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Crew Centric Design Methodology Delivers Combat Performance

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ABSTRACT

The goal of the human factors engineer is to work within the systems engineering process to ensure that a Crew Centric Design approach is utilized throughout system design, development, fielding, sustainment, and retirement. To evaluate the human interface, human factors engineers must often start with a low fidelity mockup, or virtual model, of the intended design until a higher fidelity physical representation or the working hardware is available. Testing the Warrior-Machine Interface needs to begin early and continue throughout the Crew Centric Design process to ensure optimal soldier performance. This paper describes a Four Step Process to achieve this goal and how it has been applied to the ground combat vehicle programs. Using these four steps in the ground combat vehicle design process improved design decisions by including the user throughout the process either in virtual or real form, and applying the user's operational requirements to drive the design.

INTRODUCTION

Crew Centric Design

Ground combat vehicle design must focus on the tasks required of each crewmember and how they impact the whole vehicle design; this is called Crew Centric Design. Within Systems Engineering the role of the human (crewmember) is captured in the Systems Engineering discipline called Human Systems Integration (HSI). The International Council on Systems Engineering (INCOSE) defines HSI as "an interdisciplinary technical and management process for integrating human considerations within and across all system elements; an essential enabler to systems engineering practice." [1] Crew Centric Design needs to be emphasized in all steps of the Systems Engineering process. INCOSE defines the Systems Engineering process as "an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem." [2] However, as a vehicle is being developed, or new components and technologies are integrated into an existing vehicle, hardware is not always available to conduct the required evaluations to ensure an optimal Crew Centric Design of the component and its integration. Utilizing virtual modeling tools of both the human and the operating environment help to bridge this gap allowing for both early influence of the hardware configuration and its integration into the vehicle. This paper describes a four step process and demonstrates the why, when and how to utilize virtual and actual humans and environments to ensure a Crew Centric Design approach is utilized throughout the Decomposition and Definition Phase of the Systems Engineering Development Lifecycle. These phases, as shown in the V-Model graphical representation of the process in Figure 1, include; Concept of Operations, Systems Requirements, High-Level Design and Detailed Design.

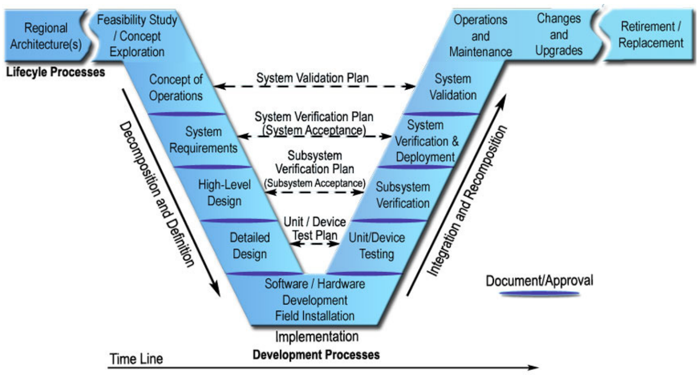

Figure 1. V-Model- Systems Engineering Development Lifecycle

Why Use Virtual Modeling Tools?

Virtual Modeling Tools have become a critical component in many industries. They are used to identify design issues early in the design process, thus improving system performance while reducing cost. For example, the U.S. military is using medical modeling tools to create advanced computer simulations of the human body. The goal of the virtual soldier project is to create holographic medical representations, or holomers, of patients' bodies. These would combine CAT scans with complex algorithms to form 3D models that behave, physiologically, like humans. Doctors would be able to test medicines and practice procedures on the models before administering them to patients. [3]

The example presented in this paper has been applied to the development of ground combat vehicles. In the past, military contractors would build a prototype vehicle and Human Factors Engineers would spend hours in the field evaluating how the soldiers used the systems / components, as well as identifying constraints such as awkward postures, difficult efforts, vision problems or trouble navigating through interactive displays. From those observations of actual soldiers, the Human Factors Engineers would draw conclusions about system operability, crew performance, and safety concerns. The problem with this method is often it is too late to go back to a design or process engineer and tell them a design change is warranted. The rationale for conducting early operability and safety evaluations based on computer modeling are much the same as doing digital mock-ups to test a design for aerodynamics or durability. It facilitates identification of possible problem areas and rapid evaluation of alternative solutions at low cost. Digital human modeling is looked at as an extension of the 3D model and computer-aided engineering (CAE) practices already in use today. With the aid of human modeling and virtual environment simulation tools as part of the Systems Engineering Development Lifecycle, engineers have a proactive method of adding the human component early in the program to guide their decisions instead of addressing the human factors later in the process.

When to Use Virtual or Actual?

With a plethora of modeling tools available to the engineer today the question is when is it right to use the virtual or the actual? The answer is typically a function of the level of design fidelity, the availability and cost of actual resources, and the level of analysis to be performed. To evaluate the human interface, human factors engineers must often start with a low fidelity mockup, or virtual model, of the intended design until a higher fidelity physical representation or the working hardware is available. For example, in the Concept of Operations Phase requirements are being defined and analyzed and only preliminary virtual images of the systems may exist.

The four steps human factors engineers would use, depending on the phase of the Systems Engineering Development Lifecycle and resources available, are as follows:

Step 1. CAD - Virtual Environment– Virtual Human

The first step uses Computer Aided Design (CAD) tools to place a virtual soldier in a virtual ground combat vehicle environment. Virtual soldiers and environments facilitate timely and low cost iterative analyses of evolving design concepts. Preliminarily Crew Centric Design decisions can be made in conjunction with the overall vehicle design.

Step 2. CAVE - Virtual Environment – Human

This allows the soldiers to be immersed in the virtual environment or Cave Automatic Virtual Environment (CAVE) to evaluate the design before hardware is built or acquired.

Step 3. Mock-up - Moderate Fidelity Environment -Human

Third, soldiers participate in an extensive evaluation of a ground combat vehicle in a vehicle mock-up. This mock-up provides the basic vehicle configuration and interior crew station packaging representative of the prototype ground combat vehicle design. This allows the soldier hands-on interaction with the ground combat vehicle-like physical environment.

Step 4. Vehicle - High Fidelity Environment – Human

This step occurs prior to delivery of prototype vehicles to the customer for test and evaluation. Step 4 takes the process to the highest level of fidelity by conducting user evaluations in fully operational prototype vehicles usually at military test sites such as Aberdeen Proving Grounds or Ft. Knox. Crew tasks and subsystems evaluations in an environment that represents combat terrains are the focus of this step.

Use of these four steps in the Systems Engineering Development Lifecycle will now be defined.

How to Use Virtual or Actual?

Step 1.CAD - Virtual Environment– Virtual Human

Modeling Tools –Jack

The first step, human modeling, places a virtual soldier in a virtual ground combat vehicle environment. While human modeling can be used in any phase of the Systems Engineering Development Lifecycle, this step is primarily used in the Concept of Operations Phase because requirements, system architecture and hardware are still being defined. The U.S. government's choice for a human modeling tool is Jack. The Jack human simulation system was developed at the Center for Human Modeling and Simulation at the University of Pennsylvania in the 1980s & 1990s. Conceived as an ergonomic assessment and virtual human prototyping system for NASA space shuttle development, it soon gathered funding from the U.S. Navy and U.S. Army for dismounted soldier simulation, from the U.S. Air Force for maintenance simulation, and from various other government and corporate users for their own applications. [5] In several recent efforts that utilized the Jack modeling tool various manikins representing a projected 2015 population were inserted into the vehicle model. The vehicle model established boundaries, including overall vehicle height, width and length, as well as initial crew space volume and dimensions. Postures and positions were developed within the virtual vehicle model for each of the occupant positions and statures. With each of the occupants properly positioned, reach zones, vision cones and crew dynamic space claims were established. These data were then used to develop requirements for seat adjustability, Warrior–Machine Interface (WMI) positions (including vehicle and mission oriented systems), stowage, etc. The Jack tool facilitated timely and low cost iterative analyses of evolving design concepts. Preliminary Crew Centric Design decisions could be made in step with the overall vehicle design.

Design Considerations and Evaluation Factors

Design Eye-Point

The process of modeling the human in a combat-based vehicle begins with establishing a design eye-point for each of the vehicle crewmembers of concern. The crewmembers are typically the driver, commander, squad leader, loader or gunner depending on the vehicle platform. This design eye-point, as shown in Figure 2, is where the soldier's eyes have an optimum viewing capability to the vision blocks, displays, controls, etc. This is critical due to the limited external vision that is available on armored combat vehicles through windows or vision blocks/periscopes. In either case the respective fields of view are limited and the crewmember's eye-point must be located in a manner that optimizes the crewmember's field of view and ground intercepts.

Once the design eye-point has been established for each crewmember position in the vehicle, a virtual manikin is positioned relative to the eye-point and from there an optimized posture is developed for that sized crewmember. Analysis typically starts with a Large or 95% percentile stature male. Once a posture and position has been developed for the largest expected occupant the smallest expected occupant, the 5% percentile stature female, is then positioned and postured in a similar manner along with any other desired size occupant.

Figure 2. Design Eye-Point

Posture

The position and posture of the manikin as shown in Figure 3, will be based on the preliminary location of structural considerations of the vehicle, in conjunction with optimizing joint angles, which affect the comfort of the occupant. The comfort level a crewmember experiences directly affects their alertness and job effectiveness. Once the postures and positions for the full range of crewmembers and crew positions are established, key elements of the WMI (i.e., pedals, steering column/wheel, joysticks, displays etc.) are positioned based on operator reach and vision zones. The required range of adjustment for the seat and possibly the WMI in each crew station can then be determined. Typically it is preferable to conduct all the positioning and posturing development work without any seating systems in the model. The reasoning behind this is that the seating systems conform to the needs and requirements of the crewmembers as they are postured and positioned rather than the crewmember conforming to the seat.

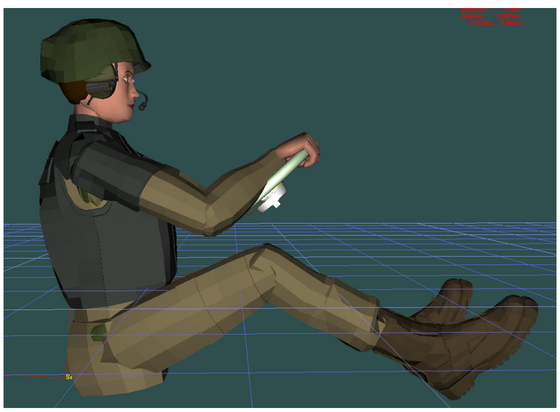

Figure 3. Posture

In ground combat vehicle design it is preferable not to use "H"-point to locate a seat model to the manikins because of the effects of crew protective ensembles, particularly Improved Outer Tactical Vest (IOTV) body armor. The ensembles impact crewmembers dimensionally and drive the crewmember's "H"-point further forward than normal causing chronic misalignment between the occupant's "H"-point and the seating system's "H"-point. It is preferable to use the Jack Seating Reference Point (JSRP). "H"- point locations on seats are generally determined with a 50%tile, Hybrid III (ASPECT) manikin and do not address the effects of body armor or any of the other gear that the soldiers wear when seated in ground combat vehicles.

Open Hatch Operations

When open hatch operations are required for a particular occupant position as shown in Figure 4, the initial crew packaging process is similar to the process outlined for a seated posture, except that they are postured based on a name tag defilade position instead of eye-point.

Figure 4. Open Hatch Operations

Reach Zones

The ability of the user to reach the required equipment and controls is captured in the reach zones. Controls and various pieces of mission equipment are located based on their level of importance as it relates to one of the three reach zones as described below.

1. The ***Primary Reach Zone*** represents the zone that the occupants can reach from their normal working position and posture without leaning in any direction, with a fully extended arm as shown in Figure 5. Such items as the steering wheel, transmission control, headlights and turn signal controls, etc., are located in the zone.

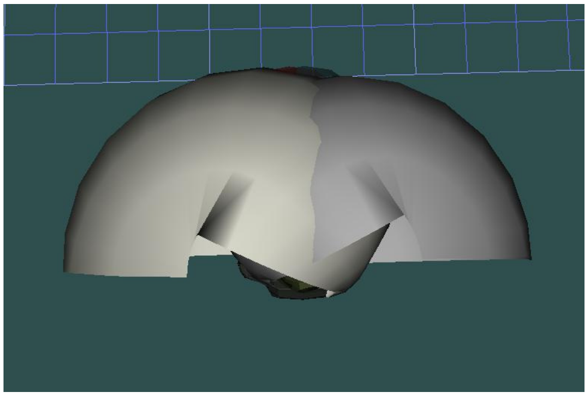

Figure 5. Primary Reach Zone

2. The ***Secondary or Functional Reach Zone*** represents the zone that the occupants could reach to easily, with some learning, while driving or operating their work station, without compromising their control of the vehicle or systems of responsibility. This zone, as shown in Figure 6, would have controls such as radios, parking brakes, HVAC controls, etc.

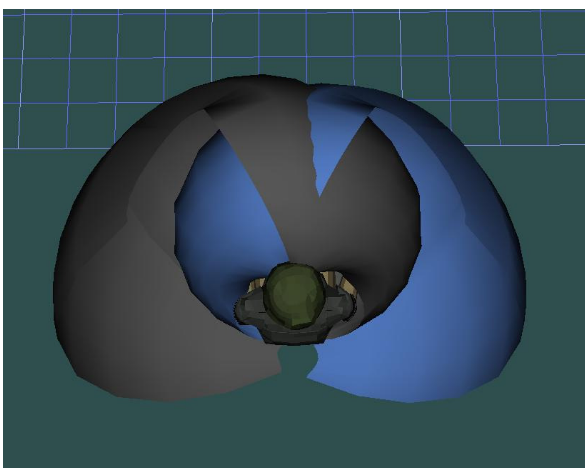

Figure 6. Secondary or Functional Reach Zone

3. The ***Tertiary or Maximum Reach Zone*** represents the zone that an occupant can reach at full extension of the arm and torso from their working position. A reach of this extent would potentially compromise their control of the vehicle or system of responsibility. This reach zone, as shown in Figure 7, would be for controls that need to be accessed infrequently during vehicle operation. For example, a power switch that is turned on and off at the beginning and completion of a mission and not accessed during the mission may be located in this reach zone.

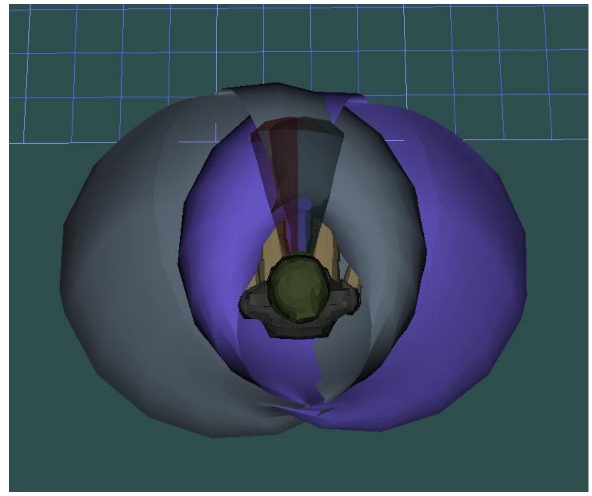

Figure 7. Tertiary or Maximum Reach Zone

Vision Cones

Once the basic occupant postures and positions are determined, the vision cones are established. In Jack the primary vision cones are 30° cones that are 28” long, positioned down 15° and straight ahead, and square with the position to the head and eyes as shown in Figure 8. Positioning of the cones in this manner provides the ideal location for primary operational displays. Secondary displays and monitors are located based on logical anatomical (i.e., eyes, head and neck joints) re-positioning of the vision cones.

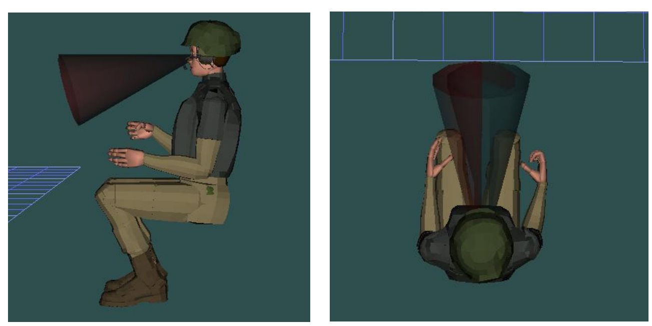

Figure 8. Vision Cones

The complete process in Step 1 is very iterative, with the human factors engineer frequently repeating portions of the process until no more changes are made to the design. The first step is the most critical in determining viable design alternatives and eliminating those alternatives that do not sufficiently meet Soldier requirements within overall vehicle constraints. This enables a focusing of design resources on the best design approach in subsequent steps of the design process. Human modeling within a virtual environment is also critical in communicating Soldier centered concerns and successes to the greater design team, program management, and the customer.

Step 2. CAVE - Virtual Environment – Human

Modeling Tool – The CAVE

The next step in this process is to move the necessary components from the Vehicle Master Model into the immersive Cave Automatic Virtual Environment (CAVE) environment. Evaluators, including human factors engineers, other design disciplines, and crewmembers are able to interact with the full scale virtual environment, including the crew stations as well as the external operating environment. This step can be utilized at any stage of the Systems Engineering Development Lifecycle but best supports the Systems Requirements Phase by facilitating evaluation and analyses of the emerging vehicle design while executing the dynamics of operator tasks. The advantage of a virtual environment at this phase is that it is low cost and flexible enough to quickly evaluate multiple design configurations. Coordinated immersion of an entire vehicle crew is also possible, allowing insight into crew interactions, task sequencing, task allocation, etc. The overall objective is consistent with the prior and subsequent steps – to gain information that can influence the design to the Soldier's benefit. This step continues to provide the benefit of rapidly changing design parameters to address known design issues, conduct sensitivity testing, and to address "what if" questions without requiring hard assets (mockups, prototypes, etc.)

A CAVE is used to create the virtual environment. A CAVE is an immersive virtual reality environment where projectors are directed to three, four, five or six of the walls of a room-sized cube. The name is also a reference to the allegory of the Cave in Plato's Republic where a philosopher contemplates perception, reality and illusion [6].

The CAVE facilitates a capability known as Mixed Reality (MR) which refers to the merging of real and virtual worlds to produce new environments and visualizations where physical and digital objects co-exist and interact in real time. MR is a mix of reality, augmented reality, augmented virtuality and virtual reality. [7] MR is a useful tool in Human Factors Engineering because it allows the Human Factors Engineer to evaluate component concepts in their environment before physical components and environments are available. Figure 9 shows the concept of mixing the virtual world with physical properties from that world. In this figure the Seat Reference Point (SRP) of a commander's seat is calibrated in the virtual commander's station and then the virtual commander's station is "tied" to the SRP so reach and vision data collected in the virtual environment will simulate data collected in the real commander's station.

Figure 9. Mixed Reality: Physical + Virtual

Mixed reality systems have been used to evaluate many aspects of user performance and accommodation including comfort, alternative vehicle displays and controllers [8], and crew external vision. These systems are critical tools for evaluating vehicle interiors with user interfaces. Measurements can be easily taken with these systems while environments can be controlled and repeated.

Mixed Reality Systems provide the ability to investigate trade-offs involving vehicle design and operator effectiveness that heretofore required a physical prototype. This will permit the engineering community to optimize the design of ground combat vehicles for the soldier, beginning early in the design and development process and continuing through product improvement. Bringing human factors into design consideration using virtual prototyping before engineering design decisions are finalized promises to be one of the most significant advances in concurrent engineering of ground combat vehicles to occur in the decade.[9]

In Step 2 of our process, the human subjects participating in vehicle evaluation would be positioned and postured in a similar way the manikins in the virtual environment were postured to validate the modeling process in Step One. By using Body Pressure Distribution (BPD) mats, Digital Goniometers and a representative seating buck, data can be collected to bridge the gap between actual and virtual. The manikins in the virtual models can then be adjusted and analyses conducted based on real world posturing in a seat with representative BPD mapping and joint angles.

Step 3. Mock-up - Moderate Fidelity Environment – Human

This step advances the design evaluation process by moving into a higher fidelity, physical model of the work station or vehicle. While physical models can be used in any phase of the Systems Engineering Development Lifecycle, it is at the High-Level Design Phase where detailed designs and integration of hardware and software are defined and can be built into mock-ups of the proposed hardware. The moderate fidelity environment, as shown in Figure 10, can be a full scale mockup or "buck", or reach the robustness of a demonstrator vehicle or vehicle prototype. This environment gives the evaluator a true feel for the vehicle packaging and crew station layout in a physical environment representative of the vehicle design intent. Physical mock-ups can be used in early phases of the Systems Engineering Development Lifecycle depending on the maturity of the design and the resources available. In a recent vehicle program, a vehicle demonstrator was used to conduct assessments of ingress/egress, crew accommodation, physical and visual access to key WMI components, operator restraint system operation, and crew external vision through actual task performance. The vehicle demonstrator served as a catalyst for Users to express how they actually operated and maintained the current system in a similar role. Human factors engineers as well as engineers of other disciplines were able to witness first hand how Users executed tasks which led to understanding Users concerns.

This step represents growth beyond the first two steps because design assessments become more objective compared to previous steps, where assessments were more subjective. For example, timed crew ingress / egress testing was conducted to determine compliance with contractual requirements.

Figure 10. Moderate Fidelity Environment

Step 4. Vehicle - High Fidelity Environment – Human

Step Four takes the process to the highest level of fidelity by conducting appropriate user evaluations in a fully operational prototype vehicle, as shown in Figure 11. and again continuing the process of validating the tools, techniques and outcomes of the three steps. This step is generally not used until the Implementation Phase of Systems Engineering Development Lifecycle when the design is fixed and final hardware and software is integrated into a prototype vehicle for final test and evaluation. At this point in the design process, functionality is the primary objective, where prior phases place a greater emphasis on fit. This step also marks a transition from component and subsystem evaluation to system level evaluation. Crew level tactical operations are emphasized over individual task performance.

Figure 11. High Fidelity Environment

CONCLUSION

A Crew Centric Design is the goal of the system engineering team throughout a Systems Engineering Development Lifecycle. This paper described a four step process and demonstrated the why, when and how to utilize virtual and actual humans and environments to ensure a Crew Centric Designed vehicle.

Through application of the four steps described above, this goal can be achieved. The process is flexible as it is not always necessary that all four steps will be utilized or followed in the order described in this paper. The process matches appropriate design visualization and analytical tools to produce information that supports Crew Centric Design throughout each step of the Systems Engineering Development Lifecycle.

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