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CREATION OF CAD ACCOMMODATION MODELS FOR MILITARY GROUND VEHICLE DESIGN

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ABSTRACT

The objective of this effort is to create parametric Computer-Aided Design (CAD) accommodation models for crew and dismount workstations with specific tasks. The CAD accommodation models are statistical models that have been created utilizing data from the Seated Soldier Study and follow-on studies. The final products are parametric CAD models that provide geometric boundaries indicating the required space and adjustments needed for the equipped Soldiers' helmet, eyes, torso, knees, boots, controls, and seat travel. Clearances between the Soldier and surrounding interior surfaces and direct field of view have been added per MIL-STD-1472H. The CAD models can be applied early in the vehicle design process to ensure accommodation requirements are met and help explore possible design tradeoffs when conflicts with other design parameters exist. The CAD models are available to government and industry partners and via the GVSC public website once they have undergone Verification.

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1. INTRODUCTION

Military ground vehicles are currently designed using requirements from Military Standard (MIL-STD) 1472H, the Department of Defense Design Criteria Standard: Human Engineering, 2020. The unifying factor amongst these is the accommodation of the central 90% of the Soldier population. MIL-STD-1472H provides little quantitative guidance for vehicle layout, so it is open to interpretation and is difficult for designers to apply consistently. The work presented on the following pages is an attempt to provide the vehicle designer with easy to use, consistent, graphical tools that make the occupant an integral element of vehicle workstation design.

Ensuring that a given percentage of the population can sit safely and perform all required tasks without

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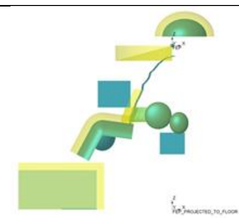
interference from the vehicle interior requires multivariate analysis methods that consider the physical dimensions of the Soldier (anthropometry) and behavioral effects (posture) in a three dimensions space [1]. This analysis is now available for some seating positions as Soldier-specific statistical population accommodation models, developed by the University of Michigan Transportation Research Institute (UMTRI), that parallel long-standing SAE Recommended Practices used in the commercial automotive and truck domains. Because vehicle designs are developed from the early concept stages forward using Computer-Aided Design (CAD) software, UMTRI's work is being encoded into parametric CAD templates that adjust based on user inputs describing the Soldier population, desired accommodation level, and vehicle environment.

The suite of CAD models, which encompass the majority of crew tasks and dismount positions in today's ground vehicles, is approximately 50 percent complete (Table 1). The models will be made available to other government partners and industry following Verification. Verification is the process of determining that a model, simulation, or federation of models and simulations implementations and their associated data accurately represents the developer's conceptual description and specifications [2].

Table 1: Model Development Status

Model Name	Data Gathering Completed (UMTRI)	Statistical Modeling Completed (UMTRI)	CAD Implementation and Verification Completed, Available to Users (GVSC ACT)	CAD Model
Fixed Heel Point (FHP): Driver[1]	2012	2014	2017	
Fixed Seat: Non-Driver	2012	2014	2020	
Fixed Eye Point (FEP): Driver	2014	2020	2021	
Out-of-Hatch (OOH)	2014	2020	Anticipated 2023	
Highly Reclined Seat (HRS)[2]	2014/ 2022	2020/ 2022	In process (on track for 2022)	
Fixed Human Accommodation Reference Point (HARP): Commander	2019	2021	Anticipated 2023	
Fixed HARP Gunner	2019	2021	Anticipated 2023	

[1] Model will be updated to include driving via screens
[2] Additional data collected to expand on recline angles for HRS model

2. METHODS

The development of CAD templates representing a wide range of Military ground vehicle workstations is possible because of UMTRI's predictive models for Soldier posture combined with automated design capabilities available in many current CAD systems.

2.1. Seated Soldier Study and Additional Studies

The automotive industry began introducing statistical population models into vehicle design in the 1960s to better understand various aspects of driver posture. The Seated Soldier Study [3] was completed to capture Soldier preferred posture and position data in driver and dismount mockups while considering the unique ground vehicle workstation environment and the clothing and equipment ensembles worn by Soldiers. Additional studies have been conducted, producing statistical models for different workstation configurations such as dismount fixed seating [4], highly reclined seating [5], and gunner and commander specific tasks [6].

The various studies have gathered data on a total over 500 enlisted men and women, in the different workstation mockups, at four Army posts. To capture the amount of space Soldier worn equipment requires, three levels of clothing and equipment were used in the studies (Figure 1). The worn equipment included: 1) the advanced combat uniform (ACU), consisting of the Soldier’s own jacket, trousers, shirt, and combat boots; 2) personal protective equipment (PPE), consisting of the ACU plus an Improved Outer Tactical Vest (IOTV), Enhanced Small Arms Protective Insert (ESAPI) plates, Enhanced Side Ballistic Inserts (ESBI), and an Advanced Combat Helmet (ACH); and 3) encumbered (ENC), consisting of the ACU and PPE, plus a hydration pack and a Tactical Assault Panel (TAP) with a Rifleman equipment kit [3].

Figure 1: Soldier Clothing and Equipment

This paper focuses on Highly Reclined Seating (HRS) which is the latest model in development. It addresses the need in certain vehicles for a low profile by modeling Soldiers in highly reclined positions. The HRS mockup (Figure 2) simulates a HRS crew workstation with reclined seat back angle, adjustable foot plate, and adjustable steering yoke.

Figure 2: Soldier in HRS Mockup with PPE

Testing was conducted using three seat back angles, ranging from 30 to 50 degrees from vertical. At the 40-degree angle, data were also gathered with three seat heights. When Soldiers entered the HRS mockup, they found their preferred position by adjusting the foot platform fore-aft and the yoke up-down, fore-aft, and tilt. Each Soldier's posture and seat position was then digitized. An additional study was conducted at UMTRI in 2021-2022 to expand the range of seat back angles for greater recline. The study included seat back angles from 40 to 70 degrees and varying hip locations (full rearward, full forward, and sitter-selected).

UMTRI's analysis of the data yielded both the average postures for individuals as a function of their body size and equipment level and accommodation boundaries capturing posture variability for everyone across the target population. In particular, the accommodation boundaries indicate the adjustment range needed for vehicle controls and the resulting positions for the equipped Soldier population's eyes, helmet, torso, elbows, knees and boots. Working models were provided by UMTRI in the form of Microsoft Excel spreadsheets for posture (Figure 3) and accommodation (Figure 4). For a more in-depth discussion of UMTRI's work, please refer to the *Development of Driver Posture Prediction and Accommodation Models for Military Vehicles: Fixed-Eye-Point, Out-of-Hatch, and Highly Reclined Driver Configurations* [5].

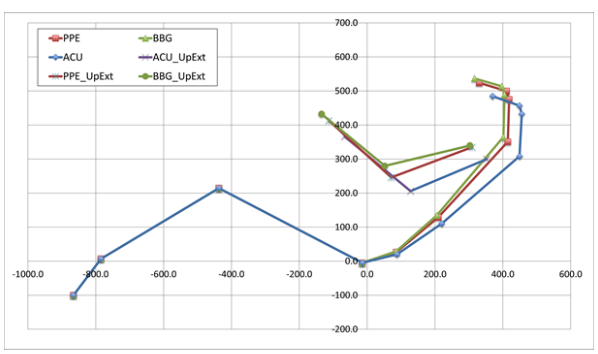


Figure 3: Microsoft Excel Posture Output

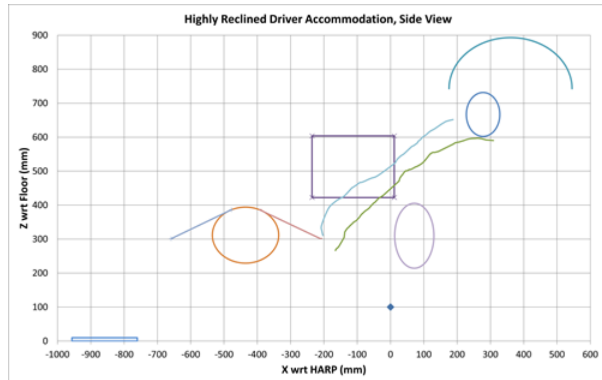


Figure 4: Microsoft Excel Accommodation Output

2.2. CAD Accommodation Model Development

The CAD version of the HRS accommodation model is being created by the Ground Vehicle Systems Center (GVSC) Advanced Concepts Team (ACT) using PTC Creo® 3D CAD software. Functionally, the foundation of the model is a parametric, geometric reproduction of UMTRI's Microsoft Excel spreadsheets. Clearances between the Soldier population and surrounding interior vehicle surfaces are layered onto the model per the intent of MIL-STD-1472H, along with direct vision zones that incorporate concepts from both MIL-STD-1472H and SAE Recommended Practice J1050, *Describing and Measuring the Driver's Field of View*, 2009 [7]. To aid in understanding how workstation design affects individuals, boundary manikins representing the anthropometric extremes for workstation design are placed in their predicted postures.

After building a static version of the accommodation model (i.e., a single instance of the possible combinations of Soldier population, desired accommodation level, and vehicle environment inputs), the process of automating the model began. This was done using a tool within Creo known as Pro/PROGRAM. Most CAD users already take advantage of the parametric nature of today's design software. For example, depending on how a model is constructed, simple changes can be propagated throughout by delving into a model's geometry and modifying dimensions. Pro/PROGRAM takes this concept a step further and allows for control of a model from outside the model tree, using relations and rules. End users of the HRS accommodation model will modify a list of parameters that are tied to the underlying geometry. Logical expressions are used to determine which portions of the Pro/PROGRAM code to execute for a given set of input values.

UMTRI's spreadsheets provide the equations necessary to reproduce the relatively simple geometric elements comprising the accommodation boundaries (e.g. centroids and axis lengths for several ellipsoids). It was possible to encode the equations from UMTRI's spreadsheets into Creo without modification or the need for further calculations, with two notable exceptions. Because the majority of human anthropometric dimensions are approximately normally distributed, the standard normal cumulative distribution function (CDF) is used throughout UMTRI's work to determine values at the desired level of accommodation. Creo does not contain an equivalent to Microsoft Excel's NORM.DIST function, so the following logistic approximation, having a maximum error of 0.00014 at z = ± 3.16, was used instead [8].

$$F(z) \sim \frac{1}{1 + e^{-(0.07056 * z^3 + 1.5976 * z)}}$$

The second exception involves the positioning of boundary manikins. UMTRI provides coordinates of body landmarks with respect to the geometric origin of the accommodation model (i.e. the HARP, a seat reference point) sufficient to locate the hips, torso articulation, head, elbows, and heels. To place these coordinates into the reference systems of the boundary manikins (an axis system located between the hips of each manikin and aligned with the torso) and calculate the joint angles needed to position the limbs in three-dimensional space, Euclidean transformations for both translation and rotation were used.

3. RESULTS

Following is an overview of the HRS CAD accommodation model's layers:

3.1. User Interface

The end user will affect the model geometry by modifying the input parameter table in the top assembly of the model (Figure 5). The inputs fall into three categories: particulars concerning the Soldier population, the desired accommodation level, and the vehicle environment. The target population is assumed to be reflected in the Army Anthropometric Survey (ANSUR) II. The user is left to specify the population gender mix and Soldier ensemble (PPE or ENC, described previously). Ideally, the accommodation level will be set for the central 90% of the target design population, per MIL-STD-1472H requirements. The primary vehicle input to the model describes the seat height (surface of floor to HARP) and the seat back angle (degrees from vertical).

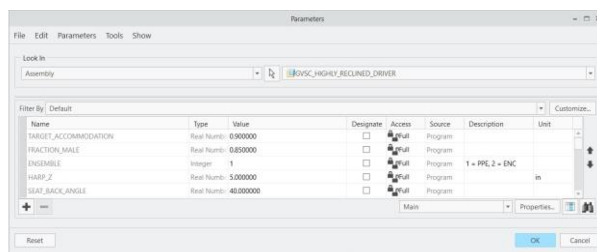


Figure 5: Input Parameters

3.2. Accommodation Boundaries

The first layer of outputs, around which the rest of the model is built, contains the accommodation boundaries (Figure 6). A HARP is referenced for the seat height to the floor. The yoke and pedal travel range indicates the size and location of adjustment needed for the population to reach the controls. Resulting boundaries for the Soldier population's eyes, helmet, torso, elbows and knees are provided.

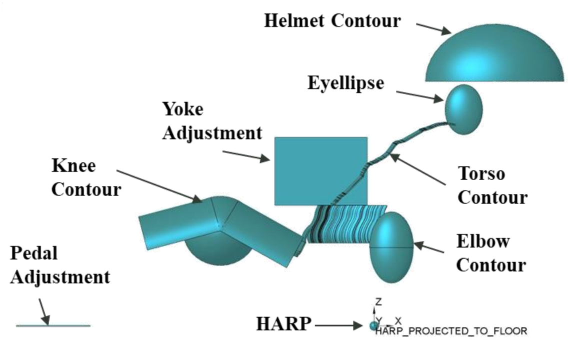


Figure 6: HRS CAD Accommodation Boundaries

3.3. Clearance Zones and Direct Field of View

The accommodation boundaries are used to develop a second layer of output indicating standard minimum clearances and view to displays. These features were developed after extensive consultation with both UMTRI and DEVCOM Analysis Center (DAC), the agency that assesses vehicles per MIL-STD-1472H requirements.

Standard minimum clearances have been provided for quick reference even though it is always possible to measure clearances directly. MIL-STD-1472H indicates that there should be 2 inches of clearance around the occupant. This clearance, which has been provided for the head (with helmet), torso, thighs, knees, shins and elbows (Figure 7), aids in the development of vehicle interior features such as overhead systems.

Crew field of view to displays was developed using a combination of MIL-STD-1472H and SAE Recommended Practice J1050 applied to the eyellipse, the geometric entity that describes the distribution of driver eye locations. This zone is used for placement of displays. The primary zone indicates a space viewable by all occupants using a minimum of "easy" rotation from at least one eye (ambinocular vision). Warning lights and displays are to be placed in the primary zone. The secondary zone is expanded to include both "easy" eye and "easy" head rotation and is suitable for cautions and alerts not able to be placed in the primary zone. Finally, the tertiary zone, which is developed using "max" eye and "max" head rotation should only contain components needing initial setup but not requiring attention while driving.

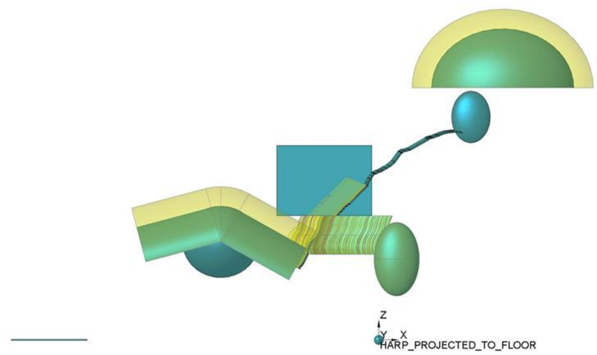


Figure 7: CAD Accommodation Clearance Zones

3.4. CAD Accommodation Model Manikin Placement

Positioned boundary manikins give the vehicle designer another reference (Figure 8). Using the same data underlying the creation of the accommodation boundaries, boundary manikins representing the anthropometric extremes of vehicle workstation design are placed in their nominal positions. This is helpful in understanding how specific individuals in the population fit into the vehicle and aids visualization for those unfamiliar with the accommodation boundaries.

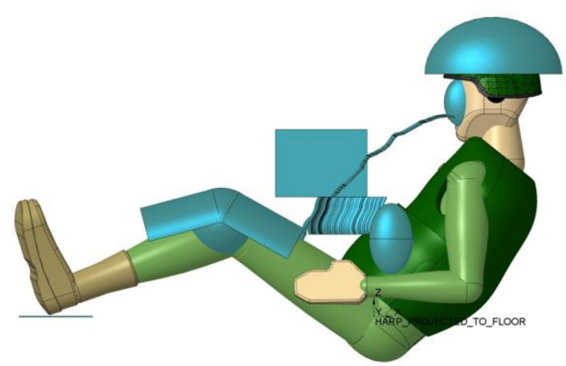


Figure 8: Manikin Placement

4. Vehicle Application

The suite of accommodation models, when applied to the design of vehicle workstations, provide the visual to build from the Soldier population outward. An example of this is shown in Figure 9. The Fixed Seat model was used for the four positions making up the dismount area. The models are positioned across from each other creating the width of the aisle using the knee boundary. Floor to ceiling height is set from the bottom of the occupant boots to the top of the helmet clearance zone. The vision zones are leveraged to aid in screen placement. The two crew positions used the FEP model to set fore/aft position of the crew with respect to the seat track travel needed. Screens are placed using the eye point of the model and horizontal/vertical yoke travel is positioned for the defined population.

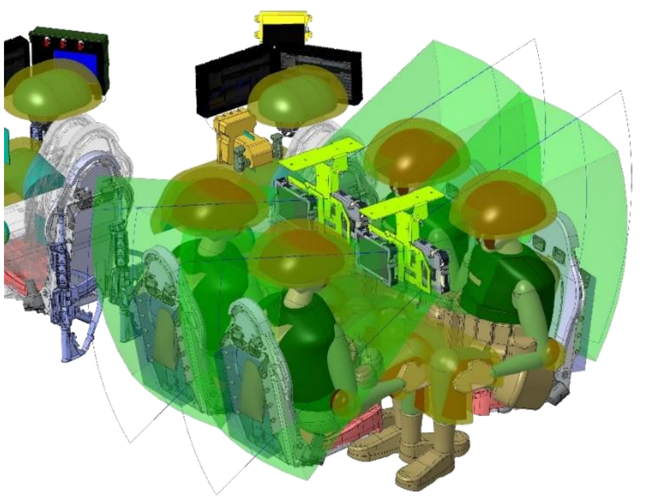


Figure 9: Example Application of Accommodation Models

5. DISCUSSION

This paper described how empirical Soldier posture and position data are being used to develop a suite of parametric CAD models for design, with the latest being the Highly Reclined Seat position, capable of adjusting to user inputs. By providing a quantitative means of assessing occupant accommodation, the new tools enable designers to follow the intent of Soldier accommodation presented in MIL-STD-1472H, the Department of Defense Design Criteria Standard: Human Engineering. The results provide a data-based method to resolve some of the ambiguity in MIL-STD-1472H for vehicle interior layout.

The CAD environment was chosen for implementation because it is the medium used by vehicle designers. In a fresh-start program, the model can be used as the foundation of workstation design and can be adjusted instantly to explore design tradeoffs and ensure accommodation requirements are met. The model can also be inserted into fielded designs to aid in maintaining or improving accommodation, or to assess the potential impact of proposed design changes.

The use of the CAD accommodation models provides the opportunity to apply Human Systems Integration (HSI) very early in the acquisition process. The model can be utilized during the Material Solution Analysis Phase prior to Milestone (MS)A and up through and including MSB. Past programs have not actively engaged HSI until MSB or the Engineering Manufacturing and Development (EMD) Phase, resulting in significant design and cost changes.

The models currently verified and available for use include the FHP [9], FEP [10], and Fixed Seat [11]. The models and accompanying documentation can be downloaded from the GVSP public website (https://www.usarmy gvsc.com/accommodation-models/).

Accommodation models with the additional layer of boundary manikins can be made available to anyone on contract with the government. Implementations of the Fixed HARP: Commander, Fixed HARP: Gunner, and Out-of-Hatch (OOH) CAD models (see Table 1) will be developed once the HRS model is complete.

6. ACKNOWLEDGEMENT

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7. REFERENCES

[1] *Design Criteria Standard – Human Engineering*, MIL-STD-1472H, Department of Defense, Redstone Arsenal, AL, 2020.

[2] *Documentation of Verification, Validation, and Accreditation (VV&A) for Models and Simulations*, MIL-STD-3022, Department of Defense, Alexandria, VA, 2008.

[3] M. P. Reed and S. M. Ebert, “The seated soldier study: posture and body shape in vehicle seats,” University of Michigan Transportation Research Institute, Ann Arbor, MI, 2013. [Online]. Available: https://hdl.handle.net/2027.42/109725

[4] Y. Zerehsaz, S. M. Ebert, and M. P. Reed, “Development of accommodation models for soldiers in vehicles: squad,” University of Michigan Transportation Research Institute, Ann Arbor, MI, 2014. [Online]. Available: https://hdl.handle.net/2027.42/120917

[5] M. P. Reed and S. M. Ebert, “Development of driver posture prediction and accommodation models for military vehicles: fixed-eye-point, out-of-hatch, and highly reclined driver configurations,” University of Michigan Transportation Research Institute, Ann Arbor, MI, 2020. [Online]. Available: https://hdl.handle.net/2027.42/163365

[6] M. P. Reed and S. M. Ebert, “Development of posture prediction and accommodation models for military vehicles: commander and gunner positions,” University of Michigan Transportation Research Institute, Ann Arbor, MI, 2021.

[7] *Describing and Measuring the Driver’s Field of View*, SAE Recommended Practice J1050, 2009.

[8] S. Bowling, M. Khasawneh, S. Kaewkuekool and B. Cho, "A logistic approximation to the cumulative normal distribution", *Journal of Industrial Engineering and Management*, vol. 2, no. 1, 2009. Available: 10.3926/jiem.2009.v2n1.p114-127.

[9] F. J. Huston II and G. L. Zielinski, “TARDEC Fixed Heel Point (FHP) Driver CAD Accommodation Model Verification Report,” DEVCOM Ground Vehicle Systems Center (GVSC), Warren, MI, 2017. [Online]. Available: https://www.usarmygvsc.com/accommodation-models/gvsc-fixed-heel-point-fhp-driver-cad-accommodation-model-verification-report/

[10] F. J. Huston II and G. L. Zielinski, “Fixed eye point (FEP): driver CAD accommodation model verification report (version 1.0),” DEVCOM Ground Vehicle Systems Center (GVSC), Warren, MI, 2012. [Online]. Available: https://www.usarmygvsc.com/ accommodation-models/fixed-eye-point-cad-accommodation-model-verification-report-7jul2021v1-0-dist-a/

[11] F. J. Huston II and G. L. Zielinski, “Fixed seat: non-driver CAD accommodation model verification report (version 1.0),” DEVCOM Ground Vehicle Systems Center (GVSC), Warren, MI, 2017. [Online]. Available: https://www.usarmygvsc.com/ accommodation-models/fixed-seat-non-driver-cad-accommodation-model-verification-report-version-1-0/