SUMMARY OF MIT SPACE SYSTEMS LAB

EXPERIENCE IN EVA SIMULATIONS

David Akin

Department of Aeronautics and Astronautics
Massachusetts Institute of Technology
Cambridge, MA 02139

The MIT Space Systems Lab has been conducting an extensive series of tests on human construction operations in space. The primary questions addressed in this research are: what are the capabilities of humans working in weightlessness?; what is the best mix between man and machine in space?; and how much time will it take to perform the basic operations of space construction? To answer these questions, the Space Systems Lab has performed experiments at MIT, in the neutral buoyancy simulation facility at the NASA Marshall Space Flight Center, and in parabolic flight on board the KC-135 aircraft of Johnson Space Center.

In order to have confidence in the results of the neutral buoyancy simulations, a first goal of this research was to determine how well neutral buoyancy simulates true weightlessness. A computer model of the human body was developed for this purpose. This model predicted the dynamics of a person performing assembly-type tasks both underwater and in space, so that the two environments could be compared quantitatively. The model was validated using pressure suits in the Marshall neutral buoyancy tank, and in parabolic flight on board the NASA KC-135. KC-135 experiments included both linear translation of large masses (similar to the body dynamics tests underwater), and angular alignment of high moments of inertia. Results of this analysis showed that neutral buoyancy is a good simulation of true weightlessness when the masses manipulated underwater are large (greater than about 50% of the test subject's body mass).

Learning, productivity, and fatigue have all been identified as critical parameters for determining the capabilities of humans in EVA. In all of the MIT neutral buoyancy simulations of construction operations in space, learning rates have been shown to be consistently higher than expected. The average rate established was approximately 70%, with a low of 55% and a high of 80%. This compares with a typical 80% learning rate for aerospace assembly operations on earth, and represents both learning how to operate in the pressure suit (Skylab A7LB's), and learning how to assemble the structure. Productivities were established using a 36-element tetrahedral truss structure, and a variety of configurations of a 55-element "tinkertoy" type structure, assembled by a single test subject or a two person team. Productivities above 1000 kg/crew hour were demonstrated, with an average for extended operations around 500-600 kg/crew hour. Productivities for similar earth operations are typically 50 kg/crew hour. A fatigue estimate was established by having a single person perform a four hour neutral buoyancy run. This indicated that fatigue does degrade productivity over time, but an extrapolated rate of 400-450 kg/crew hour could still be maintained by a test subject working at a steady pace during an eight-hour EVA.

A study was also performed in the Marshall neutral buoyancy facility to determine how the hardware used in the assembly procedure affects learning and productivity. Similar structures were assembled both in foot restraints and without foot restraints. This indicated two important results: even after learning has bottomed out for a test subject working in foot restraints, he still has much to learn if he starts working out of foot restraints; and while productivity may be marginally higher for a subject in foot restraints, nevertheless, foot restraints are not necessary at all work stations. The structural hardware can also have an effect on productivity. Tetrahedral truss structures which rigidize themselves as each tetrahedral subcell is assembled, are easier to build than prismatic lattice structures which necessitate the use of cables on each square face for stability. It was also found that high-mass bulky equipment packages could be manipulated without too much difficulty. A parametric study of the effect of beam length and moment of inertia on productivity was performed with the following result: effective moment of inertia underwater, which includes the effect of both drag and true moment of inertia, is probably the single most important parameter affecting assembly time in neutral buoyancy simulations.

In order to investigate the optimum man/machine mix in EVA structural assembly, a variety of assembly aids have been tested in neutral buoyancy. A hand-held maneuvering unit was used as an aid to structural alignment tasks, and was satisfactory in that task. A "cherry picker" manned remote work station was constructed, and tested on the shuttle remote manipulator simulator at the Marshall Space Flight Center. It proved valuable as a mobile work platform, but was limited by the geometry of the RMS, and by difficulties in interfacing between the test subject and the RMS operator. A manned maneuvering unit was tested repeatedly at NASA Marshall, and proved to be an effective and useful tool for structural assembly. The presence of an MMU led to increased subject mobility, higher safety factors with less time impact (less requirements for work site restraints), and greater ease of supplying the assembly subjects with structural components. Tests were also performed on optimal hand controller placement and design, and on the use of a head-up display to provide MMU system status.

All assembly runs were videotaped, and time-and-motion data was collected from each of the test sessions. This data indicated that the task requiring the largest block of time for all assemblies (50%) was structural element alignment, but this is a strong function of connector design. Subject translation between work stations was performed by hand over hand maneuvering along previously assembled parts of the structure. This was not a problem either in terms of time required (20%) or because of applied loads. Loads applied to the structure during assembly were measured using strain gauges installed on one of the structural elements. Peak loads were generally found to be moments applied to a structural element after one end was attached and while the other end was being worked on.

After four years of research, it is the conclusion of the MIT Space Systems Lab that no significant human factors issues limit the utility of extravehicular activity, and that the use of crew members in EVA assembly of space structures is an effective and desirable use of the versatility of humans in space operations.