

EASE

**Experimental Assembly of
Structures in EVA**

Overview of Selected Results

Presented by

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at the

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EASE Objectives

It should be emphasized at the outset that EASE was never intended to be a structural experiment: the objective of the experiment was to test, in as quantitative a manner as possible, the ability of crewmen to perform in the extravehicular environment. Although this capability has been demonstrated repeatedly on prior EVAs, EASE was intended from the beginning as a measureable activity, with a wealth of data obtained from extensive prior neutral buoyancy experience. The results to be obtained were intended to range across the spectrum of possible disciplines, from the "top-level" results of overall time correlation to detailed reconstruction of body motions and calculation of crew externally-applied forces and moments on the hardware.

EASE Objectives

To investigate and, to the extent possible, quantify the capabilities and limitations of humans in the extravehicular environment

- **Performance**
- **Adaptation**
- **Physical workload**
- **Dynamics**
- **Timelines**
- **Simulation media**
- **Task aids**

EASE Experimental Protocol – 1

This chart, and the following one, reconstruct the experimental development decision path for the MIT Space Systems Laboratory research program which led to the EASE experiment. There was no reason to explore simulation correlation for those activities in which the simulation media did not have any effect: tasks of this type typically deal primarily with detailed manual and digital dexterity. The choice made was to rather focus on tasks requiring the use of major muscle groups, and significant interaction with the local environment. Structural assembly was chosen as an ideal trial task for these types of motions. The experimental approach was to first model the motions mathematically in both neutral buoyancy and flight environments, validate the model in parabolic flight on the NASA KC-135 aircraft and underwater, then use the model to design and scale the hardware for maximum dynamic correlation between the two environments. This hardware was then used for six years, in the development of an extensive data base on human performance in neutral buoyancy simulation of EVA structural assembly tasks.

EASE Experimental Protocol – 1

- **Focus on tasks in which the unique characteristics of the environment are significant**
 - **Gross physical motions exercising major muscle groups**
- **Choose a task which maximizes desired motions and minimizes task-dependent metrics**
 - **Structural assembly**
- **Use simulation media to develop in-depth understanding of the physical principles**
 - **Body dynamics models**
 - **Dynamically scaled hardware**
 - **Six-year neutral buoyancy data base**

EASE Experimental Protocol – 2

The mathematical models discussed on the preceding page required the use of hardware with a large mass and moment of inertia (in comparison to the suited mass of the crewman). However, several procedural questions had to be answered to finish the hardware specifications. It was desired to make the task reasonably challenging for the subjects: for this reason, the connectors were designed with a minimum of allowable angular misalignment (approximately $\pm 1^\circ$). While most of the NASA EVA work station designs studied incorporated foot restraints for almost all work sites, it was determined that this would pose an unacceptable burden if made to be a universal requirement, especially for large structures such as extensive space platforms. For this reason, the assembly task was designed to be primarily performed without body restraints, and significant effort placed on means of identifying crew adaptation to the space environment. With the approval of the EASE flight experiment, the prime objective in hardware design was to maintain the same mass and moments of inertia as the neutral buoyancy hardware, to maximize correlation to the existing data base. This, to a great extent, fixed the design of the flight hardware. The required masses precluded flying a large number of components for an extended structure, such as had been assembled in tests at MIT and NASA Marshall. Instead, enough hardware was flown for a simple tetrahedron (with spares), and repetitions obtained by repeated assembly and disassembly of this basic structure. Integration limitations prevented Orbiter electrical or data interfaces with the EASE hardware, and forced the design of a data collection system based on existing visual recording means (video and film cameras).

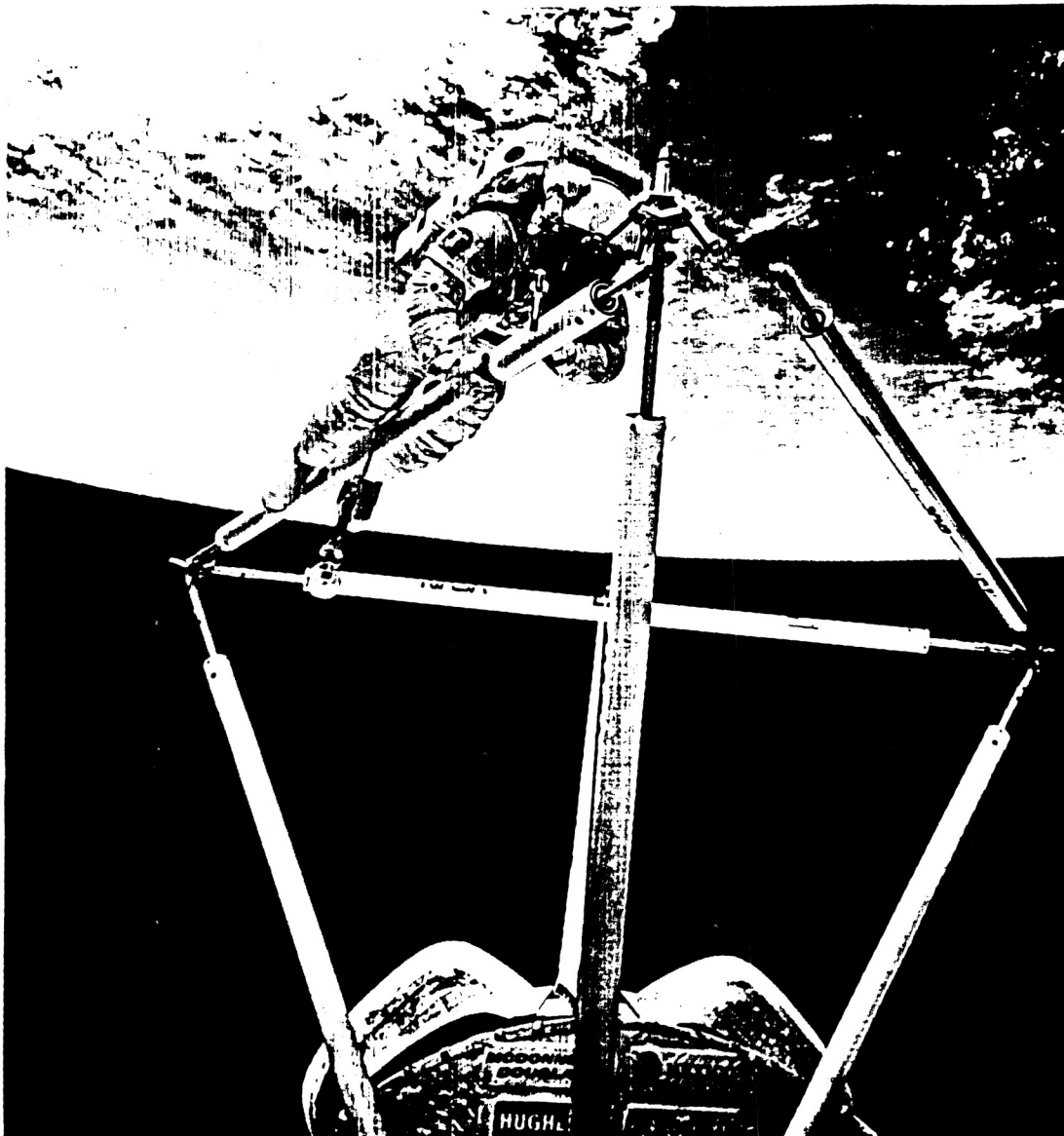
EASE Experimental Protocol – 2

- **Tailor the tasks to stretch the capabilities of the test subjects**
 - **Low-tolerance connectors**
 - **Lack of restraints**
 - **High masses and moments**
- **Design the flight experiment to validate and correlate the simulation experience**
 - **Maintain configuration, masses, and moments from neutral buoyancy**
- **Work within the limitations of the STS system**
 - **Fly simple structure and test repetitively**
 - **Use visual methods of data collection**

EASE Assembly On-Orbit

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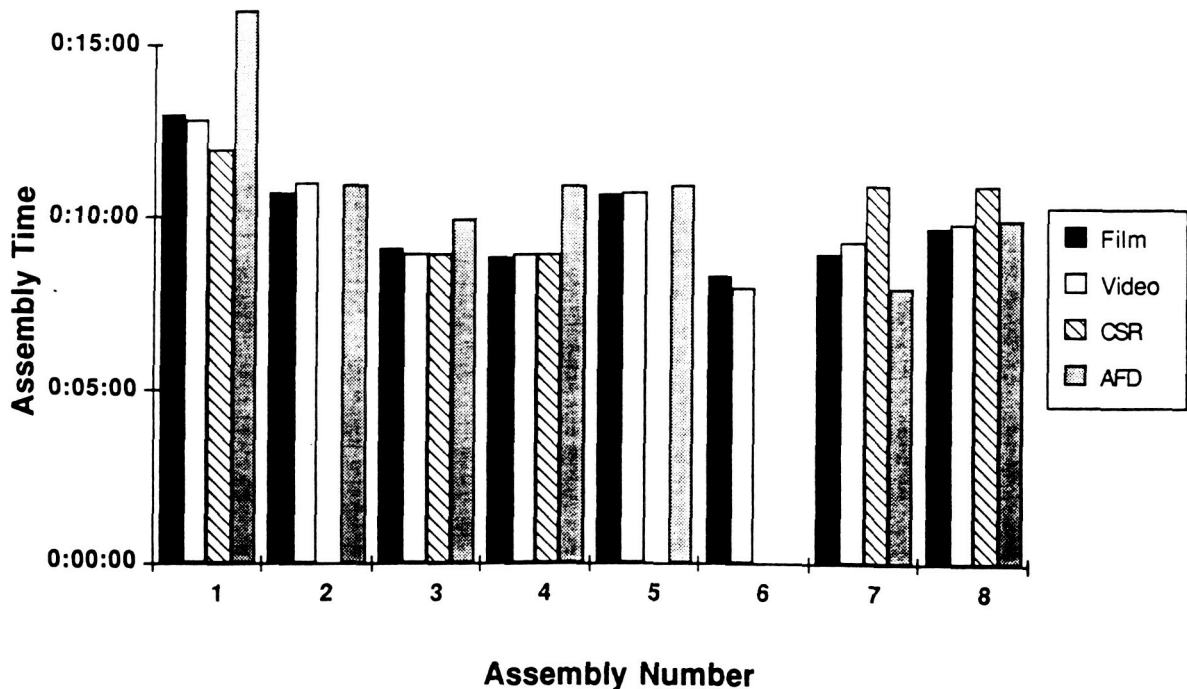
This photograph shows the completed EASE tetrahedron on-orbit. Of particular significance is the crewman at the top of the structure (referred to as the "high man"), working without fixed body restraints. The crewman at the base cluster ("low man") did have a foot restraint, to ease access to the base cluster and to hardware restraint fixtures. A completed EASE structure has a mass of 180 kg; the length of an assembled side of the structure is 3.87 m.



EASE Assembly Times Comparison of Measurement Sources

Of the most immediate concern was the correlation of assembly times on-orbit with those of the same crew during pre-flight training. Four means of measuring these flight activity times were available: post-flight times could come from the video images (with superimposed Greenwich Mean Time), and from the stereo 16mm film images (shot at 1/4 normal frame rate). Real-time estimates were made in the Customer Support Room ("CSR") during the mission, but these times were suspect due to lack of communications with the orbiter during significant portions of each orbit. The 61-B mission pilot also timed EASE activities real-time, using his wristwatch: this data source was also suspect, due to his many other duties of more pressing import. Due to the controlled nature of the post-flight timing sources, this data was used for subsequent analyses.

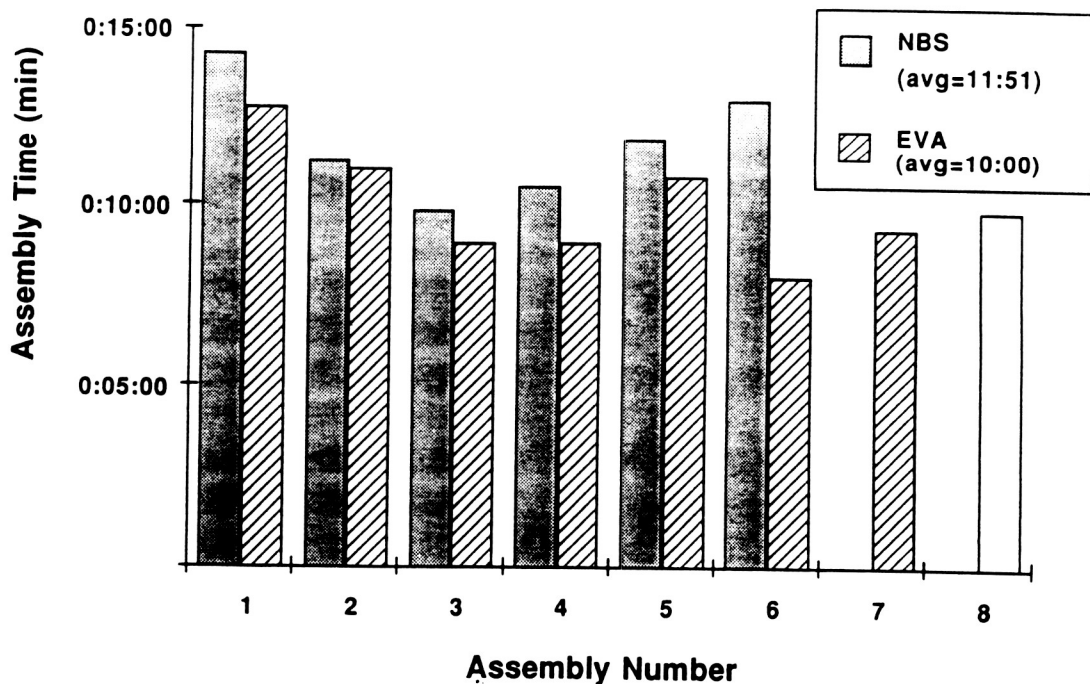
EASE Assembly Times Comparison of Measurement Sources



Neutral Buoyancy Simulation – Extravehicular Activity Correlation

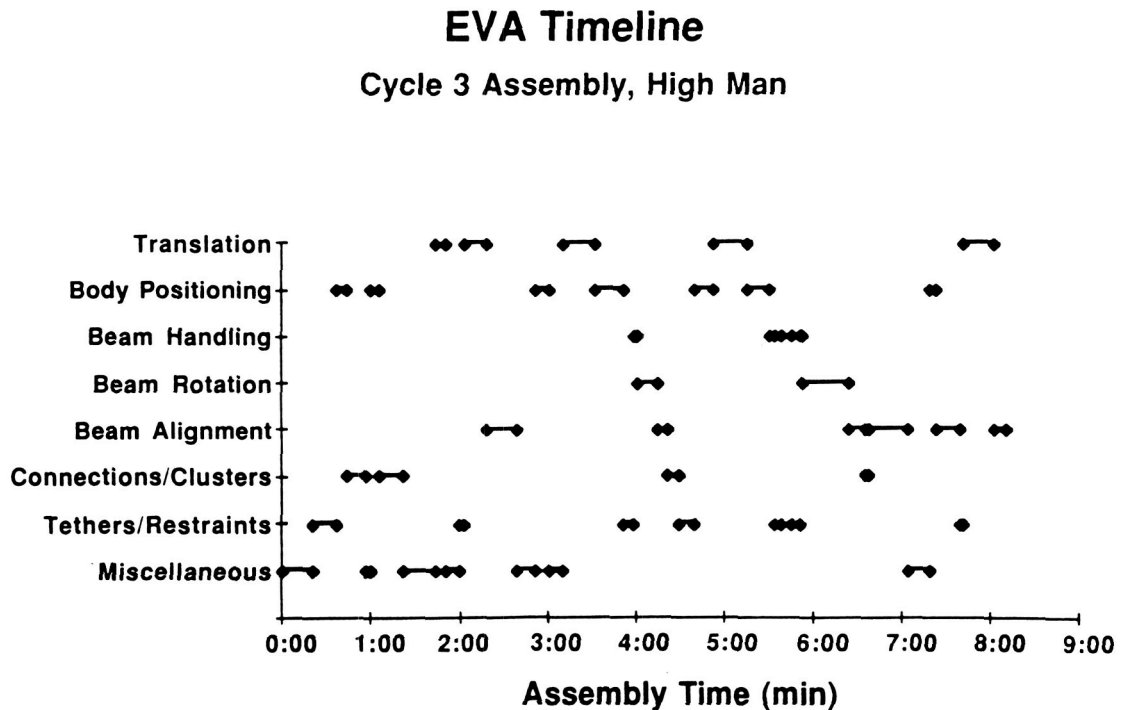
This chart compares the assembly time established on-orbit to those demonstrated by the flight crew during an integrated simulation one month prior to flight. This integrated simulation is used as the most directly applicable ground experience to the overall EVA procedure: effects of the simulation (such as malfunctions artificially induced for training purposes) have been factored out of the assembly times shown here. The six assemblies shown for neutral buoyancy represent the planned scope of EASE activities: eight assemblies were actually performed on-orbit. In both cases, the crewmen maintained their positions throughout the first four assembly cycles, then switched places for all subsequent assemblies. As may be seen, the times for each assembly on-orbit were less than that for the corresponding assembly in neutral buoyancy. On the average, the mean assembly time was 18% less in flight than in underwater simulation. The same trends are evident in both cases: decrease in assembly times over the first few runs as the crew gets warmed up and learns their unique tasks; an increase in time for assembly 5, as the crewman change positions and are faced with new tasks; and a gradual lengthening of assembly times as the crew became fatigued in the later stages of the experiment.

NBS–EVA Correlation



Sample EVA Timeline

All EASE activities were broken down into the eight categories shown on this chart. Each of the video tapes were analyzed post-flight to categorize the activities of the crew throughout the EASE procedures. This is an example of a traditional timeline analysis, which shows the activity of the "high man" (crewman working without fixed restraints at the upper level of the structure) during the third baseline assembly of the EASE structure. This represents the raw form of the data, which is further analyzed in the following charts.

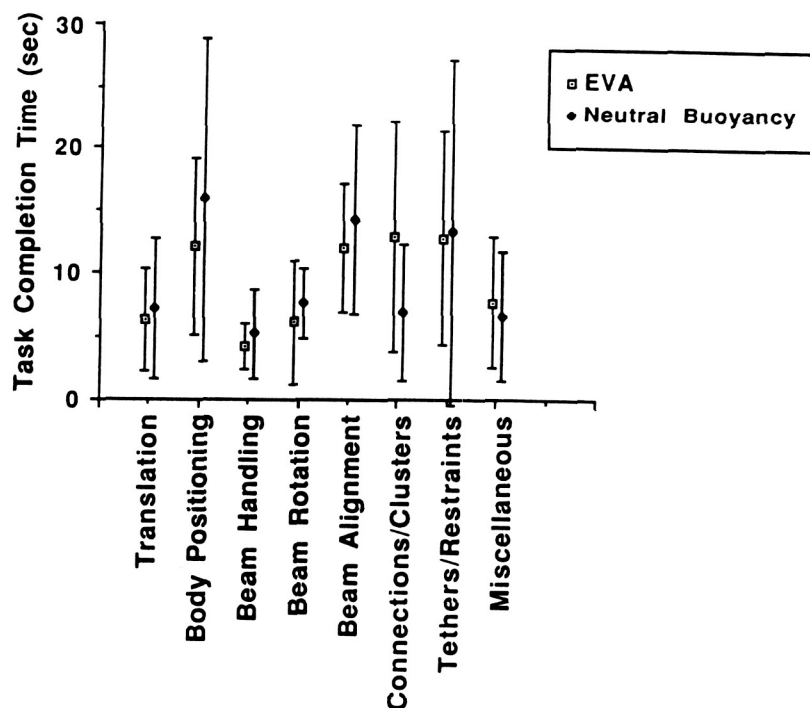


Correlation of Task Categories

In this example, the data from the "high man" position for all eight of the baseline assemblies was analyzed, along with the corresponding timeline data from underwater simulations prior to flight. The chart displays the mean and standard deviation values for each of the eight task categories. While some minor variances occur in the mean times per task between EVA and neutral buoyancy, the large size of the standard deviations in each case prevent more quantitative conclusions from being drawn from this data. Obviously, some further analysis must take place, incorporating the trends of the distribution of data in each category.

Correlation of Task Categories

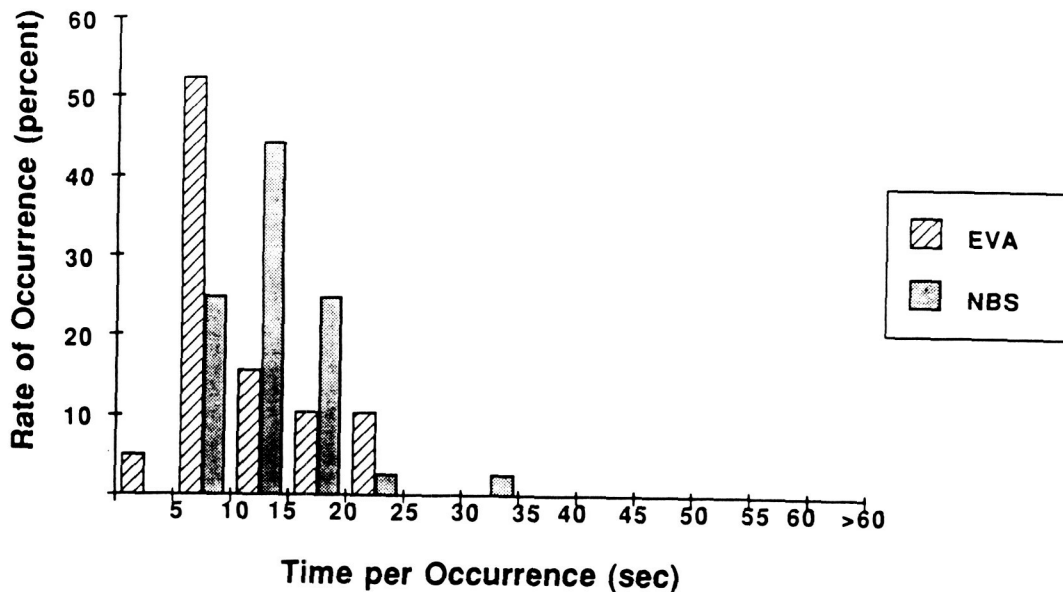
High Man, Assembly



Task Time Distribution – Beam Rotation Task

The EASE hardware was designed to emphasize the mechanical activities of assembly, particularly the manipulation of large moments of inertia. For that reason, the two most significant task categories were those of beam rotation (coarse motion of EASE beams from one end) and alignment (fine motion, prior to joint connection). Comparing the beam alignment task in space and underwater, this chart demonstrates that the neutral buoyancy simulation (NBS) case demonstrates greater mean time for rotation. This is due, in large measure, to the effect of water drag in resisting steady motion underwater. It should be noted that, due to the assembly procedures and configuration of the EASE hardware, all beam rotations included in this data base covered a total of 60° from start to finish.

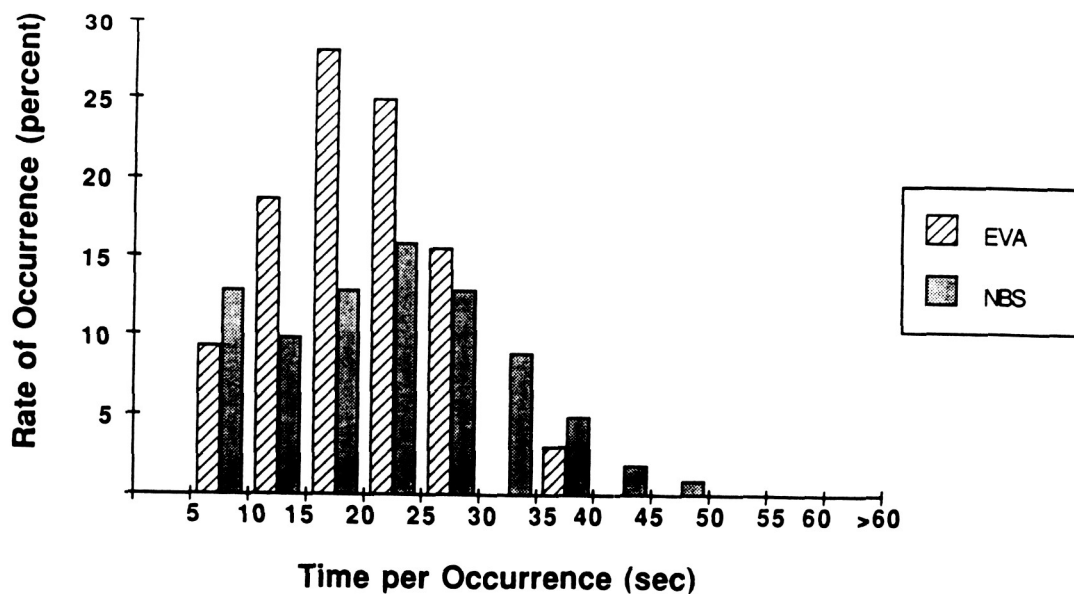
Task Time Distribution Beam Rotation



Task Time Distribution – Beam Alignment Task

The beam alignment task was assumed to begin with the completion of rotation at the approximate orientation of the cluster connection to be made with the beam. At that point, the crewman would initiate a series of fine torques to the beam, to align it to within the $\pm 1^\circ$ angular tolerance of the EASE connectors. As this chart illustrates, the distribution of times is very similar for the two environments, indicating that there are no major differences in the mechanics of this activity. However, the slightly greater mean time for alignment in neutral buoyancy is again probably due to the damping effects of the viscous environment.

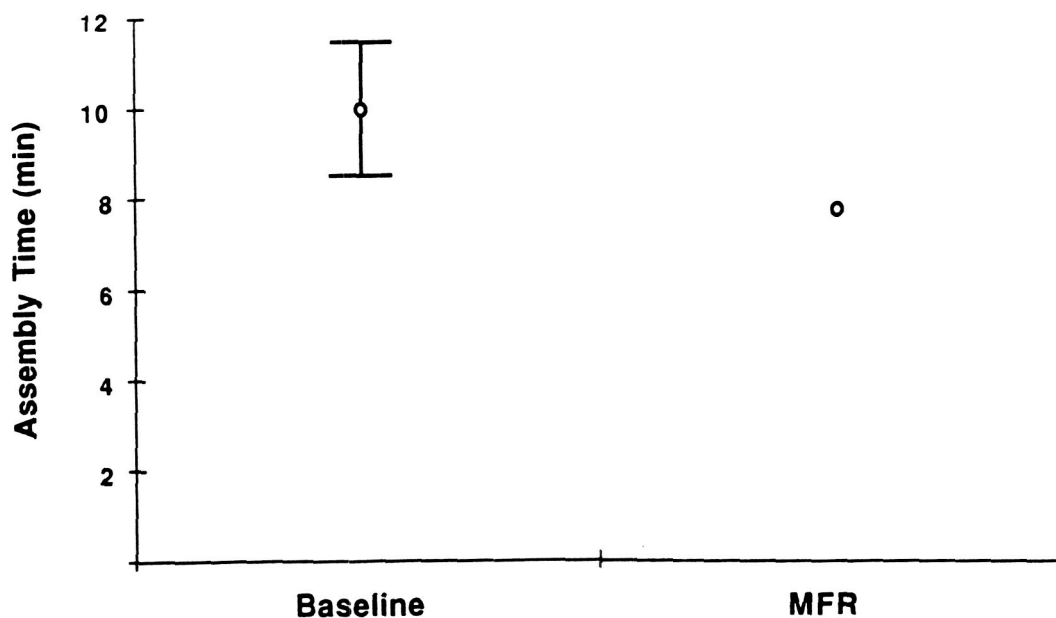
Task Time Distribution Beam Alignment



Structure Assembly Times

Eight EASE structural assemblies and disassemblies were performed on the first EVA, with an average assembly completion time of 10:00. This chart also shows that the standard deviation for these assembly times was approximately 1:40. During the second EVA, one EASE assembly was performed with the crewman in the "high man" position using the Manipulator Foot Restraints (MFR) attached to the shuttle Remote Manipulator System to provide a fixed body restraint during all activities. The time of this single assembly, corrected to eliminate other intervening tasks such as the double-beam manipulation, was 7:50, indicating that this operating mode could provide approximately a 20% savings in assembly time. This conclusion will be further examined in the following charts.

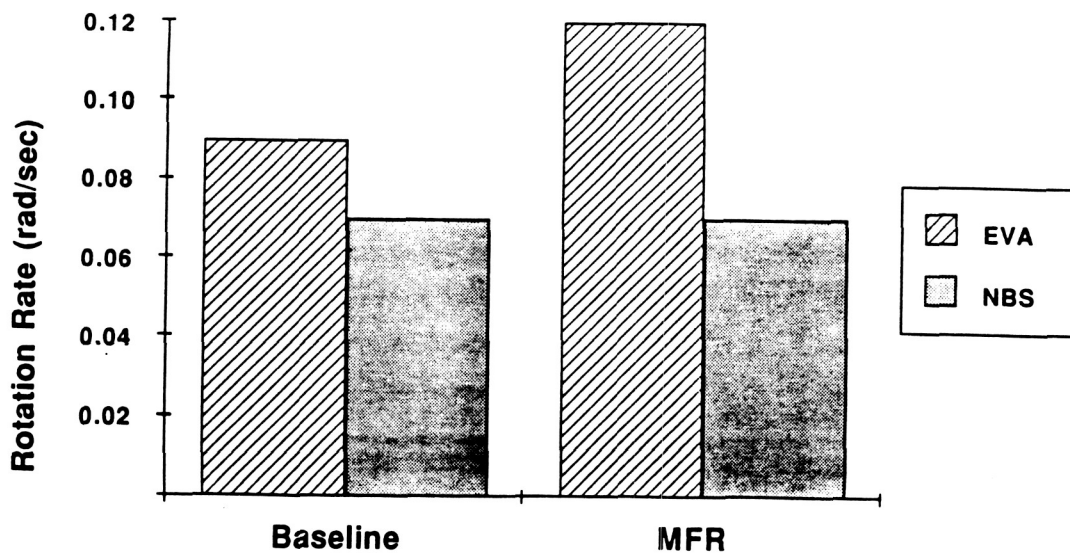
Structure Assembly Times



Beam Rotation Performance

A time and motion analysis of the beam rotation task showed the attached trends for both free-floating (baseline) and body-fixed (MFR) activities in neutral buoyancy and EVA. As may be seen, the form of restraints did not affect the rotation velocity of beams underwater, indicating that the crew tended to rotate the beams at an effective terminal velocity. In space, however, fixed body restraints allowed an average increase in rotation speed of approximately 20%. This form of large-scale manipulation is clearly improved by the presence of body restraints to resist the counter-torques of the rotation task.

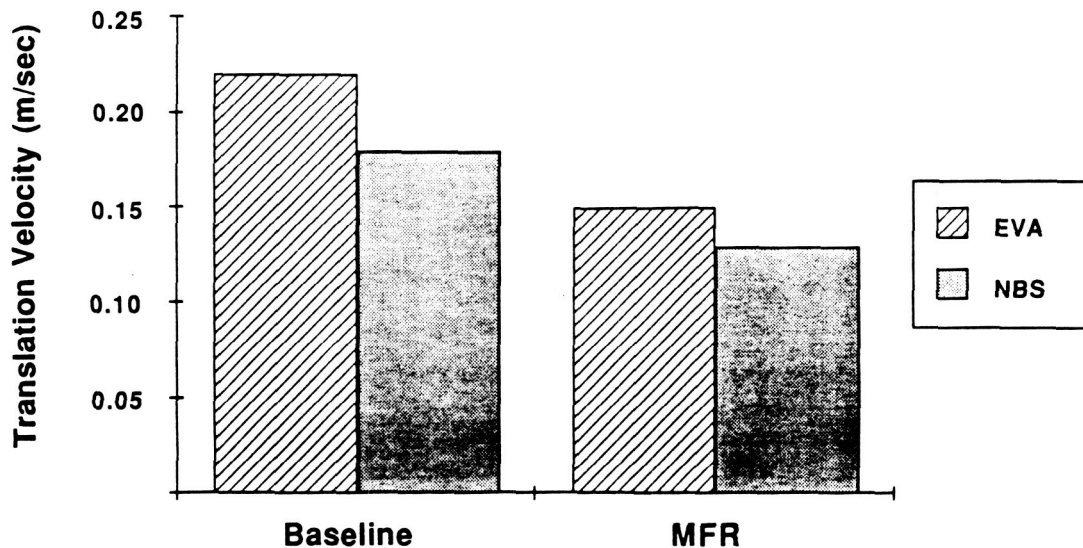
Beam Rotation Performance



Translation Performance

The other significant difference in high man assembly procedures between baseline and MFR activities was in the mode of translation between worksites: the crewman maneuvered hand-over-hand along the cross beams in the baseline case, and was moved by the RMS during MFR activities. This chart demonstrates the average translational velocities for both modes in neutral buoyancy and space. Translational velocity is slower underwater for both operating modes, again due to water drag, as well as non-standard control modes for the RMS simulator at the NASA Marshall Neutral Buoyancy Simulator. Of particular note, however, is the large difference in velocities between manual and RMS translations. Movement of the MFR was slowed by the standard operating speed of the RMS, as well as the forward location of the EASE/ACCESS experiment in the payload bay, which required significant attention on the part of the RMS operator to avoiding joint singularities.

Translation Performance

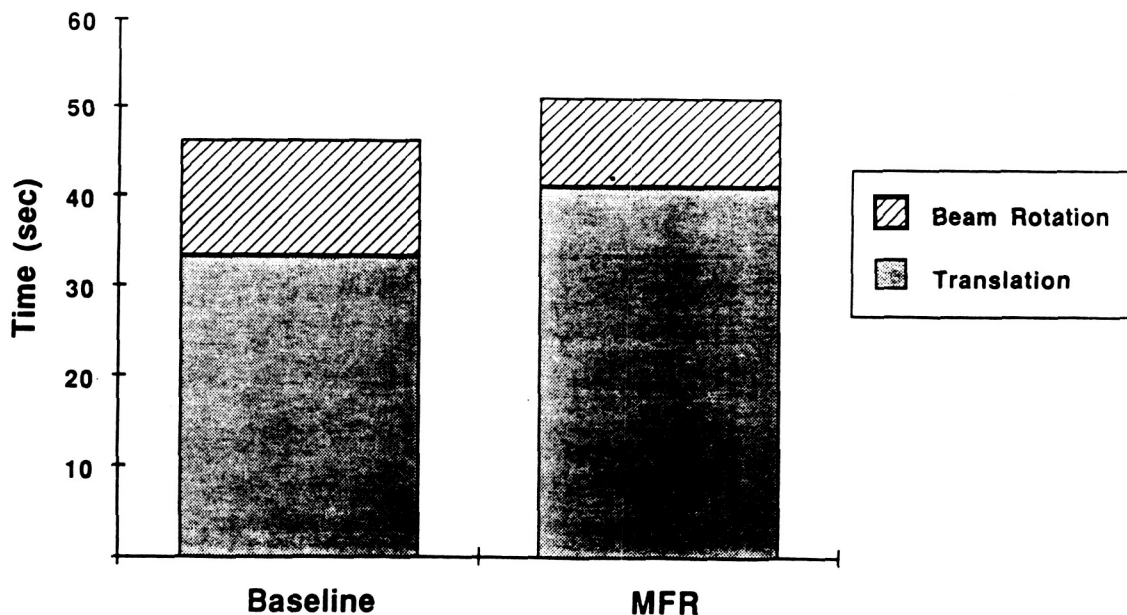


Assembly Task Performance

Combining the results of the previous two charts, the critical activity for the high man may be abstracted down to a simple compound task: translate along the length of a cross beam, and rotate the next cross beam into position. This occurs three times in the MFR assembly procedure, and twice in the baseline. As this chart shows, although the fixed body restraints facilitate the beam rotation task, any benefit is lost when including the slower translation rates achievable with the MFR and RMS. The net productivity of the high man goes down with the MFR, even excluding the overhead required with a third crewman (RMS operator) directly involved with the assembly. A review of all the data in fact indicates that the faster assembly of the MFR procedure is due to increased productivity of the lower crewman: since he is not required to translate up and down a riser to assist in the completion of the first cross beam, his time is better optimized in attaching riser beams and passing hardware to the high man.

Assembly Task Performance

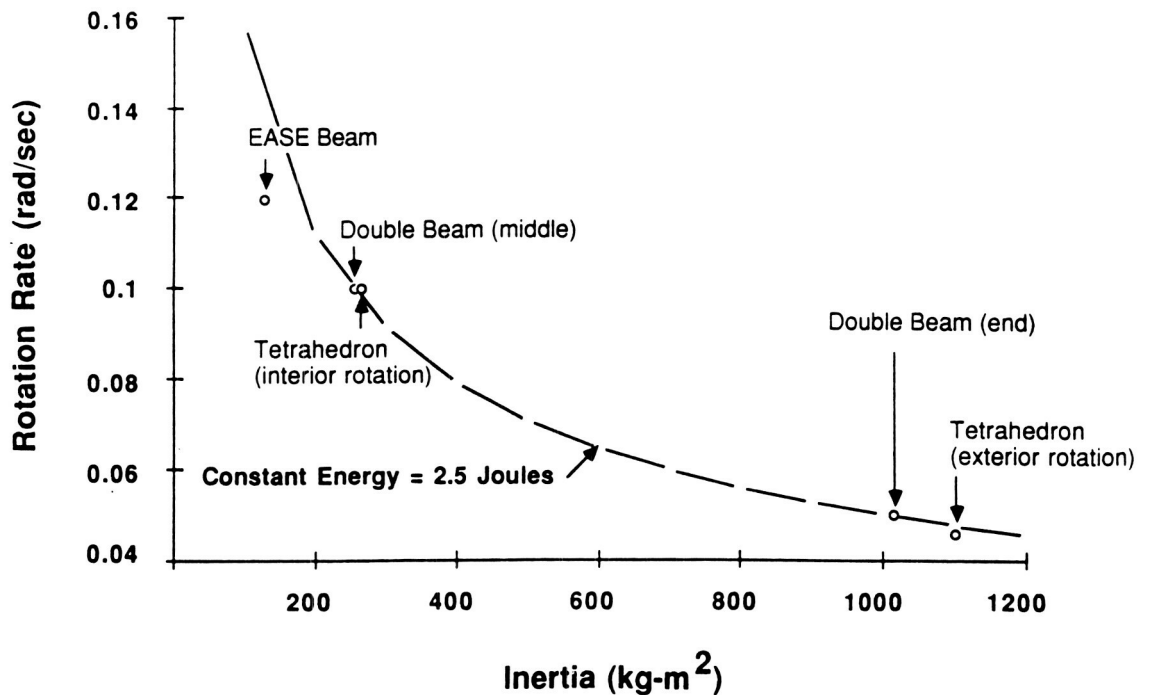
Translate Across Beam and Rotate Next Beam



Rotation Rate – Moment of Inertia Correlation

As mentioned earlier, one of the key elements of the EASE experiment was to obtain quantifiable data on the manipulation of large moments of inertia. During the two EVAs, the flight crew manipulated three different hardware items: the (normal) single EASE beams, a double EASE beam (simulating a space station heat pipe structure), and the complete EASE tetrahedron. The double beam was maneuvered through rotations at both the midpoint and one end; the tetrahedron was manipulated along internal and external rotation axes. In this way, data was obtained on five separate moments of inertia. Plotting the mean rotation rates versus moment of inertia, it was discovered that four of the five data points lay almost exactly along a line of constant rotation energy. It is extremely interesting that this should be the case, although it might be suggested that the crew mentally integrated the torque impulses to insure that all the various components, once moving, could be brought to a stop again with the same effort. One of the immediate priorities of the EASE data analysis team is to attempt to expand this correlation through obtaining other rotational data points from ACCESS or previous EVAs.

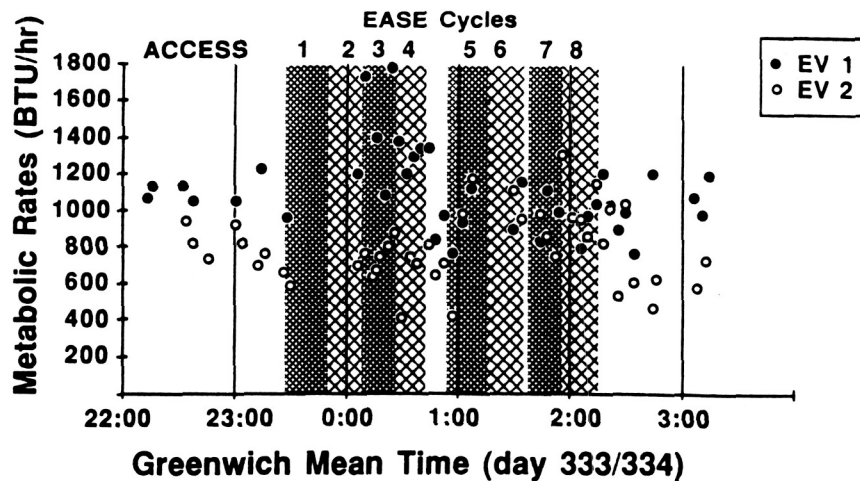
Correlation of Rotation Rate with Moment of Inertia



EVA 1 Metabolic Rates

The Extravehicular Mobility Units (EMUs) used on STS 61-B were for the first time instrumented for biomedical readouts. While the orbiter was in communication with the ground, suit parameters were read out at 2-3 minute intervals. This data was available post-flight for estimating crew metabolic rates, as a quantitative indication of workload. This chart shows the measured metabolic rates for both crewmen during the first EVA. Salient points to be noted include the fact that maximum metabolic rates for both crewmen occurred during the time they were working the "low man" position of EASE; minimum metabolic rates are observed while the crew are in the "high man" position without fixed body restraints; and that the data is too coarse for definite correlation of work loads with specific tasks. While this data seems to show that physiological demands during unrestrained assembly is even lower than that of the fixed assembly routine of ACCESS, it has been pointed out by the flight crew that this biomedical reading is not indicative of the fatigue of selected muscle groups, especially of the wrists and hands, which they noted during EASE high man activities.

EVA 1 Metabolic Rates



EASE Results

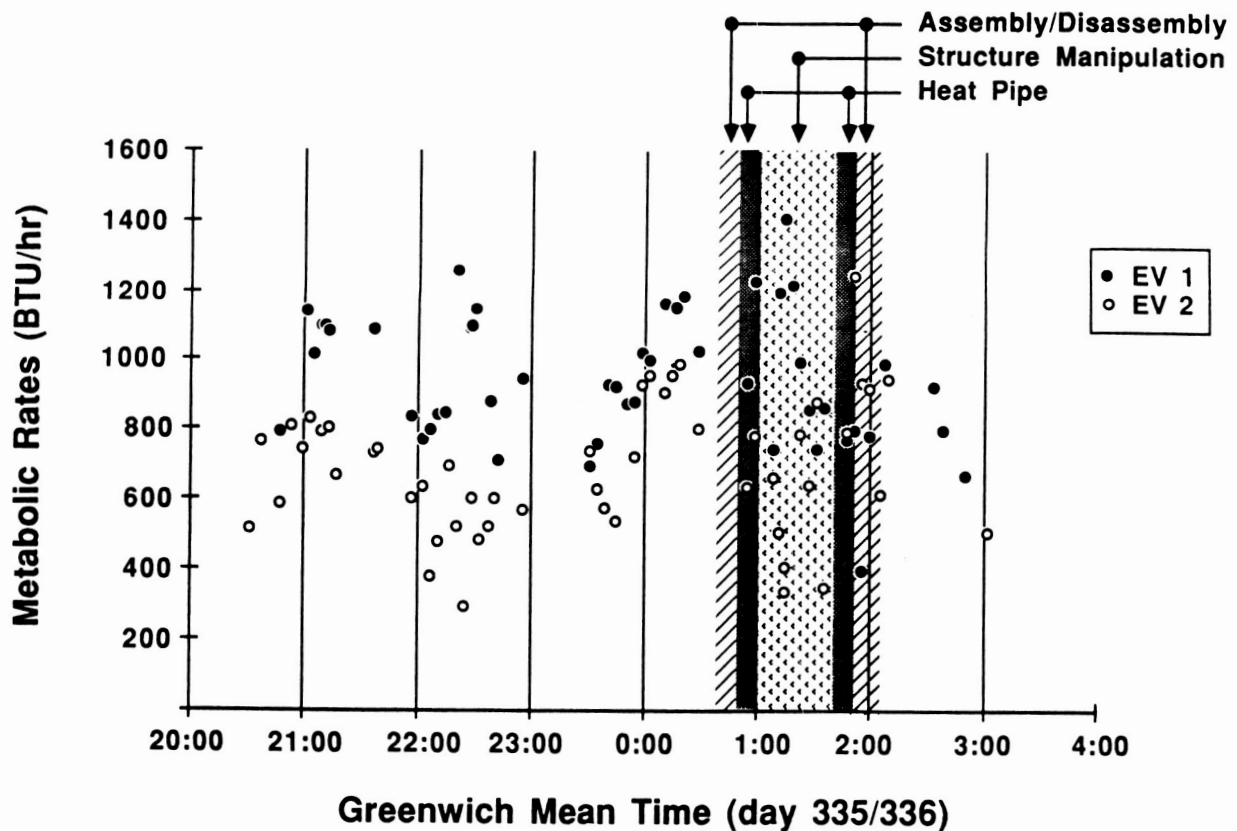
The bulk of this chart is self-explanatory. It should be pointed out that an analysis was performed, based on the stereo film data obtained during the baseline EASE activities, which enabled the estimation of energy being applied by the crewmen external to the suits. These energy levels are uniformly an order of magnitude below that shown by the metabolic rate instrumentation; even including generous estimates for basal metabolic rates and muscle group efficiencies, a substantial fraction of the crew work output is not evidenced by external motions. This energy can only have been dissipated in three modes: motions below the discrimination level of the stereo film reduction methods, closed-path kinematic loops, and work against the inherent stiffness and friction of the pressure suits.

EASE Results

- **The 61-B flight crew showed an 18% reduction in assembly time on-orbit vs. comparable NBS.**
- **Task analyses indicate no unequivocal differences between EVA and NBS for the component tasks of the EASE assembly. Time scatter for tasks is generally less in EVA than in NBS.**
- **Dynamics reconstructions show that mechanical tasks in space are performed faster and with less externally-applied effort than in NBS.**
- **Unrestrained EV operations, including manipulation of large masses and moments of inertia, are feasible.**
- **Comparative analysis shows that RMS/MFR assembly operations are marginally faster than unrestrained, due to procedural improvements.**
- **No quantifiable parameter from EASE indicates a marginal return from the wide-spread incorporation of body restraints which would justify their incorporation in all EVA scenarios.**
- **Rotation of large objects appears to be performed on a basis of constant rotation energy imparted to the task.**
- **The largest single factor in energy expenditure is the suit.**
- **No significant difference exists in energy output based solely on worksite configuration, although coarseness of biomedical data did not permit unequivocal conclusions.**

EVA 2 Metabolic Rates

As in the previous chart, results of the biomedical instrumentation system are too coarse for detail correlations with tasks. Maximum heart rates for EV1 again occurred during "low man" activities, most notably the replacement of a balky pip pin in the structure connection mechanism. Again, no mathematically significant difference can be detected in biomedical workloads between the MFR activities and corresponding high man activities of EVA 1.



Current MIT Research Objectives

This chart emphasizes that, while EASE has provided a wealth of data only briefly touched on in this presentation, it has opened up new vistas in space operations research. None of the objectives from the initial chart are resolved, although all have been addressed and much better refined by EASE data. Instead, the data from EASE have led to the development of a wealth of research topics dealing with human and machine capabilities in space. Of special note is the fact that the EASE experiment has for the first time allowed a quantitative connection to be established between the previously separate topics of anthropometrics, kinematics, dynamics, and energetics. Further study of the interrelationships of these areas holds the promise of a "Unified Theory" of space simulation, which would allow meaningful estimates of forces and energies required based solely on dimensional and kinematic descriptions of tasks.

Current MIT Research Objectives

To investigate and, to the extent possible, quantify the capabilities and limitations of humans *and machines* in the environments peculiar to space and space flight simulation

- Performance
- Adaptation
- Physical Workload
- Dynamics
- Timelines
- Simulation Media
- Task Aids
- Optimal Roles of Humans and Machines
- Control Station Design
- Novel Concepts
- Simulation Technology
- Automation Integration
- Microgravity
- Anthropometrics
- Unified Theory of Space Simulation

Participating in this discussion are Dr. Mary L. Cleave, RMS operator for the EASE/ACCESS experiments on STS Flight 61B and Lt. Col. Jerry L. Ross, EVA crewman for the EASE/ACCESS experiments on STS Flight 61B.

JERRY ROSS:

We've got some comments to make and then hopefully we've got some time for questions and answers. Well, I've kind of jotted down some notes flying in here the other day and I put them into two categories; one I called lessons learned and the other one is "surprises." Some of them can cross over either way and maybe don't fall into either category appropriately but let me go through them real quickly.

First one is the Weightless Environment Training Facility (WETF) is a good simulator. By that I mean the neutral buoyancy simulators we have - if you have high fidelity hardware in the tank and with the little bit of windage that we've learned through previous flight experience, you can really give a very good estimate as to how long a task will take, whether it's a reasonable task to do or not, and you can learn any potential problems pretty darn well.

Second comment I'd like to make is when we start considering things like space stations or starting to build larger structures in space, we need larger facilities. The WETF tank down at Johnson Space Center (JSC) is 33'x78'x25' deep and it barely satisfies the Orbiter cargo bay itself, when we start getting into payloads as small as ours or to a space telescope or something like that, we really have problems trying to simulate in a reasonable manner the task that we have to do. The Marshall Space Flight Center (MSFC) one is better, but it's not really satisfactory as far as the crews are concerned because once you get in close to a flight you don't want to have to be traveling for a good period of a day or several days going back and forth to a tank facility that's located away from your home base. That's because of many reasons - just trying to integrate the schedules to do the training. As the principal investigators (PI's) and Kitty Havens and the folks know, the last month to two months to three months is a very integrated, long hour type push. You want to be able to do that training in an integrated and a rapid manner and not have to spend a lot of time traveling to and fro. Our normal training cycle at JSC in the WETF consists of about a three hour run and normally we operate our suits at about three and a half pounds per square inch (psi). Because Woody and I knew that these were going to be very hand intensive, very long extravehicular activities (EVA's), we asked for and got approval from the safety folks and everyone else to elevate our suit pressure to almost four psi. We asked for four, and were approved for four but the hardware limitations were such that we

operated probably more around 3.9 psi in the suits. We also asked for longer runs and, as you saw in Kitty's presentation yesterday, nominally we ran for four hours in the tank and sometimes, in integrated sims, etc., we ran for a considerably longer period. We also tried to keep moving as long as we were in the tank, just to try to build up our endurance. Woody and I also hit the weights quite a bit, especially during the last two or three months to try to get in the best condition we could. I really think that was a good idea because we worked our tails off out there and we were tired when we got back inside, especially on the first EVA. We worked, especially Woody and myself, with the PIs and the Marshall folks very early on in the EASE/ACCESS evolution and I thought that was a great way to do business. I would strongly encourage people to try to get crew involvement as early as absolutely possible. We got in some early runs at MSFC, we helped make some comments that I think helped the overall evolution of the process, and we also learned a lot of things. Then when the initial request for two EVA's, one for ACCESS and one for EASE were not approved, Woody and I put our heads together at JSC, went out, knocked on some doors and got the second EVA, the DTO EVA put together and approved and I think that proved very beneficial for demonstrating the capabilities that the Space Station program really wants to know about.

The suits worked great, I can't say too much about them, they were marvelous machines, we never had any real concerns about them at all, they checked out and worked properly. I have two comments about them. First of all, Comm Mode B, which you probably didn't hear much about: one of our channels on our communications (comm) systems between the Orbiter and the EVA crewmen had some interference that was caused by some of the electronics inside the suit. The first time that it had ever been observed on flight, both suits had it. Post mission, they were able to reproduce the problem and they've got fixes in work at this point, in fact, I think they're probably fixed. The other problem was one that Woody and I had both seen pre-mission, that happened to be with the gloves. We transitioned to a new series glove, Series 3000 gloves, which were pretty much custom made for both Woody and myself. The gloves overall are an improvement over the earlier gloves we had in the Shuttle program, however, they had one problem in the thumb area of the glove, which both Woody and I experienced pre-mission and on our long tank runs: numbness in the thumb, which we, after talking to the doctors in our office, attributed to irritation of the nerve sheath along the base of the thumb. Normally, after a couple of days following the tank run, the thumb feeling would return. While we found it an irritant and something we didn't want to live with for the duration of the Shuttle program, we found it acceptable for our mission. About one hour into the first EVA, both of my thumbs were totally numb from the first joint on. My left thumb was numb for probably a month to a month and a half after we landed. Since that time, the folks have done some modifications to my gloves and I've done a series of runs using the EASE/ACCESS hardware under simulated flight conditions in the

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tank and found that fix to be satisfactory for me. Some of the other folks in the office are still having, I think, some problems with the gloves, but we're making progress.

We felt, and several other crews felt that we ought to have an I-comm or an intercom mode between the EVA crewman and the crew in the Orbiter such that everything we say doesn't automatically get relayed to the ground, which is currently the case. Anything that we say outside is automatically relayed to the ground and that sometimes inhibits the free flow of information or conversation because we know that there are other people listening in on a party line. Hopefully the suits that we have in the future will incorporate that.

This is the first time, as I mentioned yesterday, that a real time suit telemetry modification had been added to the suits. It did not change in any way the flight rules of how we would react to any type of suit problems and in fact, during the flight it actually helped us somewhat. On the second EVA, we got a call from the ground just prior to a loss of signal that both Woody and I could expect battery messages to come up on our caution warning displays on our suits telling us that we were essentially out of electrons and we did get that during the loss of signal period but that was due to a software problem that had not been updated in the caution warning system. They had put in larger batteries that had better energy output than what the software was registering and therefore we were told to ignore the messages when they came. We did and even though we knew all that stuff, it sure was a nice reminder to have in real time.

Woody and I have both pushed for, and previous crews have pushed for rest days between EVA's; we think that that is probably not only a good idea, it's probably required. Woody and I, after the first EVA like I said earlier, were both extremely tired, especially in the hands and forearms. Even though we could have gone out the next day on another EVA had we needed to, the day in between to recharge the suits and to refresh the body surely was welcome. And, I think in our case, we would have not performed as well on the second one had we gone out the day after the first one.

We've already talked about the ease with which we manipulated the structures, it really amazed me. I was using just very light finger forces to move those structures around and it was just very pleasant. I grabbed the axis at one end and I could have used it as an alignment aid. I spotted the moon right in the middle of the triangle, and I could have held it there indefinitely with very, very light forces. I shook the axis truss, it felt very rigid to me, that's a qualitative comment. The EASE structure had somewhat looser joints and when I shook it, it responded very much like it did in the water tank, it had a little bit of a ring to it. Freefloating, in my way of seeing things, is not the way to assemble structures in space. For limited applications it can be done, as we have demonstrated, and

limited is dependent upon the nature and requirement of the task. But I can't overemphasize the fatigue that was built up in our hands and forearms trying to maintain body position while we were torquing those beams around. Even if you had less massive beams to move around, I still think that the 400 pounds of mass that you are trying to position and maintain position on really is fatiguing to the hands. We did use two people, one on each end of the beam when we were putting up the aft crossbeam on EASE. That didn't seem too bad, because you had one hand that you could kind of translate with and the other hand that you are holding on to the beam with. That's all you really had to do, the beam kind of went with you, it was another part of your body almost; that way it worked pretty nicely being in an unrestrained condition. But we did feel, even though Dave showed some data that manipulator foot restraint (MFR) times in actuality may not have been any faster, from the top man's standpoint anyhow, we felt that the MFR really proved to be a great benefit to the guy on top. That's because he didn't have to maintain body position, his feet did it for him and therefore, all the energy expended was in manipulating the beam, which was a very minimal amount of effort.

I'd like to talk about suit pressure a little bit. Woody and I worked in the suits for a total of over twelve hours outside and we had a suit pressure of 4.3 pounds per square inch (psi). I am currently working on Space Station, and the current concept there is the Station will operate at a pressure of 14.7 psi. And because of prebreathe concerns, the nitrogenization and bends concerns, that's pushing us to a requirement that says you have to operate out of a suit that has an 8 psi pressure - that's if you want not to spend extended durations prebreathing O2 environment to scrub out the nitrogen from your body. Even though I know there is a lot of effort going on and I have already evaluated, at least in a glove box format, new gloves coming down line that hopefully will address the 8 psi concerns, I've not found anything yet that comes close to allowing you to do in an 8 psi suit what we did at 4.3 in the Shuttle suit and that really concerns me, because we are really pushing along in the Space Station business with a 14.7 cabin and the cure is an 8 psi suit. Unless we make some quantum jumps in the glove capabilities, we are really degrading our EVA capability by the direction we're going at this point. Once I've had a chance to evaluate the hardware more fully, maybe I'll change my mind, but that would surprise me if that happens.

Some surprises: the space suit out there in the vacuum of space is stiffer than the one we practice in. And in fact, it is a lot stiffer. Two reasons I think: number one it's a new suit as opposed to one that's been worn many times, and secondly, it's a lot colder out there - the water tank we maintain at 90 plus degrees so that the scuba divers don't get cold after a long period of time in the tank, and out there, I'm sure the suits are much colder and therefore much stiffer. That makes it a lot harder to get in and out of foot restraints, and requires a lot

more energy to be expended. Woody and I probably got in and out of foot restraints more than any other crews have ever done on the EVA's, and after both EVA's, our knees were pretty sore because of the stretching of the ligaments on both sides of the knees - getting in and out of the foot restraints.

One of the surprises that I had: tether management is always a pain and I thought maybe I had found a way to get around that a little bit, in the water tank by connecting the harpoon - the little attachment device that was used on the EASE beam - to a mini work station (that's a little tool caddy kind of carrier that mounts under the front of the suit). It has a self tending tether on it that you can either lock off at some condition or it will self tend and retract any time we let go of it. So I had attached my mini work station tether to one of the harpoons and that's the way I was going to tether the beams when I was up on top of the EASE. In the water tank that seemed to work just fine. But when I got out there and tried using it for real in zero G, I found that the returning forces on that tether were too much and they tended to battle me too strongly when I was trying to position the beam - it was always trying to torque it off in a direction I didn't want to go. And so after the first assembly of EASE on the top, I opted to lock off that tether after I had pulled out a given length of the tether. The second time it worked better yet I had too much tether pulled out, and it tended to snake around anything that was anywhere close. Finally, by the third time on top of EASE, I had just had about the right length of tether out and it worked much better. Even though Dave's data showed that the fourth cycle that I was on top of EASE was longer than the third or second, I felt that that was by far the best assembly that I had done from the top. I felt like I got into position, rotated the beams at the proper rate, and I felt like the assembly task, the making of the connection went much more smoothly than any of the other cycles had. So it's kind of interesting to see the data that he presented.

We always try to do fit checks of all flight hardware to make sure that we aren't going to get any surprises when we go out there and start handling it for real. We did a pretty good job of that, in fact we went through a full blown crew equipment interface test down at the Cape on the EASE active hardware, and you saw some slides of that yesterday. One thing we neglected to fit check however, was the little plastic clips that we use to hold the rope against the ACCESS structure in simulating the cable run, and wouldn't you guess that those little clips had been built a little bit differently from the ones we used for training. In fact, the rope would not go into the notch that was cut out for holding the rope on the side of the structure. But that didn't prevent us from doing the task. Fortunately, the rope was pliable enough that you could just kind of mash it in there and it held just fine. But if there's ever a lesson learned, it is to check everything, and if anything can go wrong,

it will, so just do it anyhow - even if they tell you don't worry because we've already done it, do it yourself.

We did have a couple of hardware problems. One of them was the ACCESS strut canister latch that was talked about by John Rodgers yesterday. My guess is that probably one of us, either Woody or myself, probably dinged it at some point as we were translating it around out there, and just bent it a little bit, such that it would not relatch. But again that was one of the things we had "what-ified" pre-mission. We had gotten approval through safety and through engineering folks that one latch was sufficient and there was no concern real time, we just pressed on, we just noted it and there was nothing else said. The EASE base cluster pip pen - I think from us being up on top of the structure and putting some fairly large motions into it, we probably created some galling down there in the pip pin area. When I pulled the pip pen out, it came out freely. I didn't think there was any concern at all about getting back in, but when we tried to reinsert the pip pen, then you saw some of the energy spikes - but you didn't hear some of the things I was thinking. After about three, four minutes of trying to get that pip pen reinserted, Woody and I just grabbed the spare cluster that was out there on the MPRESS, and pressed on with the activity. Again I think a well trained crew given some options, will grab those real quick, and we were already pushing on by the time the ground came up with any suggestions.

Another surprise to us was because of the concerns that were alluded to yesterday about excessive wear on the thermal garments - the outer thermal cover of the gloves. Early in the training and development process, the glove people went off and developed a new outer cover that had some kind of a rubberized material that they put onto the fingers - along the inside of the fingers and the palm of the glove. And that stuff worked great. We saw essentially no abrasion at all on those coverings. We did see a little bit of evidence of where the rubber was starting to pull away from the rest of the thermal garment material, but it was not of concern at all. In fact, it proved to be another surprise in that the Kapton covering that was on the ACCESS struts wanted to grab onto that rubber material in the gloves and not let go - to the point that once or twice, Woody or I had to pull those struts away from each other. It caused us to literally have to open our gloves further than we really wanted to to let go from the struts.

I guess one other thing that might be noted, if you add up all the hardware that we assembled and disassembled, we actually built quite a bit of length of truss out there, and I think that given the proper setup for Space Station, we'll be able to do that in a very efficient manner in the future.

ORIGINAL PAGE IS
OF POOR QUALITY

MARY CLEAVE:

I'm going to talk a little about the arm which was just a part of EVA II. The arm which was built by the Canadians is a great tool. It was not designed to be used in this particular way, but it worked wonderfully. We were able to get the rates increased with the help of the Canadians, and also the people that manufacture the MFR. Actually it was moving about twice as fast as it had previously, and a previous crew had said that the lower rates on the MFR were really restricting what they could get done because it took so long to get a guy from A to B. I think we would really have been in trouble if they didn't have those increased rates. Jerry said that it really didn't bother them when I bounced them around. I tried to hamhand them and he really would react against the arm. The arm will actually displace about a foot if you would really react against it because it's very light structured, electric and has little motors. It will only work if there's no gravity, so on the whole it worked real well. I would like to say if we ever do get a big pool to train in, it would be nice to have an arm in it that's like a flight arm. The guys at MSFC were very nice to let me use their engineering arm. It was not a trainer, and it really helped us to integrate. Actually, the only time we did this task all together was when we got up on orbit which made it more fun, but I think it would probably be a little easier on everybody if they had at least gotten a little more integrated to start with. Jerry and Woody spent the 45 minutes down in the air lock before they went out - when I was supposed to give them a ride that day - telling me what a great guy I was, so I figured maybe there was a little anxiety there.

JERRY ROSS:

Well you know, guys are always concerned about women drivers.

MARY CLEAVE:

That's right. That was it. All because I was a girl, I know. The surprises I had on orbit: the first one that was most important to me and which I mentioned during the movie was actually trying to tell small motions at the tip of the arm against the moving Earth - against the truss where you didn't want to bump the truss. The second problem we ran into was due to the fact that EASE/ACCESS was manifested in the front of the payload bay, which meant the arm was working the front of the payload bay, so we were always working around singularities. It would have been easier if it had been manifested further back in the payload bay, but we had three satellites which brings up the third problem. Because we had three satellite support structures in the back, we couldn't use the three back payload bay lights. That meant that we were totally dependent on the two front payload bay lights. So you're going through 45 minutes of darkness every hour and a half, it would be nice with that much darkness on a regular basis to have adequate lighting. I think you had adequate lighting.

JERRY ROSS:

Yeah, I always felt that I had plenty of lighting. We used the bulkhead light on the forward bulkhead, as well as the two forward payload head lights, and once or twice when I was way up on top of the ACCESS truss at night, I went ahead and put on one or two of my helmet lights.

MARY CLEAVE:

Yeah, he has little head lights, whereas if I was looking at him moving, I was much more dependent on Jerry's ground controlled approaches (GCA's) - his telling me where he had to be because I really couldn't see as well. And it would help to have running lights on your arm because then you could see how the arm was configured especially if you're in a regime where you can get into a singularity - where you get into the problem you can't resolve and the arm is going to move in some way, but you're not sure where it's going to move. So you don't want to have that happen right next to a structure with your friend on the end of it. On the whole, the arm operations worked a whole lot better than I expected them to, these guys were a whole lot easier to move around, and they were a whole lot more cooperative in space than they were in a tank at MSFC.

JERRY ROSS:

Mary did a super job. If we wanted to go two inches in one direction or the other, that's where she put us. That was great.

MARY CLEAVE:

Thanks. Even though I'm a girl huh? Great.

JERRY ROSS:

Now where's my five dollars? We have time for a few questions.

QUESTIONS AND ANSWERS

QUESTION:

If an EVA crewman is working 45 feet up from the cabin, would it be better to have the person inside the cabin with limited visibility operating the arm, or would it be preferable to turn the arm into a cherry picker operation where the EVA crewman could operate the arm?

ANSWER, MARY CLEAVE:

In my opinion, since I'm an arm operator, I want to keep control. With the arm in its present state, and especially in the configuration we were working with (Jerry standing on the end of it), he would not have had the visibility beneath him to tell when he was getting into problems with a singularity or a reach limit on the arm. I think he would have ended up driving himself into more problems than I could avoid by operating it from inside.

JERRY ROSS:

I agree with that. I think when you put control on the end of the arm, number one, it gets in the way of where you want to work. You have a very limited reach envelope where you can really work with two hands in an ideal fashion, and you don't want to clobber that up with something if you can help it. Secondly, as Mary said, you can't see the arm configuration behind you, and a lot of times you really have limited visibility to any structure that's relatively close to you as well. Third thing is as long as you've got an Orbiter up there, and you're working off of an Orbiter, you've got two or three people inside that are relatively underutilized compared to the guys that are out there whose utility and time you're trying to maximize. Therefore, I think that you ought to take advantage of the additional people inside.

MARY CLEAVE:

One of the concerns for the arm configuration was a decision made not to take up the software space to put any software blocks in to protect the Orbiter. So you can run that arm into the Orbiter anytime, which you don't want to do. So that's why you tend to be a little cautious.

JERRY ROSS:

Okay, I think we'll hold the rest of the questions to the panel who will be glad to answer any of them then. Thank you.