

# SIMULATING CREW INGRESS AND EGRESS FOR GROUND VEHICLES

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## ABSTRACT

*Changes to tactical vehicle architecture to improve survivability are increasing the difficulty of getting into and out of the vehicle. The available vehicle design standards, including MILSTD-1472f, provide relatively little guidance for ingress/egress system design, focusing primarily on step and handhold dimensions in isolation without considering the overall performance of the system. This paper presents a new approach to ingress/egress system design based on the use of digital human modeling to evaluate candidate systems. CAD mockups are tested using human motion simulation algorithms based on laboratory research. A highly reconfigurable laboratory mockup with instrumented steps and handholds is used to obtain human behavior data that form the basis for the motion simulation algorithms. The methodology is appropriate for assessing clearances, handhold and step placement, and for considering a wide range of body sizes and equipment levels. Simulations can reduce the need for physical prototype testing and improve the performance of the resulting systems.*

## INTRODUCTION

The performance requirements for tactical vehicles have increased dramatically in response to changes in battlefield conditions. Increases in armoring and other modifications to improve survivability drive cascading changes throughout the vehicle, including increased vehicle height and larger and heavier doors. The crews of these vehicles are also increasingly encumbered by protective equipment, communications gear, weapons, and other systems. The confluence of these trends creates challenges for the crew in entering and exiting from the vehicle.

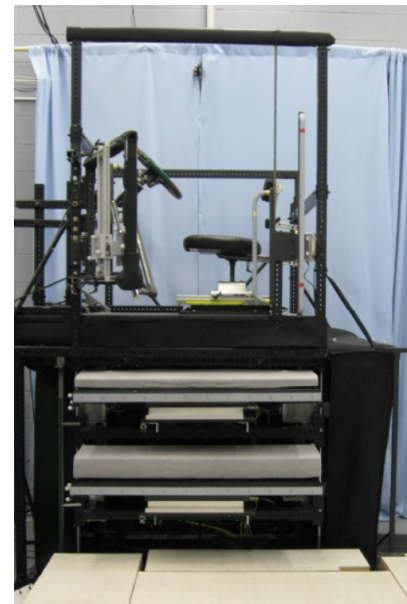
The current design guidelines for ingress/egress systems, including steps, handholds, and clearance requirements, address only a few features of the systems. MILSTD-1472f includes specifications for step dimensions, but provides little guidance on locating those steps relative to door openings and seating positions.

This paper describes (1) a methodology for gathering detailed data on ingress/egress and (2) a simulation approach for applying the results of these studies to the design and assessment of new vehicles.

## EXPERIMENTAL METHODS

Accurate simulation of crew ingress and egress requires detailed data on whole-body kinematics and the forces and moments exerted on steps and handholds. Figure 1 shows a reconfigurable laboratory that has been constructed for testing of ingress/egress systems. The floor height of the mockup can be adjusted over a large range, and the interior package layout (seat, pedals, steering wheel) can be adjusted to represent vehicles from light trucks through tall cab-over-engine trucks, including the full range of U.S. Army tactical

vehicles. The system can be used with one or two steps, which are adjustable for height and lateral position. The step configuration shown in Figure 1 is designed to replicate the step systems on conventional heavy truck cabs. The steps are mounted on force plates that measure reaction forces and moments. Handholds are mounted on adjustable brackets that can represent a range of configurations. The handhold brackets incorporate six-axis load cells (three forces and three moments) to record hand forces.



**Figure 1:** Laboratory mockup for ingress/egress testing.

The laboratory is equipped with a 13-camera VICON passive optical motion capture system. The camera system tracks the three-dimensional location of retroreflective targets attached to the participant and the laboratory fixtures. The resulting data can be used to quantify whole-body motions. Figure 2 shows the markers on a study participant. Figure 3 shows a subject performing an ingress trial with the markers.



**Figure 2:** Motion Capture markers on a study participant.



**Figure 3:** Study participant performing an ingress trial.

The motion-capture and reaction-force data are analyzed using two human modeling systems. The Jack human model from Siemens, shown in Figure 4, is widely used for vehicle ergonomics assessment. Jack provides three-dimensional visualization of the measured ingress/egress motions in a CAD environment. Jack can also provide static estimates of the joint torques required to sustain the postures associated with the ingress and egress motions, but the Jack analysis does not take into account the inertial loads associated with the event dynamics.



**Figure 4:** The Jack human figure model used to visualize and analyze motion capture data and to conduct kinematic simulations.

The AnyBody modeling system from AnyBody Technologies is used to perform musculoskeletal analyses of the measured motions and reaction forces. The AnyBody manikin, shown in Figure 5, is scaled to match the skeletal linkage of the test participant. An inverse dynamics analysis is conducted by driving the figure linkage with the measured whole-body kinematics data while applying the reaction forces at the hands and feet. The redundancy of these data (the reaction forces can be computed directly from the kinematics and segment inertial parameters) provides a check on the accuracy of the analysis. The inverse dynamics analysis yields net joint torque estimates based on the measured subject behavior. Joint torques provide a useful quantitative measure to compare alternative ingress/egress systems.



**Figure 5:** AnyBody Modeling System used for inverse dynamics analysis.

## SIMULATION METHODS

The empirical analysis methods described above are crucial for gaining a detailed understanding of how ingress and egress system design affects loads on the body. Laboratory studies are useful for developing basic design guidance, but are not practical for routine evaluation of prototype systems.

Laboratory data are most useful when they are applied to developing and validating simulation methods that can be applied to new designs. The University of Michigan Human Motion Simulation (HUMOSIM) Laboratory has developed a new approach to ergonomic simulation using behavior-based algorithms based on laboratory data [1]. This methodology has been applied to simulation of manual materials handling, standing force exertions, seated reaches, driving, and ingress/egress for passenger cars and light trucks [1-6]. The current work extends the simulation capability to include heavy vehicles with one or more steps and a variety of handhold arrangements.

## SYSTEM EVALUATION AND GUIDELINE DEVELOPMENT

The current work is motivated by the recognition that current design guidelines are inadequate. In particular, the standard approaches specify large acceptable ranges for dimensions and focus on the steps and handholds in isolation. New methods are needed that consider the steps, handholds, and vehicle obstructions as a system. Each vehicle will require a different solution, depending on the mission and design constraints.

Importantly, the military application imposes design requirements that are not present in other situation. For example, soldiers and Marines invariably prefer to exit their vehicles facing away from the vehicle. Yet, best practice for truck egress safety calls for the driver to face the vehicle (backing out, essentially), and the step and handhold design guidelines assume this behavior.

The new approach integrates prescriptive requirements (non-slip steps and handholds, for example) with a performance-based assessment methodology using human figure models such as Jack and AnyBody. A candidate ingress/egress system is assessed by conducting dynamic simulations in a computer software environment. Using manikins representing a wide range of body sizes and equipment levels, simulations of ingress and egress are conducted using the HUMOSIM Framework. Assessments are conducted in the Jack software (reach, clearance, static joint torques), supplemented as needed by dynamic assessments in the AnyBody modeling system.

## DISCUSSION AND FUTURE WORK

This paper provides a high-level overview of an experimental methodology and simulation approach that are being developed to address the need to accurately assess ingress/egress systems without physical prototype testing with large numbers of subjects. The methods are currently being developed and applied for passenger cars, light trucks, and commercial heavy trucks. Future work should focus on the specific needs of military vehicles, including the unique populations, effects of protective equipment and other gear, and the design constraints inherent in military vehicles.

## ACKNOWLEDGEMENTS

This research was supported in part by grant R01 OH00 9153-03 from the U.S. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of CDC-NIOSH.

This research was also supported in part by the partners of the Human Motion Simulation Laboratory at the University

of Michigan, who include Ford, General Motors, Toyota, Siemens, and the U.S. Army.

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