Preprint from Proceedings of the Space Operations Applications Research Conference I 3-5, 1993

The PLAID Graphics Analysis Impact on The Space Program

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Abstract. An ongoing project design often requires visual verification at various stages. These requirements are critically important because the subsequent phases of that project might depend on the complete verification of a particular stage. Currently, there are several software packages at the Johnson Space Center (JSC) that provide such simulation capabilities. In this paper, we present the simulation capabilities of the PLAID modeling system used in the Flight Crew Support Division for human factors analyses. We will summarize some ongoing studies in kinematics, lighting, EVA activities and briefly discuss various applications in the mission planning of the current Space Shuttle flights and the assembly sequence of the Space Station Freedom with emphasis on the redesign effort.

1. Introduction

A complex engineering project is often divided into several stages. For economic purposes, management must have the capability to exercise options at the end of each of the stages [1], which often includes such decisions as: continue or abandon a project, the modification of design, the re-planning the remaining stages, etc. In order to be able to select these options, two major assessments must be provided: (i) financial assessment, and (ii) technical assessment. *Financial assessment* is the calculation of cash flows for the projects [2]. *Technical assessment* is the proof of correctness or demonstration of workability [3]. The scope of this paper is concentrated on the technical assessment capability via software simulations, with emphasis on the ongoing projects at NASA Johnson Space Center.

There are several techniques used to verify the technical merit of a design, and since many of the *advanced* projects at JSC are in the designing stages, test bedding is often augmented, prefixed or substituted by computer simulations. The type of simulation testing most often used is the scenario analysis, which is the testing of a few special cases. The system discussed here is most often used for scenario analysis in order to perform a quick look verification of well-known cases, to test and review new ideas or designs [1,2] or to analyze contingency cases.

There are several software packages that provide simulation capabilities [4,6,7]. In this paper, we present the simulation capabilities of the PLAID system [4] used in the Flight Crew Support Division.

Since 1978, the PLAID system has been used to serve many groups at the NASA Johnson Space Center. These groups include Space and Life Sciences, Mission Operations, Engineering, Space Station Project Office, Astronaut Office, etc. In addition, other NASA centers such as Marshall Space Flight Center, Goddard Space Flight Center, and Ames Research Center have also made use of the system.

These groups have primarily used the system for engineering analyses, visualization of designs, and, on occasion, public relations pictures of NASA high-tech projects. The PLAID system has successfully fulfilled these objectives by serving as a computer aided engineering tool to provide rapid, economical mission support; to develop and apply unique, state of the art, computerized Human Modeling; and to perform system engineering analyses to optimize crew station design, development, and operation.

2. Facilities Description

The PLAID system is a three dimensional computer modeling system, which enables the creation of the geometry and kinematics of humans, as well as their environments.

Figure 2.1 depicts basic components of PLAID.

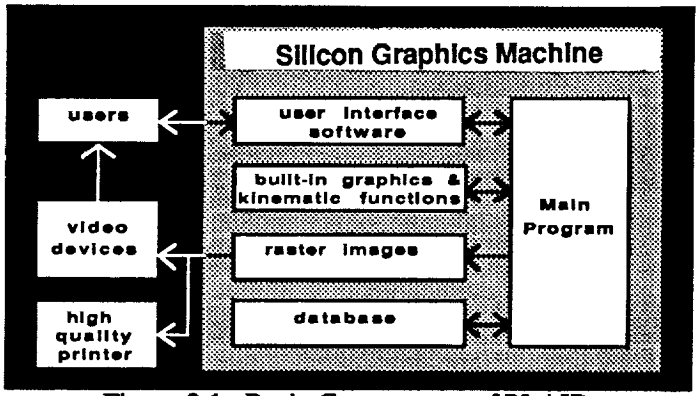

Figure 2.1. Basic Components of PLAID

2.1 ***Hardware Components.*** The system currently uses a local area network (Ethernet) of Silicon Graphics Iris workstations (IRIS)™ and personal computers, with connectivity to a network of DEC VAX computers. The workstations are high performance machines with hardware graphics rendering capabilities such as smooth shading, Z buffering and texture mapping. The other machines support image conversions for documentation purposes, as well as geometry and bitmap conversions for building, exporting and importing of models and images.

Hardcopy and video devices are used to produce imaging products. Full color prints and transparencies can be generated on Kodak XL7700 continuous tone color printer, Tektronix Phaser III color printer, and Tektronix 4693DX Digital printer. Computer generated animations are also created using Sony 3/4 inch tape recorders and 1/2 inch VHS recorders.

Use of remote video lines and the JSC site-wide computer network enable the PLAID system to support camera viewing simulations at the Space Station Mockup and Training Facility.

2.2 ***Software Components.*** Figure 2.1 shows some of the basic groups of software components of the PLAID system: user interface functions, database management functions, and graphics and kinematics functions.

The user provides the PLAID software with model information such as decomposed solid shapes, dimensions, color, degrees of freedom (rotational and translational capabilities), and interconnection relations. User commands can be stored as scripts and executed in a batch mode for complex and/or redundant operations and unattended operations.

The database management functions provide controlled access to the various projects and categories. The access control allows multiple users to share models at various stages of development with minimum conflict. The databases used in the PLAID system are: (i) the payload components database for both shuttle mission and space station projects, (ii) anthropometry database for human astronaut models, (iii) general space station and space shuttle components database and (iv) individualized databases used for special projects and research applications.

Graphical functions are varied. The user can generate wireframe views, hidden line views, false color solid model views, true color solid model views or a variety of all the views on a model by model basis. Models can also be made transparent for enhanced visualization capability. The graphical functions make use of the specialized graphical capability of the hardware.

Kinematic functions are used to control motion in the models. To simulate the SRMS, the inverse kinematics algorithm for the SRMS is integrated into the system so that the motion is accurately modeled. A general purpose inverse kinematics algorithm is used for other kinematic systems (for systems greater than 6 degrees of freedom) such as the human arm. All the kinematic systems can have their components, such as joint limits, selectively constrained by the user.

Other functions available in the system provide analyses for clearance, collision detection, quantitative lighting, human vision and human reach envelopes.

3. Capabilities

Currently PLAID provides for four basic capabilities: (i) simulation, (ii) lighting illumination, (iii) visualization, and (iv) evaluation. These capabilities help provide a realistic testbed for testing, validation, and verification.

Simulation, in scientific applications of computer graphics, is the process of interpreting the performance of an action-related task into a sequence of visual images representing an approximation of the activity. The current PLAID database enables the creation of specific viewing scenarios and animation sequences, which provide simulation visuals for mission planners to develop task procedures, and engineering designers to verify ideas and develop configuration design.

Lighting illumination is the simulation of light sources as an additional feature of the simulation capability. A light source can be characterized by its intensity, location, degree of dispersion, and the medium it travels in. These physical properties are transformed into numerical parameters that PLAID software uses to create shadows, reflection, and backlight.

Visualization is the process of arranging images in such a way that a human can see and understand the scenario. For a single view, what is in the scene is what a human would see. For an animation, a sequence of images is displayed sequentially at a frequency between 30 and 60 frames per second. This manner of display creates a perception that images in the scenario have motion. A person who views the sequence of images thinks that he/she is seeing a scenario in real motion as in a movie.

Evaluation is the final step of confirming the validity of a task. For kinematic validity, this is the confirmation of an existing solution free of collision. For lighting validation, the extent of visibility relative to light sources is evaluated.

4. Current Projects and Specific Examples

The PLAID system is currently utilized to support several engineering space projects. Some examples are: the verification of mission planning for the shuttle flight STS-51, the evaluation of reach envelopes for the SSRMS situated at different locations during the assembly sequence of the new redesigned options, and a lighting study of the space shuttle cargo bay from the Aft Flight Deck window view.

4.1 ***Shuttle Flight STS-51.*** Various mission plans have been examined for STS-51 utilizing PLAID, particularly for the Advanced Communications Technology Satellite/Transfer Orbit Stage (ACTS/TOS) spacecraft. An animation was produced of the ACTS/TOS satellite deployment from the payload bay, as well as the ultimate deployment of its solar arrays and antennas; it was to be used primarily for public relations purposes as requested by Lewis Research Center. The animation sequence depicted approximately eleven definitive stages of the spacecraft deployment, resulting in its fully operational stage, all of which is represented in a 5-minute video.

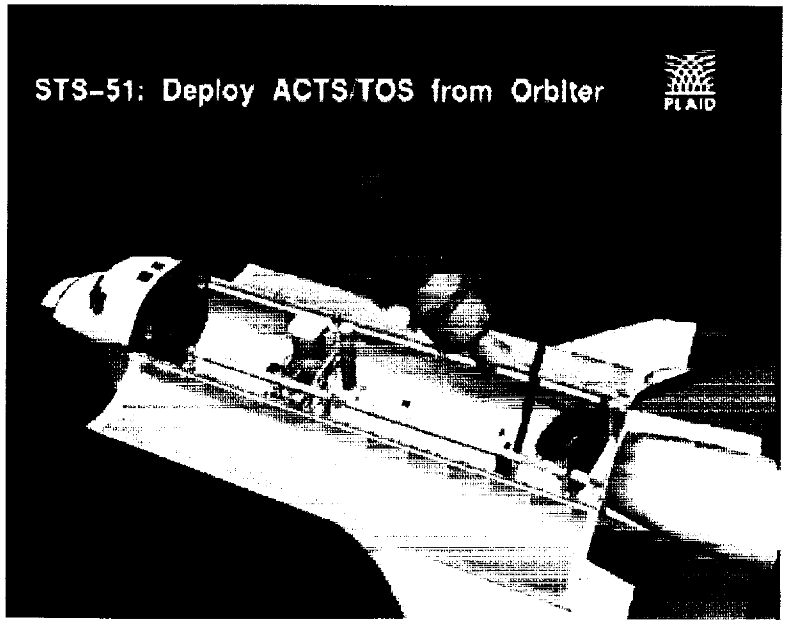

Figure 4.1

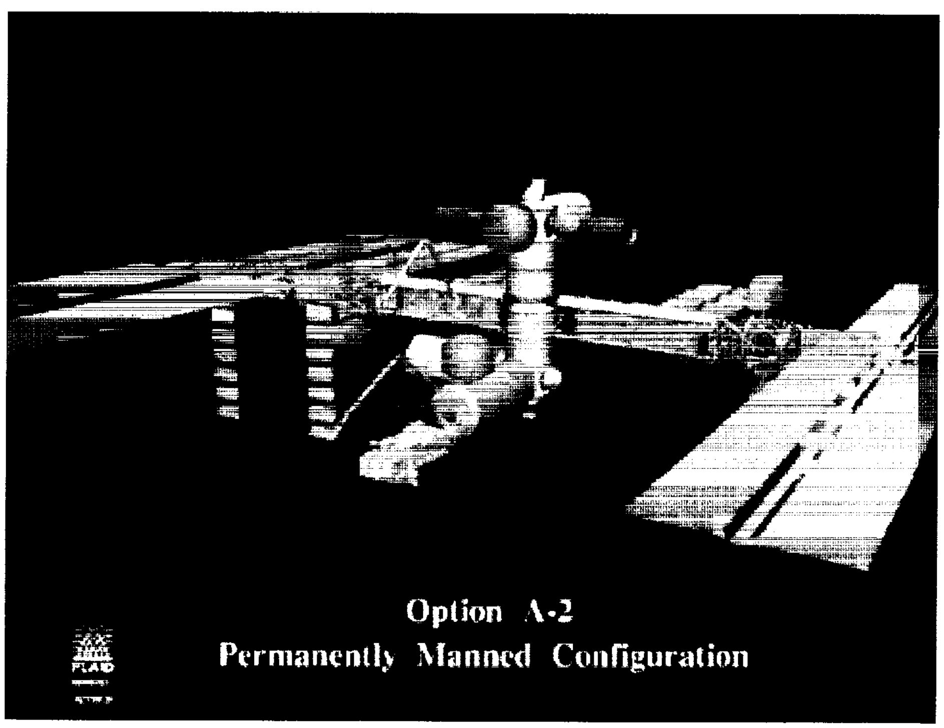

Figure 4.2

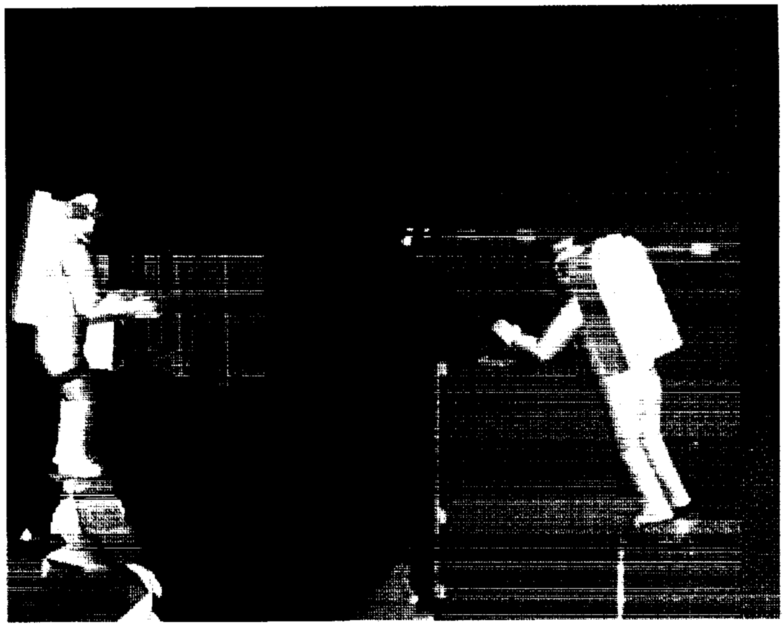

Figure 4.3

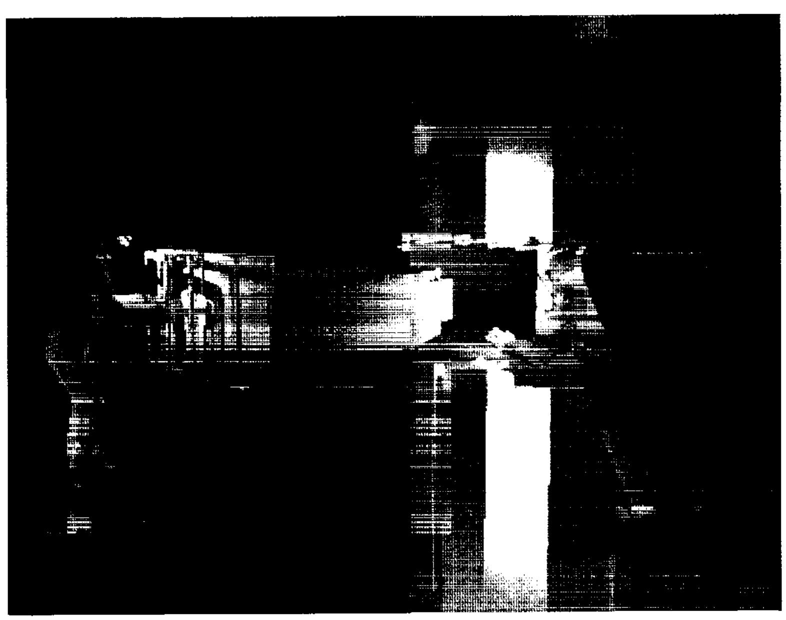

Figure 4.4

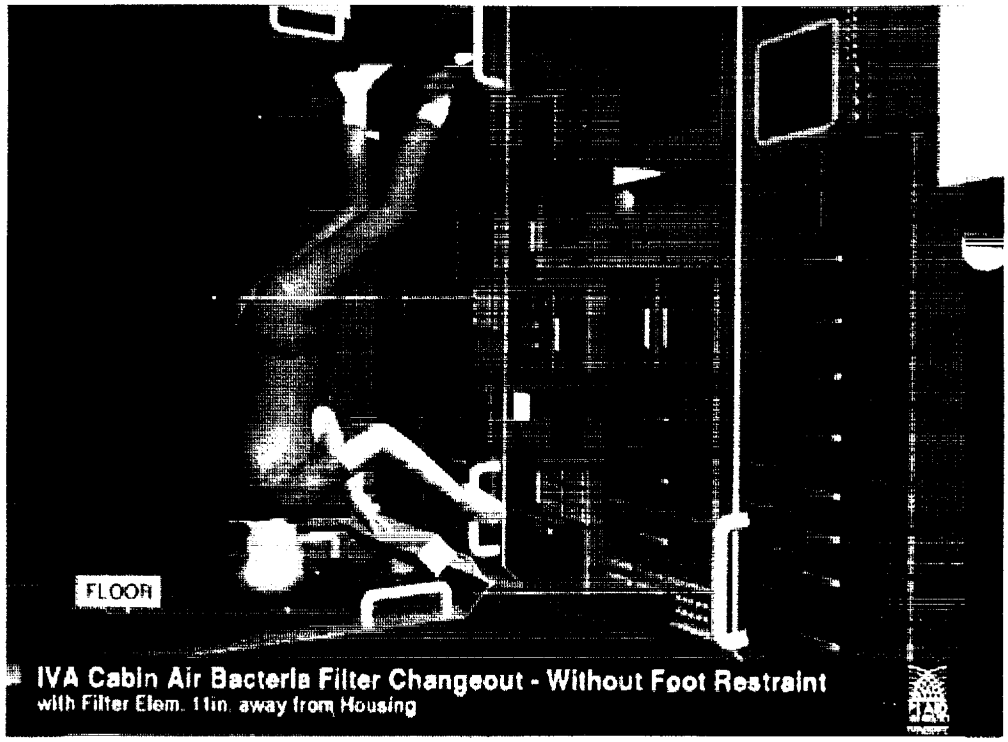

Figure 4.5

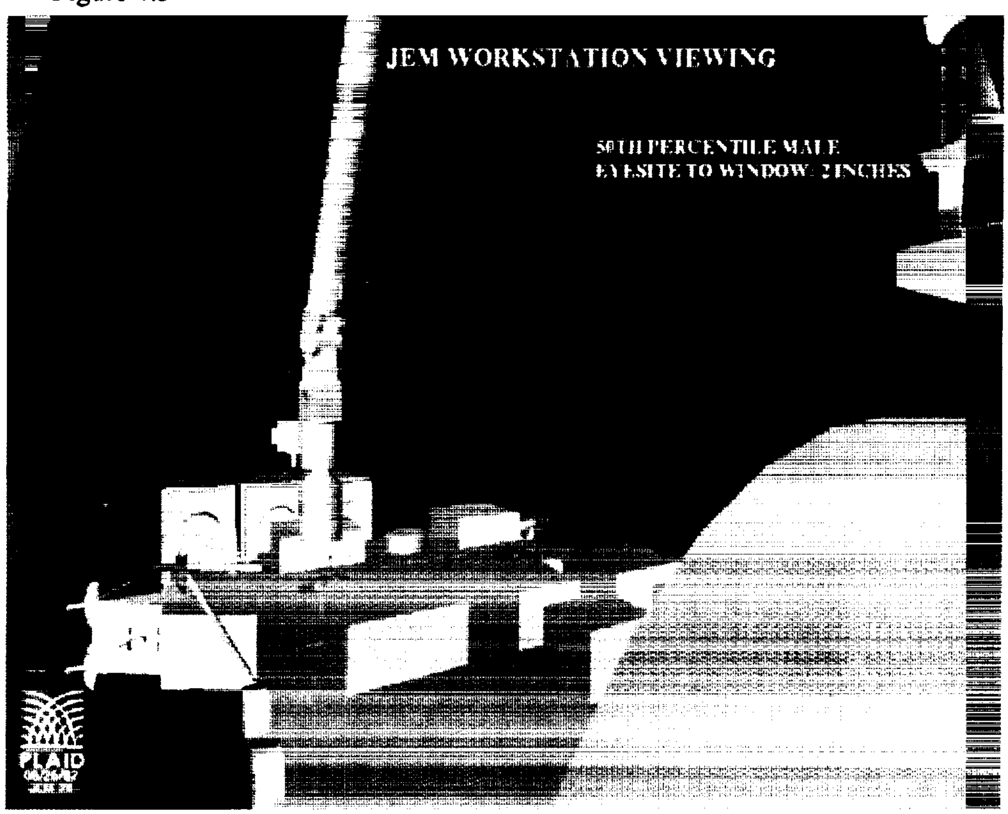

Figure 4.6

The view in Figure 4.1 illustrates a snapshot of the ACTS/TOS spacecraft being deployed from the orbiter bay.

4.2. ***Assembly Sequence of Space Station Redesign*** During the redesign phases, the space station assembly designs require almost continuous modifications. As a result, different sequences and concepts, both internally and externally, have to be evaluated in the effort to provide cost effective plans for various proposed configurations. The capabilities of PLAID to examine the designs from the payload manifest to the actual assembly construction stages, to simulate window and camera views to study visibility issues, and to provide virtual reality walk-throughs of the design enhance the overall planning and development of these redesign efforts.

The option A-2 station configuration displayed in Figure 4.2 illustrates one of the latest proposals being evaluated.

4.3. ***Lighting Study for EVA mission.*** A lighting analysis was conducted for the Hubble Space Telescope (HST) servicing mission, Space Shuttle Flight STS-61, to support pre-flight planning. Lighting is a crucial concern since the EVA astronauts must rely on the available lighting in order to conduct the changeout of the WF/PC and HSP/COSTAR components of HST. The components are of such size that they block the astronaut's field of view considerably, and the payload bay and forward bulkhead lights are all the lighting that exists when sunlight is unavailable. Various combinations of the bay and bulkhead lights were evaluated in the simulation of the changeout procedure. The results revealed that the forward and mid bay lights rendered no assistance with the present cargo configuration.

Figures 4.3 and 4.4 illustrate the difference in the shaded rendering with and without the lighting capability. This analysis exposes the more realistic representation of the lighting attributes at this proposed worksite. The results of this lighting analysis examplified the use of the lighting models with respect to complex visibility issues, and in the optimum selection of lights and payload arrangement.

4.4 ***Human Modeling Analysis.*** PLAID provides the ability to integrate an anthropometric scale-modeled human in the modeled geometric environments created on the system, in order to examine human performance issues. The anthropometric data is collected from astronaut candidates in the JSC Anthropometrics and Biomechanics Laboratory, and is used to generate human models with realistic joint limits and user-specified size characteristics. The models are utilized in EVA suit, as well as unsuited, to evaluate human-system interactions and reach envelope considerations.

The viewing analysis of the feasibility/clearance assessment of the IVA crewmember changing out the cabin air bacteria filter in the U.S. Laboratory module is depicted in Figure 4.5

4.5 ***Viewing Analysis.*** Viewing requirements are prime considerations for all aspects of space exploration. Both direct viewing via windows, orthogonal and isometric viewpoints, and indirect viewing via cameras constitute the majority of the analysis performed.

The maximum visibility of a 50th percentile male viewing through the Japanese Experiment Module (JEM) window is represented in Figure 4.6.

5. Research Activities

5.1 ***Virtual Reality.*** Virtual reality gives the user the illusion of immersion in a computer-generated environment. The illusion is created by generating three-dimensional stereo images from a viewpoint controlled by the user's actual head position.

Virtual reality has been added to the PLAID facilities [9], on both hardware and software levels. Three dimensional visual immersion forms a natural extension of the PLAID graphics facility's visualization capabilities. An investigation is being made of the advantages and limitations of virtual environments for planning and analysis of prescribed EVA/IVA tasks.

5.2 ***Human Modeling.*** The goal of research activities at the GRAF is to create a realistic human computer model. Present work is directed mainly towards developing a human strength model and controlling motion of the computed figure to produce realistic motion, especially the arm reach motion.

Research work at the GRAF lab is a cooperative effort between various NASA facilities and universities. Current and past cooperative efforts include: (i) human modeling research with the University of Pennsylvania, (ii) muscle research with the University of Texas at Austin, (iii) strength measurements with Texas Womens University, (iv) realistic human reach envelopes with NASA/JSC Work Station Design Group, and (v) lighting model validation studies with NASA Lighting Lab.

A dynamic strength model for the arm based on empirical data has been developed [10]. Maximum isolated torque data for the shoulder, elbow and wrist joints were collected using a LIDO dynamometer. These data were reduced into a tables of polynomial coefficients and organized for convenient storage and retrieval. Strength prediction equations between a person's lean body mass and the maximum torque that can be exerted have been developed. In addition maximum isolated torque measurements for the waist, hip, and knee are currently being collected. This strength model could be used to determine if an individual has the amount of strength needed for a task. Future work will extend this model to allow estimations of the amount of work done and possible fatigue during a task.

Essential to accurate reaching with the arm is a comprehensive model of the shoulder. The PLAID model of the shoulder simplifies the complex motion into two joints, a clavicle joint and a humerus joint. Equations determine the interdependent motion of the clavicle and humerus, allowing them to move together. Measurements of reach sweeps for 14 subjects compared to within, on average, 1cm of the computed reach [5].

To simulate realistic human reaching, a rapid algorithm has been developed for computing joint angles of the computer human figure. This algorithm can be used with magnetic trackers on an actual person in a virtual reality environment to allow rapid and accurate motion of a human computer model. The research work serves two purposes: (i) making the process of creating an animation less time consuming and (ii) producing a more realistic motion of the EVA astronauts.

6. Conclusion

It has been demonstrated that PLAID software is a valuable computer aided engineering tool for the NASA community. The wide range of support provided by the graphics facility has further illustrated favorable acceptance from engineers working in various space projects. The ongoing research efforts and extensions to the PLAID capabilities in the future will insure that the PLAID users are provided state-of-the-art tools.

Acknowledgments

We wish to thank Dr. Ann Aldridge and Mr. Mike Goldsby of Lockheed Engineering & Sciences Company, and Dr. Trung Pham of McDonnell Douglas Aerospace Company for critical review and comments on this work. Also, we wish to thank Mr. Edmond Khouri of Lockheed Engineering & Sciences Company for encouragement and support.

All pictures used in this paper are the results of teamwork by A. Aldridge, S. Chedid, M. Goldsby, L. Hancock, M. Helm, J.J. Huang, J. Maida, J. Nguyen, A. Pandya, K. Tran, and A. Wheaton.

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