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Creation of the Driver Fixed Heel Point (FHP) CAD Accommodation Model for Military Ground Vehicle Design

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The objective of this effort is to create a parametric Computer-Aided Design (CAD) accommodation model for the Fixed Heel Point (FHP) driver and crew workstations with specific tasks. The FHP model is a statistical model that was created utilizing data from the Seated Soldier Study (Reed and Ebert, 2013). The final product is a stand-alone CAD model that provides geometric boundaries indicating the required space and adjustments needed for the equipped Soldiers' helmet, eyes, torso, knees, and seat travel. Clearances between the Soldier and surrounding interior surfaces and direct field of view have been added per MIL-STD-1472G. This CAD model 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 model will be available once it has undergone Verification, Validation, and Accreditation (VV&A) and a user guide has been written.

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CREATION OF THE DRIVER FIXED HEEL POINT (FHP) CAD ACCOMMODATION MODEL FOR MILITARY GROUND VEHICLE DESIGN

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ABSTRACT

The objective of this effort is to create a parametric Computer-Aided Design (CAD) accommodation model for the Fixed Heel Point (FHP) driver and crew workstations with specific tasks. The FHP model is a statistical model that was created utilizing data from the Seated Soldier Study (Reed and Ebert, 2013). The final product is a stand-alone CAD model that provides geometric boundaries indicating the required space and adjustments needed for the equipped Soldiers' helmet, eyes, torso, knees, and seat travel. Clearances between the Soldier and surrounding interior surfaces and direct field of view have been added per MIL-STD-1472G. This CAD model 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 model will be available once it has undergone Verification, Validation, and Accreditation (VV&A) and a user guide has been written.

INTRODUCTION

Military ground vehicles are currently designed using requirements from Military Standard (MIL-STD) 1472G, the *Department of Defense Design Criteria Standard: Human Engineering*, 2012. The unifying factor amongst these is the requirement to accommodate the central 90% of the Soldier population. MIL-STD-1472G 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 an easy to use, consistent, graphical tool in which the occupant is an integral element of vehicle workstation design.

Ensuring that a given percentage of the population can sit safely and naturally while performing all required functions, including driving, requires multivariate analysis methods that consider the physical dimensions of the Soldier (anthropometry) and behavioral effects (posture) in a three dimensional space (DoD, 2012). 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 Society of Automotive Engineers (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 a parametric CAD template that adjusts based on user inputs describing the Soldier population, desired accommodation level, and vehicle environment.

The first CAD accommodation model being created is for the Fixed Heel Point (FHP) driver workstation. The FHP model is applicable to ground vehicles, such as Army tactical wheeled vehicles, where driving is controlled via a conventional accelerator pedal and

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steering wheel. The FHP model may also be used in other workstations, having horizontally and vertically adjustable seats, in which the crew are required to interact with vehicle controls and displays using hands and forward vision (Zerehsaz, Ebert, and Reed, 2014).

METHODS

The primary developments that have made it possible to create a reusable CAD template representing FHP accommodation are UMTRI's predictive models for Soldier posture and the utilization of automated design capabilities available in many current CAD systems.

Seated Soldier Study

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* (Reed and Ebert, 2013) was completed to capture Soldier preferred posture and position data in a driver mockup while considering the unique ground vehicle workstation environment and the clothing and equipment ensembles worn by Soldiers.

The *Seated Soldier Study* gathered data on 145 enlisted men and women as drivers at three Army posts. Soldiers wore three levels of clothing and equipment (**Figure 1**) including: 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 (Reed and Ebert, 2013).

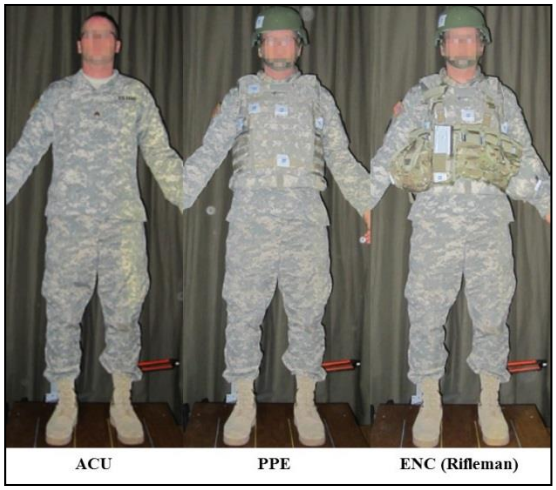

Figure 1: Soldier Clothing and Equipment

The driver mockup (**Figure 2**) simulates a Fixed Heel Point (FHP) driver workstation, including an accelerator pedal, steering wheel, and adjustable seat.

Figure 2: Soldier in Driver Mockup with ENC

When Soldiers entered the driver mockup, they found their preferred driving position by adjusting the seat's fore-aft (horizontal) and up-down (vertical) positions, as well as seat back angle. Each Soldier's posture and seat position was then digitized.

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

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across the target population. In particular, the accommodation boundaries indicate the seat adjustment range needed to reach vehicle controls and the resulting positions for the equipped Soldier population's eyes, helmet, torso, and knees. Working models were provided by UMTRI in the form of Microsoft Excel spreadsheets (**Figure 3**). For a more in-depth discussion of UMTRI's work, please refer to the *Seated Soldier Study* (Reed and Ebert, 2013) and *Development of Accommodation Models for Soldiers in Vehicle — Driver* (Zerehsaz et. al., 2014).

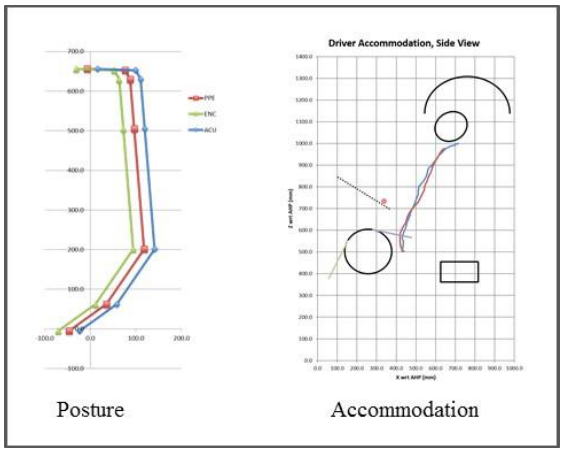

Figure 3: Microsoft EXCEL Workbook Output

CAD Accommodation Model Development

The CAD version of the FHP accommodation model is being created by the Tank Automotive Research, Development, and Engineering Center (TARDEC) Advanced Concepts Team (ACT) using PTC Creo® 3D CAD software. Functionally, the foundation of the model is a stand-alone geometric reproduction of UMTRI's Microsoft Excel spreadsheets. Clearances between the Soldier population and surrounding interior vehicle surfaces are being layered onto the model per the intent of MIL-STD-1472G, along with direct vision zones that incorporate concepts from both MIL-STD-1472G and SAE Recommended Practice J1050, *Describing and Measuring the Driver's Field of View*, 2009. To aid in understanding how workstation design affects individuals, boundary manikins representing the anthropometric extremes for workstation design are being 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 FHP 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 values 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 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 (Bowling, Khasawneh, Kaewkuekool, and Rae Cho, 2009).

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

The second exception involves the positioning of manikins. UMTRI provides coordinates of body landmarks with respect to the geometric origin of the accommodation model (i.e. the accelerator heel point (AHP), the lowest intersection of the manikin's heel with the floor when the foot is on the undepressed accelerator pedal) sufficient to locate the hips, torso articulation, and head. 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.

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RESULTS

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

User Interface

The end user will affect the model geometry by modifying the input parameter table in the top assembly of the model (**Figure 4).** 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-1472G requirements. The primary vehicle input to the model describes the nominal location of the steering wheel center with respect to the AHP (Zielinski, Huston II, Kozycki, Kouba, and Wodzinski, 2015).

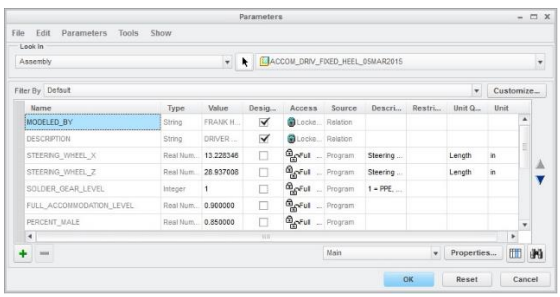

Figure 4: Input parameters

Accommodation Boundaries

The first layer of outputs, around which the rest of the model is built, contains the accommodation boundaries (**Figure 5**). A surrogate steering wheel, at the user specified location, as well as a steering wheel preference line, based on population data, are provided to assess steering wheel placement. The seat track travel window indicates the size and location of seat adjustment needed to reach vehicle controls. As in the SAE Recommended Practices, this information is related back to the occupant through the design H-Point of the seat (i.e. hip-point, the location of a standardized occupant's hip in relation to the seat). Resulting boundaries for the Soldier population's eyes, helmet, torso, and knees are provided.

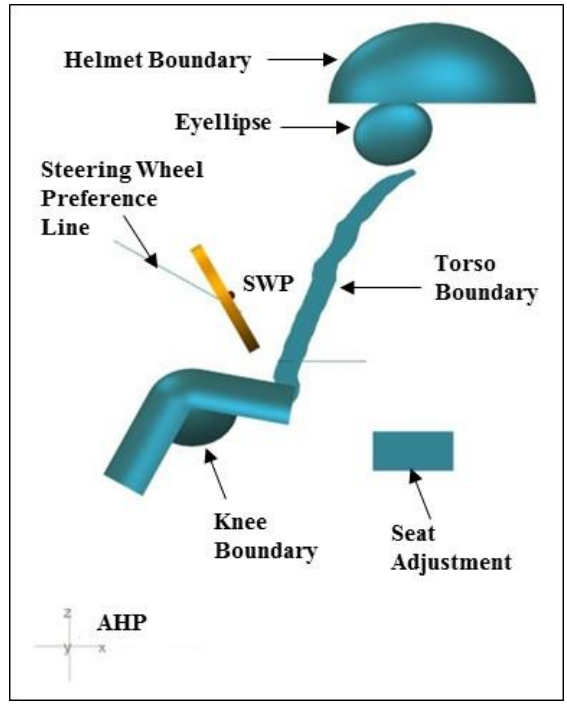

Figure 5: FHP CAD accommodation boundaries

Clearance Zones and Direct Field of View

The accommodation boundaries are used to develop a second layer of output indicating standard minimum clearances and driver direct field of view. These features were developed after extensive consultation with both UMTRI and the Army Research Laboratory (ARL) Human Research Engineering Directorate (HRED), the agency that assesses vehicles per MIL-STD-1472G requirements.

Standard minimum clearances have been provided for quick reference even though it is always possible to measure clearances directly. MIL-STD-1472G indicates that there should generally be 2 inches of clearance around the occupant. This clearance, which has been provided for the head (with helmet), torso, thighs, knees, and shins (**Figure 6**), aids in the development of vehicle interior features such as instrument panel knee bolsters and overhead systems.

Driver direct field of view (**Figure 7**), divided into primary, secondary, and tertiary zones, was developed using a combination of MIL-STD-1472G and SAE Recommended Practice J1050 applied to the eyellipse. These zones are to be used for prioritizing the placement of controls and displays. The primary zone indicates a space viewable by all occupants using a minimum of "easy" rotation from at least one eye

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(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.

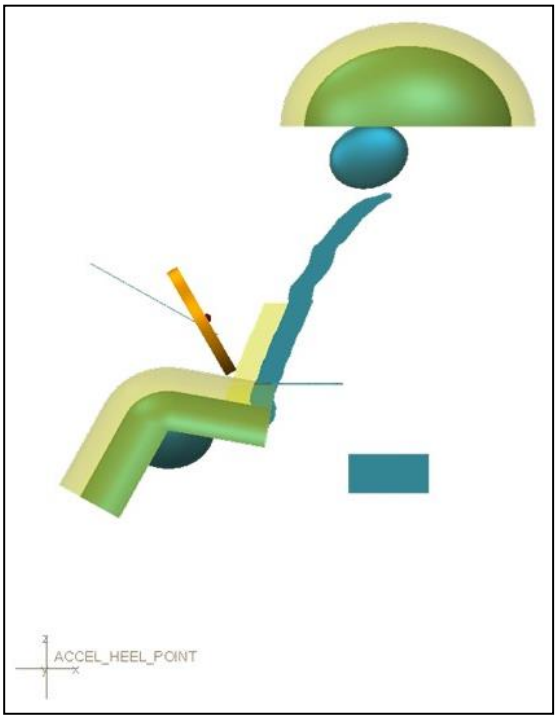

Figure 6: CAD accommodation clearance zones

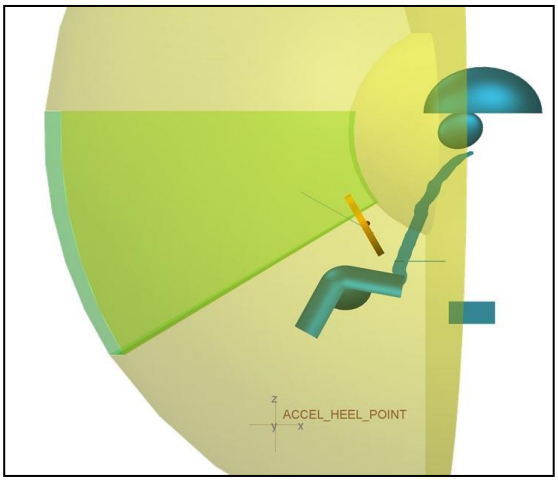

Figure 7: CAD accommodation direct field of view

CAD Accommodation Model Manikin Placement

Positioned boundary manikins give the vehicle designer another reference for design (**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.

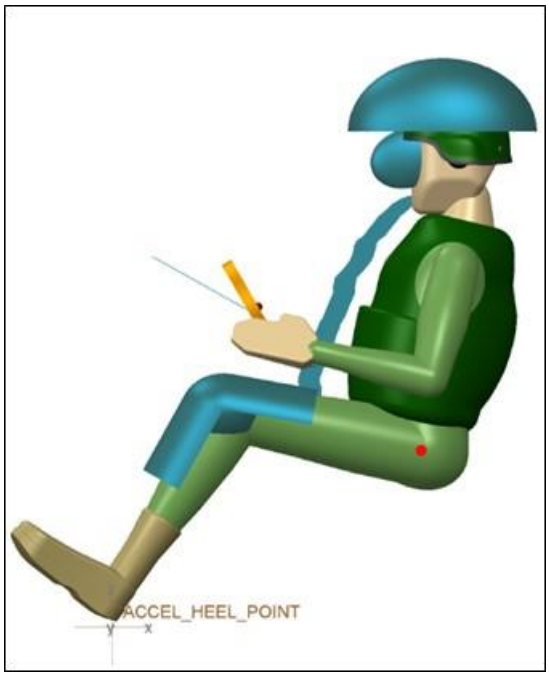

Figure 8: Manikin placement

DISCUSSION

This paper described how empirical Soldier posture and position data have been used to develop a working CAD model of the Fixed Heel Point driving 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-1472G, 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-1472G for vehicle interior layout.

The CAD environment was chosen for implementation because it is the medium used by

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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 when opportunities for design changes arise.

The FHP CAD model will be made available to other government partners and industry following Verification, Validation, and Accreditation (VV&A) and the development of a user guide. Currently, the *FHP Accommodation Model V&V Plan* (Zielinski and Huston, 2016) has been created and the CAD model is starting the process of verification at TARDEC. ARL HRED plans to complete validation of the model in Fiscal Years (FY)17-18. The techniques used to develop the model will then be applied to other modes of driving not explicitly considered in MIL-STD-1472G, as well as squad seating, to create a full complement of tools representing Soldiers in ground vehicles.

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