Digital Human Modeling

H. Charles Dischinger, Jr.

National Aeronautics and Space Administration (NASA)

1.1 Template for contributors [Heading 1]

1.1.1 Formatting and style [Heading 2]

The development of models to represent human characteristics and behaviors in human factors is broad and general. The term "model" can refer to any metaphor to represent any aspect of the human; it is generally used in research to mean a mathematical tool for the simulation (often in software, which makes the simulation digital) of some aspect of human performance and for the prediction of future outcomes. This section is restricted to the application of human models in physical design, *e.g.*, in human factors *engineering*. This design effort is typically human interface design, and the digital models used are anthropometric. That is, they are visual models that are the physical shape of humans and that have the capabilities and constraints of humans of a selected population. They are distinct from the avatars used in the entertainment industry (movies, video games, and the like) in precisely that regard: as models, they are created through the application of data on humans, and they are used to predict human response; body stresses, *e.g*. (see Lämkull*, et al*., 2009), or ability to perform work effectively.

The development of these anthropometric Digital Human Models (henceforth, DHM) was dependent upon advances in computing and display (visualization) capabilities in the late 1980s (Badler, et al., 1999). Much of the development work on DHM was done at the University of Pennsylvania, with funding and collaboration from a variety of governmental (primarily the U.S. Department of Defense and NASA) and industry partners (Badler, et al., *ibid.*). The characteristics of a DHM that make it useful and appropriate include:

1. Its internal structure mimics a human skeleton,

2. It moves like a human and can be positioned to the postures of real humans,
3. It is sized to population data on human anthropometry and biomechanics that define both dimensions and constraints, such as range of motion,
4. It exists in an integrated software (virtual) environment and thus can interact with other applications, such as Computer Aided Design (CAD). This enables the DHM to grasp virtual objects and otherwise manipulate them and to distinguish between these objects and those which interfere with the DHM free movement.

Application of models in space design

The primary use for DHM in space applications is in the development of designs for workspaces. DHM enable iterative evaluation of a large number of concepts and support rapid analysis, as compared with use of physical mockups. They can be used to evaluate feasibility of escape of a suited astronaut from a damaged vehicle, before launch or after an abort (England, *et al*., 2012). Throughout most of human spaceflight, little attention has been paid to worksite design for ground workers. As a result of repeated damage to the Space Shuttle which adversely affected flight safety, DHM analyses of ground assembly and maintenance have been developed over the last five years for the design of new flight systems (Stambolian, 2012, Dischinger and Dunn Jackson, 2014). The intent of these analyses is to assure the design supports the work of the ground crew personnel and thereby protect the launch vehicle. They help the analyst address basic human factors engineering questions: can a worker reach the task site from the work platform provided; can she or he see the task site; can she or he control tools, which, if dropped, might damage the system? Figure 7.3.1 provides an example of such analysis for a future NASA launch vehicle. [figure 7.3.1 here]

In-space systems for operation by astronauts have long been targets for DHM analysis, given the focus on mission success and concerns for astronaut safety. Figure 7.3.2 illustrates the analysis of the design to support astronaut tasks for an International Space Station glovebox.

[Figure 7.3.2 here]

Use by the analyst

The use of DHM is a specialized skill that requires a thorough knowledge of human factors (subject-matter expertise in task analysis and knowledge of human capabilities and constraints) and training on and experience in the use of the particular model. It is essential to understand that, as with models of all types, use by a practitioner lacking expertise in these areas will result in incomplete or, worse, incorrect results. The understanding of human factors enables an analyst to identify the work task and properly posture a model for that task. For example, a model may indicate that a human can reach a handle to be rotated. The analyst must know that simple reach may be insufficient, if a torque is required. In microgravity, the rotation torque may be such that a restraint is required. For the same task in 1g, the torque might require that a worker adopt a crouch to achieve the forces needed; this crouch might coincidentally affect the visual envelope or lighting requirements adversely. Since most models do not inform the analyst of the needed changes, or they do so incompletely, the analyst's expertise with the DHM is essential to a good result. Figure 7.3.3 demonstrates several of these issues. The worker's wrist and arm orientations are likely inappropriate for the tasks of connector mating, which may require torques. Moreover, this worker cannot see the task site (see inset). At a gross level, the task site (connector panel) can be reached, but there may be difficulties for the worker.

[Figure 7.3.3 here]

Limitations and challenges of the models

The human body is mechanically extremely complex. Simple motions, such as walking in a straight line or grasping a tool, involve many simultaneous joint rotations, often through multiple planes. These almost never appear, either to the mover or the observer, to be discontinuous or to require independent control. From a practical standpoint, a DHM must be easily posable in a realistic way, in order for the analyst to get accurate results. The complexity associated with human joint action, capabilities, and constraints is challenging and expensive to model, and not all DHMs include features that support this need. DHMs that are packaged with CAD packages, for example, are often very limited in their utility as worksite-analysis tools. The analyst must understand the objectives of her or his application and be knowledgeable of whether a particular DHM will support those objectives.

Well-developed, fully capable DHMs require a great deal of skill and time, for an analyst to be able to represent workers in a naturalistic way. As mentioned above, Figure 7.3.3 illustrates an apparently infeasible task. It is possible the task can be performed by a 95th percentile person; the issue illustrated may be an artefact of the challenges in the use of the DHM. One way to mitigate the difficulty of accurately predicting natural postures associated with different tasks is to combine the DHM with a motion capture system and a virtual display (such as a head-mounted display) of the system being analysed. This enables an actor to simulate the tasks while an analyst records the body positions assumed by the DHM as it follows the actor (see Stambolian, 2012, and Dischinger and Dunn Jackson, 2014, for space application; for theory, see Ausejo and Wang, 2009). Since the actor understands the visual and work envelope requirements, her behaviors become inputs to the model. Addition of this capability shortens the time for analysis of gross tasks.

Again, decisions about shortcuts require analytical expertise to know whether they might compromise the results. For example, a naturalistic representation in a DHM of a hand gripping a tool or a handle or knob is difficult and often frustrating, even with input devices that sense hand and finger positions. The analyst must decide how important this is for a particular assessment. If the work being simulated is the task of removing a connector from a panel, it might be very important, because hand clearances are important for these tasks, which often affect flight safety. If the task is simply to show that a wrench can be placed on a fastener head, the representation of the hand grip is not the most important aspect of the analysis.

Even more important for the analyst than skill in managing the model is human factors expertise. She or he must be fully conversant with human capabilities and constraints and be skilled in the basic human factors tools, including task analysis and process modelling. Analysts must be able to characterize the design through these analyses and identify all points for which human touch or cognitive tasks are required. For example, a touch task might be turning a knob; the associated cognitive task might be a decision about which way and how far to turn it. Only after identifying all the tasks can the analyst begin to apply the DHM to the assessment. This is one of the primary reasons human factors expertise is required; task and process analyses are not often skills that designers are trained in, and very few designers are familiar with human capabilities and constraints.

While DHM are useful for the analysis of touch tasks, they are still lacking in the ability to provide feedback on cognitive tasks, such as decision-making. The example above alluded to the turning of a knob; as illustrated, the analyst can use the DHM to assess the physical envelopes required to perform the task, and even to assess whether displays, such as labels or readouts, are in the field of view. The DHM cannot read even simple labels, such as an arrow, to "know" which way the knob is to be turned. Analyses associated with such decisions are beyond current DHM and are the responsibility of the human factors analyst.

Future space designs will require DHMs, and these tools will become more capable and easier to use. Nevertheless, these tools will always require analysts whose primary focus is the human factors aspects of the design. In order to assess the ability of the design to support the population of operators, analysts must understand the population, the environment (*e.g.*, gravitational regime, or lighting) and the specific tasks a human operator will be expected to perform. The DHM will never know all these.

References

Ausejo, S. and Wang, X., 2009. Motion Capture and Human Motion Reconstruction. In: Duffy, V. (Ed.), Handbook of Digital Human Modeling. CRC Press, Boca Raton, pp. 38-1 – 38-13.

Badler, N., Phillips, C., and Webber, B., 1999. Simulating Humans: Computer Graphics, Animation, and Control. Oxford University Press, Oxford, pp. 2-22.

Dischinger, H., Dunn Jackson, M., 2014. Computer-Aided Design Tools to Support Human Task Worksite Design. Conf. Presentation: Department of Defense Human Factors Engineering Technical Advisory Group, Meeting 68, 19 – 22 May 2014. Aberdeen Proving Grounds, MD.

England, S., Benson, E., Cowley, M., Harvill, L., Blackledge, C., Perez, E., and Rajulu, S., 2012. Comparative Ergonomic Evaluation of Spacesuit and Space Vehicle Design. In: Savrendy, G. and Karwowski, W. (Eds.), Advances in Human Factors & Ergonomics 2012: Proceedings of the 4th AHFE Conference, 21- 25 July 2012. CRC Press, Boca Raton, pp 374-383.

Lämkull, D., Örtengren, R., and Malmsköld, L., 2009. Digital Human Modeling Automotive Manufacturing Applications. In: Duffy, V. (Ed.), Handbook of Digital Human Modeling. CRC Press, Boca Raton, pp. 42-1 - 42-17.

Stambolian, D., 2012. Human Modeling for Ground Processing Human Factors Engineering Analysis. Conf. presentation: 2012 IEEE Aerospace Conference; 3-10 Mar. 2012; Big Sky, MT. Available from: https://ntrs.nasa.gov/search.jsp?R=20110023216

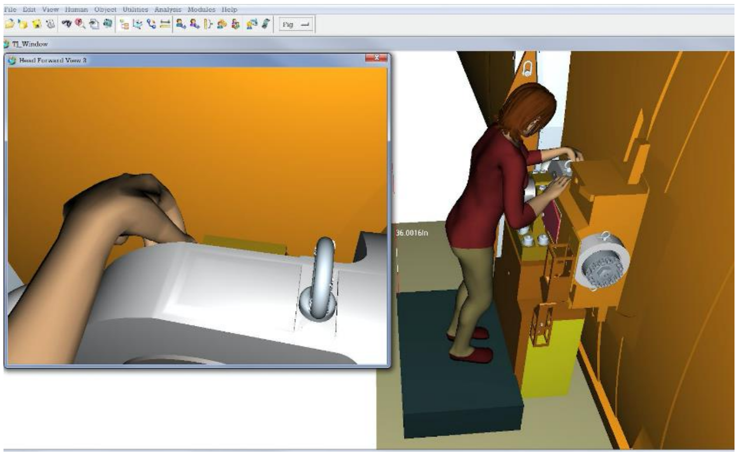

Figure 7.3.1. A female ground worker is shown performing a task on a launch vehicle. The analyst has positioned the DHM on a work platform to assess her reach, visual, body, hand, and work envelopes, as required by the task. The visual envelope is partially represented by the inset, to show that the worker must lean forward to fully see the item being manipulated.

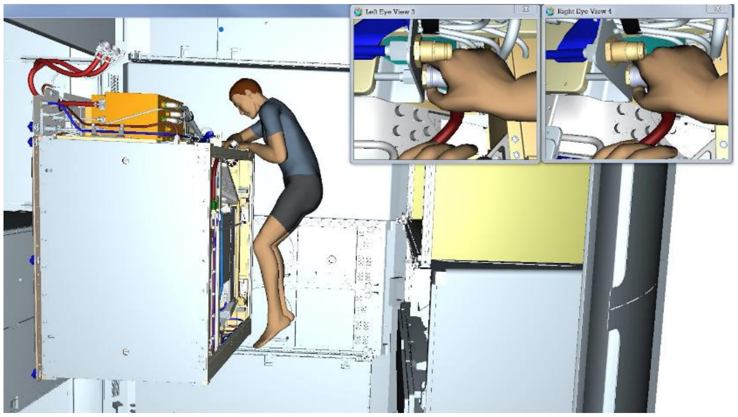

Figure 7.3.2. An astronaut on the International Space Station performing maintenance on a glovebox. The 95th percentile DHM is posed to represent the “neutral body posture” assumed by humans in microgravity. He is shown reaching into the interior of the glovebox to disconnect a fluid connector. The insets, showing the views from each eye, demonstrate that the worker has the reach, visual, and hand envelopes to perform the task safely. The analysis is repeated using a 5th percentile astronaut to assure all crew on the ISS can safely accomplish the work.

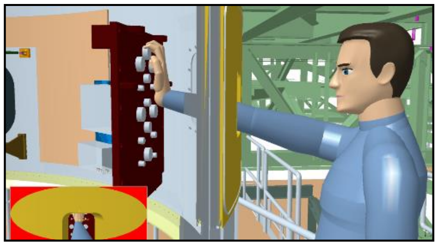

Figure 7.3.3. A ground worker is shown reaching through a port in the side of a launch vehicle to an electrical connector panel. The analyst has positioned the worker to demonstrate the field of view available to the 95th percentile worker. Note the awkward hand orientation; a better illustration might be accomplished by meticulous adjustment of the model, but this is time-consuming, even for expert analysists.