threshold) and maneuvering on the ground (e.g., touchdown with a 3 sigma lateral dispersion of no greater than plus or minus 27 feet from centerline; taxi such that the main gear come no closer than 5 feet from the edge of the taxiway; average 15 mph during taxi, maneuver across active runways and in the gate area, etc.). Since any External Vision System needs to provide equivalent performance/functionality as airplanes with forward windows, the above requirements become success criteria for the implementation of the XVS. Airplanes equipped with an XVS must be able to demonstrate this equivalent performance in order to achieve a viable system.

The visual angles subtended by the forward display and the side windows have been designed to meet Aerospace Standard (AS) 580B (which has subsequently been replaced by Aerospace Recommended Practice 4101/2 and Advisory Circular 25.773-1) and the 3 second rule, which are two certification criteria that are defined with respect to the design eye reference point. In actual operation, however, the flight crew is not constrained to this eye position for all flight tasks. In fact they rarely sit at the design eye position and they do move their head to "get a better view" of the outside world. The questions that arise are: how much movement of this type actually occurs; what operations generate this movement; how flight critical are these operations; and whether the vision provided by a combination of ARP 4101/2, which now contains the 3 second rule, and the side windows permits adequate visual task performance for critical HSCT operations. One design goal of any airplane program is to have no operational restrictions as a result of the airplane configuration. Therefore in defining the exterior field-of-view for the XVS it is necessary not only to consider the guidance provided by ARP 4101/2 but also to determine the operational field-of-view requirements. If deficiencies in operational performance are found with the current visual field, mitigation strategies should be examined. The requirement to use larger XVS displays to achieve adequate operational performance could provide significant technological, economic and operational risks. This is especially true if the forward field of view imposes operational limitations on the airplane.

In reviewing the above issues, it was decided that problem mitigation strategies should be identified after the problem, if any, is fully characterized. The key questions, therefore, are: what situations cause the crew members to move their head/eyes to expand the exterior field of view in order to get visual information normally obtained from the forward transparency; how critical are these situations; and how far does the flight crew member move their eyes in response to the situation. These questions were the focus of the study described in the following sections.

2.0 Test Objectives

Since a reduction of the information currently obtained from the forward transparencies could have an adverse effect on specific operations that the flight crew may want or need to perform, the primary objective of the head movement evaluation was to examine the reasons for and extent to which the crews move their heads to expand the external field of view. The test evaluated pilot performance in two high fidelity operational flight deck simulators (the 777 and 737 simulators) and conclusions were to be derived from empirical as well anecdotal data.

Specific areas of interest in the study included:

a) Determination of the three dimensional space that describes the position of the pilot's eyes during subsonic airplane operations, "the geometric eye box". Definition of the movements generated by operational situations that occur with current airplane configurations and an "eye box" that defines the extreme limits of movement possible with a lap belt constraint;

b) Documentation of the descriptions of operational situations that generate the head movement behavior and the criticality of these situations;

c) Transfer of these geometric relationships to the HSCT flight deck geometry and determine the operational impact of replacing the forward transparencies with displays of the current configuration.

As a conservative approach to these objectives, the study explored operational situations that were defined by very senior and experienced transport pilots

3.0 Evaluation Subjects

Two factors were used to select the pilots for this study, experience and stature. One of the factors that determines the amount of movement that a pilot can perform (and thus the extent of the eye movement box) is sitting height. Therefore an attempt was made to use a pilot group that has a representative range of sitting height in the evaluation. Because we were asking the pilots to describe operational conditions that would require expanded field-of-view, it was necessary to use experienced commercial transport pilots.

A total of 17 experienced transport pilots were used in the study as the flying pilots (7 from Boeing Engineering Flight Test and 5 from Boeing Flight Crew Training and 5 from United Airlines). All the pilots had some experience flying the line both domestically and internationally. Since the simulators in which the testing occurred were the 777 and 737 flight decks, all the pilots were type rated in one of those airplanes. The 777 was the current airplane for 8 of the pilots with an average of 960 hours in type (range of 200 to 2500 hours) and the 737 was the current airplane for 9 of the pilots with an average of 2445 hours in type (range of 800 to 4500 hours). Furthermore, the pilots had experience in a wide range of other aircraft such as: 24% in the 707; 53% in the 727; 100% in the 737; 35 % in the 747 classic; 82% in the 757/767; 47% in the 747-400; 59% in the 777; 6% in the DC9; 6% in the DC10; 6% in the A310; 6% in the A320; 35% in military transports; and 53% in GA aircraft. This permitted the pilots to draw from a rich base of experience when defining those situations that would result in head movement.

The pilots had a mean of 25 years flying commercial aircraft. Their average number of flight hours was 10,500 with a standard deviation of 4,100 hours. All the pilots had experience in either the 777 or the 737 from the left seat and thus were familiar with the sight picture from that seat. Sixty-four percent of the pilots used corrective lenses when they flew. They all flew regularly into Class B airspace with an average of 218 times a year. Seventy-one percent of them also flew regularly into non-radar controlled airports an average of 34 times a year. Eighty-eight percent of them operated in weather requiring de-icing an average of 13 times a year. All the pilots regularly flew into airspace with high traffic density an average of 203 times a year. Finally 88% of them regularly operate at airports with high traffic/obstacle density, an average of 165 times a year. Table 3.0-1 summarizes these biographical data from the pilots who participated in the test.

The pilots ranged in height from 64 inches to 75 inches. This range does cover the 5th percentile to the 95th percentile for men (66” to 74”) but does not reach the 5th percentile for women (62”). The average height for the evaluation pilots was 70.9 inches with a standard deviation of 3.4 inches.

Table 3.0-1 Summary of Pilot Biographical Data

Parameter	Mean/ Percent	Standard Deviation
Years Flying Commercial	25.0	7.9
Total Number Flight Hours	10,500	4,281
Flight Hours in 777	960	781
Flight hours in the 737	2445	1508
Flights per Year into Class B Airspace	218	177
Flights. per Year into Non-Radar Controlled Airports	34	54
Required de-icing per year	13	12
High traffic density per year	202	184
High ground density per year	165	142
Wear Corrective Lenses	70%	

4.0 Technical Approach

4.1 Overview

The operational head movement evaluation was used both to determine the extent of head movement made during both flight and ground operations in order to expand the external field of view and also to document the operational situations that require the expanded field of view. The evaluations were conducted in high fidelity operational flight deck simulators with active out-the-window scenes. The following sections describe the evaluation design, rationale for choosing the measurement conditions, the tasks that the pilot performed, and the evaluation procedures. The basic paradigm was to have the pilots sit in the flight deck, describe the operational situation and then demonstrate the head movement required to perform the visual task.

4.2 Test Facilities

As Chapanis (1990) points out, when designing studies that are to be extrapolated to specific applications, the guiding principle should be “similarity”. The evaluation of any aircraft flight crew interface therefore becomes a problem of realism (environmental, workload, perception, etc.) and the amount of realism required to accomplish the study is dependent on the objectives of the test. The environment created by the test facility must be realistic enough to enable the generation of data that will generalize to flight situations. In order to accomplish this goal for the current evaluation, it was necessary to use flight decks that position the pilot’s eye in both height off the ground and distance from the windows equivalent to the proposed HSCT geometry. The evaluations were conducted using 737 and 777 operationally configured simulators. The 777 flight deck represents the appropriate eye height off the ground and the 737 flight deck has approximately the correct distance to the windows. A fixture was developed that permitted the pilots to hold a locator in front of their eyes in such a way to allow the x, y, and z location of the eye to be recorded. Section 5 presents a detailed description of the data collection resources

4.3 Evaluation Design, Rationale and Controls

The measurements described in this section were designed to permit the evaluation of requirements for extended external field of view during air and ground operations in a realistic operational environment (i.e., required or desired head movements). The evaluations were also designed to identify the operational situations that generate these movements. Measurements will also be made to define the maximum head movement box (with and without shoulder harness) in order to describe the potential field of view that currently exists on operational flight decks..

Operational Head Movements: Certain operational situations may require that the pilot move from the design eye position in order to see something in the external scene (e.g., seeing traffic may require the crew to move forward and look up). Each pilot was sent a pre-test instruction package that requested that they think about and briefly record situations that would require them make these movements away from the design eye position. This allowed them to give more thought to the situations than would be possible during the evaluation period. Prior to the evaluation sessions, a number of domain experts were consulted to compile a list of situations that would potentially cause a pilot to move in order to expand the external field of view. During the evaluation sessions, eye position measurements were collected for those situations that the pilot had recorded on their questionnaire. These were designated as the “primary” situations. The pilot was then asked about any of the pre-defined situations that they did not mention. If the pilot agreed that there was head movement involved in these situations, the measurement was designated a “prompted” situation

The head movement data was collected for four flight phases, takeoff/climb, cruise, approach/landing and ground handling. These phases were chosen to be representative of a full operational flight and should have captured any situation which would require head movement (both normal and non-normal). Although the actual flight phases were not flown, the pilots were asked to describe operational situations that could occur and the flight phase in which the situation is most likely.

During this measurement process the pilot was asked first to adjust the seat to the position that would be “normal” for that phase of flight. If there was more than one “normal” position for a flight then all positions were recorded. The pilot then demonstrated the eye location that achieved the required external vision for each defined operational situation, the lap belt was worn for all sessions. The assumption is that operationally they will follow procedures with regard to the restraint and seat system.

The eye location and operational situations generating the head movement were recorded in detail and a final compilation of the eye movement and operational situations was documented.

Maximum Head Movement: Although the head movements of interest were correlated to operational situations it is important that the maximum head movement envelopes be described and related to the external vision. Situationally driven field of view requirements basically put the pilot’s eye in a specific position in the flight deck to meet the requirement. When maximum extensions are measured the stature of the pilot plays an important role (i.e., a 6’3” pilot can lean farther than a 5’2” pilot especially when restrained at the waist). Therefore, a range of sitting heights was examined. It was the intention to take these measurements with and without shoulder restraints. However, the results of the preliminary test sessions indicated that the inertial reel harness did not restrict the pilot movements. Therefore, the evaluation was performed with only the lap belt in place. Five measurements were taken for this condition. The pilots started at the relaxed eye point then move: 1) as far left; 2) as far forward and left (approximately 45 degrees); 3) as far forward; 4) as far right and forward and 5) as far right as they could and still see over the glareshield. These measurements were used to establish the extreme movement envelope and the effect of sitting height on this movement.

4.4 Evaluation Procedure

During the evaluation, each pilot was scheduled for a two-hour block of time. The test session began with an introduction briefing and any questions that the pilots have on the written material that they have been sent, were answered at this time. This took place on the specific flight deck so that the actual window arrangement could be used for illustration. The pilot's initial impressions were collected at this time.

The next portion of the test session was devoted to measuring the maximum movements. As described in the previous section, each pilot was asked to move to a position as far left, left and forward, forward, forward and right, and full right as they can to expand the external field of view. The pilot used the eye-locating fixture to produce the position data. The location of the extreme eye position (left eye for outboard and straightforward movements and the right eye for inboard movements) was recorded because it is that location that will drive the final eye box. Measurements were taken at each head/body extension position. This process was done with lap belt restraint only.

After the extreme eye/head movements were recorded, measurements were taken for both the air and ground situations that the pilots had indicated needed head movement to expand the visual field. Each pilot was asked to relate the operational situation that requires an expanded external field of view and to demonstrate the movement necessary to obtain this field of view. While demonstrating the movement, the pilot again held the eye-locating fixture over the "extreme eye". The x, y, and z location and direction of gaze of the eye was recorded and associated with the driving operational situation.

5.0 Facilities - Hardware and Software Detail

One of the most important aspects of any applied testing program is the selection and development of the test facility in which the evaluation will be performed. The environment created by the facility must be realistic enough to generate data that address the objectives of the test and can be generalized to the airplane of interest. In the present evaluation, the operations being evaluated required a facility that was geometrically true to the airplane and had a realistic outside visual scene. The following sections describe the Integrated Airplane Systems Laboratory, the 777 simulator and the 737 simulator that were used in this study program.

5.1 Integrated Airplane Systems Laboratory (IASL)

While engineering for other aircraft models is conducted at the Boeing Integrated Airplane Systems Laboratory (IASL), the facility was created primarily to support the 777 product development effort. The facility houses fixed-based engineering simulators for the currently produced commercial models (737, 757/767, 747, and 777) as well as a generic motion simulator which has 6 degrees of freedom. A fixed-based research cab is also available there. Engineering simulators or “cabs” are different from typical training simulators in that they are easily reconfigurable from a software and hardware standpoint. Design changes that affect the flight deck of any given model are frequently implemented in engineering cabs before production begins. Therefore the Boeing Company places great importance on flexible simulation facilities.

Although the simulation cabs comprise a significant ongoing effort, of prime importance to the 777 Program is the Systems Integration Laboratory (SIL). The SIL integrates the avionics and electrical systems via production wiring harnesses which may be “flown” under a pilot’s control. The high-bay wing of the 518,000 square foot facility contains the mechanical and hydraulic test rigs which were key to the 777 flight control systems development. The IASL also contains labs and shops for light manufacturing and fabrication of test equipment.

5.2 777 and 737 Flight Deck Simulators

The 777 and 737 engineering cabs normally incorporate hardware line replaceable units (LRUs) which process the avionics data generated from the simulation computers. However, during times of initial and continuing development, the hardware performance is simulated by software-generated signals. In the current simulation effort, software was used to model the flight displays, Airplane Information Management System (AIMS), Primary Flight Control System (PFCS), and the Autopilot Flight Director System (AFDS) LRUs, to provide realistic interior environments.

The outside visual scene for both simulators is generated by an Evans and Sutherland ESIG 3000 system. In the 777 cab, the scene is displayed on a wide system that features a 200-degree wrap-around field of view. The system yields a 15° up and 25° down view in elevation. See Figure 5.2-1. The system consists of a series of 5 projectors mounted atop the cab projecting onto a single piece concave mirror in front of the cab. See Figure 5.2-2. The single mirror allows the pilots to look around window posts without dealing with seams in the view. The focal point of projection is located halfway between the two pilot eye reference points. In the 737 cab, the outside scene is presented on four 27-inch diagonal Glass Mountain monitors.

5.3 Data Collection Equipment

In order to quickly identify the three-dimensional coordinates of the pilot's eye for each scenario, a system of 3 retractable lines was developed. The three lines were marked in one-inch increments and attached to a stationary board placed behind the pilot's seat. The holes that the lines ran through on the board were spaced 14 inches apart in a triangular arrangement (see Figure 5.3-1). The lines were joined at one point to a rod that was held in place while the researcher measured the length of the lines. For each position, the researcher would record the length of each line that would then be used in a computer model to recreate the coordinates.

Since the geometry of the attachment points on the board was known and the eye reference point in the simulator was marked, the various eye positions were easily identified relative to the eye reference point. This system was chosen over the magnetic head-tracking system that was originally identified as the measurement tool because electromagnetic interference caused by the close proximity of the simulator structure caused unacceptable variations in the measurements.

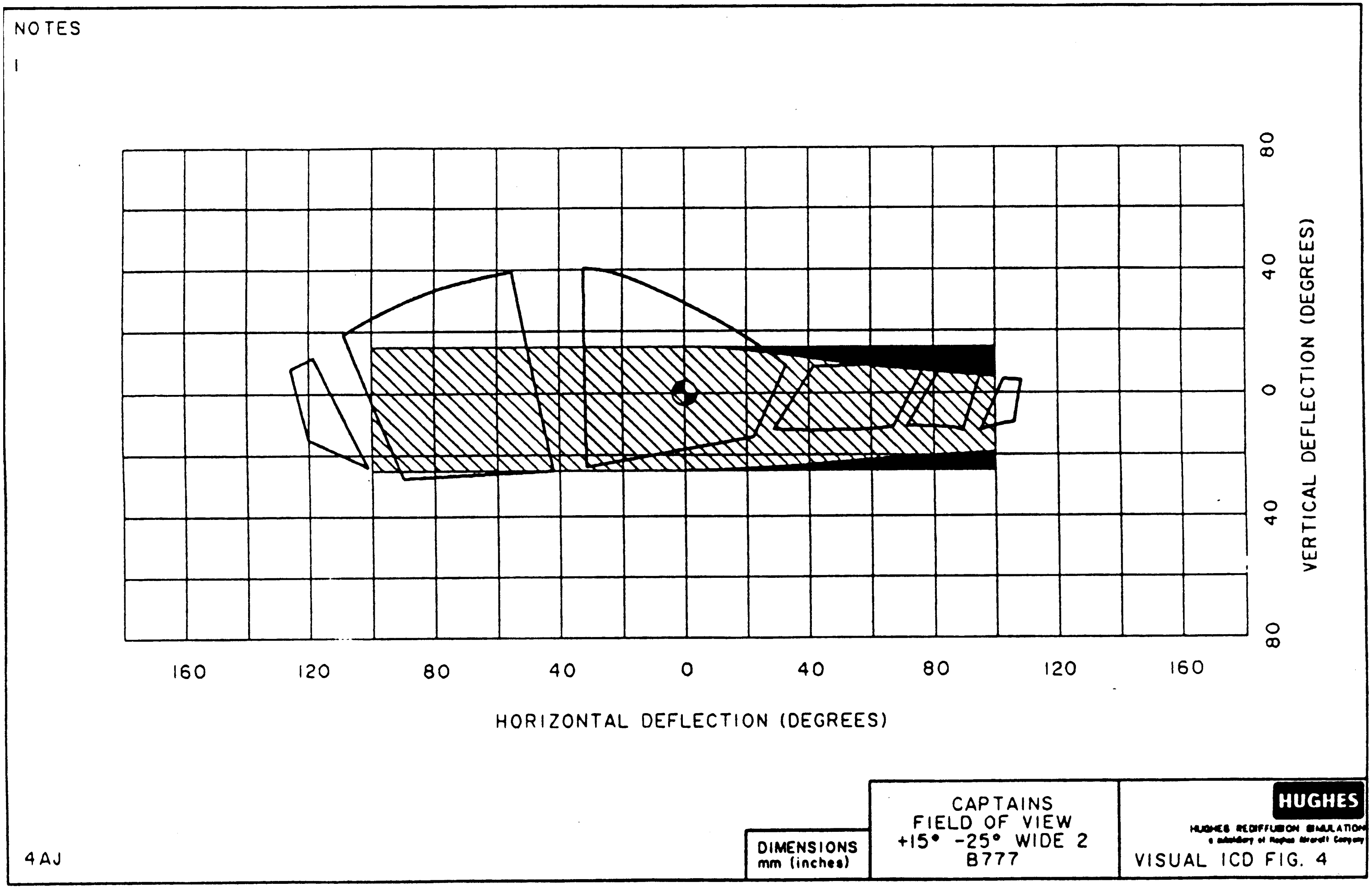


Figure 5.2-1 ESIG Visual Field of View

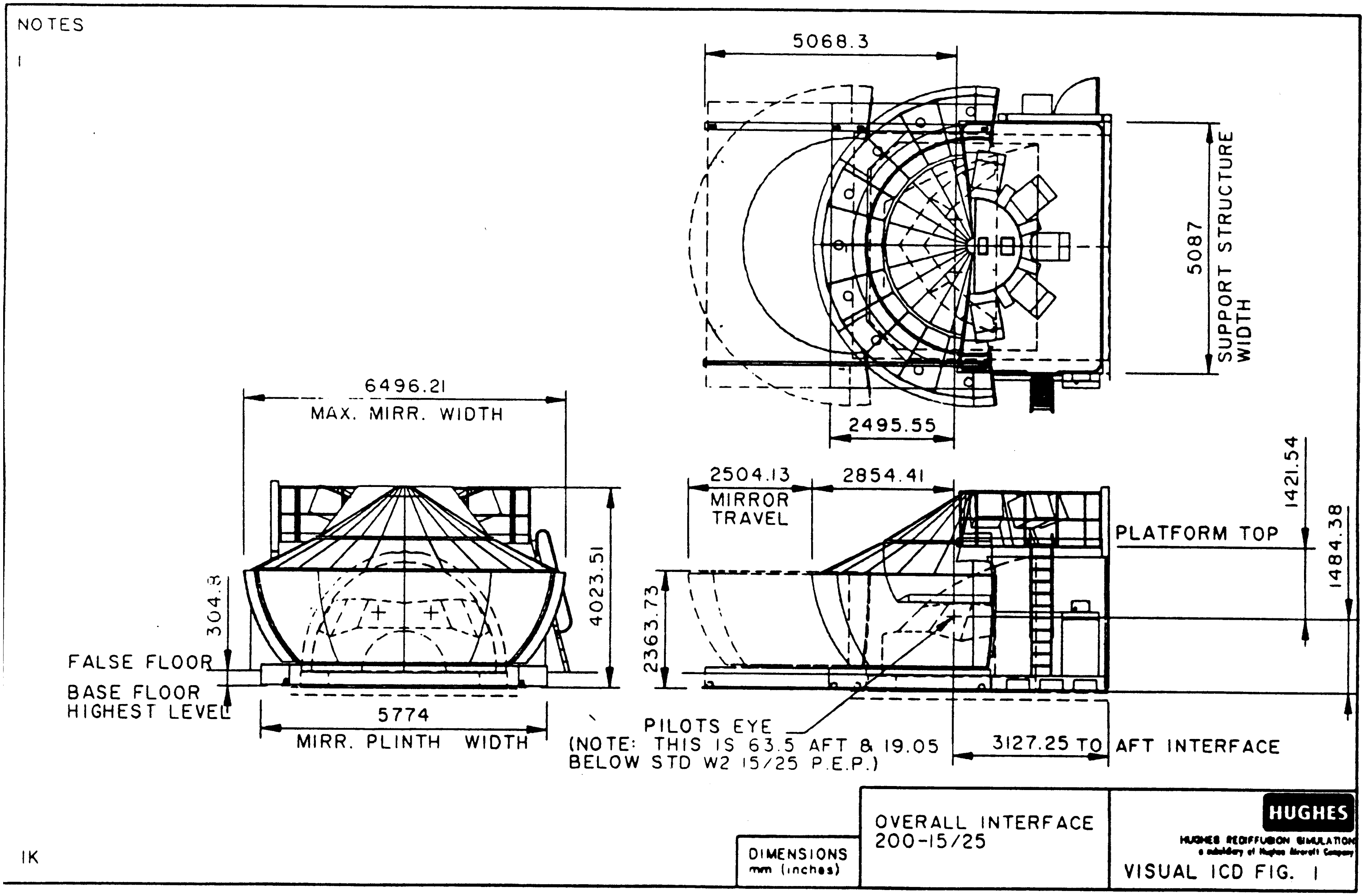
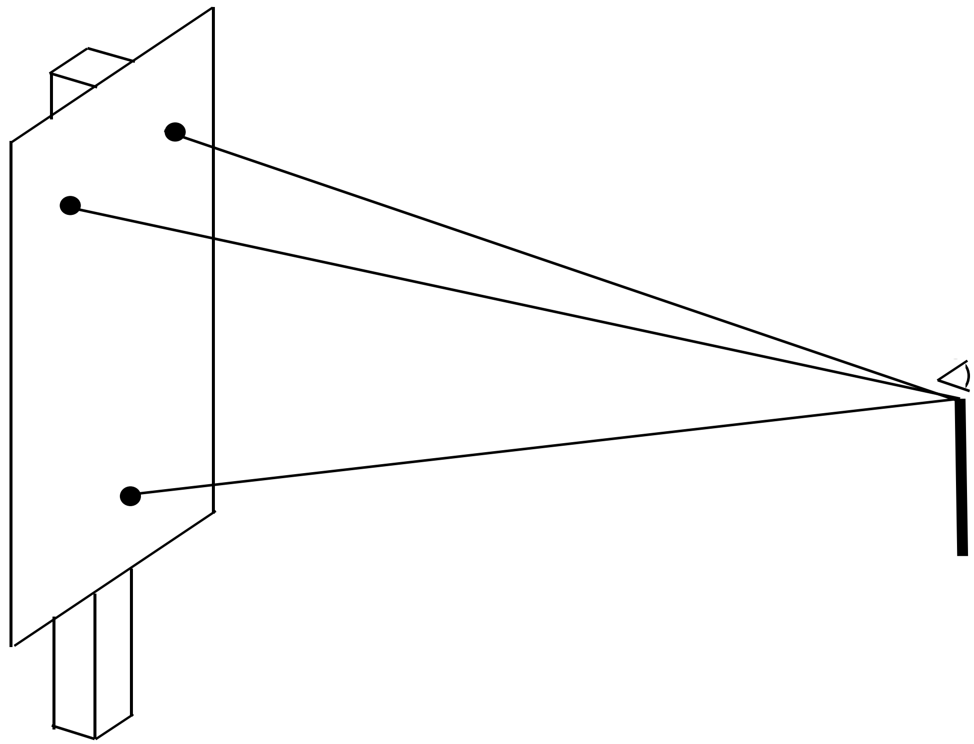


Figure 5.2-2 777 Configuration Cab Visual System Diagram

Figure 5.3-1 Eye Measurement Fixture



6.0 Data Collection Plan

The data that was collected during the head/eye movement evaluation falls into three general categories: situational (anecdotal) data; objective (eye position) data; and biographical questionnaire data. By combining these three data sources, a comprehensive description of the operational aspects of head movement as a means of expanding the outside field of view can be made.

6.1 Operational Situation Descriptions

The pilots were sent a questionnaire prior to the evaluation session (see Appendix A) so that they could describe the situations that would generate head movement during airplane operations. Furthermore, pilot input was obtained throughout the evaluation to more fully establish the conditions that would require the various head movements. Finally, at the conclusion of each evaluation session the pilots were given the opportunity to expand on their inputs.

6.2 Objective Measures

Two types of head/eye movement were measured during the evaluation, situation dependent and maximum. During each excursion from the nominal eye position, the position of the extreme eye in x, y, and z were measured relative to the design eye position. The direction of gaze (window being used) was also determined. These data were recorded for both the operationally generated, situation dependent movements and the maximum movement trials. During each session, an observer also recorded what is occurring on the flight deck. These observations focused primarily on the pilot seat position and changes that are made as well as the window being used for the vision task. These data have been tabulated to provide some insight into any changes in operation that occur and to identify those tasks using the visual field covered by the XVS display.

6.3 Biographical Data

The questionnaire that the pilots completed also had a section that was designed to obtain biographical information about the pilot (see Table 6.3-1). This data provided insight into the experience level of the pilots.

Table 6.3-1 Sample Biographical Data Section

Inboard Vision Test Flight Crew Questionnaire

Name:____ Age: ____

Organization: __________________________________

Current Position: ________________________________

Current Type Certificates: _________________________________

Number of Years Flying: ___________ Total Number of Flight Hours: _____________

In the space below please identify the aircraft you have flown, next to the airplane indicate the approximate number of hours.

B-707 __________	DC 8 __________	A 300 __________
B-727 __________	DC 9 __________	A 310 __________
B-737 __________	MD80 _________	A 320 __________
B-747 __________	DC 10 _________	L 1011 _________
B-757/767 _________	Military Transport __________	
B-747-400 _________	GA __________	Other __________
B-777 __________		

Do you regularly fly into Class B airspace?

Yes _____ No ______

Approx. how many times a year _____

Do you regularly fly into non-radar controlled airports?

Yes _____ No _____

Approx. how many times a year _____

Do you regularly operate in weather requiring ground de-icing? _________

Approximately how many times a year? _______

Do you regularly fly into airspace with high traffic density? _______

Approximately how many times a year? _________

Do you regularly operate at airports with high ground traffic/obstacle density? _______

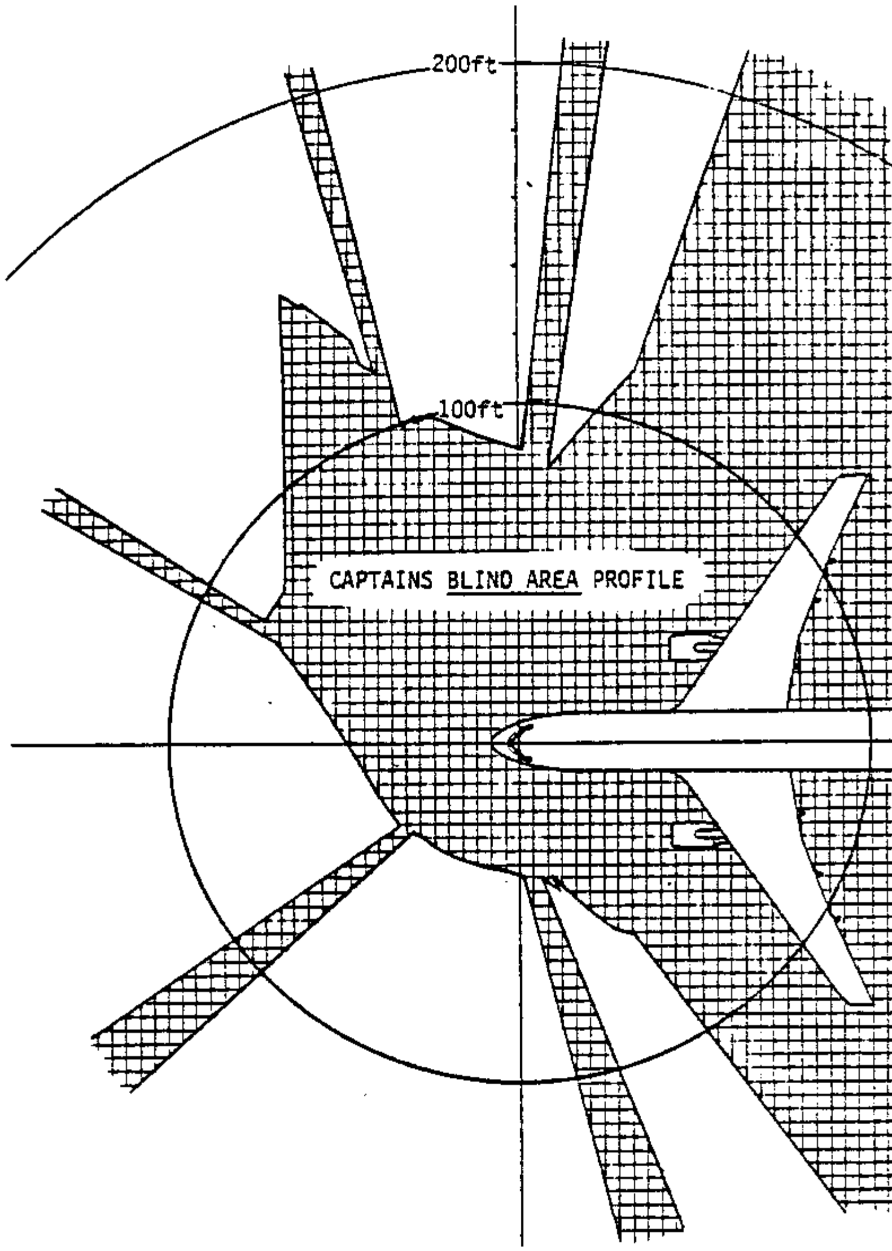
Approximately how many times a year? _________

7.0 Data Reduction and Analysis

The following paragraphs describe the specific data reduction procedures were applied to the data obtained during the study. These data have been defined earlier as objective measures (eye position measures), operational situation descriptions, and biographical data

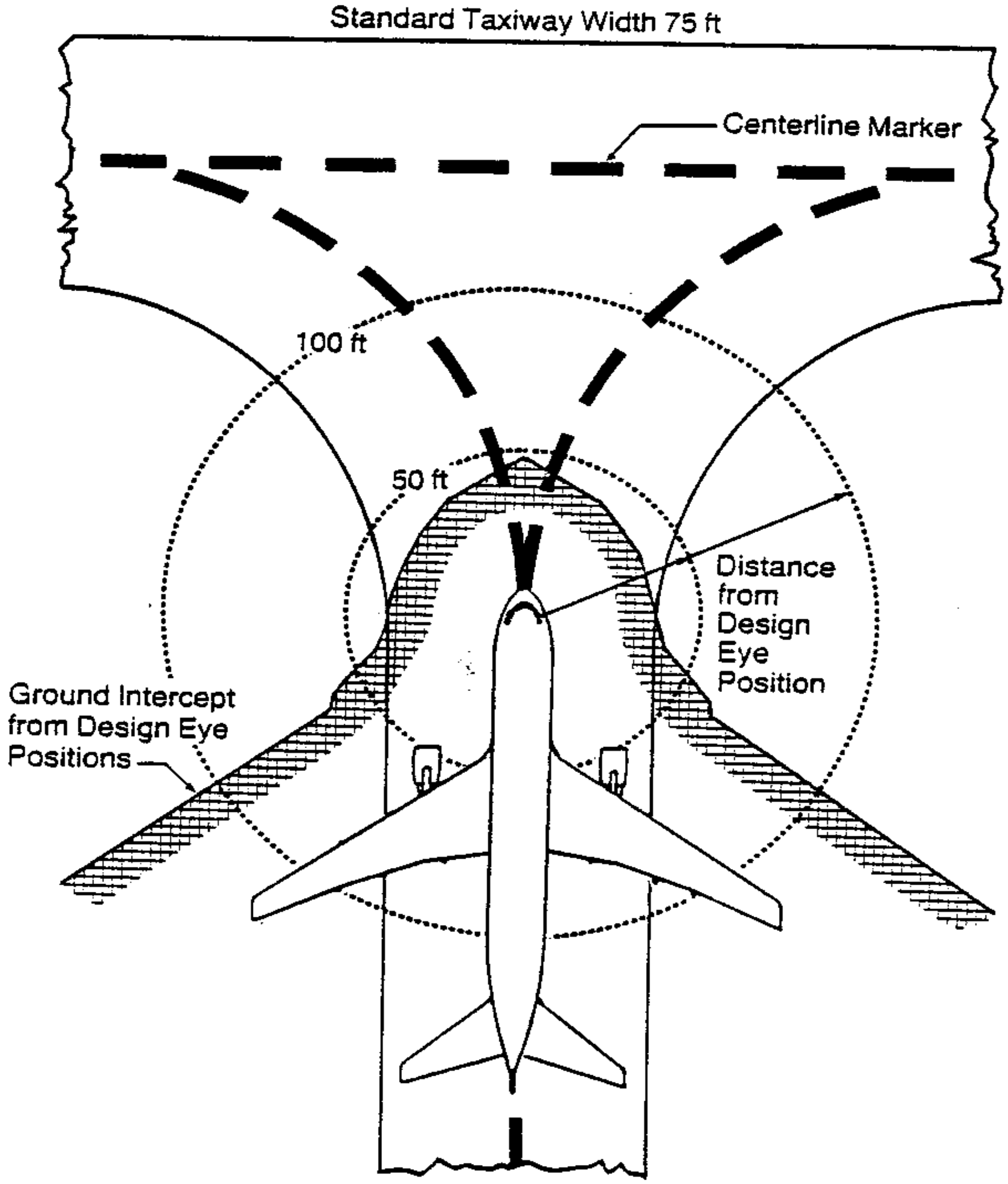
The operational situations driving head movement were evaluated by operational domain experts and categorized as either a required operation or a desired operation. The eye locations were then grouped into these two categories. An average eye box was constructed for each category. Using vision polar techniques, the “blind area profile” (for an example see Figure 7.0-1) and the “ground intercept vision outline” (for an example see Figure 7.0-2) were produced for the 737, and 777 airplanes. A second set of these vision polars was produced using the calculated eye boxes. These were considered baseline acceptable coverage. A vertical representation of the vision polar was also developed. The plots were then developed for the current HSCT/XVS configuration. A comparison of the baseline with the current HSCT configuration was made to determine where modifications need to be made to accommodate the required operations.

Figure 7.0-1 Example "blind area profile" using the design eye reference point as eye position.



767 CAPTAIN'S BLIND AREA PROFILE MEASURED FROM HIS ERP

Figure 7.0-2 Example of the "Ground Intercept Vision Outline" from design eye reference points



767 CAPTAIN AND FIRST OFFICER GROUND INTERCEPT VISION OUTLINE FROM DESIGN ERP POINTS

8.0 Results

8.1 Operational Situation Results

The following section describes those operational situations that resulted in head movement in order to expand the external field of view as reported by the pilots. Although the evaluation process asked the pilots to describe head movements for all flight phases (including ground handling), the vast majority of the in-flight reports were for the approach and landing phase. Those reports for other flight phases fell into two categories, looking for traffic and sightseeing. The traffic scan head movement was the same regardless of flight phase. Therefore, the results for the in-flight reports will be presented together. Both the "primary" (situation designated on the pre-evaluation form) and the "prompted" (situation described by the experimenter during the evaluation session) situations are reported below.

General: A large number of the pilots (59%) commented that the majority of head movements occur on the ground and are associated with taxi and gate operations as opposed to runway operations. The 737 pilots reported more head movement than the 777 pilots. Almost all of the pilots (88%) reported that they used head movement to look out the cross-cockpit windows as a "feel good" crosscheck but that procedurally they requested the pilot sitting in the right seat to clear that side of the airplane. A number of the pilots (41%) commented that the flying pilot should not do a lot of head movement in flight (especially in approach) because under certain circumstances the movement could cause vertigo and/or disorientation. Therefore the operational situations that they provided were exceptions rather than common occurrences. Only two of the pilots changed the position of their seat during the evaluation session and both of them raised the seat slightly during short final in low visibility.

Air Operations: The air operations that the pilots reported using head movement to expand the external field of view fell into six categories: 1) looking for/at traffic; 2) performing parallel approaches; 3) performing circling approaches; 4) flying short final in low visibility; 5) checking for icing or flight control movement; and 6) acquiring landmarks. Eighty-two percent of the pilots reported head movement to look for traffic as a primary situation. The majority of these (65%) commented that the movement would normally be a swiveling action rather than a movement toward the window. When they did demonstrate a movement toward the window (front and side) they said that it would be more to look at the traffic as a point of interest rather than to identify a threat. The implication was that threats could be seen from their normal seated eye position.

Checking for icing and flight control operation was cited as a primary head movement situation by 41% of the pilots and a prompted situation by another 30%. The head movement was quite different for the two airplanes. For the 737 pilots (64% of the reporting pilots) who can see the wing out of the side window, the movement was to look back out the side (#2) window to see icing on the leading edge and to see flight control movement. The 777 pilots cannot see the wing so they move forward and look down at the windshield wiper post to detect icing. Even though this forward movement does use the front window, we do not expect to have windshield wipers on the HSCT.

Circling/visual approaches were cited as primary head movement situations by 35% of the pilots and as prompted situations by another 47%. The 737 pilots were more likely to mention this situation, 56% of 737 pilots had this situation as primary while only 25% of the 777 pilots did. All of the pilots used the cross-cockpit side (#2) window to do this task. Furthermore it was felt that it was the pilot in the right seat who should pickup the runway environment during a turn to the right and that the captain was doing a crosscheck if anything. The comment was also made that for a turn to the right, the right seat pilot would be the better person to fly the approach.

Twenty-four percent of the pilots had parallel approaches as a primary head movement situation and another 24% had it as a prompted situation. All of the pilots that called this situation on their questionnaire were 737 pilots. Of those that demonstrated head movement for the situation after prompting one was a 737 pilot and 3 were 777 pilots. The head movement was generated by a desire to see an aircraft that was on a parallel approach and was behind the ownship. Therefore, the head/eye movement was toward the side window (#2) looking toward the rear.

Twenty-four percent of the pilots cited low visibility short final and landing as a primary situation that resulted in head movement and another 12% demonstrated movement after prompting. This situation was the only one that was reported by more 777 pilots (4) than 737 pilots (2). Interestingly, most of the pilots reported that they moved their head forward anticipating the appearance of the runway knowing that it would not make the runway appear any earlier. One pilot said that he moved forward and placed his hand on the glare shield to shield his eyes from the instrument lighting so that he could see better in the low visibility.

Finally, thirty percent of the pilots documented sightseeing as a situation resulting in head/eye movement. A desire to point out landmarks to the passengers causes them to move toward the side window (#2) to expand their downward field of view.

Ground Operations: There were three major categories of ground situations that the pilots reported resulted in head/eye movement in order to expand the outside field of view: 1) performing the taxi; 2) maintaining visual contact with ground handlers and obstacles; and 3) detecting approaching air traffic when holding to enter/cross an active runway. Differences in the situations requiring head movement were very apparent between the 737 and 777 pilots.

Taxiing the airplane was cited as a primary head movement situation by 71% of the pilots and a prompted situation by another12%. The reasons given for the need to expand the external field-of-view were quite different for the two airplanes. The 89% of the 737 pilots that moved their head during taxi (67% primary and 22% prompted), reported that they were looking for runway/taxiway markings and features as well as for ground traffic or they were looking around the window post. Only one of these pilots moved toward the front window reporting that it was “to see runway markings quicker in low visibility conditions”. Although he indicated that he felt that it really didn’t allow him to see the markings and signs any quicker, it just made him feel better. Seventy-five percent of the 777 pilots reported that they performed head movements during taxi (no prompted responses were recorded), however, the purpose given was quite different. They reported that, pilots use the side window much more to check airplane position when turning extended bodied airplanes on the ground (all the reported movements were toward the side window).

Checking marshalers and ground handling personnel was cited as a primary head movement situation by 64% of the pilots and as a prompted situation by another 24%. All of the 737 pilots reported looking for ground personnel as a head movement situation (89% as primary and 11% as prompted). Seventy-five percent of the 777 pilots performed head movement to see ground personnel ((50% primary and 25% prompted). All the pilots reported that even though they used the front window for this task, it would not be an operational issue for the HSCT because the procedure was to stop the airplane until they had visual contact with the marshaler. The 777 pilots who were familiar with the taxi-cameras commented that the camera setup permitted them to see the ground personnel at all times.

Finally, acquiring visual contact with inbound traffic while waiting at a hold line was cited by 82% of the pilots as a head movement situation (35% primary and 47% prompted). The larger windows of the 777 again appear to have a large affect on the results with only 12% of the 777 pilots calling out this situation on their questionnaire (primary) and 55% of the 737 pilots listing it as primary. Even though this situation was cited by most of the pilots, they were quick to point out that the use of the front window to see inbound traffic approaching from the right would be a cross check only since it was the first officer’s responsibility to clear that area.

8.2 Objective Data Results

It was the initial intention of this study to define those flight crew head movements that were performed to provide necessary expansion of the external field of view in order to respond to situations that are critical to flight/ground operations. These data were then to be geometrically examined with respect to the HSCT field of view and recommendations made for modifying the XVS display system if necessary. After analysis of the operational situation descriptions provided by the subject pilots, it became apparent that there were no situations that required the expansion of the outside field of view covered by the XVS displays (the direction of movement and window used for each of the situations described by the pilots are presented in the section above). Therefore, It was decided to use program resources in higher priority efforts rather than reduce and analyze the objective eye/head movement data.

9.0 Discussion and Conclusions

In answer to the question as to whether head movements are required to expand the external field of view over that provided by the vision polar resulting from adherence to the recommendations presented in ARP 1401/2, the results indicate that the field of view provided is adequate to perform all flight critical operations. This position is supported by the differences observed between the 777 and 737 pilots which demonstrated that the larger windows of the 777 (conforming to ARP 1401/2) reduced the tendency to move toward the windows to see outside, even though the pilots were farther from the window in the 777.

The geometry of flight is such that all of the critical visual operations that would be covered by the XVS displays occur close (in angular relationship) to the flight path of the airplane. Therefore, the field of view of the displays is adequate to enable these tasks to be performed. This combined with the threat of head movement induced vertigo or disorientation tends to reduce the amount of head movement reported. Although almost all of the pilots said that they had to move their head to look for traffic, the movement they described was a swiveling action and thus not used to expand the outside field of view but rather to see out all the windows. When they did go toward the window to see traffic, it was generally longitudinally closer to them but vertically separated (e.g. 1000' going in the opposite direction) and they were looking at the traffic as a point of interest (i.e., what airline? what kind of airplane? etc.). A small number of pilots said that they moved toward the front window slightly to detect traffic "sooner" even though they knew it would not help. This same "feel good" movement was described by a small number of pilots for short final approach in low visibility. All other head movements used the side windows and will not have an effect on the size of the XVS displays. The conclusion for the flight data is that there were no flight critical requirements identified by the test pilots for move toward the front window to expand the external field of view.

As the majority of the pilots indicated, most of the head movements are associated with ground operations where distances to objects are less and therefore a larger field of view may be necessary to see them. Moving the airplane around the airport resulted in the most head movement situations during ground operations. Even though the pilots from each of the test airplanes had completely different reasons, the head movement described by both groups was toward the side window that would pose no problem for the XVS displays. The pilots of the 777 with its larger side windows did not report a need to move their head to pick up signage and markings even though they sit farther from the taxiway. This indicates that the side windows of the HSCT, which provide comparable external vision, will also permit these signs and markings to be seen without head movement.

Two ground operations that generated head movement were defined as critical operations, maintaining visual contact with ground handlers and detecting approaching air traffic when holding to enter/cross an active runway. Almost all the pilots cited the visual contact with ground personnel as a head movement situation. However, all the pilots reported that even though they used the front window for this task, it would not be an issue for the XVS because the operating procedure would be to stop the airplane until the ground personnel took a position that was visible from the flight deck. A further mitigating technology was cited by the 777 pilots that had experience with the taxi-camera system which they reported permits them to see all the ground personnel and objects at all times. Therefore, this situation that requires head movement toward the front window can be overcome with either a procedure or a supplemental technology and does not require modification of the XVS display size.

Finally, when an airplane is stopped at a hold line before entering or crossing an active runway, the flight crew is responsible for visually checking for arriving traffic as well as traffic on the runway. In order to check for traffic arriving from the "inboard" side of the airplane the flight crewmember has to move his/her head down to get more upward field of view. Even though this is considered a critical operational situation, all of the pilots said that the head movement was a "feel good" cross check because the pilot on the side of the approaching airplane is responsible for clearing that side. Therefore , the situation is a critical operation but the head movement is not needed to perform the operation.

The final conclusion drawn from all the pilot input was that the XVS displays (forward and inboard) are sized correctly to meet ARP 1401/2 and to perform all critical flight and ground operations.

10.0 References

Chapanis, A., Some Generalizations About Generalization, in Selected Readings in Human Factors, M. Venturio (Ed.), Human Factors Society Inc., Santa Monica, 1990, pp 11-25

Society of Automotive Engineers, Aerospace Standard: Pilot Visibility from the Flight Deck: Design Objectives for Commercial Transport Aircraft (AS 580B), Society of Automotive Engineers, Inc., Warrendale, PA, November, 1978.

Society of Automotive Engineers, Aerospace Recommended Practice: Pilot Visibility from the Flight deck (ARP 4101/2), Society of Automotive Engineers, Inc., Warrendale , PA, February 1989

Appendix A

Pilot Head Movement Questionnaire

Pilot Number: _________

Date: _________

Head Movement Evaluation

Flight Crew Questionnaire

External Vision System: Head Movement Evaluation

Pre Evaluation Questionnaire
Section 1 - Biographical Data

Name:____ Birth Date: ______
First, Middle, Last Month/Day/Year

Address: ____
Street and Number, or P.O. Box

____
City, State, Zip Code

Phone: Home - (____)________________ Work - (____)_______________

Do you wear corrective lenses when you fly? ☐ Yes ☐ No

Employer/Organization: ___________________________________

Current Position: ________________________________

Current Type Certificates: _________________________________

Years Flying Commercial: ____________ Years Flying Military: ___________
Approximate Approximate

Total Number of Flight Hours: _____________
Approximate Hours

In the space below please identify the aircraft you have flown, next to the airplane indicate the approximate number of hours.

B-707 __________ DC 8 __________ A 300 __________

B-727 __________ DC 9 __________ A 310 __________

B-737 __________ MD80 _________ A 320 __________

B-747 __________ DC 10 _________ L 1011 _________

B-757/767 _________ Military Transport __________

B-747-400 _________ GA __________ Other __________

B-777 __________

Do you regularly fly into Class B airspace? ☐ Yes ☐ No

Approx. how many times a year _____

Do you regularly fly into non-radar controlled airports? ☐ Yes ☐ No

Approx. how many times a year _____

Do you regularly operate in weather requiring ground de-icing? ☐ Yes ☐ No

Approx. how many times a year _____

Do you regularly fly into airspace with high traffic density? ☐ Yes ☐ No

Approx. how many times a year _____

Do you regularly operate at airports with high ground traffic/obstacle density? ☐ Yes ☐ No

Approx. how many times a year _____

Section 2 - Pilot Situation Descriptions

Questionnaire Instructions

Operational vision needs and design vision requirements are not necessarily the same thing. During design, the design eye point is used as the reference for both the internal and external vision geometry. During airplane operation, however, the flight crew rarely sits at the eye reference point. Seating position is a matter of preference and/or procedure and often changes with flight phase. There are some situations in which the crew member either has to or wants to move out of the normal seated position to get a "better" look at something outside the airplane. The purpose of this evaluation is to identify those situations that cause crew members to move their heads in order to see something outside the airplane and when we get into the cab to measure how much head movement is needed. This pre evaluation questionnaire should be used to develop a preliminary set of situation descriptions to provide a starting point for the cab session.

In the space provided below (use extra pages if you need to) please write a short (1-2 sentence) description of situations that cause you to move closer to the windows to see something outside the airplane. These situations could occur either in the air (e.g., see traffic, see ground features, see weather, etc.) or on the ground (e.g., see obstacles, see markings, see signs etc.). Please identify the situation, when it happens, which window you looked out, how important the movement was (i.e., was the movement required to operate <u>or</u> did you feel more comfortable getting the increased vision <u>or</u> were you just double checking some information). In the first part of the questionnaire, please relate only those situations with which you personally have experience in your current type rating. The next part will ask you to describe situations that could require head movement to see something outside the airplane even though you personally have not experienced the situation in your current airplane.

Part 1

Head movement situations you have personally experienced in your current airplane.

Situation Description: ____
____
____
____
____
____

Flight Phase: ________________________ **How Often:** __________________________

Window:________________ **Importance of Movement:**

- ☐ Required for Operation
- ☐ More comfortable to see
- ☐ Just double checking

Situation Description: ____
____
____
____
____
____

Flight Phase: ________________________ **How Often:** __________________________

Window:________________ **Importance of Movement:**

- ☐ Required for Operation
- ☐ More comfortable to see
- ☐ Just double checking

Situation Description: ____
____
____
____
____
____

Flight Phase: ______________________ **How Often:** ________________________

Window:_______________ **Importance of Movement:**

- ☐ Required for Operation
- ☐ More comfortable to see
- ☐ Just double checking

Situation Description: ____
____
____
____
____
____

Flight Phase: ______________________ **How Often:** ________________________

Window:_______________ **Importance of Movement:**

- ☐ Required for Operation
- ☐ More comfortable to see
- ☐ Just double checking

Situation Description: ____
____
____
____
____
____

Flight Phase: _________________________ **How Often:** ___________________________

Window:_________________ **Importance of Movement:**

☐ Required for Operation

☐ More comfortable to see

☐ Just double checking

Situation Description: ____
____
____
____
____
____

Flight Phase: _________________________ **How Often:** ___________________________

Window:_________________ **Importance of Movement:**

☐ Required for Operation

☐ More comfortable to see

☐ Just double checking

Part 2

Below please describe additional situations, other than those you just described, that you think might result in head movement closer to a window to see something outside the airplane. Use all of your flight experiences to develop this portion of the list.

Situation Description: ____
____
____
____
____
____

Flight Phase: ____________________ **How Often:** ____________________

Window:________________ **Importance of Movement:**

☐ Required for Operation

☐ More comfortable to see

☐ Just double checking

Situation Description: ____
____
____
____
____
____

Flight Phase: ____________________ **How Often:** ____________________

Window:________________ **Importance of Movement:**

☐ Required for Operation

☐ More comfortable to see

☐ Just double checking

Situation Description: ____
____
____
____
____
____

Flight Phase: ________________________ **How Often:** __________________________

Window:________________ **Importance of Movement:**

- ☐ Required for Operation
- ☐ More comfortable to see
- ☐ Just double checking

Situation Description: ____
____
____
____
____
____

Flight Phase: ________________________ **How Often:** __________________________

Window:________________ **Importance of Movement:**

- ☐ Required for Operation
- ☐ More comfortable to see
- ☐ Just double checking