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Evaluation of an Anthropometric Human Body Model for Simulated EVA Task Assessment

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One of the more mission-critical tasks performed in space is extravehicular activity (EVA) which requires the astronaut to be external to the station or spacecraft, and subsequently at risk from the many threats posed by space. These threats include, but are not limited to: no significant atmosphere, harmful electromagnetic radiation, micrometeriods, and space debris. To protect the astronaut from this environment, a special EVA suit is worn which is designed to maintain a sustainable atmosphere (at 1/3 atmosphere) and provide protection against the hazards of space. While the EVA suit serves these functions well, it does impose limitations on the astronaut as a consequence of the safety it provides.

Since the astronaut is in a virtual vacuum, any atmospheric pressure inside the suit serves to pressurize the suit and restricts mobility of flexible joints (such as fabric). Although some of the EVA suit joints are fixed, rotary-style joints, most of the mobility is achieved by the simple flexibility of the fabric. There are multiple layers of fabric, each of which serves a special purpose in the safety of the astronaut. These multiple layers add to the restriction of motion the astronaut experiences in the space environment.

Ground-based testing is implemented to evaluate the capability of EVA-suited astronauts to perform the various tasks in space. In addition to the restriction of motion imposed by the EVA suit, most EVA activity is performed in a micro-gravity (weightless) environment. To simulate weightlessness EVA-suited testing is performed in a neutral buoyancy simulator (NBS). The NBS is composed of a large container of water (pool) in which a weightless environment can be simulated. A subject is normally buoyant in the pressurized suit; however he/she can be made neutrally buoyant with the addition of weights. In addition, most objects the astronaut must interface with in the NBS sink in water and flotation must be added to render them "weightless". The implementation of NBS testing has proven to invaluable in the assessment of EVA activities performed with the Orbiter and is considered to be a key step in the construction of the International Space Station (ISS).

While the NBS testing is extremely valuable, it does require considerable overhead to maintain and operate. It has been estimated that the cost of utilizing the facility is approximately $10,000 per day. Therefore it is important to maximize the utility of NBS testing for optimal results. One important aspect to consider in any human/ worksite interface is the considerable wealth of anthropometric and ergonomic data available. A subset of this information specific to EVA activity is available in NASA standard 3000. The difficulty in implementing this data is that most of the anthropometric information is represented in a two-dimensional format. This poses some limitations in complete evaluation of the astronaut's capabilities in a three-dimensional environment. Advances in computer hardware and software have provided for three-dimensional design and implementation of hardware with the advance of computer aided design (CAD) software. There are a number of CAD products available and most companies and agencies have adopted CAD as a fundamental aspect of the design process. Another factor which supports the use of CAD is the implementation of computer aided manufacturing (CAM) software and hardware which provides for rapid prototyping and decreases the time to product in the design process. It is probable that most hardware to be accessed by astronauts in EVA or IVA (intravehicular activity) has been designed by a CAD system, and is therefore represented in three-dimensional space for evaluation.

Because of the implementation of CAD systems and the movement towards early prototyping, a need has arisen in industry and government for tools which facilitate the evaluation of ergonomic consideration in a three-dimensional environment where the hardware has been designed by the CAD tools. One such product is Jack which was developed by the University of Pennsylvania with funding from several government agencies, including NASA.

While the primary purpose of Jack is to model human figures in a ground-based (gravity) environment, it can be utilized to evaluate EVA-suited activities as well. The effects of simulated gravity must be turned off by turning off "behaviors". Although Jack provides human figures for manipulation, the primary instrument to be evaluated for EVA mobility is the work envelope provided by the EVA suit. An EVA Jack suit model has been developed by NASA-JSC and was utilized in this study. This suit model provided a more restrictive motion environment as expected for an EVA suited subject. As part of this study, the anthropometric dimensions for a 50th percentile male were compared with basic anthropometric data and were found to be representative for the population group expected in the NASA flight program. The joints for the suit were created in a manner which provided consistent performance with EVA reach envelopes published in NASA standard #3000.

In order to fully utilize the EVA capabilities of Jack, the EVA suited subject must be validated in some manner. The best available standard for the ISS is the NBS testing facility at Marshall Space Flight Center (MSFC). Subsequently, it was determined that the optimum test for Jack was to compare it with NBS studies.. Therefore the Jack suit model was visually compared with still photographs of an NBS testing scenario. One important aspect to consider is that the actual EVA suits do provide some adjustments for sizing to the particular dimensions of the astronaut. Therefore the photographs of actual NBS testing will document the sizes for people with varying body dimensions. A case in point is that a male astronaut whose height is 50th will probably not have a legs, arms and a torso which are all precisely 50th percentile. Subsequently, it is anticipated that there will be some variations found in comparing any "standard" computer generated model with actual subject data.

One great strength of using a computer generated subject is that the subject and environment can be manipulated with great ease. Unlike actual EVA and NBS testing, there are no time limits for breathing, etc. In addition, "camera" views can be placed literally inside of objects to provide information that might otherwise be unavailable with physical testing. The cost per hour of computer animation is much less than current NBS testing; emphasizing the utility of this form of evaluation. The important question remains as to whether this testing is indeed indicative of the data provided by NBS testing.

The time duration of the study and length limitations of this report preclude a thorough demonstration of the visual comparison of Jack with NBS data; however the study was focused on NBS photographs which demonstrated difficult tasks performed by several different astronauts. The actual task evaluated was the deployment of an Orbiter payload which carries the Space Station Remote Manipulator System (SSRMS). This task involved removing the pallet (LDA) carrying the SSRMS from the payload bay and attaching it to a module of the ISS. After the LDA was secured, eight long bolts were removed from the SSRMS which held it to the LDA during flight. These bolts were approximately 40" in length and their removal provided a good illustration of the reach limits of the astronauts during EVA. In order to untorque and remove the bolts the astronauts feet must be secured in an Articulating Portable Foot Restraint (APFR) which could be attached to one of several different Worksite Interface sights (WIFs) located on the LDA assembly. Once an astronaut had removed the bolt, it was handed to the accompanying astronaut for stowage in a bolt stowage assembly on the LDA for the flight back to earth.

The Jack figure which illustrates the reach difficulty for this task for a 50th percentile male is illustrated in Figure 1A. The "matching" NBS photograph is illustrated in Figure 1B. It should be noted that this photograph involves a [illegible] astronaut whose basic dimensions are approximately 60th percentile. The slight difference is evident in the comparison; however the Jack model reach envelope is visually accurate to less than two inches. The Jack figure which illustrates the reach difficulty for this task for a 5th percentile female is illustrated in Figure 2A. The "matching" NBS photograph is illustrated in Figure 2B. It was fortunate for this study that a 5th percentile female astronaut was available for the NBS testing. In this case the Jack simulation was once again accurate to less than two inches.

As a final observation, the Jack model(s) evaluated in this study did function well as a simulation of the NBS testing. On the average, the Jack model reach envelopes were a conservative estimate of reach envelopes observed in NBS testing. This was viewed as a positive side effect since it would provide for a margin of safety during computer evaluation. It should also be noted that this "side effect" is expected since the computer models will provide normal, comfortable reach envelopes whereas the NBS test illustrated astronauts stretching to extend their normal reach envelopes. It is my firm conclusion that computer models such as Jack should be utilized to their fullest potential for any human-machine interaction...both EVA and IVA.

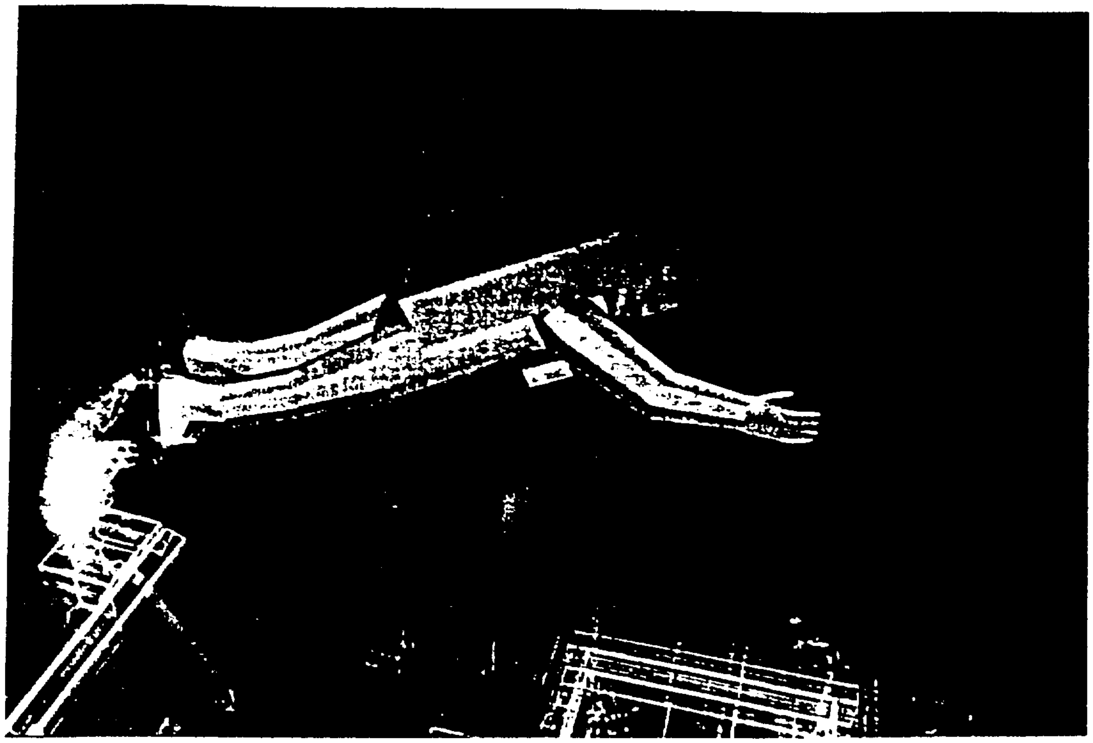
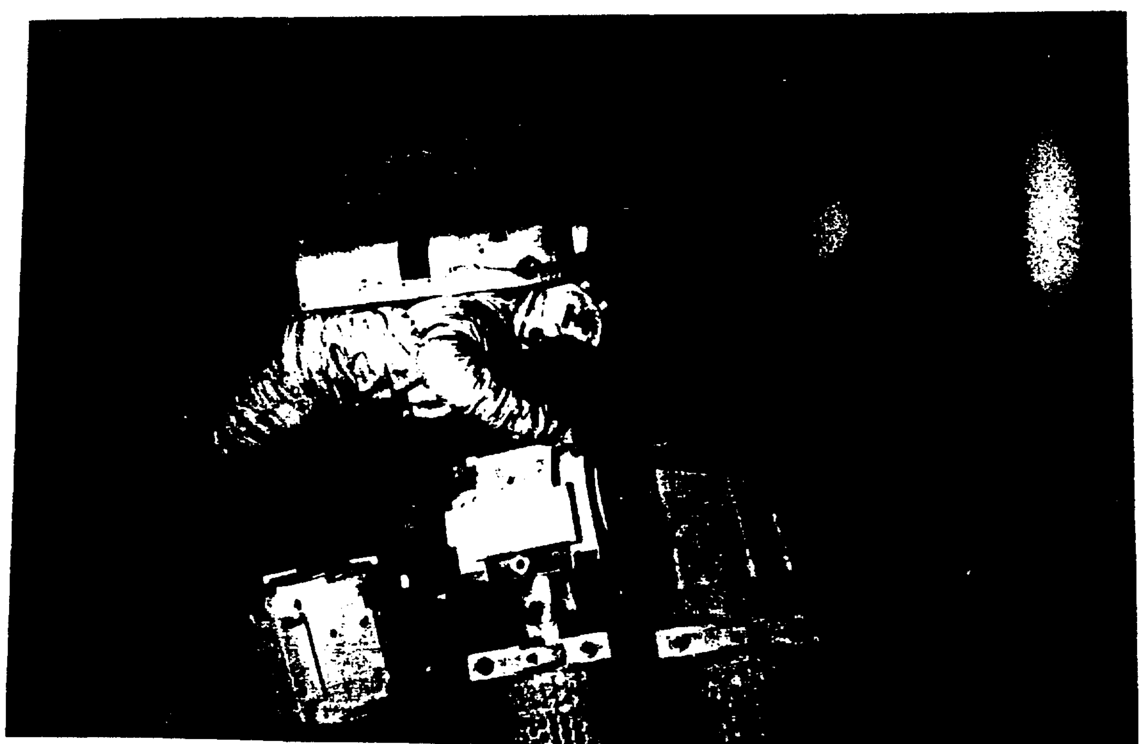


Figure 1A



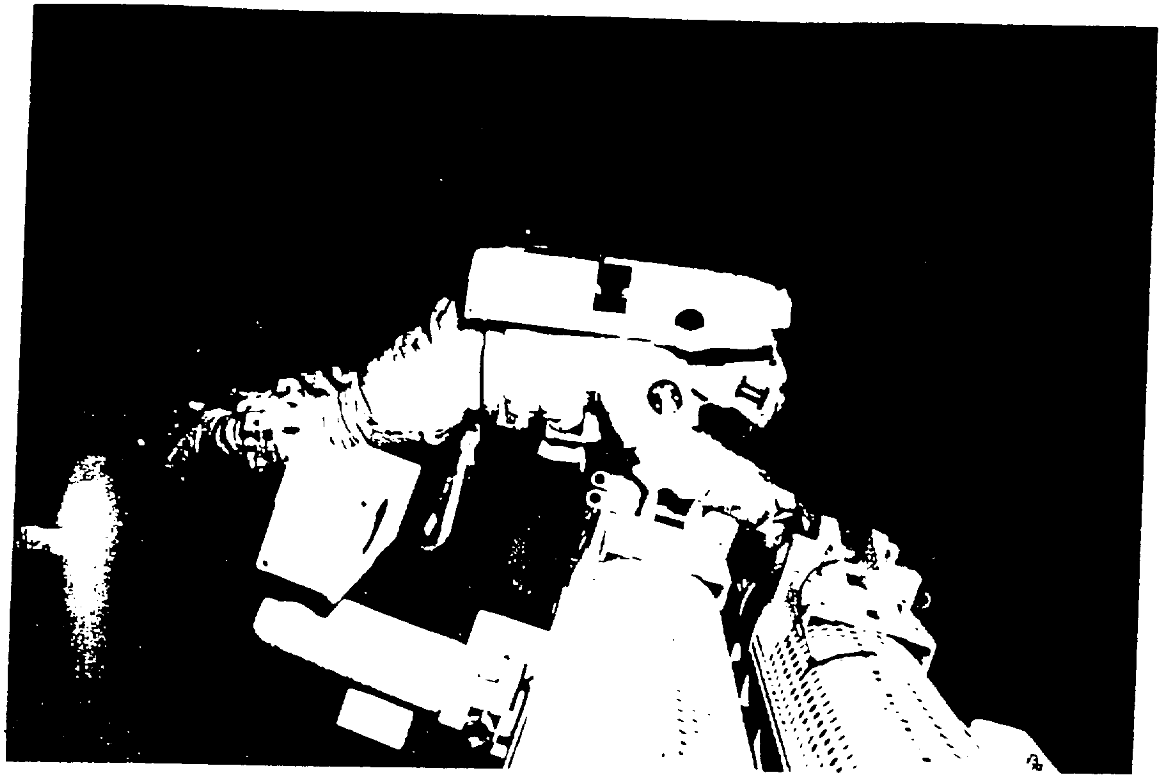


Figure 2A

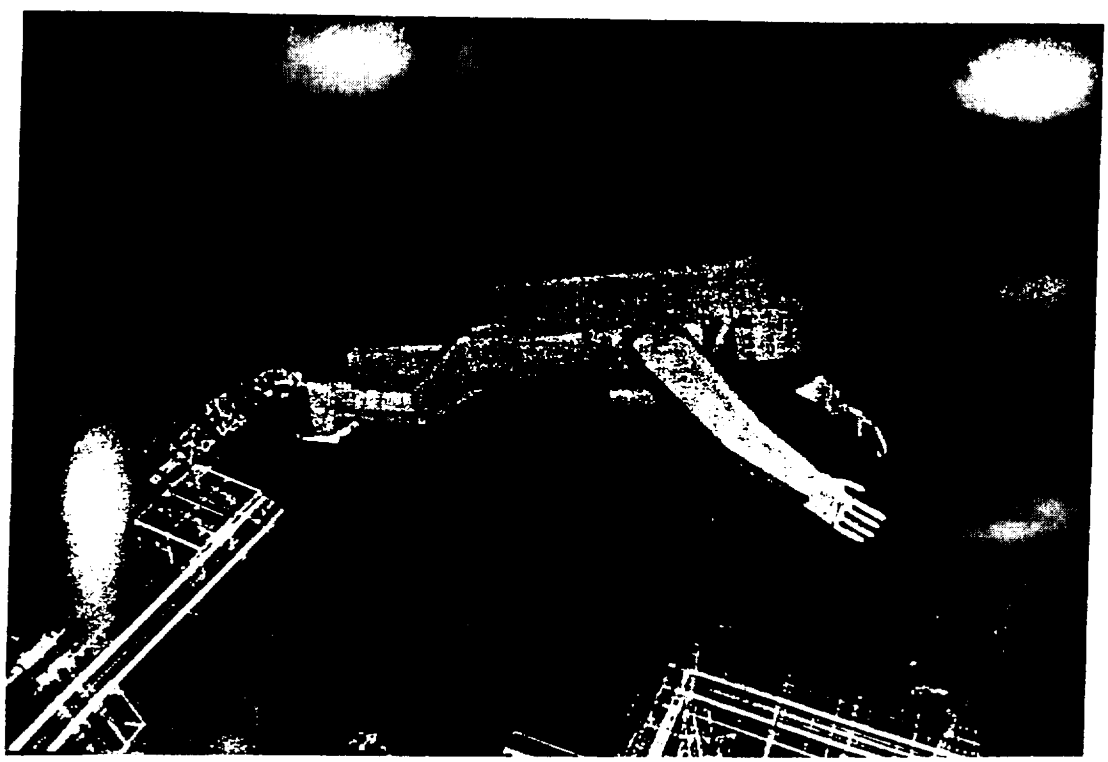


Figure 2B