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HIGH-FIDELITY MOTION SIMULATOR RAPID COCKPIT IMPLEMENTATION DEMONSTRATED USING A BLACKHAWK CONFIGURATION

Dean P. Giovannetti, NASA Ames Research Center

ABSTRACT

This paper describes the development (eight months from conceptual design to full-motion data-gathering simulations) of a low-cost, high-fidelity UH-60A Blackhawk motion-rated simulator cab utilizing the Interchangeable Cab concept developed by the NASA-Ames Research Center's Vertical Motion Simulator (VMS) Simulation Laboratory. The Project resulted in the design of a low-cost simulation system to replicate helicopter/shipboard launch and recovery envelopes, thereby reducing the reliance on expensive at-sea developmental flight tests. This paper focuses on the structural and mechanical areas of the project, and how the Simulation Laboratories' rapid design and fabrication concept was used to accomplish the program's demanding requirements. Key areas discussed are: developing a compact, low-cost, wide-field-of-view, night-vision capable, cross-cockpit visual system; integration of a 4-axis dynamic seat shaker; and design and fabrication of a motion-rated Blackhawk simulator cab capable of operating on NASA's Vertical Motion Simulator motion system.

INTRODUCTION

The NASA Ames Simulation Laboratories (SimLab) were approached by the Joint Shipboard Helicopter Integration Process (JSHIP) Test and Evaluation Program, sponsored by the Office of the Secretary of Defense, with a requirement to design, build and integrate a low-cost UH-60A Blackhawk motion simulator. The system would be used for simulating and evaluating test processes and mechanisms that facilitate ship-helicopter interface testing via man-in-the-loop ground based flight simulators. The goal of the project was to develop, in a very short time period at minimal cost, an accredited process for simulating helicopters landing on ship decks. The project required identifying, analyzing, and developing a simulation system to support helicopter/shipboard launch and recovery envelopes. Utilizing the NASA-Ames Simulation Laboratories Interchangeable Cab (ICAB) system provided the fastest and least expensive approach to accomplish project requirements.

Principal areas of the project reviewed in this paper are: developing a compact, low-cost, wide-field-of-view, night-vision capable, cross-cockpit visual system; design and fabrication of a motion-rated simulator cab capable of operating on NASA's Vertical Motion Simulator motion system, and integration of a 4-axis dynamic seat shaker. Although not discussed in this paper, additional noteworthy areas of the project include: development of a low-cost, high-resolution, PC-based image generator; development of a visual database capable of simulating accurate ship and deck motions, a 3-dimensional textured ocean and other visual effects; and development of a ship dynamics model, with airwake, representing various wind and ocean states.

To accomplish the goals of this project it was necessary to develop, design and build a state of the art, low-cost, motion-rated, simulator cab with a wide-field-of-view visual system. The JSHIP office requested that a UH-60 helicopter cockpit interior be replicated for the project. The cockpit flight control mechanical systems and displays, seating, and field of view were to replicate the UH-60A cockpit. Visual display system requirements included a 220 x 70 degree, night-vision goggle compatible, continuous, out the window field of view. To meet these requirements, SimLab designed a unique visual system consisting of five off-the-shelf, high output CRT projectors combined with custom mirrors and rear projection screens. The complete visual projection package is extremely compact, fully motion-rated to 3g's, and provides all the benefits of a spherical screen at significantly reduced cost. Electrohydraulic servo controlled flight control inceptors and a 4-axis Dynamic Seat are provided at the pilot's station. The dynamic seat provides body force cueing (motion) for investigation of small displacement high-frequency motion, while the VMS provides large motion cues. All flight control mechanical characteristics, including force trim release and force trim control systems, are identical to the aircraft and were designed, fabricated, installed and made interactive with the simulation math model developed for the project. A 6-channel sound system provides high-fidelity UH-60 sound reproduction.

The new simulation system developed by SimLab provides the Department of Defense an outstanding platform for developing wind-over-deck launch and recovery flight envelopes that will increase interoperability of helicopter units not specifically designed to go aboard Navy ships.

SIMULATION LABORATORIES

The NASA Ames Simulation Laboratories are built on a design and operating philosophy aimed at supporting the widest possible range of aeronautical research. The concept is based on a building block approach that involves maintaining as distinct resources a conglomeration of simulation elements or components that can be integrated to form a complete system in a variety of different ways. The entire collection of simulation components, support equipment and associated facilities located in the Flight and Guidance Simulation Laboratory and other nearby buildings is familiarly known as *SimLab.* The simulation system interchangeable approach allows the simulator configuration to be modular to meet the needs of specific research by employing only those components necessary for a particular test, tuning these components specially for the test, and using the most appropriate interchangeable components to suit specific test requirements. Utilizing the modular design approach, specialized equipment can be integrated more easily, and facility improvements can be implemented, by up-grading individual components rather than the entire simulator. The SimLab approach of doing business offered the JSHIP Program the least expensive approach to completing their simulation research requirements and was the only laboratory capable of doing the work within the required eight-month schedule.

VERTICAL MOTION SIMULATOR OVERVIEW

The Vertical Motion Simulator (VMS) at NASA-Ames Research Center has been in operation since the mid-1970's. The VMS is a one-of-a-kind simulation research and development facility offering unparalleled capabilities for conducting studies and experiments involving some of the most challenging aerospace disciplines. The VMS Motion System is a very large, six-degree of freedom, electromechanical/electro hydraulic servo system. It is located in and partially supported by a specially constructed 73 feet wide by 36 feet deep by 120 feet high tower. In operation, the motion system and ICAB use virtually the entire interior volume of this tower. In addition to its size, another unique feature of this facility is that it can simulate the physical cueing environment of a large range of vehicles. Five cabs representing the cockpits of a variety of vehicles, each with its own field of view, instruments, controls, visual displays and audio cueing systems. The motion platform consists of a 40-foot long beam, which travels ± 30 feet vertically. On top of the beam is a carriage that traverses the whole length of the beam. Situated on top of the carriage is a gimbal system that provides ± 4 feet of lateral travel, ± 18 deg. of roll and pitch and ± 24 deg. of yaw. (See Fig 1.)

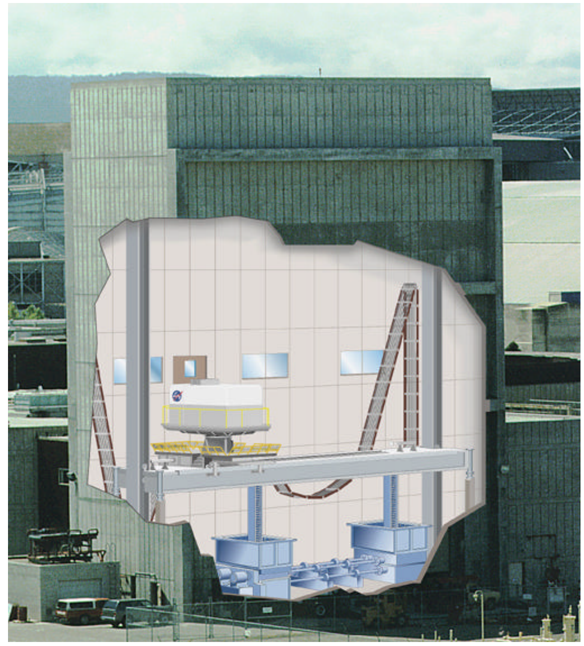

Figure 1: *Photograph of VMS Tower with cut away view and artists rendering of motion system and interchangeable cab. Note size of tower in comparison to automobiles in lower left of picture.*

INTERCHANGEABLE CABS (ICAB'S)

Five Interchangeable Cabs (ICAB's) are maintained and operated by SimLab and provide the capability to simulate the cockpit/crew station for a wide range of aerospace vehicles. The ICABs are built up around essentially identical structures that furnish a basis and framework for installing and mounting the numerous items that make up an aircraft cockpit crew station. The basic design and construction of the ICAB's are illustrated in Figure 2.

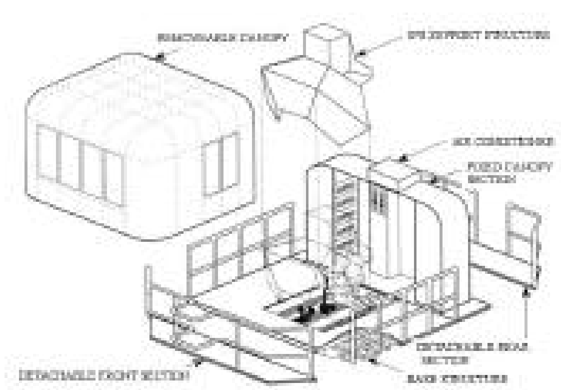

Figure 2

In order to achieve the desired interchangeability, the ICABs are built to rigid mechanical, hydraulic and electrical interface specifications. The structure of each cab is composed of four substructures: the base structure, the fixed canopy section, the removable canopy and the Image Presentation System (IPS) support structure. The base structure is a large flat weldment fabricated from aluminum channels, tubing and plate. It forms the floor of the cab and serves as the attachment to the Motion System. All other substructures are bolted to it. Detachable front, rear and side sections, facilitate transporting the cab between the off-line development area and the VMS. The under-floor structure is designed to provide three adjacent oil-tight bays to accommodate the electrohydraulic control loaders used to simulate the primary aircraft flight controls. The three different locations allow for either a single, centrally located pilot station or a two-seat, side-by-side arrangement. Wiring harnesses, hydraulic lines, junction boxes, instrument panels and consoles, electrical power outlets as well as other items are mounted directly to the base structure. The fixed canopy section forms the rear wall of the cab, providing a sturdy structure for mounting a number of items including cab lighting, sound system speakers, pilot observation cameras, head tracking support equipment and standard aircraft-sized equipment racks. The removable canopy section forms the front wall, sidewalls and roof of the cab. Its primary functions are to enclose the equipment contained inside the cab, and provide a sound/light barrier to prevent distractions to the pilot. As its name implies, this section can be easily removed with an overhead crane allowing unrestricted access to the other internal items and substructures. The image projection system varies markedly from cab to cab in Field of View (FOV) capabilities. Each IPS is tailored to a specific class of aircraft such as Helicopter, Space Shuttle, Large Commercial and/or heavy lift military aircraft, Tilt Rotor, Military Fighter and, to be discussed shortly, JSHIP. No one compact visual system exists that can provide the cumulative FOV requirements for each class of listed aircraft, hence the need for 5 cabs. Lastly, all five cabs have removable access porches and can be retrofitted with a wide range of pilot inceptors, seats, instrument panels, etc., from SimLabs inventory of aircraft simulation equipment.

The advantage of the ICAB design approach is not only utilized for flexibility but also for efficiency. While any one cab is on the VMS motion platform, the others can be reconfigured and prepared for the next vehicle they will simulate. When an ICAB reconfiguration is complete the cab is stored until the current simulation on the VMS motion platform ends. When the simulation currently running on the VMS motion platform is completed, the ICAB used for that simulation is replaced with the readied ICAB in storage. It takes approximately one eight-hour shift to change ICABs on the VMS motion platform and prepare the motion system for a completely different simulation. The short time it takes to exchange cabs allows almost constant utilization and availability of the VMS motion system.

JSHIP CAB DESIGN AND FABRICATION

The JSHIP Cab was developed using the SimLab ICAB system. Typically, the ICAB with the FOV of the aircraft being simulated is used for the simulation; however JSHIP had FOV requirements beyond the capability of any existing ICAB. The cab FOV, like the interior of the cab, had to replicate a UH-60A Blackhawk helicopter. This requirement demanded a complete new design using one of the existing ICAB's. The solid lines in figure 3 represent the FOV of a UH-60 Blackhawk helicopter from the pilot's eye reference point. The gaps represent window, doorframe and instrument panel visual obstructions. The dash-dot line represents the FOV provided with the visual system designed by the SimLab systems engineering group. Note the new visual system does not provide the entire UH-60A FOV. However, the FOV areas critical for the simulation experiment were provided, and the areas omitted went unnoticed by the pilots. Additionally, the FOV had to be continuous and the image system had to be compatible with night-vision goggles.

Visual System

Numerous commercial off-the-shelf visual systems were explored, but none were small enough to fit within the confines of an ICAB nor did they provide the required FOV. Cathode Ray Tube (CRT) systems could not meet the large FOV requirements and dome projection systems were too large and heavy for adapting to an ICAB. Therefore, a new visual system was designed and built by the SimLab systems engineering group.

First it was necessary to determine if the project required a collimated or non-collimated system. A collimated system provides a scene focused at infinity, which is excellent when viewing objects at a distance. A non-collimated system lacks focus at infinity, creating an overall scene that perceptually has less depth than the equivalent collimated scene. However, all of the JSHIP simulation work consisted of landing on ships and close-up viewing of their decks. Using a collimated visual system for close-up viewing can be problematic because focus at infinity does not give the pilot good close-up depth perception.

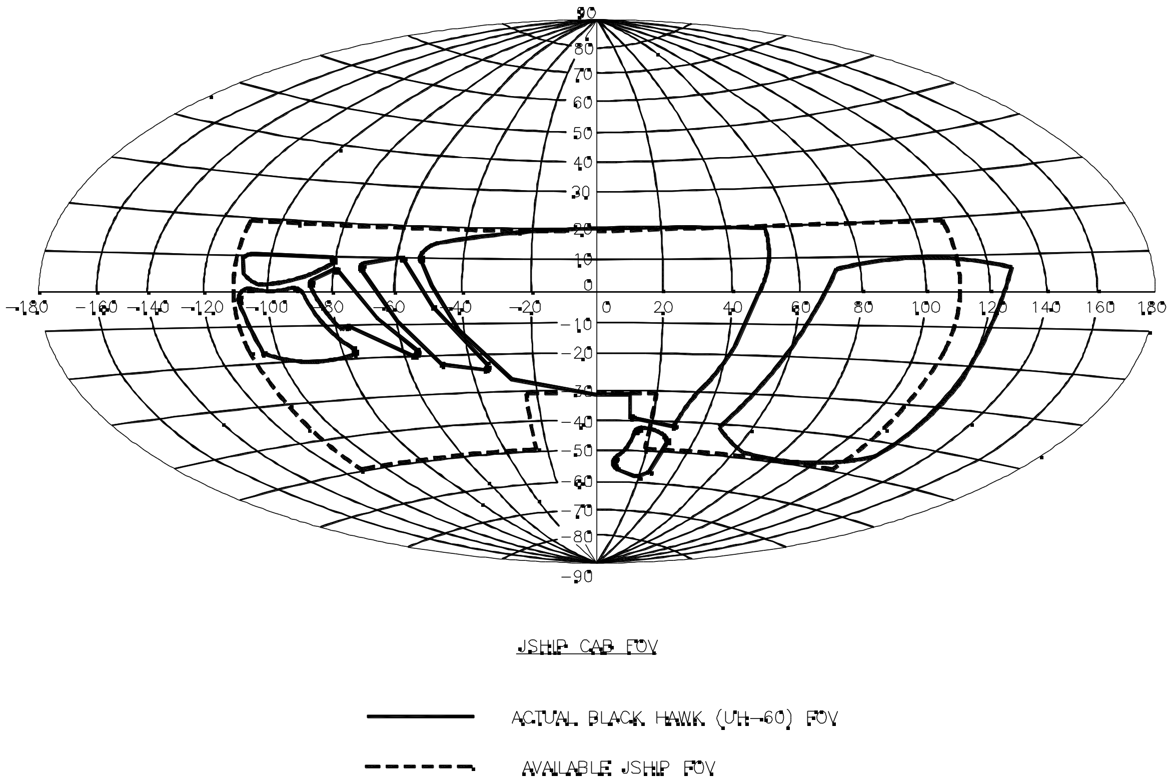

Figure 3

Consequently collimating optics can give false cues for near objects, potentially causing the pilot to fly the aircraft into or through the landing target. Hence, a non-collimated system was selected for design. The comparatively compact ICAB configuration in conjunction with a wide FOV requirement made for a challenging visual system design.

The visual system was designed from the pilot eye reference point. Typically, the pilot(s) seat(s) are central to the ICAB, dictating the location of the eye reference point. Eye reference coordinate information determined what internal cab real estate could be utilized to locate the visual system. Working with engineering design data provided on the BARCO Projection Systems web site, the SimLab systems engineering group was able to quickly develop a visual system layout. The system consists of five identical projection structures designed, fabricated and installed into an ICAB. Each structure consists of a BARCO 707 CRT projector, one flat mirror, and one flat rear-projected screen manufactured by the Stewart Filmscreen Corporation. The screens are Stewart Aeroview 100 rear projection screens with a peak gain of 1.0 plus/minus 10%. The structures were designed so they can be placed side by side to generate one large screen with a continuous FOV. Figure 4 shows the structures placed together and the resulting flat panel rear-projected visual system. When assembled, the 5 screens generate one large continuous FOV screen, which matches the JSHIP requirement, with seams between each screen that are imperceptible during simulation. The screens are supported around the perimeter by special triangular wedge-shaped tubing. The angle of the tube is designed such that it does not interfere with the projector light path and prevents any shadowing of the image at the edges of the screen. Stewart Filmscreen bonded the screens to the frame edge with a transparent material that allows the projected image to reach the entire screen edge.

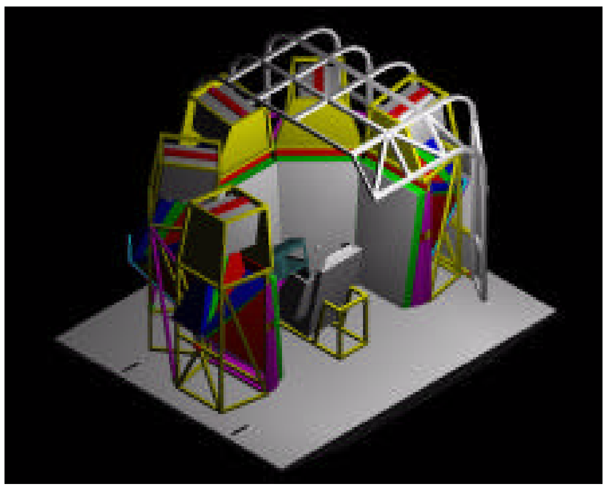

Figure 4: *Digital rendering section view of the JSHIP ICAB showing the projection system, pilot seat and a partial view of the removable canopy.*

Visual masking representing windows and doors not shown.

This technique allows numerous screens to be placed side by side and assembled into a much larger screen that is structurally supported throughout the screen instead of just at the edges, with seams that are imperceptible when an image is projected. The mirrors, also supplied by Stewart Filmscreen, are first surface and bonded to a one half-inch thick honeycomb laminate structure for support and mounting. The mirrors are mounted to the structure at three points, which are independently adjustable for mirror, screen and projector image alignment. Each screen is cut into a trapezoidal shape with sides tapering inward from top to bottom. The screens are mounted 40 inches from the pilot eye reference point. Each screen is angled back 8 degrees from vertical with respect to the pilot eye-reference-point, making the variation of distance from pilot eye reference point to any point on any screen less than plus or minus 2 inches. The small eye to screen distance variation helps reduce eye refocusing as the pilot scans from one side of the screen to the other, minimizing eye fatigue during long simulations.

Structural Design

A thorough structural finite element analysis was performed on the JSHIP ICAB and IPS system. Because night-vision goggle capability was required, CRT projectors were used instead of LCD projectors. CRT projectors are much larger and heavier than LCD projectors, and required special attention given to the structure to make sure it would not fail under the high acceleration capabilities of the VMS motion system. Extreme caution must always be taken when engineering any new motion simulator. All components, both on the motion system and the cab, must be able to withstand the worst possible combination of dynamic loads the system is capable of generating without failing and injuring the pilot or damaging the simulator system. An extensive detailed structural finite element analysis was performed on the JSHIP ICAB. Figure 5 depicts one of many Finite Element (FE) stress analyses performed on the JSHIP ICAB and IPS. This type of analysis is usually very costly and time consuming. However, SimLab already had a thorough FE model of the VMS/ICAB system that was tailored to incorporate the new visual structure. The slight modification to the model was less work than developing a model for a new cab from the ground up. The ease of converting AutoCad and SolidWorks drawings of the new visual structure into FE Code greatly reduced design analysis time and cost.

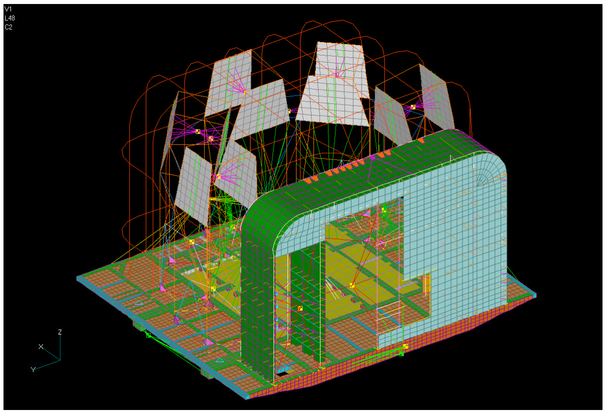

Figure 5: *Finite Stress analysis of Jship ICAB and IPS*

Instrument Console

The instrument console was designed to replicate a UH-60 Blackhawk instrument console but was equipped with only those instruments necessary to conduct the simulation. The unique aspect of the console is that it was designed as a single-seat console instead of a dual-seat console as in the UH-60 Blackhawk. The simulation did not require a co-pilot, and building a cab with co-pilot seat capability would have added considerably to the cost of the project. The challenge was to design a single seat simulator that convinced the pilot he was flying in a real UH-60 Blackhawk helicopter with a co-pilot seat and equivalent FOV.

This challenge was resolved with a novel design solution applied to the instrument console. A simple visual mask was designed and installed that replicated all the obstructions the pilot would have in the real helicopter. Locations of items such as co-pilot seat, door and window frames, etc., and the visual obstructions they produce, were replicated in the cab with masking. The masking produced the same co-pilot visual obstructions a pilot would see in an actual UH-60 Blackhawk, which gives the pilot a perception of a co-pilot presence during the simulation.

Dynamic Seat

The dynamic seat was designed for use in an Apache helicopter crew-training simulator (Figure 6). The seat provides small displacement motion or force cues at frequencies large motion systems are not capable of producing or where it is not practical to design the large system with high frequency capability.

Figure 6

The small displacement, high frequency capability of the dynamic seat is useful for reproducing motion cueing such as airframe buffet, landing gear touch down, runway spacer bumps, runway rumble, gunfire, etc. The seat provides 4 degrees of control utilizing 3 axes of motion. Independent axis motion in the vertical direction is provided separately in the seat bucket and seat pan. The seat pan raises and lowers the entire seat, whereas the seat bucket raises and lowers by itself. The seat back provides independent longitudinal and lateral motion. Although not used for this simulation, the shoulder harness and seat belt can also be driven to loosen or tighten via commanded control input.

The seat was easily incorporated into a SimLab ICAB. As described in the Interchangeable Cab section of this paper, all ICAB floors are built-up I-beam structures designed with the understanding that varying components would be fastened to the structure. Therefore, numerous attachment points were designed into the base, allowing integration of components such as the dynamic seat an easy task.

Figure 7 is a photograph of the finished interior of the JSHIP ICAB with the visual system projecting an image of a ship at sea.

Figure 7

SUMMARY

The JSHIP simulation was an outstanding success. Over 3000 simulation experiment data-gathering runs were completed during two separate simulations, each lasting 4 weeks. Although this paper addresses the mechanical aspects of the JSHIP project, it is important to acknowledge that all development aspects of the project were equally successful. The SimLab interchangeable cab concept, utilizing highly configurable cabs and an inventory of cockpit components that can be shared among all cabs, permitted the JSHIP office to rapidly develop a safe, high-fidelity, low-cost simulation.

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