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WELDING IN SPACE WORKSHOP

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submitted to

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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1.0 INTRODUCTION

The Welding in Space Workshop was held on November 8-9, 1989 at the Morris Auditorium in Building 4200 at Marshall Space Flight Center. Attendance of over 225 persons indicates that there is a tremendous amount of interest in this activity. Conveying this interest to the NASA program managers for the Space Station and other new initiatives will be a major undertaking.

The goal of the workshop was to provide a forum for discussion of the potential for welding in space, its advantages and disadvantages and what type of programs can benefit from the capability. Over the two day workshop, it was apparent that a major problem exists in trying to sell space welding capability to program managers who were not in attendance.

Review of the various presentations and comments made in the course of the workshop suggests several routes to obtaining a better understanding of how welding processes can be utilized in NASA's initiatives in space. They are:

(1) Development of a document identifying weld processes and equipment requirements applicable to space and lunar environements.

(2) More demonstrations of welding particular hardware which are to be used in the above environments, especially for repair operations.

(3) Increased awareness among contractors responsible for building space equipment as to the potential for welding operations in space and on other planetary bodies.

(4) Continuation of space welding research projects is important to maintain awareness within NASA that welding in space is viable and beneficial.

2.0 AGENDA

1989 WORKSHOP ON

WELDING IN SPACE TECHNOLOGY

NOVEMBER 8-9, 1989

NOVEMBER 8, 1989

7:30 a.m.	Registration Begins
8:30	George F. McDonough, Director, Science & Engineering Welcoming Remarks
8:45	Robert J. Schwinghamer, Dep. Dir., Space Trans. Systems Introduction

MORNING SESSION

9:00	Murray Hirshbein, HQ/RM Pathfinder Program Mgr. Overview of Pathfinder Program
9:45	Chip Jones, Marshall Space Flight Center/EH42 Welding Development for Space Assembly, Construction and Repair
10:15	Coffee Break
10:30	Hal Conaway, Rocketdyne Overview of Recent Visit to Soviet Union
11:15	Hank Babel, McDonnell-Douglas Space Systems Space Station - The First Application of Space Welding in the Free World
12:00	LUNCH BREAK

AFTERNOON SESSION

1:15	Koichi Masubuchi, Massachusetts Institute of Technology Historical Space Welding Overview
2:00	Boris Rubinsky, University of Calfornia-Berkeley Plasma Arc Welding

2:45	Break
3:00	Bill Hooper, Martin-Marietta Manned Space Systems Electron Beam Welding in Space
3:45	Kevin Watson, Rocketdyne Extra-Vehicular Welding Experiment
4:30	Bill Kaukler, University of Alabama in Huntsville Laser Welding in Space

Thursday, November 9, 1989
SESSION III Committee Working Groups

Participants will itemize issues related to the topics, suggest general approaches, list concerns. Steering committee members will be in charge of moderating the discussions and recording the inputs of participants. A copy of the discussions would be included in the conference proceedings, and mailed out afterwards, along with the written inputs of the speakers.

8:00 Welding Tasks

Anticipated welding tasks in support of construction, repair and maintenance.
Moderation: Art Nunes

9:30 Concurrent Engineering

Approach to quality assurance through design, process technology, and inspection.
Moderation: Chip Jones

10:15 Coffee Break

10:35 Operational Considerations

Review of safety, power, contamination, EVA, and other operational concerns as they relate to space welding. Considerations for shuttle experiments.
Moderation: Carolyn Kurgan

12:00 Lunch

1:15 Robotics

Description of robots considered for use in space and how an interface needs to be described.
Moderation: Chip Jones

2:15 Test/Simulation Facility

Design of a terrestrial facility for simulating potential space welding tasks . Major elements in design of a training facility for astronauts, and simulation facility for troubleshooting problems.

Moderation: David Hoffman

3:15	Coffee Break
3:30	Committee Reports on Defined Goals

3.0 PRESENTATION TRANSCRIPTIONS

3.1 Robert Schwinghamer's opening remarks.

Welcome to MSFC. Welding has always been important at MSFC. Welding has always been important in aerospace industry. Some of our most toughest and challenging problems have been associated with welding. We actually built the first stage in Saturn V; in fact three of the first stages of the Saturn V. That was the first of the large scale welding of the 2219 alloy. We did have some problems. There is a big tower out there where we did the circumferential welds around the cylinder in the vertical position. We had to shut down for six weeks but we were going to the moon! It turned out to be a grounding problem. We fabricated a large copper expanding ring, put it at the outlet, it guaranteed a continuous path so that the magnetic field effects were not changing the welds. With this we were successful at building the S-1C stages. There have been a whole host of problems since, and I think there will continue to be.

It's just amazing how the technology has been advancing. I cannot imagine with that as a prologue that we can go into space and spend any length of time, and then not able to do decent welding in space. With the advent of the Space Station, what you people do here today, may very well chart the course for the future maintainability and reparability of the Space Station. As I say, it's just inconceivable that we won't do welding in space when we get into the Space Station activity. There are three objectives here (at this workshop): We want to develop a certain sensitivity to the requirements and the potential uses of space welding. Also, what I think will come out of this will be an orderly review of the current status of space welding and of history. You can learn a lot looking at what has gone before. The third objective is to sharpen up the scope and direction and priorities for future work. I went through the list of attendees and it reads like a who's who of the welding discipline. We didn't miss too many.

I thought I would show a couple of viewgraphs. To give you some idea of how long we've been welding (in space). That's the M-512 Experiment that flew on May 14 1973 in Skylab. It was the free world's first Space Station. That was a very interesting experiment. There were actually several experiments performed in it. It was actually an electron beam arrangement. It was done by Westinghouse. Jack Lousma made the welding experiments, I believe. The next viewgraph shows one of the tapered disks that was used in order to give some idea of the beam power effects in zero gravity; also the drop through and what kind of influence the absence of gravity might have. That was a tapered disk, and one of the first runs, it was at a fixed power level. Whats immediately apparent is that the meniscus forces are very strong in the absence of gravity. The next viewgraph shows a welding experiment, there again we learned about the efficiency of the wetting effects in zero gravity. We've been interested in space welding a long time ago. In 1958, the first eb welder came to this country. It came to the Hanford site in Washington. The AEC used it to weld plutonium elements or something. We heard about it, and then built one. We did a few basic experiments.

Things in welding have progressed somewhat erratically. I think were back on track now. And we got good forward momentum; with the advent of Space Station we have a lot of challenges here; a lot of opportunities to develop and use equipment which was not used before. That is a brief introduction.

3.2 **Dr. Murray Hirschbein, Program Manager for Structures And Materials at OAST at NASA Headquarters** also presented some information describing the Pathfinder Program and the new initiatives which were being pursued by NASA and described some areas in which welding processes could have an impact.

Why the Pathfinder Program? It was established a few years ago to support space exploration. In that activity there are a variety of technologies that I will be referring to. We have an area in that activity of In-Space Construction for large structures in space. Within that activity we have an area for in space welding and its centered here at Marshall Space Flight Center with Chip Jones as the primary investigator. As part of his activity, he proposed to hold this workshop. We thought it was a very good idea. We had difficulty fitting welding into the scenarios we were doing because the community we were dealing with was not nearly as expansive nor as knowledgeable. I'm here largely to learn. I'm hoping what we get out of this is some better directions for what the potential is for welding in space. We have a long term program that we will be be developing here. What you do here in the next two days can have a significant influence on what is done technologically to develop the capability to do some welding in space.

Some of the history I'd like to go through first. Pathfinder is a technology program. It's specifically focused on exploration missions, both manned and unmanned that will support explorations of the Moon, Mars, robotic missions. It's largely trying to develop those enabling technologies that are not fully developed today that will be necessary to carry out these activities. It's based both on long term and some focused activities with some rather strong demonstrations. Technology in the past has been carried out to some rather low level. We have often done things where we have taken them to the degree of laboratory activities but never carried them a whole lot further.

NASA is broken up into a number of large organizations. The key technical one involve the Office of Manned Space Flight which is the Space Shuttle, Space Station, Office of Space Science and Applications and where I'm from: the Office of Aeronautics and Space Technology. Were charged with doing all of the activities in aeronautics, the only office in aeronautics. We also have responsibility for areas of advanced technology that are not associated with any other specific programs. Some of those cross-cutting and breakthrough areas such as 'how you build large structures in space' those beyond Space Station, are the responsibility of the OAST. This grew out of in-house capability and years of planning. Around 1986, we set forth with the Civil Space Technology Initiative which was first effort to develop advanced capability in technology. It was focused on specific areas and was limited to what we were going to do in low earth orbit. In particular, Operations was to build capability in fundamental robotics, artificial intelligence; Transportation was focused on Earth to Orbit transportation and we pursued an activity in aerobraking. You'd come back in, slow down in the atmosphere and merge back up with Space Station in orbit. We pushed areas in space science in both sensors and large space structures to be enable astrophysical instruments to be put into orbit, such as the Hubble II Space telescope.

About this same time there the National Commission on Space that was instituted by President Reagan to help guide NASA in achieving his goals in his Space Policy. They were critical in the level,of technology NASA had been pursuing. They suggested that instead of a mere 2% of the NASA budget for new space technology, that it be raised to 6%. Aggressive proposals for missions both manned and robotic were the result. Missions back to Mars and the Moon, missions to Jupiter. The Commission strongly supported an exploration activity. National Research Council said so little had been done since the Apollo days. Space Station was going at that time but the fundamental technology level was still low. What lead to Pathfinder was the exercise by the Sally Ride Report. In six months, the report came out that outlined four primary missions: Mission to Planet Earth, the Earth observing stations and low orbit stations that are currently being pursued by the Office of Space Science and Applications.

This was a carry on of NASA's traditional job. It was concluded that that mission be pursued regardless what else was taking place. Another mission in there was the robotic exploration of space. This was taking the Viking spearhead and carrying it further to a broad class of exploration missions that would be focused largely on robotics without human presence. The two others that are most known, and which caused the greatest interest was the return to the Moon, this time to stay. The other was to go on and look at a Mission to Mars, a thing that we have never done. There was considerable controversy about which should be done. Even after the report came out in the ensuing years, until this summer, when President Bush made his speech on the 20th anniversary, you had two groups of people: those who said "well we went to the moon, why do it again?" and those who are a younger group and to whom this was a new adventure. The critical elements that came out amongst all these missions, focusing back on the NSC comment, was that the level of technology that was required to support these exploration missions was in fact not well developed. And it was questionable whether or not we could commit to any of these missions with the scope that was being proposed with the level of capability that the agency had at the time. When the question was asked, everyone answered no. OAST at this time had just started its program in the Civil Space Technology Initiative. We were looking further as to what would come next. We were poised at that time to pursue this question about what would it take to accept the challenge of going back to the Moon on to Mars or what have you. What was created out of that was project Pathfinder.

Pathfinder focused very strongly on the Sally Ride Report. Those of you who read it will realize it is a very fine report. What we know about these explorations missions which have been developed over the past few years does not deviate much from what came out in that report. The details do, but the concepts were very good. The critical technologies that were put forth in that report are still the ones that are dominantly very important. I'll try to bring in some of what happened in the last 90 days.

What I'm giving you now is a bit historical, and a quick overview and descriptions of Pathfinder have changed somewhat since the speech in July which outlined what the path would be, back to the Moon, then on to Mars, included in which would be the robotic type exploration missions. There is a bit of a flux redefining the key technology elements should be, what their priorities are, which ones should be added to the list, which ones should be taken out. Scenarios for what the trip will look like, or what NASA's plans will be in the next 20 years are still being formulated. Very much at the core of that is this particular activity because the responsibility for answering the technology issues still fell back on OAST. This was our core program. Plus for the last two years we have been working closely with the Office of Exploration, which was the outgrowth of the Sally Ride exercise to make sure our plan dovetailed very nicely with their plans for exploration. It was fortuitous that their particular exercise for the last two years, they've been defining a vast array of scenarios and technology profiles and whatever that fit very well with President Bush's speech. It was never anticipated when the office of Exploration was put together, that this speech would have such an impact. Just the fact that we may be going to the Moon and Mars may not seem like that much. For those of us who were trying to establish technology programs and those in the Office of Explorations that were trying to establish mission profiles, there was this continual discussion of what we were going to do. President Bush's speech did a tremendous amount to crystallize not necessarily when we were going to do it or the specifics of what were going to do, but the sequence of what we were going to do and what the long range goals would be. It was a tremendous help. The last 90 days, NASA has been involved in preparing a plan, a cursory plan at best, of what it would take to carry out these missions. This planning process will be going on for some time.

The key areas that were put in Pathfinder two years ago, funding began FY89, we were funding the areas of in-space assembly and construction since January. Chip and company have had very title money. This a very opportune time for you to help us to decide what needs to be done plus it seems an excellent time for a gathering such as this. But the areas we concentrated in had to do with transportation, outside of low Earth orbit, to the Moon, to Mars etc.; exploration on the surface, once you get there both robotic and manned; Space Operations which includes in-space assembly and construction. We're trying to get beyond Space Station, not duplicate things that can be done on Space Station, but to attack those issues that have to do with things like a very large Mars Transfer Vehicle which could be couple of million pounds in orbit, have an aero-brake a hundred feet across. Things we simply don't know how to build. Issues have come up indicate that vehicles, when they hit Mars, what is left of them, the g-level on a vehicle of a few hundred thousand pounds, it started out at 2-3 g's, some of the numbers now peak as high as 7-8 g's. We have never built any large structure that had to sustain these kinds of loads. The idea of building aerobrakes became a very critical element in this activity.

The other element was Humans in Space. We had an activity supporting living in Space Station but not an activity for living on the Moon. The Apollo suits were not suitable for extended stays on the surface of the Moon or Mars. Reliability and reparability and resistance to dust all had to be much higher. The general aspect of keeping humans safe and healthy for an extended period on the Moon, and then more critically for as long as three years on the round trip to Mars was one of the most limiting factors. In this case we deal strongly with the Office of Space Science and Applications who has responsibility in areas of human health.

The elements of Pathfinder: within Transportation, there are three primary areas, the chemical transfer of propulsion relates to the propulsion that is very close in. It is advanced transfer of propulsion with the biggest payoff currently both going from low earth orbit to the Moon or from the Moon on to Mars. The high energy aerobraking should be differentiated from what was said before. Under the Civil Space technology Initiative, we looked at the return from the Moon under aerobraking. Those speeds are from 9-11 km/s. When you come back from Mars, you'll be coming back at speeds of up to 14 km/s. The kind of thermal protection that you need is substantially different. The temperatures are much higher, also the radiative heating is higher. The same kind of activities will not work. If you get to Mars, and you'll be needing to use aerobraking to stop, because you'll get there pretty quick, the same kind of aerobrakes that we use on the Earth though the shapes will be different, but the materials and structures would be very similar. This is because the CO_2 atmosphere and the very low density can result in heating loads that can be sustained. We actually have two activities here. It remains a critical area in general, because the aerobrake is propulsive deceleration and the option is chemical rockets. The payoff for carrying a heavy aerobrake is substantial. Other options that do exist are nuclear electric and nuclear thermal propulsion which is much farther down the line. That has a significant potential to even exceed the benefits of aerobraking. This is not a major area being pursued, but is considered one of significance for whatever kind of mission we go on.

Once you get there, the activities that were involved with surface exploration start with the planetary rovers. These kind of rovers are both manned and unmanned. The initial impetus had to do with a scientific robotic mission, the Mars sample return mission for example. The types of rover that would be put down would an unintelligent rover that would simply grab a sample and come back or a very intelligent rover that would stay a very long time, navigate significantly by itself, etc. Navigation is a critical point. Unlike the Lunar mission, you have a twenty minute round trip signal time for communications to Mars. The path planning and navigation become very difficult. Well associated with that type of program, was a scientific activity to decide what is scientifically that you do while you're there, this largely has to do with acquiring samples of soil or air. the state of the art in remote scientific activity 2 years ago was pretty much the same as what we had in the era of Apollo or Viking. The instrumentation on Viking could not detect elements such as oxygen, there was no capability to do mineralogical studies. There was no capability to take a sample of the unweathered rock or core samples. The unweathered rock is extremely important to the geologist, because it will tell them more about the evolution of mars than anything else. You need to bore into hard rock up to 10 cm deep and they want several of these. The only way to accomplish these is by remote. The degree of sample analysis that you can do would vary substantially. You have the possibility in a mission like this which is a multi-billion dollar mission of grabbing a lot of samples and just running back to earth, finding that you just got 5 kg of the same kind of rock that you picked up in the first place. You also have the possibility of picking up thousands of samples doing extensive screening and only bringing back 5 kg of the best possible material for study.

Autonomous lander goes back to our experience with Viking. It landed very close to a very large rock. Our knowledge of the Martian surface was not good. You may recall there was a half of a large rock to the left 2 foot high. It was luck that Viking did not land on the rock. That's not something we care to have happen again. What autonomous landing will look at is actually two areas, one is precision landing, which would support activities on the Moon, or repeated landings on Mars, where you know exactly where you want to be and you want to land there precisely without having to have people at the wheel. If you're going to do a robotic mission, that's clearly what you have to have. A longer range activity would be to isolate those hazards that you can see and avoid them on the way down. We're likely to have an accurate surface map of Mars. Once we get the first lander down, any piloted mission or advanced robotic mission would be able to do a precision landing at this spot. But the first one would still have to avoid whatever hazards that may be there. A lot of this is AI, pattern recognition and what have you.

Surface power is advanced photovoltaics etc. Photonics is an interesting activity that is getting a variety of reviews. The purpose of photonics came about trying to develop systems with a high degree of fault tolerance. Again, going out to Mars for three years, experiencing radiation, what have you, required a system that could do this and not only correct itself if it had a failure but also have few failures. The principles behind photonics is to replace electrical circuits with optics. They have the advantage of being a couple of orders of magnitude faster than electrical circuits, they use far less power, but they're also much more reliable. They're not affected by radiation and their tolerance to electromagnetic radiation is extremely low.

Humans in Space. This returns to the whole problem of keeping people safe and alive in space. This is a combined activity in technology and human health which is a science activity. EVA suit is to develop a suit that doesn't weigh 600 lb.. as does the suit in Space Station. A suit that is not affected by dust, like the Apollo suits. Even the Shuttle suits take nearly a year to refurbish. We don't have suits designed for multiple use. If people are going to be on the Moon for an extended period of time, or even shuttled back nd forth, you cannot bring a couple hundred pounds of suit all the time. You need life support packs that have high reliability and ease of refurbishment. The scenarios for putting people on the Moon and Mars are not a lot of people. You may have 4-8 people for a few weeks to months and ultimately a couple of years. You're not going to able to bring the suit to a repair shop and you cannot bring it back every time it needs to be fixed. The weight penalty is just too high. With the Space Station suit, its a heavy suit, even in a 1/6 g Moon environment or 1/3 on Mars, it just becomes to tedious to perform an extended EVA. Phisico-chemical life support is straight forward. Technology required to close the loop on life support. This is unlike the controversial one on the bottom. Refurbish the water and oxygen both within the suits and within a module on the Moon. Not to be diminished is the dust factor. It has to be kept out of all habitable modules. You must ensure no-one brings any dust in. It has to kept off radiators to maintain efficiency.

Health and human performance. It deals with the psychological and physical problems that have to do with weightlessness and close confinement. Eight or 4 people confined in a small vehicle for a couple of years can be very disturbing. The critical element, creating the concern, is weightlessness for a couple of years. The missions to Mars can be as short as a year with a two week stay on the surface of Mars. The other problem is that if you abort the mission, you cannot slow down when you get there, you could be three years in space. Even one year is a concern. The Russians aren't hiding the fact that when their astronauts come back after a year in space, they're not in the best condition. There is concern that if somebody is not really physically impaired when they get to Mars, how long does it take to build up their capacity so they can function well in a 1/3 g environment. They will be carrying space suits and the like, and will likely have a few weeks on the surface the first time we go.

Associated are two activities, were two activities, one was to build an artificial gravity spacecraft, one that spins. The parameters that are associated with that are disturbing, because we don't know the rotation times people can tolerate. We know we need to keep it down to 1-2 rpm. At 1 rpm , 1 g, the best conditions, you need a 200 m spacecraft across. We will need a dumbbell on the end of a tether or beam, and then coming back together. You can get them smaller, depending on the limits people can take. There is a lot of discussion about how much time people will have to spend in an artificially created gravity. It may only during sleep, or during work part time.

The other issue is radiation protection, both on the surface of the Moon and in space. This is critical for the Mars mission as well. The solar flare emission can be deadly, it was serious when folks were on the Moon. Heavy nuclei galactic cosmic rays can be devastating during the Mars trip. There have been estimates that a couple of hundred tons of shielding would be necessary to be carried for the Mars trip. Part of the reason is the poor capability of predicting the interaction of radiation with structural materials. A lot has been done biologically, but determining what the dose will be after a solar flare, even with a shield, may be no better than a factor of two. The non-linear relationship between dose and shielding, you can vary the shield by a factor of 2-3. Aluminum would have to be 3-7 inches thick if it were used as a shield.

Bioregenerative life support has been proposed for a long time by the OSSA. That is literally growing plants etc. in space. If you want to look at the ultimate long term capability of self-sustaining, that's it. Now there is a degree of concern about viability. Many of these things I have been telling you about may or may not survive the key technologies that come out of these current planning exercises.

In Space Operations will be the part that will ultimately involve this group. I want to say more about in-space assembly and construction next. The autonomous rendezvous and docking had its origins again with piloted missions to Mars, you want to come back up autonomously, rendezvous, and return. There's also concern about what the astronauts will do after a Mars trip, having been weightless for a while, will they be able to come back? An interesting story, during the Apollo days when Aldrin was piloting the lander back to the Eagle, he and Collins forgot who was in charge. Both tried to dock with each other. In their euphoria, they hit pretty hard, fortunately not much happened. But 50 million miles away and Mars, if that happened, it could be serious. The cryogenic fuel depot that supports the space transportation, will have fuel systems up there for several months. Space Nuclear power has been going for some time. In fact this is the only space nuclear program in this country at the present time. It's primarily between DOE and NASA. DOE has the biggest part. This a critical element of some of our activities. If you're looking at the potential for things like nuclear electric propulsion or large amounts of power for recourses processing, you're looking at an SP-100: Space Power - 100 kW electric. However, current advances enable this to go up to a Megawatt. The actual power unit puts out 4 Megawatts of heat. By using it for a Stirling Cycle, you can get almost a Megawatt. These are not huge units. A big payoff, almost as esoteric as welding in space, is resource processing on the Moon. There is a substantial amount of oxygen on the Moon. Lunar soil is 40% oxygen. Like beach sand is high in oxygen. It's not the easiest stuff to get out. The minerals we're dealing with are not a whole lot different like those on earth. They're largely metallic oxides. By reduction by hydrogen and other chemical processes, well understood on the earth but not the Moon. We can produce oxygen by the tons. Where this has a big payoff, is in operating vehicles in the vicinity of the Moon. There had been proposals to bring 1000 tons of oxygen back to low earth orbit which turns out to be competitive from bringing it back from earth but no so much any more. A further payoff, you can get some pure metals: iron and aluminum. Some of the issues that have to be determined is to what extent these materials can be used to construct things on the Moon. The potential for welded process to fabricate structures on the Moon is clear. Right now it is not a high priority activity. People are not sold on the idea that it can be done. Optical communications are very high rate.

In-Space Assembly and Construction. The cartoon is from the National Commission on Space. I want to distinguish from what we are concerned with in the In-space assembly and construction element of Pathfinder from the others. We're concerned with building things that are large, not only large but also things that can take a substantial load. I indicated earlier that huge aerobrakes may sustain up to 9 g's when entering the Martian atmosphere. You're not going to put something that large into space i one shot, you're going to have to construct it there.

How its going to be built has a wide variety of activities. Smaller ones that are fully deployable, bigger ones that are a shell over a truss, other's that are thin shells, whether or not bolted, welded or whatever is pretty much in the open. Until people prove the fact welding in space is viable, and economical in a sense of no EVA, good welds, inspectable welds, and minimum weight, it's not likely to occur. But I want to differentiate from the Space Station activities. The activities we're going to concentrate on in In-space assembly, will be with that kind of structures. The current state of the art in building things in space, is twofold. What Bob Schwinghammer said earlier, a few welding experiments and the Russians built trusses. But our experience is literally in the construction of trusses. This is the Access truss on the Shuttle. It did two things that gave people confidence Space Station could be built. First of all the astronauts cam back from building this thing and said it was easy. Also, they correlated what they had done in space with the efforts in the neutral buoyancy tanks. Up to that time there was concern you could not build these things, it could deploy. It would be a deployed package, you pushed a button and it would deploy...maybe. If it didn't you had to fix it, and there were no volunteers. The point is we have only a primitive capability to build these structures. Also that it doesn't take a massive experiment or demonstration to convince people that something previously thought interesting but not feasible was the to go.

The program that we put together, which is partly supported here, and we support the work of Chip Jones at MSFC in In-Space Welding, it's across the NASA Centers. We have four major Centers, Langley is the lead, JPL, MSFC, and JSC. From a programmatic point of view, we made the decision that in order to have these activities, like welding, accepted by the community at large, we had to involve people at research centers like Langley, we had to also involve people at other development centers who would ultimately be the users of the technology. The funding for '89 in this program was very low, for Pathfinder the overall funding was $40 million dollars. The ironic part about it is that you're caught between housing people on earth or in space. When we got the program, we were told by the Congress committees that if they didn't like the idea of exploration in space we never would have gotten this program at all. Within these programs, In-Space construction and assembly has always been a high priority item as no-one knows how we're going to build these things.

We have four major areas that we're concentrating on. The one that interests you is the second one, manipulation of large things that could weigh a couple of hundred thousand pounds; not something that can be done by an astronaut. My interest here in the welding activities is not to involve astronauts. We're trying to keep astronauts out of the picture as much as possible. For some reasons, if you're moving big things around, it's dangerous, you want to do it as extensively as you can. Therefore you want to do as much as you can from the safe confines of Space Station or even from Earth if in low earth orbit. Joining methods. This is both mechanical and welding. MSFC is involved with both. Heavily loaded mechanical joints, like large trusses, segments of an aerobrake, put fully loaded fuel tanks on a vehicle, put a propulsion module on a vehicle. The issues for welding are a lot less clear. When we had our program planning sessions, they said don't do this, no project manager would buy off on welding. The other arguments like from Chip Jones, were that the payoff for leakproof joints, from the fact that welding is by far the lightest and strongest joint you could think of, gave it merits that should be pursued. We traded it off with limited funds for bonding. It partly had to do with the quality and presence of the work at MSFC, the likelihood that metallic structures would be th first joined into large heavy structures, that would be the payoff. Furthermore is the development of integrated robotic methods for building large structures in space.

The current mode in designing structures is not to design them to be built. A key element is to look at processes that look feasible on the ground and determining how you will do them in space to assure you get a good weld. What kinds of constraints to ensure steadiness, can't have pieces moving round a few inches, what kind of fixtures you need, what separations, to set the parameters to establish technology guidelines like in the ground for producing welded joints. This will go in concert with the work on bolted joints. There is no clear decision that welding and bolting are separate. The other centers are looking at other bolted concepts. MSFC is doing just the welding of joints. We're going to do this in the form of focused test beds. As I said, carrying things through to just join a piece of pipe together won't work. We want a framework that promotes transfer. We're trying to produce an aerobrake. We're not trying to design one. We're not to actually build one, but we're trying to determine what the constraints are for an aerobrake both building and putting one on the front of a vehicle.

Our focused problem looks something like this. That's an early concept of a Mars transfer vehicle, aerobrakes for Mars and return. The framework you see was developed by Langley as either a free-floater next to a Space Station or as an integral part of Space Station. The structure has not been well defined. It's cartoonish. Whether or not you can operate and build with that framework is not known. What we want to do is establish what these facilities should look like, what kind of devices to hold these things together, what procedures to determine stability, what order of parts have to be brought up so that you have a stable structure. To worry about such things as if there's interruption, if the Shuttle is down, or if there's a period of time that if you can't go up there, that you have a stable structure, thermal distortion from solar heating.

The same thing with a manipulator on the end. The kind of manipulator we're talking about could be as big as 300 feet long, carry loads of a few hundred thousand pounds. A critical element could be seen on the graph on the right. Because it is so large, the natural frequencies of that manipulator gets down to a few tenths of hertz. When you get into that range, it is extremely difficult to control. Even in the Shuttle, rms is a difficult instrument to control. When it's unloaded it will vibrate for a long time. It's not good for exerting high loads, or precise control. What precise means for a Mars transfer vehicle, is not clear. Unless we can solve this problem as well, the viability for an on orbit construction capability is highly limited. We have a well defined list of deliverables. The welded joint is clearly spelled out. Current plans are that in the 92 time frame we would have a nice laboratory level demonstration. By the late 90's we like to be able to demonstrate simulated robotic welding on Earth but for a suitable simulation to convince people and show large structures can be built. We would like to this in an integrated mode not just welding off on the side, but by simulating in a laboratory environment what kind of operations it takes to build a large structure and integrating into that welding as an integral process.

Finally just to recap. We still look at Pathfinder as it currently exists as the core for any more broad exploration program that may take place. Going on the Moon when you may have to build structures on the moon which include a processing pilot plant for oxygen, permanent habitats, laying out cabling, and whatever. That's yet to be defined, but the origins of any of those programs will still come from this one. While the funding levels for Pathfinder are currently low, in 90 they're undetermined, the potential for the out years is very substantial. The degree to which we can incorporate welding as an integral part of those activities in a realistic manner, will depend on our abilities to convince those people that are now firming up some straw man missions, that this a viable thing to do. You can do your part by providing the rationale and the proof that there is a user community that this is a viable thing to pursue.

3.3 SESSION #1 - WELDING TASKS

Art Nunes - MSFC. Good Morning Ladies and Gentlemen.

I would like to open the Welding Tasks working group with a short discussion intended to stimulate the kind of inputs we hope to evoke from this session. My method will be to describe some imaginary welding tasks of the sort that might conceivably be carried out in Space some day and then open the floor for other suggested tasks or for pertinent comments from you. This session is devoted to an attempt to visualize more clearly exactly what role welding can and should play in the Space environment.

We recall that welds tend to be light in weight in comparison to mechanical joints and that great pains have to be taken to make mechanical joints leak tight, while sound welds or brazes are naturally leak tight. Furthermore mechanical joints usually require rubbing of surfaces, for example screw threads, and high vacuum friction demands special consideration that seizure and galling be avoided. I might comment that you would expect to have to lubricate a bolt so that you could load the threads properly in vacuum applications. I am told that solid lubricants, when you rub them together, give out particles. The whole process of mechanical joints is not as simple as one might think. Mechanical joints often require careful pre-fabrication alignment or on the spot machining and therefore there certainly seems to be plenty of scope for welding to compete with mechanical joining processes for in-space fabrication, repair or maintenance.

Now, first let us imagine the fabrication of a 100 foot diameter metal umbrella to be used as an aerobrake for landing on Mars. The aerobrake is too large to be launched into orbit fully assembled, so it is to be assembled on orbit. Here we see automatic welders closing up the seams between the aerobrake sectors. I envision them as looking like large roller skates attached to long poles or rails. the poles are positioned along the joints initially by assembly robots and then the roughly positioned welder is started. The joint is precision tracked by a laser feedback system and welded by an electron beam. The same device can produce x-rays with the activation of an attachment so as to expose film under the weld and check weld quality. If need be, remote operation of the device through a TV camera mounted on the skate can be used to effect repairs.

Here we are concerned with a butt weld where the edges of two plates are placed in contact and joined by running a molten puddle up the seam. The puddle needs to be just wide enough to accomodate the set-up gap and lateral position variation. It is not difficult to estimate the power requirements and speed limitations for making such a weld, as well as the heat that must be dissipated from the system. Electron beam welding is a space proven, efficient process. For electron beam welding something like 75 % of the power feeds into the beam and the beam then pretty much transfers all of its power to the metal surface to do welding work. A laser, on the other hand, would give up maybe 15% of its input power to the beam and then, depending on the reflectance conditions at work, possibly anywhere from 10 to maybe 50 % of the power to the weld itself.

Laser sensor based seam trackers are currently under development for use in ground based welding systems and look very promising.

Second, let us consider the fabrication of a truss constructed of six inch diameter high strength composite tube struts. The robotic assembler places a strut in position between short tubular extensions from metal nodes. Metal ferrules bonded to the end of the strut bear a cylindrical sleeve which is slid down over the node extension. A doughnut shaped sealed orbital welder is clamped over the sleeve. You saw some pictures of orbital welders yesterday. A traveling electric arc then makes two fillet welds, joing node to sleeve and sleeve to ferrule. With tighter tolerances and a bit of pre-distortion by the robot assembler to compensate for residual thermal stresses, a lighter single butt weld might be used instead of the two fillet welds.

Third, let us move on from construction to repair tasks. According to the June, 1987 report on "Major Repairs of Structures in an Orbital Environment" prepared for Marshall Space Flight Center by Grumman Aerospace Corporation, the most likely causes of structural damage are accidental impact, space debris impact, and micro-meteroid impact, in that order. Here we imagine that a run-away robot has punched a five-inch hole in the skin of a habitat module (This would be probably be 0.19 inch thick 2219 aluminum,) and damaged an underlying channel structural member. Due to the precaution of keeping people out of modules where fabrication work is underway, we imagine no fatalities. Inside a sound module, a patch is rolled and shaped to fit the module surface. A pair of angle structural members are also prepared for reinforcing the damaged channel member.

A teleoperated robot with a nibbler tool designed to collect its nibbles as it works, trims the hole and structural member. Next, a space suited astronaut enters the evacuated module to inspect and if necessary to correct the site preparation. and to clamp in place the patching elements and a teleoperated electron beam welder. The astronaut leaves the chamber while the welding operation takes place. For complicated repairs a number of reclamping and inspection operations may be required. We shall not consider here the subsequent repressurization and leak checking operations.

Fourth, let us consider a maintenance operation. We imagine tanks of oxygen being installed on the Space Station. The tank is clamped to the oxygen manifold, its 304L stainless steel delivery tube is matched to a like tube in the manifold. The tube ends are joined inside a short sleeve containing an annular segment of brazing metal. An induction heater melts the brazing metal and seals the joint. The same heater opens the joint for replacement.

This finishes the scenarios that I'm going to propose. I now am going to throw the discussion open to any of you who wish to participate in proposing potential applications of space welding.

Koichi Masubushi, MIT. You have a list of four cases. It is very important to have a much longer list of potential examples. I'm sure that many people can contribute, and you can come up with a long list, maybe 100 processes, maybe 50; let's say 50. The federal government cannot afford to support all 50 so you must select three or maybe four with high potential. Then you support these; that is important.

"What about all the others in the list - the many others? I think that there is a potential in western society to utilize some volunteers. There are a lot of volunteers in the world. They do good things. Superconductivity, was started by just a small effort. Penicillan is another example.

If you go back in history, there are many. 50 years from now, it is impossible to pin-point which may be needed. If volunteers develop something out of their back yards or spend their own money, then I think there should be some mechanism within the federal government for them at least to recover for taking the risk. It should not cost too much for the federal government. I think that this mechanism probably will develop a vast potential that western society has. These are a few comments. I will summarize it. One, let's make a long list asking for many comments. Then we come to the list of processes. I think I would like to have the people in NASA to think about what is there any way to encourage some kind of volunteer effort. I think there are alot of people. In other words, when I talk to students, they are so fascinated. So I'm sure that there are many entrereneurs in the world who may have some ideas.

David Tamir, Cal Poly Space Systems - I have two viewgraphs that have to do with the tasks on the Space Station. This out of an Aerospace America magazine, shows a joint Boeing and MSFC project, done in the Neutral Buoyancy Tank. Here is a patch repair which Boeing described as both an adhesive and mechanical joint, as shown from the inside of the crew module.

You can see the very direct application for a fillet weld around that patch, which would give permanent reinforcement. As said in the Boeing report an adhesive or mechanical patch would be a fast solution. It would be time effective, but it would not be permanent.

A. Nunes. - In the Grumman Report, accidental impact ranks higher than micrometeroid impact for potential causes of damage on a space station. Those little patches, while they will probably deal with the third kind, the micrometeroid impact, will definitely not be adequate to repair a gash in the side of the space station, so far as I can see. I want to thank David for bringing that up as an example of potential competition for welding.

Don Dees - Boeing Company - Space Station Program. There is a lot better access to the inside wall on the proposed module. External bracing is on the outside. You don't really have a nice flat surface. Probably at least two thirds of the inner surface is nice and smooth as you saw in that photo. So an inside repair, as compared to an outside repair, might be more efficient most of the time. The consideration for a temporary patch is probably the most expedient. The damage, be it caused by meteroid, debris, a loose robot, or what have you will tend to deflect the sheet metal inward. Most likely that will have to be knocked back out, straightened up some. There is approximately a 1 inch wall clearance between the outer wall and the inside hardware. If that envelope has been exceeded then it's going to have to be pushed back before you can do any kind of repair. Most of the damage should be held below the structural critical flaw limits. Slow release of atmosphere that could occur through a permeable non-metallic or rubber type of seal. The advantage of welding would be a permanent seal.

Another thing to consider is repair and replaement of tubing, especially if we go with the body mounted ammonia or freon radiator systems, whether by welding techniques or built-in disconnects, in case of damage to a debris shield where we have an underlying heat exchanger or station expansion requirements.

Lee Wilbur - United Technologies. Welders and welding technologists are going to want to look at mechanical fasteners as a means for clamping in space. Something that the astronauts can handle conveniently and that can be removed or can be welded in place is needed. Butt welding of large structures is going to be a challenge, ecause of a tendency to get a lot of movement. For joing tubing, I like the sleeve induction brazing. It may be desirable to develop a brush electode plating capability in space, say for putting down nickel plating for a nickel brazing operation, to assure wetting.

A. Nunes - What about something like the Soviet electron beam spray coating?

Lee Wilbur -I think that that would be better than using a water-based solution in Space. I think that that would be highly effective.

Just north of Newport News, there is a company called Inductron, that was formed by some retirees from Langley that has developed a hand-held induction unit. The induction unit is called a Torobonder. It is used for the heating of adhesive and I think it could be applied as well to induction brazing of a sleeve joint. My company is looking at this right now.

A. Nunes - I've been rather conservative in the scenarios that I've picked. I've tried to follow the practice which has been established; EB welding does seem to work in Space. I've also tried to accomodate the fears of people who don't want to hold an EB gun in their hand by suggesting that we develop a teleoperated system. Would anyone care to comment on the feasibility of teleoperated welding?

Warten Jemian - Auburn Universtiy. I would like to reinforce ideas already expressed nicely yesterday in the presentations regarding computer simulation for design and process control. There's an article in a recent issue of Journal of Metals, October 1989, on intelligent processing of materials that applies to this.

Astronauts setting out for Mars, I think would be very well served by a full on-board simulation facility able to simulate the welding operations such as attaching a patch or applying a segment to a structure. The computer simulation system that I envision will involve or provide certain scenarios which have been worked out in advance. In the event of a need to control remotely with the 20 minute delay time for signal transport back and forth from Mars, an active interaction with the system would not be possible after setting the system in operation. Space and remote (tele-)operations are closely related. We should think of performance weldability and required properties, not just filling the gap without cracks.

The big advantage of the simulation is that it can be made to control the weld parameters so that there is no danger of getting into the wrong domain and producing faults and unexpected results. This way we can possibly eliminate or certainly reduce the need for inspection and repair after the welding has been done, as is the main thrust Journal of Metals article. This is a long range project. I believe we ought to be collecting information now. I think we should think ahead and I think we should think big.

Attilla Szabo, Martin-Marietta. My colleague, Bill Hooper, and I have been working on this on-orbit electron beam welding project for a couple years now. There have been a lot of advances lately in electron beam equipment. Very small flexible high voltage cables are available that would allow attachment of an electron beam gun to the end of an articulated arm or manipulator. Right now we're doing a study to determine how long that cable can be without having voltage transients in the line. To maintain the focal length of the beam and to stop radiation, we're studying a cylindrical leaded shield extending from the bottom of the gun to the workpiece. We've been working on a simulated patch for the space station, essentially a lap joint with partial penetration into the bottom member to avoid emission of residual beam energy such as would occur through a full penetration. This shield kept in contact with the workpiece through sliding seals would maintain the gun to work distance. We envision a much lower electron beam accelerating voltage to minimize the amount of radiation produces. With the lower accelerating voltage and generally higher beam current we don't get quite as narrow a spike that most people associate with eb welding. It makes some very nice looking welds in lap joints for Space Station repair applications.

A. Nunes. Yesterday, Bill Hooper indicated some hestitation about using an electron beam gun by hand. As it isn't too large, one could conceive of mounting the gun in some some kind of cradle which could be placed up against a wall to deal with particular joints and then programmed or simply teleoperated from wherever the operation is desired. This could be run as if it were a hand held welder, but wirhout any immediate danger to anyone in the vicinity. What would youn think of this?

Attilla Szabo - That certainly sounds like a good plan to me.

Glenn Ziegenfuss - Technical Director for AWS. The American Welding Society is very pleased to be participating in the workshop and we think that it is a very exciting area. It seems to me that the welding tasks fall into two categories. One is fabrication or construction of items in space that are too big to send up in a single unit, and the other is repair and maintenance. For construction we need more information from the planners regarding what they would like to do in Space. For maintenance and repair perhaps we should look at analogous situations in other areas other than Space. For example, yesterday there was a talk about repairing small tubes that are close together, pipes along the wall and those kinds of things. An analogous situation is steam generator repair in a reactor environment. Repair welds are made remotely with very small equipment as a routine matter. I think some of that technology could be transferred. A Space Station or habitat millions miles away, is somewhat like a submarine located under the sea for long periods of time. (Submarines have a weight problem too.) The Navy has spent much effort to analyze maintenance and repair capability requirements for survival and self sufficiency of submarines.

A. Nunes. In trying to think about what construction processes should be developed we have come into contact with a problem. If designers are not aware of the processes we have, they are going to design structures in such a way that will not take advantage of welding and by the time we see the structures that the designers are proposing it may be too late for us to make the contribution that we would like to make. Are there any structural design types here. (3 raised hands) One of the things we hoped for from this get together, was some kind of interaction between the various disciplines.

Joel Williamson - MSFC. I'm in the structural development branch. I work with Art and others on the Pathfinder program. My concerns include the mechanical joints. I think Art's right, we're going to need to know what processes are available before we design future systems.

Regarding Space Station wall repair: whether induced by the impact of meteroid debris or by other external or internal sources, petaling of the internal wall of the Space Station is often seen. Petaling is metal forced out [like the petals of a flower]. A big problem with adhesively based patches is that often all these edges have to be ground off to have a nice smooth surface in which to put that patch. It may be difficult to remove these petals when the air is escaping from the module or when the module is sealed off and evacuated. A patch may have to be made from the exterior side the damage source side. With welding it wouldn't be necessary to remove all those petals. The patch could be be put on and the seal that the weld would give could be counted on.

A lot of impacts don't just generate holes, they also generate flaws, which might not go all the way through the walls. A problem with any kind of adhesively based patch is that propagation of these flaws can take place with the constant pressurization and depressurization that a module is going to see over its ten years. Welding might be able to repair flaws, a real advantage over adhesively based repair systems.

One more thing: there is a lot of work being done in the area of lunar shelter construction, especially with the President's new initiative. A possible welding application would be joining sections of a pressurized shell that might be covered over with lunar soil. These sections would only have to be thin enough to support the weight of the lunar soil as well as the internal pressure that's generated, so, we might see very thin sections, say 0.05 inches, plus some kind of bladder in the inside that would help hold the pressure and to help insure that there are no leaks.

A. Nunes. The latter would presumably be a vacuum welding process because if you have an 0.05 inch shell, it would be so easy to punch through it.

Joel Williamson - Absolutely. Some process that wouldn't allow burning through so easily would be needed.

Another thing to think about. A lot of designers now are using aluminum honeycomb structures because they give such good structural strength.

Also what about welding processes in a partial gravity field or zero gravity field? Would you use the same equipment?

A. Nunes - I think from what we've heard from Boris and some of the other things that I've seen, gravity will probably not be significant. There will be some effects, but gravity will be minor compared with the effects of pressure.

Earlier in the session I suggested that for preparing a joint to be repaired, one might use a nibbler. Surface tension tends to confine the molten metal to the surface. Possibly petals could be removed from a surface simply by circling it with an electron beam cut without a tendency to splatter much material. One would want to collect any emissions however.

David Tamir - We have to give an equal amount of thought to robotic welding and to manual welding. The presentation yesterday about the Soviet's space welding efforts showed them to be very much prone to manual activity, not, I think because they do not understand advantages of robotic welding. An astronaut we've been talking to at Cal Poly (we've been talking to astronauts over the past year when we worked on the EVA Welding Project) expressed a need for an arsenal of hand or manual tools unanticipated scenarios. I think a manual welding system is needed.

I think that we need to have a system that can be converted from welding to cutting. I'm not at liberty to discuss the efforts of Rockwell and Cal Poly on their gas tungsten arc welding process which has been modified for vacuum, but I can say that there is a way to do cutting and welding with such a process.

Let's assume a power down scenario. With the Get-Away-Special gas arc welding in space experiment we have made a welding experiment that works off batteries. It incorporates a rechargeable battery pack system that can support about half an hour of welding. The battery pack can be put into a back-pack type and maintained for an emergency scenario.

The astronauts' feelings, are strongly against reliance on automation only.

A. Nunes - I'd like to make a distinction between automatic and robotic operation and teleoperated tools. I believe RPV's (Remotely Piloted Vehicles) are rather popular in surveillance by the military. As far as I know, these work quite well. I would not want to rely wholly on an automated system, but I would contrast a remotely automated system with a system based upon actual operator participation through a TV interface. There is a possibility of getting much of the capability of hand-held welding with a teleoperated system.

What do you think, audience? Could I see a show of hands? How many think a hand-held welding capability, would be a necessity for an astronaut. (Majority votes yes.)

Kevin Watson - Rocketdyne. From a systems standpoint, I think we would be willing to apply fairly heavy resources to the development of the specific processes and supporting technology necessary to undertake major assembly and construction operations. This would require the development of manipulators specifically designed to do the welding process, because I think the welding processes we're talking about have positional requirements, speed requirements, accuracy requirements that exceed the capabilities of the space manipulators we have today and possibly exceed the capabilities of the manipulators currently being planned under contract. Over the next twenty years, welding applications are almost certainly going to be in the area of repair, rather than assembly and construction. The level of resources one would want to apply to a repair capability used rarely if ever, would not support development of manipulators designed specifically for welding, nor can we rely on the manipulators that exist. We need to retain other options that offer more flexibility and tie up fewer resources, both from the standpoint of budget and of space. A. Nunes - I should like to suggest that the development of a weld head mouinted on a universal "roller skate" that runs on tracks, a small set of tracks for making local repairs and long rails for major fabrication, might not amount to the major project required to develop a robot arm or the equivalent for welding..

Chip Jones - MSFC. I think that we're getting outside of our subject area. We're trying to talk about applications of welding and we need to talk about what we might use welding for.

On the lunar base, one of the major activities which is envisioned at this time, is a production facility, possibly for liquid oxygen or liquid propellants. There should be plenty of power there for welding operations.

Regarding battery operation, the Skylab electron beam welding experiment was battery operated.

Mike Casper, Martin-Marietta. One application that I haven't heard talked about at all is the salvage of satellites in geo-stationary orbits. This would require some telerobotic capability. Also large structures in geo-stationary orbits present some unusual problems primarily in transit time to and from orbit. Some type of tooling to be used in very remote location would be very beneficial. Dave Dickinson - Ohio State University. Some people are talking about getting external tanks up into orbit and then using those external tanks for construction of space stations. This would require cutting up the tanks and then rewelding them back together again. I think that we've only touched the tip of the her;. There's a reason why there's over 80 different welding processes down on Earth. Some of them are very versatile like the electron beam and perhaps the gas tungsten arc process that Rocketdyne is developing. There are other very specific processes like magnetically impelled arc welding that is very specific for putting tubes together. We have just begun mating processes to the two ativities we have been talking about: maintenance and repair is one thing and original construction is another.

A. Nunes - It's hard to conceive how a large structure like one of those external tanks could be made into a habitat without welding.

David Tamir - The M512 experiment apparatus on Skylab, was used for a number of applications, some of them not related to welding or brazing at all. Welding apparatus served for combustibility, flammability experiments, and has interest to the microgravity experimenters, particularly in the area of high temperature metallurgical solidification. The electron beam gun can supply a very high amount of energy at a "point." Welding apparatus is good for more than just welding and should not be seen too narrow a perspective. Developmental support for welding apparatus may be available from non-welding sources, for example Microgravity Sciences.

Hank Babel - MacDonnell-Douglas. One of the problems in the Space Station Program is carrying up the debris shields. Our latest estimates for Workpackage 2 over our baseline bid is an additional 43,000 pounds which is a Shuttle and a half launch. That's based on an environment that was established in 1971-1972, which we know is completely invalid, because there is much more debris up in Space than that. So when Workpackage 1 requirements are added into that growth and the new model, well in excess of 100,000 pounds shielding weight is contemplated. Those kinds of weights are prohibitive and NASA Headquarters is currently going through all sorts of analyses on what risks they are willing to take in this particular area. There are some very large structures still floating in Space. They're all of different configurations. A question is, "Is there any way you can capture that debris, bring it together, reconfigure it, and put it around some of the critical components where you would like to have extra shielding?" This would help reduce or eliminate having to carry the shielding up from Earth.

Hal Conoway- Rocketdyne. There's another area that,as we saw yesterday, that the Soviets have spent a lot of time on and that is the standard cosmic radiation deterioration of apparatus and equipment, and the reflying of thermal barrier coatings. The Soviets claim that within two years optics are sufficiently deteriorated so that they are virtually useless. I think that we cited that recoating of lenses and mirrors; I would call that routine maintenance, as opposed to the repair of damage which we have been talking about. There is an whole area of routine maintenance where we might like to modify the electron beam vapor deposition process for reapplying thermal barrier coatings or for recoating reflecting surfaces.

David Tamir - We mentioned cutting, but we mentioned it very briefly. I think in all the experiments which we plan to do we should demonstrate cutting, because I think that cutting is as important as welding.

Chips from a sawing type process are difficult to contain. With a very clean cutting process, you wouldn't have to deal with chips. There are numerous applications for cutting: reshaping, trimming unwanted metal, accessing, etc.

Boris Rubinski - University of California at Berkeley. I want to present a comment made to me by Carolyn. Inside the Space Station there are going to be situations in which small parts break. Yesterday I commented on the negligible, perhaps not significant effect of gravity, relative to high power welding systems with plasma jets, high laser energies, and high electron beam energies. For a small soldering process, in the absence of the high power effects gravity might really become more significant. This is an area that one might want to investigate.

Dan Rubicki - Martin-Marietta Michoud. I feel that a lot of the repair scenarios that have been brought up were a little bit standardized. Each and every repair, be it a skinline or a truss, is going to have its own characteristics. Every manual application or manual welding application that may be applied to a space repair needs to be adjustable as how that operator uses it. For robotics, complex fixturing, adjustable in accord with the particulars of the apparatus, will be required for manual welding, human manipulation of the apparatus to correct misfits, etc. will be required.

David Tamir - The Rockwell - The Cal Poly Get-away-special is not a vacuum experiment - it simulates the inside atmosphere of the Space Station. We are probably going to be welding within the atmosphere inside the crew modules. Tools need to be as versatile as possible in space. It would be best to have a single tool for both vacuum operation and for inside atmospheric operation if the combination is possible. At Rockwell and Cal Poly, we have given that a lot of thought and think that its very important.

Dave Dickinson - Ohio State - We've been talking about repair and the need for repair. It seems to me tha NASA has probably done some statistics about how many hits a structure the size of the Space Station might take in a typical year and perhaps how many of those hits would be piercing blows.

Don Dees - The current requirement is 99.5% fail safe. 99.5% of the time we will not sustain a penetrating hit. We don't plan on a module having to go to a vacuum requirement at all. If the event occurs, it's outside that realm of possibility. It's independent of the size of the structure. We're doing testing now to define how big and how bad is a penetrating hit it going to be. Our plan or requirements right now are that the first ten years it's 99.5%. With LDEF coming down in December, we expect the models to be corrected for meteroid debris. We will also have information on thermal control coatings and the micrometeroid or sand blasting effect on the life of thermal control coatings. If we have to replace coatings, on orbit, we'll need to consider why we can't use a less efficient, longer life coating in the beginning. LDEF is going to have a major impact on assessment of meteroid debris, micrometeroids, coating life, and damage tolerance.

David Tamir - There is a picture in an aerospace magazine of a hit on a Space Shuttle window by a paint chip from another satellite. It almost penetrated all the way through the window.

Chip Jones - I appreciate everybody's comments so far. I think that we've has some constructive ideas I would encourage you if you have any more ideas about applications. If you could ennumerate them on the sheets that were provided. We'had a few turned in already.

3.4 Session #3 - OPERATIONAL CONSIDERATIONS

Carolyn Kurgan - I have a little bit of different approach to my workshop than so far you've seen. What I have tried to do was identify what categories fall under operational considerations for welding in space, and I have listed them here and will try to present some of the facts as they apply to these different areas. I would like to start off with operational environments. We have discussed how we are going to have welding in space that would be done outside the shuttle or Space Station and also applications that are going to be done inside a vehicle. Inside a vehicle, we may have a case where we have had a puncture in a common module and so we no longer have atmosphere and room temperature conditions. Also, we may be doing minor welding applications where we would be in a laboratory environment. In the EVA conditions, generally space vacuum level goes from the 10-6 to 10-4 torr range. The temperature extremes are +-250 degrees Fahrenheit. I guess what I was trying to get across here was to remind people that our welding applications are going to have to consider the temperature and the material we will be welding and what effect is that going to have on our process and how can we include all of that in our development efforts that we do. And lastly, the cargo base steady state conditions are a little less extreme than general space conditions. Now on utility consid-erations, I know that somebody has already mentioned the fact that should we have self-contained utilities or should we depend on those available on the orbiter or space station and yet unidentified lunar base or whatever we may have. We are limited to DC power provided in Space Station and the orbiter with that kind of power we require to invert that to AC and then be able to control our power supplies. Now that approach is maybe we lose our efficiencies of our process and would result in generating more heat, which has to be accommodated for. On the orbiter, there is a payload active cooling kit where we can get some heat control that we generate, but the Space Station will not have those kind of facilities available. So, I would like to put forth "Does anybody have an opinion on going towards self-contained utilities, or depending on what is available?"

K. Matasubuchi - I don't have any answers, but I would like to make a comment of a general nature. I think that you are raising an extremely important issue, that is depending upon the requirement or availability of power or contamination level and many other operational constraints can have tremendous constraints on the processes that we can use. The reason I say this is that three years ago, November 1986, there was a conference organized by NASA and many NASA people attended and somehow I was invited to attend. This was called Space Station Workshop, and I don't know what group of NASA organized it, but it was held in Washington, and that is the place I was asked to give a talk on welding for one hour. There were so many questions, it lasted three hours. But I attended other sessions in discussing contamination and so on. Boy, I was so shocked when listening to what they were talking about that I said, "Boy, there is no chance of welding" because they are talking about, again, I think they are mainly talking about living quarters, not cargo bay, so living quarters you know is almost like living in an airplane, like eight people living in an airplane or something like this, and the whole water supply and everything enclosed. Therefore, they have very stringent requirements. It's really a balance between the two, one is how to accomplish the mission and the other is how to assure the safety and comfort of the crew members. Of course on one approach is to take a chance and if somebody gets hand burned, it is still okay, that's one approach.

The other approach is the more careful approach, and depending upon how to do this, your are eliminating many processes and therefore I think there is a very important need for some of you people to have good communication with the operations people because this must be done within NASA meeting one need. I would like to add one comment, which is the comment which may help you. I already told one of my students to develop expert system depending upon the requirements, you know, the power requirement, disturbance, the safety, and so on. If you have very relaxed requirements, there are a hundred processes. If you start lowering some of the requirements becoming more and more stringent, many processes start to disappear, and if you go way down here, you get nothing left. Since this student is working on expert system, we have asked him to develop such a system. It may be a crude system, but may become available within a couple of months. This is just one solution, but what is most important is the first one I made, that is it is extremely important to have communication between the research people and the operations people and make sure that what we develop is acceptable to them rather than waiting to develop something and ask them whether it is useful, but I think the earlier the better I think in selecting some processes.

Carolyn Kurgan - Does anybody else have a comment on utilities?

Chip Jones - I would like to make a comment. We talked about carrying along our own power and things like that. One of the things that I have had some discussion with people about is the fact that the welding process is a high powered kind of process where you have to apply a lot of power, but maybe not a lot of total energy in the whole realm of things. One of the things might be that you have sort of like a solar powered calculator where you only do calculations every once in awhile, but the solar batteries are charging up all of the time and then it is ready to give that spurt that you need, so there can be a certain amount of batteries. Maybe it wouldn't be absolutely isolated, but they would constantly be charged and ready to make a weld and then have to be recharged later, and they could be charged at a very low rate depending on what the rate of welding was, but that is a possibility of having either self-contained or depending on the power of the station or whatever vehicle you are on or this combination between the two.

Kevin Watson - Again, talking about repair, and when you are talking about the orbiter and Space Station you are talking repair, I think that the utilities that are available or adequate for repair operations. Now you would not want to commit primary payload power for an ongoing continuous operation day to day to day, but if you have damage or a specific component that has been degraded that you want to repair, then I think you could budget the power necessary to make a repair for a limited time. So, I think that the power is adequate and the other utilities are adequate to support that type of an operation.

Bill Kaukler - I have a question about the power on the Space Station, and that is a question about the distribution of the power over the structure. If you are going to power the welding process electrically, you will have to tote the welder to the site where the damage occurs, assuming there is power available at that site where the damage exists. My question, that I think needs to be addressed, is how available is the power over the structure and what are the consequences of using, so to speak, an extension cord to try and deliver that power to the electrically powered welder?

Carolyn Kurgan - I don't know myself how it is going to be distributed through the Space Station. There are going to be three locations on the outside of the station as I mentioned here with 1 kilowatt support power for any EVA applications, but where those are, I think that's a real good point, and how long of cables do we want to have hanging out there and should we depend on the space station power, as somebody mentioned earlier, if we have some kind of damage to our power system then we don't have any power available. I heard that there is going to a maintenance work station on the Space Station in one of the lab modules, and I am not sure that it is going to have welding capabilities with it or if they were expecting to just limit that to...I don't know, maybe somebody from Boeing might know that answer, but I am not sure if they have accommodated for welding in the Space Station currently. I guess here is an issue, we have to find out what kind of space station power is available.

K. Masubishi - Regarding the power, I think we need to think about at least three: Number one is the pole of power, and of course many welding processes require large power. Number two is the fluctuation of the power, something like stud welding would use like 1,000 amperes and is only less than 1 second and creates a tremendous surge in this power, it causes a disturbance. The third one is that it screws up computer because you know it creates a big difference and then the computer is screwed up next to the machine. And if I say anything like this, I am sure people aboard the Space Station would not like us. These are very important factors and we should be careful about many things. In other words, number one approach is a self-contained power such as the battery system that you mentioned, or we need to isolate, somehow shield the disturbance or have a shielded system that will not create the power disruption.

Don Dees - Trying to answer a few of these questions, I am not sure on the access of power from the modules. Depending on where you are at is what voltage and type of power you have. There is a central bus out on the truss where most of the power where will be coming into the modules. I believe that it will come through the primary module, the Boeing modules and then the European or Japanese modules are linked outside of ours through an internal bus within the modules I believe. But, the primary access, especially in case of some failure, is probably going to be external and then simple power cord or attachment points would be a minor thing. And to answer your question on weld repairability - there is no requirements or capabilities defined yet. Basically, our requirements are that we have none. There is not hardware to do it with and basically we don't have a requirement to do anything that would require welding. It is kind of like work package two said is basically the general attitude of NASA is welding as far as the baseline of our contracts is not a requirement to be done in orbit. There are a lot of things that could be nice if you could do it and future activity long term may be needed, but to build the station and get it operational, it is not required at all and basically has been baselined out.

David Tamir - To add to Dr. Matsubushi's remarks regarding the fluctuation in power I am not too familiar exactly with the electron beam or the laser, I am sure it is to some point similar. With the gas tungsten arc welding for example, when it is employed at the rocket and we are to make the space shuttle engines, they are trying to do a lot of robotics with that welding to increase the kind of of performance we are looking for and there have been a lot of problems with EMI (electromagnetic interference), which I think Dr. Masabushi was getting at, and if you are planning to have tiller robotics, anything that is automated of that sense, you are going to have a lot of computer technology with that that is very sensitive to EMI, and if anybody here is from those companies they are going to have to address that in their design if they want to integrate that with the welding process. So, that is something that is very important and it has been giving the welding industry a lot of trouble in the past.

Nathan Brown - Speaking once again about the EMI, it was one issue that was not up on the chart that needed to be brought up and discussed. EMI, I am not a welding expert, I do work with the electrical interfaces on the shuttle, and from past experience a lot of the experiments we get in come in and they exceed our EMI requirements. To give you sort of a feeling, a lot of the local radio stations here exceed the EMI requirements as far as the emissions are concerned. So, welding applications, if you do generate a lot of EMI, both in the conductive realm, that would be current spikes, and the immediate realm, the generation of electrical fields, at least the orbiter itself has some pretty stringent requirements on that. So you would have to incorporate into your design quite a bit of shielding or isolation. As far as the power requirements, you have the 1750 watts of continuous, or the primary payload, that is a one-quarter section. The 7 kilowatts is dedicated for a whole experiment. Time lighting would allow you to use more of that 7 kilowatt capability. Another capability is that you can have up to 12 kilowatts available for 15 minutes on a 3 hour average. So, we can reach those kind of capabilities with the orbiter for an experiment on a particular flight. Once again, I am not a welding expert and I am more interested in finding out what kind of capabilities the shuttle would have to provide in order to allow for welding experiments to be conducted.

Carolyn Kurgan - Okay, is there any other comments on power utilities?

Atilla Saba - Just one comment about the availability of power - The main reason we are pursuing electron beam welding is because of its high efficiency in converting incoming power to welding energy, especially again we are more concentrating on the patch repair of Space Station damage or what not and with the 2-3 kilowatts of power an electron beam can produce very satisfactory lap welds through nearly 1/4 inch thick aluminum which a laser couldn't touch just because of its inherent inefficiency and the reflectivity off the aluminum surface. The arc welding processes, again, cannot approach the energy density and therefore the efficiency of the electrical energy conversion into the thermal energy. So, I think from a Space Station on a limited power availability standpoint, electron beam would be a clearcut leader in that area. Just a comment.

Chip Jones - I would like to suggest that we add to our list there on power considerations - I know it looks like we have limited it to space shuttle, orbiter, and Space Station facilities, and of course self-contained - add to it also the hybrid of self-contained and dependent utilities, and also look at what possible utilities that we might have on some sort of a Mars vehicle and a construction facility in space that Murray had suggested, a possibility of a construction facility that Langley is working on and we should add that to the list of possibilities. We probably don't have the kind of definition that we do on Space Station. The same way with a lunar base, if we had some sort of a lunar base then that might be another one.

There is also another vehicle that we probably will talk a little bit about in the robotics area and that is the OMV. The orbital maneuvering vehicle is targeted to be something of possibly a repair type facility, and if we would like to suggest to somebody they might use that OMV to do a welding task, then we need to know what sort of utilities are available on it as well. So, we need to add some of those.

W. Jemian - As an educator, I would like to suggest that you put on the list somewhere, maybe under utilities or separately, some weld training facilities so that the astronauts or whoever is up there on that space station won't forget how to weld or braze or whatever.

David Tamir - I have another comment on utilities - one that is missing is gas because certainly for tig welding you need a gas supply and with EB welding you want to avoid gas, but if you were using laser welding EVA you don't need it, but if you tried to do laser welding EVA in a pressurized environment, an oxidizing environment, or partial vacuum EB welding in that environment, you are going to want an inner gas for oxidation protection. So then you have the question of what gas is available, what's the supply, and then also once you have introduced this inner gas into the environment, do you need to get it out somehow or because its inert can you just maybe reduce the nitrogen content of the environment a little bit or maintain the oxygen component by decreasing your nitrogen content. Those are just some little side issues I think should be looked at.

Carolyn Kurgan - Good point. That should have been on here definitely. Anyone else? Okay, next I tried to start listing what the equipment is we are going to be using up there for welding in space and this is somewhat general, but we will have to do some kind of joint surface prep, or maybe we won't I don't know, but there will be cleaning, cutting, and grinding if we would want to do something like that. On the power supply, we have vacuum compatible versus a pressurized unit. Now in that arena, the vacuum compatible power supply, would that be limited to be vacuum environments only or could we use it inside the pressurized module also? And then again, on the inverter that is required for most power supplies that we'll be considering and cooling systems and I think, my opinion anyway is that we would have computer control with us. On the accessories, a few that I have started, which again gas should be put on this, inert gas of some kind, cables and grounding, would we have to do anything different in that regard up in space to help assure these astronauts, for example if it is EVA that they wouldn't become the ground in the electronic circuit? Are there any comments at all on equipment considerations?

Jim Covan - If you are doing this preparation for your weld in space, you have got a space debris problem. It is going to be considerable if you have seen what the paint flecks can do. So, you are not going to have the same ability to prepare surfaces that you are thinking about normally.

Art Nunes - I think that one of the considerations that is of some importance in connection with a weld power supply is what do you do with the heat that is generated in the power supply? For instance, if you have say an EB power supply, if you have a kilowatt you have to get rid of 250 watts maybe of power just from your power supply and this would tend to bear on whether a vacuum, lets say an open to vacuum system is used or a canned pressurized system. Presumably a canned pressurized system would have greater opportunities for some kind of coolant system that would be required to remove the heat generated in the weld power supply, and of course any other system that would be less efficient would generate even more.

K. Masubushi - In addition to the gas, I would like to suggest to you to add dust, noise, and temperature. Again, you know when I was attending the conference I think they are very much concerned about the dust, noise, and also even the temperature. When you weld the temperature goes up. I think this would depend upon whether you are talking about the living quarters, cargo bay, or outside. I am sure there are differences. I think the requirements in the living quarters are very, very stringent.

Carolyn Kurgan - Okay, this is the start on the safety considerations that I could think of. For heat protection, I should have broken that up into materials in the vicinity of the weld area. What I showed here is the maximum temperature for the space suit is 230 degrees for 1 minute, which is just one thing that has to be considered in manual welding. There is also the arc light or radiation, surfaces and instruments which an astronaut is going to be exposed to. I am sure they don't want to have a case of cutting open their suit. There is also electric shock and redundancy to be considered. Is there anything else to be considered?

Chip Jones - I would like to make the comment of, also under redundancy, I guess it is not really a safety consideration, but maybe safety in the mission of welding - one of the things is that as we make a system more and more complex and we tell them that this is how they are going to put it together, if that fails then what is the cost of the system that can be reasonably considered not to fail when you get up there. So, if we are depending on welding to put it together, we have to look at the redundancy of the welding system and the way it is designed from an electrical standpoint so that it will withstand the mission requirements in that.

K. Watson - I believe there are two things that you have left out here. One is going to be control of ejected material because that is going to be of serious concern to a suited astronaut EVA, and another is control of toxic fumes that can be developed in any kind of welding process.

Boris Rubinski - I want to just share from our experience with the vacuum chamber that we have. As you recall, it is a large vacuum chamber, it is 6 feet by 12, and when we do welding, let's say a 20 second well, and when you go in the chamber again it is really warm after 20 seconds, and it's a huge chamber and it's really warm. Furthermore, when we do the weld, probably at a distance of 1-2 feet from the region which we do the weld we can see small metal particles clinging on the wall kind of disposed throughout the whole area. I don't know under what category this should fall, safety or anything else, but I think this should be a primary consideration when any welder is considered. Also, I am working on semi-conductor crystal growth and we are doing vapor deposition. Now the method that we are using is that we have a laser beam that impinges on a surface and vacuums any deposits on a particular surface, but that is exactly the method we consider for welding here. So, the chances that there will be very small, fine debris that will eventually condense on the space craft, on the space suit, the chances that if we do weld inside the space craft, you will have debris all over of very fine, perhaps supermicron even or micron kind of size is something to be considered. I think it is a tremendous hazard.

Mike Nance - There are a couple of other areas too. One in that the radiation should be electromagnetic interference and EAC constraints has to be considered in dealing with a lot of these power supplies, and also with the arc itself. Secondly is beam direction - the ability to convince people that if you don't have the beam pointed in the correct direction and if for example you have a target and you miss the target, can you absorb that beam by another plate behind it or whatever? So, those are two other considerations.

Jim Covan - One thing that I don't know if it has been mentioned, it seems like we are talking about autogenous welding and we should think that for most practical applications you need to introduce wire feeding to really get something practically done and that changes a lot of things. It is another system that has to be incorporated with welding and up there with the astronaut having two hands to manage his position in a zero gravity environment, a lot of technology has to be developed to allow wire feeding and that again poses all kinds of problems.

Jack Weeks - Reading the Grumman Report, referring back to that, a lot of the contamination concerns were taking into consideration there for machining and a lot of the EVA activities as far as being able to remove material and contain that material outside the vehicle. A lot of the concerns here about the small micro particles and all of this, is that I don't see why that same containment method couldn't be used if you had the filtration system and everything. And another thing is identifying what environment you are going to be working in outside of the vehicle. I mean, I am not sure anybody would expect the astronaut to step outside the vehicle with a hand-held torch and not having something to shield himself from it, as in a working station or the portable working station. So, I guess that environment has to be identified too.

Jim Covan - I think that one thing you need on that list is automation because you are going to have remote processes, especially having both the software and the mechanical considerations to bring into it.

? - I think the concern about vapor deposition is a real problem and the micro-particles coming off, but an added effect is basically a de-alloying effect where you can have very volatile alloys coming out of a metal alloy that will basically cause you different problems with the mechanical properties of the weld as well as an added toxicity problem which would be a safety concern if you were in a habitated area.

Hank Babel - It is very minor, but you really need to consider it, and that is are you going to be welding in the daytime or at night? You go through a 90 minute cycle and close to half the time it is dark and what kind of lighting are you going to provide in order to see the area that you are going to be working on or are you going to preclude doing any welding at night?

Carolyn Kurgan - That's a real interesting point I think we forget about. Does anybody else have any ideas on safety considerations? Okay, that kind of leads right into the contamination issues and we have addressed a lot of these already. You see, I have a very short list compared to what's already been identified in these last two days. I think we are all pretty much in agreement that we will have to contain just about any contamination we can generate, and as has been mentioned in this Grumman report, they planned on having a collapsible bag type set-up that went around their welding gun and area that they were going to be welding, which is a pretty good approach, but I am sure it is not the only one that we could consider. Are there anymore ideas on contamination?

Hank Babel - If Kevin doesn't say it, what about the gas that is coming out of the torch?

Carolyn Kurgan - That's right, in that environment, that's true.

Kevin Watson - An inert gas isn't really going to have a strong effect on most of the other elements on the station. Being inert, it is not going to react with them. You know, you have the metal vapor perhaps that you need to be concerned, but the welding gas shouldn't have a strong effect on things. It will dissipate and not do anything. I think another contamination issue is contamination that we have to deal with that is imposed on us because the environment is not necessarily pristine and there are things being released by the orbiter, there is off-gassing from other payloads and so forth that can be deposited on surfaces that we might have to weld, there is atomic oxygen that we could have to contend with, oxidized surfaces, and so forth. So, contamination goes two ways here.

? - If you look at the Marshall 527 materials list, you will find that even inert gases above a certain concentration are going to be considered toxic.

Don Dees - Another concern is that if you did trap all of these small metal particles, they haven't been oxidized. Once you bring them back into an atmosphere, basically you are going to dispose of them, you have a hazard in those metal particles now having an oxidized surface when you put them back in an atmosphere. This should be considered.

Hank Babel - I just want to comment about Kevin's comment relative to inert gases. There are very strict requirements about any gas going into free space because it then increases the molecular column density which is specified by NASA and you interfere with any viewing experiments. So, you are not allowed to vent gases indiscriminately. It has to be analyzed in terms of all of the other gases that are being allowed to be vented and dumped into the environment.

Carolyn Kurgan - Okay, the last area in my workshop covered possible shuttle experiment considerations. I don't think that we will be able to convince people that we can weld in space without doing a few experiments in space first. How many that takes, I guess, is our community's decision. I am sure we would all agree that we need to optimize the results we can get out of whatever experiment we plan and that's what I have tried to do is to list some of the means we could do to optimize each experiment we flew.

Dwayne McCay - Since you are starting the experiment section, I would like to make some general comments that I didn't make earlier today because Chip didn't want to talk about them at that point and time, but he said that this was the right session, so I will through it in here. One was the vote that we took on tele-operation, etc.

Now, I know the young man has been talking to a lot of astronauts and I have run across a few too every now and then, and they all want to do everything. I mean, all astronauts want to do everything by hand, that's just the way they are. They are not necessarily capable of doing any of those things by hand, but they still want to do them. We have a variety of Spacelab experiments to prove some of those comments. They are also very talented gentlemen that are able to do a lot of things that the rest of us couldn't do, but to think that we could really have a hand welding device that wasn't strongly automated, a lot of technology has to be developed before we can do hand-held welding of any kind of sophisticated equipment in space. Astronauts are always going to want to do that.

I mean, you are right, they want a bag of everything so they can do all of those things, and then they may not have time to do it, etc., but they certainly want to try. I don't think we are going to fly vacuum welders for some period of time. We are going to be flying pilots and physicians, etc., most of whom aren't very good at welding, but they sure can be trained to do some of those things.

So that's one comment. The second thing is that they will be doing a lot of blind welding. If they are going to be doing welding, repair welding, etc., you know, the feedback, control systems, etc. to be able to tell them when they are through, when the have a proper weld, etc., there is a lot of technology being developed, even if it is handheld welding. You know, you are not going to do conventional wire feed welding by hand in space or any other conventional welding by hand in space. Another comment is, on your charts you say 0g. In reality, it is not 0g and we all know that. You don't want to get into the kind of trouble that I got into. You ought to change that to micro-g because at some point you are going to find that there are processes that are affected by the gravity level. Dr. Rubenski has talked about that generally it is vacuum that is of concern to us. Well, there is really two regimes that we are dealing with here in all of these processes, and of course I am research oriented, so I am more concerned with the physics of the situation than I am necessarily a good weld, and so maybe I shouldn't even be here. But, the vacuum has a very strong effect on the external process. There is no doubt about that. And it may have strong effects on such properties of the weld as porosity. Things like alloy loss, modification of the alloy, the weld properties, etc., that is certainly something that can happen, but probably a minor concern with regard to the changes in porosity and some of the other effects that may happen when we begin to weld in very low vacuum such as we have in space.

But, microgravity and the lack of gravity will be important within the weld material itself. How it important it will be remains to be established, but any truly significant high energy key-holed type solidification experiments, etc. in a microgravity environment have yet to be done at some period of time and this would fit into your experiment section because it certainly does need to be done some time in the near future.

And then I had just one question. I wasn't sure what the purpose of this workshop was, but my understanding from listening to our colleague from Boeing chat or talk or comment is that fact that basically welding on the Space Station zeroed out as I understand, that's not part of the initial design. So, my question is, is your workshop to convince the people that that is wrong and that we should re-evaluate that situation or are you looking at evolutionary space station, the new concepts that we are looking for for downstream, etc. where we make sure that welding is part of that? I mean, I just want to make sure I understand which issue we are addressing.

Chip Jones - As conference chairman I suppose I am obligated to answer a question like that, and I appreciate your restraint so far Dwayne. The purpose of the conference is all of the above. We would like to establish what the critical issues are in welding in space and that is the basic purpose in this, and I think there is some education that needs to go on on both sides, NASA as well as outside NASA, and hopefully some technology transfer between the two and determining who are the people we need to talk to in certain areas and what are the type issues we need to raise, and so far I think we have been doing pretty well in that regard. I would suggest that we expand possibly on another note under shuttle experiments expanded beyond just the shuttle necessarily and talk about experiments that might be performed beyond shuttle and also maybe even what experiments might need to be performed on the ground also and what things can be investigated on earth outside of the need for an orbital type experiment.

Hank Babel - I would like to build on that thought just a little bit Chip. One of the areas that many of us are thinking about, is how to use the Space Station itself as a test bed. That thought has been raised by a number of other speakers and it is not going to be easy, particularly now with the first permanently manned configuration to assembly complete which may be as long as ten years later now. They are talking now that the first element launch would be like 1995 and you are really talking about assembly complete maybe 10 years or longer after that, maybe 15 years. But at least one of the other areas in the materials area to use it as a test bed I have received some favorable reception to that type of thought and I would at least like to offer it is that we shouldn't exclude the Space Station itself as being a test bed because my concern is how many experiments will you....(tape ran out) and we received a very favorable response about cooperative efforts relative to experiments in space. It seems to me that you at least should consider the possibility through NASA International of cooperative efforts in doing some experiments with the Soviets. I think you might get a lot earlier flights than we might get on the shuttle.

Chip Jones - Along the same lines as Hank was talking about, in talking to some people on robotics, there was a suggestion that (we are going to get into it in the robotic session, but it sort of applies in this area also) it might be possible to suggest an experiment for a piece of hardware called the flight telerobotic servicer, which is an intelligent robot type device that is being developed and that might be one task that the FTS might be asked to do as one of its proof of concept, and so that might be one way that we could get an experiment is to use it to demonstrate that.

Dave Dickinson - I would like to respond with a prejudice that I have to the question of what is the purpose of this conference, and to do that I would like to use an analogy. Back in the early 1900s when welding was just beginning to start, there was a lot of construction, bridge building, and even pressure vessels that were all put together by mechanical joints, riveting and things like that. What it took was a few explosions and a few disasters and things like that for people to begin to look at welding as an alternative manufacturing technique. I kind of liken where we are right now to that same time. We are beginning into a whole new era where I think welding might prove to be a better construction technique for space construction. I think that one of the purposes of this conference is to air all of the ideas that we are putting out here, to try and get us beyond that point where in the analogy we were with the riveted joints.

David Tamir - I guess the comment that I want to make has to do with my past summer job. I worked at Goddard Space Flight Center on get away special payloads and other kinds of payloads, and I have been hearing from Mr. Babel that the Space Shuttle is booked, you could say, solid. I mean its true, but not true. Because of the disaster, many payloads that were going to fly, they were committed initially, but they are not ready to fly and a lot of them dropped out of the picture, and there are a lot of openings for payloads to go up on the shuttle. If you really want to get a payload flying, you can find the way to fly it, and I think that the community here can put together the kind of support that a payload would need to get pushed through the network and actually fly. For example, we are going to fly the get away special space welding project probably this coming August and they are going to be flying about 3, they call them get away special bridges, they fit about 12 cans, which each can can accommodate an experiment. They have one planned for August, one for the following December, and then another one I believe for the following June. At this point, the get away special program, even though all the reservations have been put out, a lot of those reservations are not really being used, so there are payloads that you can actually get a hold of and use them pretty quickly to fly.

The situation is that right now Goddard is worried that those flights would not be filled with enough experiments because the people have just dropped out of the picture over the past few years and they need some extra experiments, so if anybody really wants to put an experiment together, get a hold of the Goddard Space Flight Center.

Carolyn Kurgan - We may finish early here and get a longer lunch than planned. At this point, before we do break for lunch, we do want to thank all of the support that we have had in this conference, the UAH, and Gary Workman in particular gave quite a bit of support to us in putting this together, and also the local AWS section and SAMPE. If anybody has any kind of comment here before lunch...

Ray Maynor - Before you leave, we would like to thank these people for allowing us to participate in this and we would like to invite you to become a member of AWS if you are not and we would also like to invite you to our meetings. This would be on the table out front. If you would like to be on our mailing list, please put your name and address on it and I would be glad to add you to it. We meet at Madison, at the, I'll give them a plug, Port of Madison Motel every fourth Thursday evening in most cases and if you would like to be a part of our program and be a program even for us we invite that too. Thank you very much.

Chip Jones - As far as coming back after lunch, our schedule should have started at 1:15, so since we are breaking a little bit early, I would like to ask that you come back at 1:00 and that way we can have a little bit more time for discussion and also maybe get out a little bit early if some of you need to go home. Thank you very much.

3.5 SESSION #4 - ROBOTICS

Chip Jones - I renigged on my promise to get started at 1:00, but we are going to try to get going here. The next session is the one that I am going to be trying to moderate and that is what I have called robotics. I would like to mention that if you haven't already seen these green sheets, it would be good if you could look those green sheets over and see if there might be, there is a couple of places where we have places for you to input information and two of the important ones right now are whether you would like to be part of a working group in this area that would continue on and try to talk about some of these issues outside of this conference and beyond this conference in this workshop that we are trying to do today, but more on a continuing basis and be kept up to date with some of our thinking in those areas and that sort of information. I started out with some broad subject areas here as far as manipulators.

I think it is appropriate at this point to give some information about what kind of robots are being considered for use in space right now and maybe that will give us a little bit more insight into what might be designed for say a welding specific type robot. In my Pathfinder Program, at this point I am not commissioned in the pathfinder assembly and construction in space effort, I am not commissioned to develop robots as part of my welding task and I have not really considered it part of my task. However, part of my task as I mentioned yesterday in my presentation is to try to develop the interfaces that we might expect and how we might interface with the robot system. It is not our purpose as a part of the pathfinder program, in welding at least, to talk about robotics from the standpoint of designing robots per se.

There is some effort going on in the Pathfinder Program, in other parts of the Pathfinder Program, that is discussing robots and the development of robots, but I would like to talk about these things. I have broken them down into some of the earlier systems, what I call the manipulator system, which is sort of like teleoperated type systems. Secondly, what we call robotic systems that are more like traditional robots as we think of robots today, and also what could possibly be a welding specific type robot or an end-effector.

In addition to that, I think it is appropriate to put in this workshop some discussion on advanced controls for welding. One of the things that has been mentioned throughout today is what is the level of automation required for welding in space, and what can we see about that? And I have a lot of ideas about that since that is my general purveyance, but I would like to hear from the audience and the people that are interested in what sort of topics we might consider for the level of automation required and some of the automation issues.

I feel like there is a lot of opportunity for the development of autonomous welders as we have talked about before, autonomous welders being something that would not require a lot of hand assembly, and I think that is one of the major thrusts of the Pathfinder Program that I am working on right now is developing welding techniques that concentrate on automatic assembly as opposed to piece by piece hand assembly that, for instance, the way they are planning to assemble the Space Station trusses.

I would like to look at it from that standpoint, but also there are some things to be done if we decide at some point that with a manual system if there is some sort of automation or intelligence that we can put into the torch that will reduce the amount of training and supervision that a welder would have to have or an astronaut would have to be involved in in order to make a weld that met the design requirements.

We have found in terrestrial welding systems that I have been involved in that men are great welders, the only problem is that they are not very consistent welders over the total of a program and we have spent a lot of time and effort looking at ways to automate welding and would like to figure out ways to get the man out of the instantaneous control loop of the welding process and allow him to have more supervisory control and less intimate control necessarily of the welding process.

What I would like to do to get started though, I have a friend of mine here, Ken House, from the NASA group here in the Information and Electronics System Laboratory that is involved in robotics and he is going to tell us a little bit about some of the robot systems that he has been involved in and give you a flavor of what kind of automation in robotics that they are looking at on some of his programs.

Ken House - Thank you Chip. I guess I work in the control electronics branch and we have a robotics team and essentially Chip has asked me to try to provide a little bit of information about some of the robotic systems that we are looking at and maybe capabilities and a little bit about maybe how a potential welding application or a welding gun might be incorporated into one of these systems.

But essentially let me start off with the Space Station because I think I can point out a few things from this chart that Chip included on his previous chart. You are probably familiar with the shuttle RMS and it is not depicted on this slide, but there is a space station RMS which is identical to the Canadian arm that is on the shuttle 60 feet long and I guess it is essentially a tele-operated, tele-controlled robotic arm. It would be used in Space Station assembly for essentially moving modules into position and other maneuvers between the orbiter and the station truss assemblies and what have you.

The station RMS is mounted on a mobile service center which is this platform and essentially it will be designed to have the capability to traverse along the length of the truss to essentially move to different locations in different truss segments and allow operations. It is a mobility base essentially to get the either EVA astronaut or the material that is being positioned into place.

There is one other robotic arm which is in the back of the Japanese module. It is an RMS type arm that they intend to use for doing experiments and experiment manipulation. Their experiments will take place on this exposed facility at the back porch of their module essentially and it has different locations and modular attachment and grappling and holding devices that they intend to use for the experimentation and what have you.

I am not sure of how we would interface with them essentially to use their robotic arm. I think that there are other people that are more familiar or more knowledgeable on that. I guess, like say, Work Package I here at Marshall, there would be someone in the chief engineer's office maybe that could make that contact and close the loop, say Denny Cross just for an idea I guess. Essentially, the international partners are covered under a totally separate organizational structure at the program office in Reston, Virginia. So, how those interfaces are handled, I am not knowledgeable enough to speak about that, but it wouldn't surprise me if an experiment or some other welding application was developed that would be a potential for say an external experiment.

One other vehicle that enters in, I guess when we talk tele-robotics and what not, is the OMV, which is essentially designed, I believe, to have a mission and at one time have a place on the station. I guess the program plans are somewhat dynamic, and I am not sure exactly what the final configuration would be, but essentially the OMV would be launched from the orbiter and would be available on orbit to do positioning and manipulation and capture and retrieval.

One of the other bullets on Chip's chart was the satellite servicing system and the OMV would figure into that system also in that the satellite servicing system is a concept to allow recovery and retrieval of damaged or tumbling satellites, a satellite that has lost its attitude control or has undergone some other abnormality that essentially they would mount a pair of grippers or some kind of a capture device on the front of the OMV and the OMV could chase it down and capture it.

I have another chart that I will show, the Flight Tele-robotic Servicer, but essentially one other robotic application that I can think of, in the U.S. laboratory module under the space station prime contract, Boeing had essentially proposed to provide a laboratory assistant robot within the laboratory module that would traverse the length of the module and be available to say to go to a work site and allow dextrous manipulation within the volume of a rack and I guess I throw that out, as far as I know it's not a funded part of the program at this time, but there has been quite a bit of planning done and I think it is a matter of whether the funding is available whether or not the robot will be in there.

If there were an experiment to look at welding, say internal, I am not sure I am just guessing right now, but if there were some kind of welding experiment that had to be done inside the laboratory then it may be possible if that robot were on the station to use it in some manner.

Let me jump on to the FTS, which is probably more, from what I understand of the sessions that I have been to here the last two days, this may be more in line with the kinds of activities. Essentially, the Flight Telerobotic Servicer or the FTS is a special purpose, well, I guess maybe a general purpose, it is to be a highly dextrous manipulator, essentially two arms with each arm having seven degrees of freedom, a vision system, here is the artist's concept, but essentially these are all requirements and pretty close to, I guess Martin-Marietta is the contractor on this and this is their concept. There is a third arm or a leg which is a stabilizing leg and essentially the concept here is there is a grappling fixture on the rear. The Space Station or the shuttle RMS could capture the FTS using the grappling fixture and move it to a location on the truss structure, at which time the third leg or the leg, the third arm, could attach itself and clamp to the truss structure. Then, the FTS could be manipulated.

It is teleoperated with limited autonomy, and so an astronaut could essentially have the vision capabilities to see what the task is and essentially here they are showing the change out of a propulsion thruster unit on a CMG cluster and there would be special purpose indefectors and special purpose tools that would be designed and built for the FTS to allow these kinds of tasks.

In addition, and at one time in the program, in previous years, this FTS was designed to be a smart front-end on the OMV, and this same grapple fixture that is on the rear of the FTS would be, well, it would be like the universal grapple fixture that would allow an RMS to pick it up or the OMV to pick it up and essentially then the OMV would provide the mobility for the FTS to move it to the work site and to allow the different operations.

I guess from what I saw on the electron beam welding gun that we had the presentation on yesterday, it would seem to me that with this robotic device, or telerobotic device, that would be a very interesting task to develop a gun and maybe even let this thing get out on a truss somewhere or get out in space on even a flight experiment and weld some materials just to do some testing and to see how well an astronaut or the operator could control the welding process using the teleoperations.

Now, one aspect in the development, I guess the FTS was just, the contract was just let in July of this year, so they are in the preliminary design phase, but they have two developmental test flights, and one is on 1992 and the other one is 1994 I believe, in which they are going to test certain aspects of the control system and of the manipulator arms and that type of thing. It may be that a simulated welding trajectory control could be developed and implemented and integrated into the developmental test flights.

I have recently seen an announcement, which was like a research announcement or a call of an opportunity in which they were soliciting activities and tasks and other ideas and descriptions of activities that the FTS could perform on these developmental test flights. I guess, if you have any questions at any time, I guess go ahead and ask them. This is Martin-Marietta. Yeah, Martin-Marietta is the prime contractor. Goddard Space Flight Center is the NASA center that is managing the development of this activity.

Jonathan Jones - The tools that the FTS uses, would they have to be designed for the grippers that the FTS has, or would the grippers be interchangeable for different tools? Now I am thinking particularly for the EV gun or something like that.

Ken House - I guess the arms come down to like say a wrist joint, at which time the plans are to design like a general purpose interface to which different end-effectors and grippers could be attached. If you needed a gripping capability, you could have that built into an end-effector, which would essentially mount to the end of the wrist and there would be some limited resources across there. There would be probably some type of data line. There may be some kind of a video line. I am not sure that there is any power available through that + joint.

In fact, recent conversations with the project office at Goddard has indicated to me that they don't intend to supply power through the arm to the end effector, but you know, I guess umbilicals or some other means would be available. I would imagine that the power requirements for welding are probably much greater than what this thing could withstand through the arms, through the wiring and what not.

Here is a chart that outlines just a few of the specs on the FTS I guess. Essentially, it is designed to weight less than 1500 pounds and 2 kilowatts peak power I guess and that would be the power consumed by the FTS. I guess they do intent to have batteries for a limited amount of like saving time, but essentially the FTS would be a user of power and would be tapping into a space station utility line, or it would have to get its power from the OMV, the Space Station, or whatever was carrying it at that time. Essentially, it is a tele-robot, it is tele-operable, but I know one of the concepts that they are talking about, is to have pre-programmed sequences such that, say the RMS could move the FTS into a certain vicinity and it could register to some landmarks, essentially attach itself and then it could go through the sequence performing say routine repetitive tasks where all of the materials were at a certain location and it essentially knew its environment, knew its universe. But the idea in having the tele-operations is to allow the ability to adapt to different environments and to adapt to, you know allow some flexibility such that if the truss piece wasn't exactly where it was in a robotic move it would essentially miss it, but with the tele-operations the astronaut could make the corrections and essentially grab the piece or make the manipulations.

Let me just point out one thing on this chart and I will go to the next one. The repeatability, 0.005 inches, is in the design spec and incremental motion 0.001 inches, the absolute accuracy in the design spec is 1", but I guess the understanding is that that's not as gross as it seems, but it is more of an eighth of an inch nominal accuracy.

I guess the FTS essentially is designed to be in the first element launch of the space station or in the early launches to assist in these tasks or even to provide for truss assembly. The structural interface adapter installation, they would like it to be able to do ORU changeouts and thermal utility connection mate and demates and also provide visual inspection and maybe even some kind of surface inspection or insulation. In what they are calling phase II in the augmentation they would want to add some of these other tasks that are a little more complicated, like changing out of the reaction wheel on the Hubble Space Telescope and provide in site maintenance and servicing which may be of a general and of an unknown nature, more like maintenance and repairs if something goes down and needs to be changed out that's not a scheduled activity.

And I guess I added in the growth or in the augmentation essentially I think there is a process whereby tasks that are accepted by the community could be added to the capabilities, or to the toolbox essentially of the FTS. I guess the project office at Goddard has what they call a mission utilization team and those team members are charged with investigating and developing the tasks, the activities, and essentially the mission of the FTS. I guess I contacted them concerning this conference, this workshop, and mentioned to them about the possibility of welding or using the FTS for welding and they had never thought of it or had been approached with that type of thing, but they did express interest in the proceedings and I think they would be very workable partner with someone to try to develop a welding system for a tele-operated welding system essentially. Does that answer your question? I guess that's about what I have here.

One other thing that we have been looking at on the robotics team has been on the Pathfinder Program, I guess we have the planetary missions, the lunar initiative, the mission to Mars and that type of thing, and among the planetary missions at the Marshall Center we have been looking at a manned rover for planetary exploration and that type of thing. One concept that we came up with was a rover for planetary exploration and we call it the mapper mission adaptive planetary exploration rover. Essentially, from what we understand on the Pathfinder Program and what now, if we go back to the moon and set up a lunar basis there will be construction activities, there will concrete structures that would have to be erected, and I imagine there would be welding and typical fabrication activities to essentially build a base there on the moon or you know on a Mars mission even. This is just a concept essentially, but it could be that if the technologies develop with the FTS using the FTS and the manipulator arms and what have you, that same technology could be transferred and implemented on one of the surfaces of the rover, let's say, and then maybe could provide the capability to do welding. This is your chart again. Essentially, I tried to cover what I could on these four robotic systems, and that is all the material I have at this time. If there is any discussion or questions, I would be happy to try and answer them.

?- We have implemented robotics into our manufacturing area, and one of the things that we have found that better identified some of our end-effector requirements is to be able to map out and identify what the reach and working envelope of that arm is around the structure that we are working on. How big of a task would it be to identify all of the surfaces that are within the working envelope of those arms that you described, you know the available utilities on this Space

Station, and maybe identify the surfaces that are out of reach or inaccessible, and you know, see what the need is for possible repair on those surfaces?

Ken House - I think the reach envelope on the FTS has been defined and I don't have that information with me right now or know what it is, but the truss distance is on the order of several meters I guess. The FTS is designed to be fairly anthropomorphic in the sense of when the astronaut is controlling it from a work station they want to make it realistic, or when the astronaut moves his arm, the FTS would essentially move an arm and they want the scale to be similar. There is a nice diagram that has the reach envelope, but I just don't have it with me. I would say it is on the order of 10 feet from the end of the foot to the most extended position of the arm. Yeah, that's true. I could include that in the minutes or with the package when we put this in here.

Ken Fernandez - Ken, do you know, since they did not consider welding as one of the tasks, and I think a large number of the people in the group have utilized robots for welding applications and they know that a lot of the early work in welding was hampered by the robots inability to tolerate the EMI generated by the welding process, if they are going through a design phase it would be probably be in our area to see that they have the proper noise models and can design the mechanism to tolerate that. Also, there are some other nice things in addition to teach/repeat programming that would be nice that would be the ability to respond to sensory offset commands and that type of thing, which is pretty common on industrial robots.

Ken House - I guess in the morning I started to talk on something and then he suggested that I bring it up now. First of all, when we were asked for a show of hands on manual versus telerobotic welding, all of people responded and I would like to qualify at least my response that yes I enthusiastically endorse manual welding, but probably I would think only for repair in emergency situations in which indeed you cannot afford to do without the adaptability and ingenuity of, as David pointed out, the operator. However, I don't think that indeed you want to rely on the operator's consistency and training and predictability when you are trying to do high quality welding. Another point, maybe related, we have been talking constantly about an end-of-arm tool that would do welding and sort of the reference always is for a welding torch.

It is not clear to me that indeed that ought to be the direct analog of what we have in an industrial system where you have the arm and a torch doing the welding directly. Maybe what you want to do is to have some kind of other tool that contains some of the accurate manipulation elements itself at the end of the end effector, which you actually move around with something like the FTS, given of course the kinds of accuracies that you have been quoting. Even that would also help to address some of the safety concerns if indeed you manage to have within the tool somehow captured a local environment, and again I don't have a solution, I am bringing it out for discussion.

Related, I guess, is also this whole issue of tele-operation versus telerobotics and the people say at Langley talk about tele-robotics when they talk about the FTS and systems like that exactly because they anticipate having the system positioned somewhere by the operator, but then performing a specific operation that has been pre-taught.

Let me try to explain that based on some of the experiences that we had a few years ago. About 6 years ago, we tried to do some simulated master-slave welding, and again in a direct tele-operation, it was almost impossible to keep, and I have data to actually qualify some of the experiments, the speed constant of the arm. It seems like the most appropriate model would be one where the operator, essentially in the simplest case, teaches the first and last point something similar to what we do in an industrial robotic situation and then the arm itself takes on for the actual performance of the straight line or whatever explicit path control.

But one can even take that even one step further, not simply in the specification of the path, but rather as a whole task. Something that the robotics people talk about in terms of task level programming and so on, where you specify the operation itself, weld there or weld this member, as opposed to the individual elements.

And finally, I guess another observation that has been coming to me during the morning was that it seems like we are trying to envision processes for space welding that seem to be direct adaptations of terrestrial welding processes, and I guess it is the tendency always to do that when you are trying to automate a process.

On the other hand, I think an old professor of mine gave a controls class years ago and gave the example of a sewing machine. If indeed we tried to make an automated sewing machine today with all we know about manipulators, we may well have put a needle in the end of an arm and try to move it up and down as opposed to try and redesign a process that indeed tries to really address the task and the environment and whatever else. Professor Masabushi likes to point to the early automated welding equipment, which essentially was an adaptation of manual stick welding, but having a big hopper with all the electrodes which were fed down and then pushed by a mechanism until people figured out that it is probably more appropriate to actually have a roll of wire which you continuously feed, which again the operator does not really have the capability of doing, but a machine may. So, we should probably make an effort to be open-minded about the kinds of new processes which we should envision possible for space operations.

Chip Jones - Thank you Ken. We had talked about in the same line that John just brought up, I think we can safely say that we have moved down into welding specific type ideas and I think there has been some talk about the adaptation of orbital type tube welding heads because that seems to be one of the areas that lends itself towards translation in space welding, but I have also tried to look at some other systems and some other ideas there such as the automotive system that I showed yesterday in the presentation. And I would like to encourage that we talk about maybe some other systems and come up with some ideas of some beyond that of the ones that we have just been talking about right now, if anyone has any information on what they might like to see in that area. Do we have any other general comments about that?

M. Abidi - You have mentioned autonomy quite a few times, but I don't see a definite list or properties of the sensors that you need to add to the robotic arm or the robotic system to accomplish autonomy, particularly for laser profilers and vision systems. Vision particularly is very suitable for those type of things because the settings can be controlled and since you don't seem to have a direct input in the first phase of the definition of the robots that are going to be on the system, are there any thoughts in adding some robots specific for welding, or how do you envision getting in the loop of doing some robotic work if the robots that are programmed for the Space Station do not handle those kinds of things? If the FTS is not equipped with the mechanisms that will allow you to use the vision system in a set up that will be suitable for welding, how do you envision to do autonomy, or how do you envision to implement autonomy and such things? Basically, Mike, our question is, is there still a way by which you could influence the robotic design so that it can accommodate welding?

Chip Jones - Okay, I don't suppose we know that answer to that right now, unless somebody in the audience would like to volunteer it.

Ken House - I would say on the FTS program, it is very early in their design phase and they are in a mode right now of gathering the requirements for the system and compiling those in a complete set that the people can pretty much agree to and decide that someone could design and build a system to those requirements and I would think within the next 6 months, there will be a review of those requirements in their preliminary requirements review at which time then they would begin their preliminary design. At the end of the preliminary design phase would be another review cycle that would allow, you know, critiqueing and essentially modification. I guess I am thinking that if a robotic welding concept could be formulated and put together and essentially defined in a lot of the crude parameters of resources, weight, power, and video requirements, that type of thing, like whether you need color cameras or black and white, and that type of thing, then there is a mechanism whereby those comments could be used to influence the design.

Chip Jones - I would like to go on to say that as far as what sort of sensors would be required, I had planned to include in part of this some information on that. We have been working in our lab at Marshall on different methods of improving the controls of the welding process so that we could improve the quality of the weld. Those represent basically making sure that the weld is on the seam, which would be some kind of a seam tracking process.

In addition to that, something that would give us information on the process itself. One of the sensors that we are looking at is a system that would profile the weld bead and give us an idea of what the solidified shape of the weld is as we are going along and if we could see trends in the shape of the weld bead, the idea would be to then modify the welding process, and we have a working system that works on one process that we use for the external tank. It is in a pre-production form, but that is something that we are working on, but there are a lot of places to go beyond that.

There has been a lot of work by Rocketdyne to direct process monitoring sensors, ways to measure the volume and shape of the molten material in the weld and try to determine factors that are critical to the weld quality based on that. All of those have not been defined. I think, as far as autonomy and automation, with respect to welds, in my experience to this date, most welds are pretty well empirically defined as far as what sort of parameters it takes to make a good weld on a particular application and then there has been some work done on automation, but usually it automates one small aspect of the process rather than from an all inclusive aspect and it's only applicable for a narrow line of applications. It will work for one application and not for another. I think that there is a lot of interest that has been in that, but that is still an area that needs to be addressed. I think on top of that, there is a wealth of information.

I think that Edison Welding Institute, and also Vanderbilt University, on looking into what can be derived from the process itself, say the arc signals itself without having to add sensors on top of that, and using innovative techniques in how power is delivered to the welding process in an arc process. For instance, usually what you try to do is just get a certain amount of volts and a certain number of amps and keep that pretty well constant as long as your weld doesn't change.

There has been some work done at Ohio State and a lot of different areas about using innovative ways to modify the power supply characteristics so that you can exact better control over the process and not necessarily try for just a constant power input, but have the power input adaptive to what the welding process needs. And those are the kind of things that are potentially useful for a space base thing.

For instance, the Soviet Union did some welding in mig welding. They had tried to use it and they found that there was a problem with the way that the wire melted and went into the process and they pretty well deemed it unsuitable for that reason. That was back in '69, and I wonder now, if we had more suitable power supplies that could detect that the droplet transfer or the spray transfer or whatever was not working like we wanted it to, those sort of things could be adapted on the fly with the power supply characteristics so that that could be brought under more control.

So those are areas that are potential for development that would significantly help the process. I don't want to monopolize the conversation, but do we have any other comments?

Dave Dickinson, Ohio State University - I would like to comment on your welding specific systems, the question you just asked a minute ago, and particularly to consider end-effectors for tube and pipe welding. What we have been talking about, or what I have heard for the past two days is orbital welding kind of techniques. No one has mentioned the Babcock's power system where they are proposing to make an electron beam weld, but use magnetic coils to wrap that electron beam all the way around, 360 degrees, the tube and then unwrap it and make the weld as it goes along. That sounds like a beautiful end-effector design to me.

A second type of thing that I would just like to throw out is that we have been talking about getting room between tubes on a rack for these type of orbital things, but there just isn't enough room, an inch or something or half an inch somebody said between pipes. There is a system developed for a magnetic impaled arc welding kind of systems where you just take a coil on the top, a coil on the bottom and alternate that coil and make an arc spin around the tube. With something like that, you could put just the coils on the top and you wouldn't have to worry about the space in between the tubes as long as the rack mounts were large enough to get the coil on the top and the bottom. Again, an end-effector for something like that might be of interest for consideration.

Chip Jones - Are there any other comments? I have a little bit more to say on this. As far as manual welding systems, I think I may be repeating myself just a little bit, but there is room for development in the area of intelligent manual welding systems. There are several approaches that I think have merit to put, for instance, sensors - if you decided that there were tasks that only a man could do with a welding torch, you could potentially put a sensor in the welding torch itself to try to intelligently sense it while the man still went about the task. It might even be transparent, the control system transparent to him. Just as an example that comes to my mind is for instance is one of the problems with a man trying to maintain a consistent weld with a man operating the manipulation is that a man would not be able to keep the travel speed constant and maybe the arc length constant if you had an electron beam system or if you had a more conventional arc welding system. But there is no reason why we couldn't have sensors in there that would detect the length and the speed of his hand as it traversed across whatever he was welding. If you knew what material it was and the thickness of it, then there is no theoretical reason why you couldn't tailor the output of the power supply to compensate for the irregularities of the man's hand.

I feel like that in theory, the sensors that are available for that sort of thing, and the ability of the power supply to tailor its control are pretty well consistent with the capabilities and the possibility for something like that to happen. The reason that I am throwing a lot of these things out here is because I would encourage you to think about these kind of things and possibly propose some studies and some work on automation type issues. And I might reiterate once again that the Pathfinder Program that Murray has commissioned me to do is to look at ways that go beyond simple hand operations and go into more automated assembly because the assumption is made in the Pathfinder Program that we are limited by EVA time and the amount of expense and so forth to the mission that EVA requires, and so there is a lot of interest in that program for systems that would automatically put things together and not require a lot of human intervention and human time to accomplish those tasks. They feel like that if something is so big that has to be built in space rather than carried up in one piece that it is going to be so big it would take just tremendous amounts of labor to assemble and that might become prohibitive, so that's a slant to the program that is very necessary and I would tend to slant any kind of consideration you have towards those ends.

Monji Abidi - Are there any formal guidelines on the sensors available on the rover that you are trying to get? At what stage can one suggest a particular system?

Chip Jones - On the lunar system that was described earlier. Ken, would you care to answer that?

Ken House - I guess that was just a concept for Pathfinder? Well, let's say like the rover or the mapper. Essentially that is in a concept stage right now and we are in a study stage to essentially try to define what would be required of a rover and the capabilities and what would be involved, such as the sensor systems, the power system, the control system, the drives, the motors - that's a new start program for NASA I guess.

So, it's just beginning and I would say it is just ripe for opportunities for people with innovative ideas to have an impact and influence in the direction.

Along those same lines, I was sitting her thinking, I guess NASA has a small business innovative research program and it seems to me that the concept of someone building an end-effector that could essentially, let's say, fit on the end of the FTS arm and hold an EB torch or some other contained unit, let's say like the idea of the FTS is maybe not precise enough to make welds, but essentially the FTS could be moved to position on the end of the RMS and maybe use some kind of a box or package to position close enough to the pipes or the truss, whatever had to be welded, and then some mechanism inside of this black box, let's say, would actually perform the welds or do the precise manipulation or what not. That concept would be acceptable and to me the SBIR program is an ideal mechanism whereby small businesses and what have you can propose those types of concepts and essentially, a lot of times, receive the initial funding to flush out the concept and later go into a developmental stage, like the phase II parts of that. I am not aware of any funding opportunities at this moment to do studies for welding in space using robotics.

However, I would think that essentially in the Code R programs or even in one of the projects or maybe in the advanced development program of space station that there would be an opportunity to pursue that kind of funding to develop some concepts. It seems like a pretty exciting area to me. I would be interested to work with anyone essentially to pursue the robotic aspects of the welding.

Chip Jones - I would like to follow on to what Ken says, that is, I say, would fall under my task in the Pathfinder Program to look at the welding relationships to robotics that would fall under this kind of an idea, welding in space. Do we have any other comments at this time? We have talked a lot about space station applications and how pretty things are pretty well set on space station and there is limited possibilities for the development of welding for space station, but we didn't maybe say very much about the potential for suggestive Space Station experiments that would involve welding, and I think that is a good idea that we could suggest welding experiments. And I think someone did say something a few sessions ago about the possibility of suggesting a space station experiment that would look into the qualification of welding for future missions beyond Space Station, maybe not to build a space station or even repair a space station, but to possibly build or repair the in space assembly and construction facility if that ever comes about or farther experiments beyond Space Station.

It would still be associated with space station, but would be more of an experiment on space station as opposed to an experiment for space station application. So that's another possibility.

If we don't have any other comments, and I don't see any other hands, I would like to move along with our presentation. We are right about on time. Our next moderator is David Hoffman, who is going to talk about test and simulation issues and facility type issues and that is an area that I think is going to be very important to us.

3.6 SESSION # 5 - TEST AND SIMULATION FACILITIES

David Hoffman - The first time I glanced at this topic I thought, what's required in this discussion? Do we want to design some kind of facility dedicated for welding in space, training and simulation, or what? And I think, maybe some time down the road, something like that will come about, but for the purpose of this discussion I think it will suffice just to talk about some of the facilities that are generally used, or can be used, to train astronauts or simulate some of the tasks.

I might add too for the purposes of this discussion, I think we are mainly concerned with training and simulation facilities as far as human factors go, not necessarily process development.

I think that it is accepted that the welding process is going to have to work in a vacuum. So, vacuum chambers or low pressures or what have you are going to be necessary for process development. But I think we are mainly concerned in this discussion with just some of the human factors. Two different areas that I have identified that I think that we need to be concerned with: As far as training for welding inside, some kind of vehicle, assuming it is still pressurized, and also, which in that case you are concerned mostly with just micro gravity. And training for welding tasks outside, some kind of vehicle, EVA, which you have to be concerned with wearing an EVA suit and micro gravity concerns.

Well, if anyone has comments or if they think there is any other categories that should be added to this, this was just kind of a general summary of where welding tasks might take place and different conditions. I am sure there are many different conditions in which a person might have to weld. Well, what kind of a difference would there be in welding in an EVA environment? I mean...yeah there would be some, well yeah, there would be some kind of in between...a heckler, a NASA heckler right here! No, uh... there ought to be something in between

EVA or a task that we would have to do on earth here.

Gary L. Workman - Construction, assembly, and repair is going to be something to look at too, and it is going to be different from the Space Station type activities.

David Hoffman - That's a good point. I didn't mean to down play that. As far as some of the facilities that we would generally identify with simulation or training right now. Vacuum chambers, which I mentioned of course we are using here to do process development in, but what are some ideas as far as the requirements? What are we going to require of an astronaut as far as training before he goes into an EVA environment? Are we going to put him completely inside of a vacuum chamber and make him operate the process? And that's just taking into consideration the vacuum environment and not the micro gravity. Or maybe an option to this would be what we saw in Mr. Conoway's presentation of the Soviets, the vacuum chamber which had an end cut out of it and a torso of a space suit and arms fitting in to the back of the vacuum chamber.

? - Should efforts be made to build the vacuum chamber large enough so that an astronaut could actually go inside and try. I see that it's possible. I mean, it might take some money and effort, but it will give tremendously more feeling to what is actually happening in vacuum.

? - I was payload crew training, and one thing that you might look at would be maybe a supplemental activity where you could look at a number of issues relating to some type of a welding process in space. If you want to look at tele-operation, you could certainly set up a work station to control such a process. You could also set up mock-ups of the mechanisms and put them in vacuum chambers and you could do a lot of research on the ground I think to determine what level of automation might be appropriate aside from simulation in a 0g environment. Has anyone looked at, say, a joint effort with some of the other laboratories that are working in related fields?

David Hoffman - Right now at this point we haven't looked into that much, but that's a good point, something that will have to be addressed.

? - Another facility that is available for variuos checks is the space station full size mock up and the ECLSS mock up which are over in Building 4755. If there was any work done on any of the experiments or a rack design had to be fitted into a rack, then that is another test facility that needs to be added to that.

David Hoffman - Moving on down the list here. Now some of these yesterday and in some of the discussions today got into some of this, and there were good examples yesterday of the use of the neutral buoyancy simulator and the KC-135 research aircraft. Also, I have added here some type of robotic remote manipulation facility, if telerobotics or whatever, will be used and we need some kind of facility to do simulation as far as that is concerned.

Gary L. Workman - I would like to point out in the KC-135 there is a lunar parabola. You can get there 60 seconds, which is longer than the 25-30 seconds we talked about yesterday, but if you want to get into the lunar base activities, the KC-135 can handle that also and you get twice as long and you get about 1/6 g for this particular experiment.

? - I am representing a test laboratory and we have both topics I and II, pressure chambers, neutral buoyancy, and right now both facilities are being re-worked and in fact in the next two years we will have probably one of the world's largest vacuum chambers. It will be the size of the cargo bay of the shuttle and will hold something as big as the cargo bay. It is really scheduled for x-ray calibration facility for Hubble Space Telescope. Neutral buoyancy simulator is available and that is scheduled to be back in operation probably in January/February time frame. And at this time there are plenty of opportunities for testing at the neutral buoyancy facility and at the smaller vacuum chamber facilities.

David Hoffman - I might add also, I don't know if everyone picked this up yesterday in some of the discussion, but there is a neutral buoyancy simulator at Johnson Space Center and also at Huntington Beach at McDonnell-Douglas, they also have a neutral buoyancy tank. If there are people here who have been involved in some of these things, we might want to address some of the pitfalls of some of these facilities as far as simulating tasks and how difficult is it to simulate tasks in these types of facilities, what are some of the pitfalls, how well they simulate an environment.

David Tamir - I would also point out that there is a low gravity drop tower facility in the NASA Lewis, so obviously you can't put a man in that, but for other testing facilities that is available.

David Hoffman - Are there any other comments?

? - Yesterday there was some modeling shown that showed that the gravity effects were very negligible, so all you may need for simulation may be just low pressure chambers, you may not need a neutral buoyancy or a KC-135 aircraft for that.

David Hoffman - I think that for the most part was described in the welding process itself. A big concern with the astronaut using any type of apparatus whether it is a gun or a torch or what have you, would be the effects of gravity. You know, they have to have some way to brace themselves so they can manipulate the apparatus or something along those lines.

Boris Rubinsky - I would like to qualify what I said yesterday. My analysis dealt with plasma arc welding. It was not a generic analysis for all welding. In plasma arc welding, you have a situation in which the pressure that is being developed by the plasma jet has essentially to compete with gravity and surface tension and gravity is negligible, or that's what the analysis shows, that the effect of gravity is not as dominant as the effect ofvacuukm on the plasma jet. However, I can envision other welding situations in which you don't have a pressure that is as high of that as the plasma jet and in those situations gravity might have an effect.

For example, as I mentioned earlier, if you want to solder something, you might have a situation which gravity might have a significant effect. So, one has to look carefully at different processes and study them. Besides, I think that one definitely has to demonstrate the theory before one can go and take future steps. So I think there is a need to demonstrate the effect of gravity anyway.

David Hoffman - Thank you. Again, I might add that deals more with the interaction of the process itself regardless of the effects of gravity on the welding process. The astronaut, or whoever, will still have to deal with the effects of gravity as far as manipulation of the apparatus and things along this line.

Boris Rubinsky - I would like to mention the need for sort of an instrumentation observation during welding operation. I think it is extremely important to do some experiment because there are so many surprises you know. We know some, but we do not know many things, so it is important to do experiment. However, experiment tends to be expensive no matter how you say.

However, I think that this has been brought up a number of times yesterday and today. There are many techniques, analytical and simulation techniques we have. However, there are some fudge factors in these simulation techniques, therefore if you have a measurement of observation during operation,it would really increase your accuracy of analysis and therefore instead of making thousands of experiments which you cannot do, maybe ten experiments can give us a lot of information, then we can even estimate what can happen in a real space environment. So, I know these experiments are very important, but within the limitations of budget, I think it is important to have some kind of instrumentation or even observation system.

Jim Carter - I am not a welder, but in the last few months I have had a chance to work with the M&P lab on furnishing a facility for some of the welding experiments and one of our concerns of course was the contamination problem.

David, I think has a slide of this chamber. Could you put that up there a minute David? This particular chamber was developed in the past few years for high altitude aerodynamic work, and thus it had a very high pumping capacity and was able to maintain a low background pressure and this fit the needs of the welding experiment that Chip and his people contacted us about.

In our study to design the experiment for that, Mr. Art Nunes gave us some good recommendations on what our contaminations might be and we weren't so concerned about all but one, which was of course the vapor deposition on the inside walls of the chamber. I did some study, trying to get a hold of some of my colleagues in the vacuum industry, and really no one had ever done any welding inside a chamber such as gas type welding, etc. So, really all we had to go on then was just vacuum technology background.

We are designing this experiment now then to just include a shroud inside the chamber just trying to protect the walls of the chamber from this vapor deposition. The M&P people have a window of testing in this chamber for approximately 6 months, at which time we will remove the shroud if it's contaminated, and of course replace it. I think the main point that I want to make here, I am sorry I have taken so much of his time David, but the main point that I want to make is that I am a facilities type person and we don't want to overlook the needs for ground base facilities.

Of course, since the dreadful event of the Challenger, we all know that there is much greater emphasis on testing now at Marshall Center, and this is the time too you know to bring out these requirements for testing in these ground base facilities.

Bill Kaukler - I wanted to retort to the point about the lack of need for microgravity type simulation. And I can't emphasize enough the need for simulating microgravity welding. I don't want to toot my own horn, but yesterday I showed that there was some difference in the strength or the hardness of the weld performed at low g versus high g. I am not saying, and I don't think anybody here would say, that it is impossible to weld in space. I think that it is possible to weld in space, but the microgravity condition may in fact allow the formation of a weld that is inferior than that of the one you would form on the ground. I, on the other hand think that in fact it might be superior in microgravity conditions since the surface tension of the weld pull is the controlling force for the formation of the weld bead itself, and since gravity has an effect on the shape of the weld bead, things like undercutting, heat transfer, the shape of the pull, penetration...everything could be affected by gravity.

And add to that the possibility of an interaction with gravity effects and for instance electromagnetic convective effects that we don't know that may in contribution or synergism or whatever make for a worse or better weld. I am talking for instance strength differences of maybe

20%, and if we are going to make good welds, we need to know a priori that the welds will in fact be better or if they won't be better, by how much, so that we can account for the loss in strength.

David Hoffman - Are there are any other type of innovative ideas for facilities that might be used for training astronauts or simulating some of the tasks that we might have to do?

Chip Jones - I don't know how innovative it is, but I think we ought to consider the three basic areas. I think that Dave has eluded to them, but one is what kind of testing we need to do to qualify these processes for use in space. If we just have an idea that some particular process might be useful there needs to be testing done before we start trying to really develop it seriously for space use.

In addition to that, once you have it qualified to some level, you probably want to continuously qualify it as you go towards a launch condition or an experiment definition phase, but in addition to that, once you have got a system you have decided to put into space and you are counting on it to be used in space, there will probably need for, a simulation facility is the way we referred to it, but a simulation facility for when the astronauts, for instance are trying to get it into place and make a particular weld or something like that, or however it might be used.

There is going to be a need for a simulation facility so that if there turns out to be some sort of a problem, an anomaly, and they call us back on earth and say, "We are having this problem", we would have some kind of a facility that we could go to and try to simulate that problem. I think that that is traditionally the way that those sort of things have been approached on previous missions, such as the lunar rover, well most of the missions they try to simulate things here on earth. And of course as Dave has talked about, the training facility for getting the astronauts trained so that they can learn to use it. I would suggest that we might consider the development of a vacuum facility in the KC-135 possibly. I know that there has been some talk about that, but a vacuum facility in the KC-135 that would give us a two dimensional approach to qualifying processes and possibly training as well, but at least to start out with there might be a possibility for some use on that.

David Hoffman - Although, as has been said by a lot of the people who have been up here, a lot of emphasis will be put on making some kind of a welding apparatus that is very user oriented or easy to use by crew or whomever. Is there any kind of general feeling on training for crew as far as basic welding skills? Will we just train them to use the apparatus or is their a need for training people to actually weld first? Say, some kind of 2 week crash course of welding.

Kevin Watson - This is one of the issues that we have looked at in the Instep Program that we were doing a little bit since it is, to a great extent, a manual welding oriented experiment, and what I would anticipate is that there would have to be some preliminary basic training in welding and just shirt-sleeve bench top type work so that they become familiar with the process and then go through sort of an escalation of the fidelity of the simulations that they are experiencing and that would include going from bench top work to a whole range of things including shirt sleeve work and the KC-135 suited work in a man rated vacuum chamber maybe just some suited work in a laboratory or glovebox type work and things like that. You take incrementally so that you increase the difficulty and complexity step by step, and then your final simulation would perhaps be suited work in a KC-135 would be the closest you could get and that would also serve as your primary baseline data that you would use to compare your experimental results against.

? - I think your simulation is going to be very important. We talked yesterday about the wetting characteristics being different and your puddling. That's going to present a major problem if you think you are going to weld in space like you do here if you are going to do manual welding or robotic welding for that matter. The puddling effects are just going to be different, and as this gentleman just said you are going to have to start out step by step, these men are going to have to know how to weld, and then you are going to have to take them along the course to where you know they are not going to ride this bicycle the first time they get on it. You better provide them a bicycle to practice with.

Dave Dickinson - I may be answering your question in a different way, but I am sure in the simulation we need some kind of a method for training welders. In other words, there are some cases in which the astronaut must have some welding skills. However, when you think about it in many operations, I think that we must do it some in a different way, direction that is, to develop joining techniques which do not require too much welding skill. My idea of instamatic welding is just one of the ideas, and there was in the past for so many years we always felt we have been doing the same thing over and over again.

In other words, we always assumed some training is needed, even we always assumed the person who must do welding must go to the weld job to be done. But you know you can always think of it in an almost opposite way, that is the idea of instamatic welding is that it is almost completely enclosed and you just push a button and weld. So I think you know there are many different directions we should explore. A good example is a camera. Many years ago cameras were very complicated and then Kodak developed the instamatic camera which is simple and now Fuji has developed the throw away camera, we just buy film and it takes pictures. So this is a radical approach, but I think we should look into many radical approaches.

M. Abidi - There is a lot of work that has been done in undersea welding. How much of that can be used? I took part in a conference that occurred on November 7-8,1989 just days ago in Washington, D.C. in which a number of projects were reviewed by NASA headquarters and half of those, the title was Telerobotics - The Visual Definition of Current Capabilities, so we dealt with robotics, but quite a bit of that was on welding. So, how much do you think the under sea experience could more or less help in defining the sites that you might consider building or designing for you to train those astronauts?

David Hoffman - I don't know if I can answer that myself, but any kind of added experience like that in some kind of modified environment is going to be of benefit. For instance, the tasks that are done in a neutral buoyancy simulator kind of corresponds to this type of thing.

David Dickinson - Regarding the similiarity between the undersea welding and the space welding, there are similarities and also there are differences as well. When you think about neutral buoyancy, this is a major similarity. However, the big difference exists in the water. The water is a very,very unfriendly environment and it is far different from space. So this effect is very different. However, there are basic similarities as well as differences. However, when you go to the need for unmanned system, I think there are again similarities. In other words, in both cases if you go very deep or far away, we must develop unmanned systems, in other words, systems which do not require human beings. And also, a very different thing is this, when you are talking about like robotics and so on on the earth, in welding many other operations, you do welding, but there are so many other things you must do such as put plate together, clean it, weld it, and do inspection and so on. So welding is one part of many, many operations.

Therefore when you have this automated system, human being is always present in between. But when you develop a system like undersea, we just cannot put people in it, so we need to develop a system which does not require people. So the bit similarity again is the reduction of human participation. How can you reduce a number of people needed?

? - Another thing that we have to keep in mind is that we are changing out these crews on Space Station every 90 days. So you are not looking at somebody that you are going to train and put up there that is going stay up there as a welder. They are going to have all of these other things to do and they have got all of this training to do to take care of everything that is up there and we only have just a short time to train each crew.

David Hoffman - Okay, that's a good comment.

Art Nunes - I think we could possibly make a compromise and exploit certain features that would not be used by the ordinary industrial welder. For instance, I am thinking that the amateur bicycle rider might use training wheels and aids might be developed to enable a welder to function with a greater level of skill than might be expected by an industrial welder using typical industrial procedures.

Furthermore, another kind of aid comes to my mind. I don't know whether the people here are familiar with the painter's mile stick, which is a kind of, just a stick that you put up against a painting instead of your brush or steady your hand when you need to brushin intricate details and things of this sort could probably be invented and used to enable low skilled people to do work at a much higher level of skill I would think.

M. Abidi - As a follow up to your remark, there is the need obviously for training an astronaut that you cannot take as much time as you would if you were going to be using him for quite some time and that brings again the idea of having a mechanism that can correct for small errors, correct for velocity, correct for position, a system like an RCC device that will allow you to follow a path which is the seam though the overall movement could be shaky there could be an indicator by which the astronaut is asked to speed up or slow down, raise or lower the torch in order for it to follow a pre-determined path or a fixed relative position with respect to the plates and things of that nature and that adds more and more the need for accurate sensors that can be integrated at the end-effector level or near the weld to where you can basically eliminate that jitter that might be introduced.

David Hoffman - Okay. I think definitely whatever kind of training or simulation is done is going to be somewhat dependent on the process and sophistication of the process. Obviously if it is going to require more manual skills that welders have today, then possibly a greater amount of training and simulation and things like that will be needed.

Kevin Watson - I appreciate the comments about taking the human intervention out. If we are going to make subjective welds where we have the human input, then the training is going to become more important. If we can take the subjective decision making out of it, in other words, it is not the feeling in the back of the man's neck that yes that metallurgy happened, we can put in systems that say we study the puddle oscillation, now we become a quality control person where we monitor the system, process control, and then you are not going to have to have the manual dexterity and the training. You are going to teach system management. We should certainly reach for that goal, to take the subjectivity out of it. For one thing, our quality people will live with us. Otherwise, you know, they are not going to feel too comfortable about it here on earth when the man up there who we hope isn't busy says, "Well it looked good to me."

David Hoffman - Okay, that's a good point. I think most people are in agreement that the easier it is for whoever it is that has to operate these types of apparatus that the better off we will be. Are there any other comments or suggestions?

Chip Jones - All right, thank you Dave. I suppose that brings to a close the planned discussions that we had and I would like to open the floor to any subject areas that maybe people think that we did not cover that we should cover and certainly open the floor outside of the facilities realm or any other realms that we had scheduled for today and certainly open the floor for that sort of thing. Do we have any comments along those lines?

Don Dees - Will the attendance and mailing list be part of the proceedings so that other people can follow up on discussions?

Chip Jones - I believe that is the plan, that the proceedings will include a list. In fact, we have had some lists out on the table out front. I don't know if there are any left or not. Do we have any other comments?

K. Masubuchi - You have mentioned that you are in the process of forming working groups per topics. What kind of formal arrangements have been finalized on that and how do you envision doing that? Could you tell us a little about the areas that you intend to have?

Chip Jones - The formal provisions that we have made for that so far has simply been the expression of interest in these subject areas. We haven't defined exactly how that would take place and I think that we have had some informal discussions during these two days about the possibility maybe of a follow on conference to this that maybe would expand the scope of what we have talked about in the last two days and one of the things that these working groups might do would be to plan for what would be involved in this type of a discussion in a larger conference, maybe off-site that had more advertisement and things like that than what we did in this particular one. I feel like that this type of an arrangement that we did in the last two days was appropriate given the level of development that has occurred up to this date.

Hopefully, at some point and time, and we decide that it would be fruitful for us to put together something more formal, then I would expect that these working groups would have an input on what areas would be covered in an arrangement such as that. We have a place on the green sheets for people to provide comments on how soon they think another operation ought to be held and what scope it should have...should it be smaller, should it be larger? I can see some advantages that might have happened in this discussion. If it was smaller, things would have been done differently, but also, if it were larger things would have been better in some ways too. So, I think that the size that we have had, especially given the level of interest that we have found as we started talking about this, I think it has turned out just about appropriate. But we would certainly encourage you to provide input on your green sheets, and to me personally of course, either today or at anytime you can call me on the phone and talk to me about that. I think Boris has a comment.

Boris Rubinsky - Isn't NASA Marshall supposed to be the center for welding research? There are other people including myself whose monitors are at Langley, is there any decision with respect to who is going to be the central group monitoring research in space or something of that nature?

Murray Hirschbein - There are two different areas being covered here. The Instep

Program is not focussed in any particular area within The Office for Aeronautics and Space Technology. It is across that entire area and it involves all of the NASA centers in a fairly uniform basis. So, the experiments were distributed as best we could across the centers, having something like 42 of them. We split them out among those centers that showed a strong interest. The Pathfinder Program, each of the elements that I described yesterday is located in one of the appropriate discipline divisions. The one on in space assembly and construction is in the division that I am in, which is the materials and structures division, and we have direct control over the kind of activities there. For that particular program, if it deals with the Pathfinder or whatever comes out of these kinds of activities, we are going to focus our activities in welding at Marshall.

If it tends to be related to these more broad based technology experiments, which are really your show, you are the ones who propose these experiments and they are carried out the way you want them to be carried out and NASA is not telling you how to run these experiments. The activities in Pathfinder and the like that Chip is involved with is our program within NASA and we have a lot more control and we are centralizing how we are going to do that.

And as I say, for that program we will keep our activities here at Marshall as the focal point.

Chip Jones - Okay, we have another comment.

M. Abidi - I just don't want you to go to dinner too early. The other comment has to do with the alternative technologies. There is a definite sense that the technologies evaluated currently for space applications are earth technologies and I think that this was mentioned. Is there any mechanism, and I think these comments were made, but they would like to repeat them perhaps, is there any mechanism to encourage or to facilitate the development of alternative technologies to those used on earth that might be applicable only in space, and I cannot give you examples because I don't know of any, but is there any thinking in that direction?

Chip Jones - There is no specific thinking that I know of, except that one of the reasons for this conference is to provide a forum for alternative concepts to be presented, and of course whenever we decide that this meeting is adjourned, that doesn't mean that inputs are cut off at that time, but we wanted to give people the opportunity to understand what we were doing and provide a seed for inputs to be given at a later date and certainly I have done my best to solicit within the framework that we have been given authority to look at alternative technologies. And certainly, I think that if we are to be cited for a weakness maybe up to this point I would say one of the weaknesses might be as you mentioned, the fact that we are taking existing terrestrial technology and trying to apply it in Space. I guess that has to be balanced against the technical risks that are involved. I mean, if you come up with something brand new, you don't know what kind of problems you can run into.

But, I feel like that, given the level of technology right now, maybe it is prudent to approach it that way, but certainly we are looking for proposals beyond that mode of thinking. Do we have anymore comments, general or specific? If not, I would like to thank everyone for being here and participating in our workshop.

It looks like we still have a pretty big group for as late as it is. I know a lot of people had to catch flights out of here and things like that and it has weeded us down a little bit, but I appreciate the level of commitment that everyone has given to the workshop in providing us inputs because you have done us a great service, and I hope that the information that we have given out has been useful to you as well. I look forward to working with people if they are willing to provide proposals and we would like to consider those. So, if there are no further comments, I would like to say that the meeting is adjourned.

4.0 SPECIAL COMMENTS

Several attendees submitted special comments with respect to welding in space activities. Dr. David Dickenson, Chairman of the school of Welding at Ohio State University, wrote on his questionnaire "I think this workshop was perhaps the most significant event during the past decade on the needs of technology development for space construction." Dr. Dickenson also recommends that a joint NASA/AWS committee be established to develop a recommended practice guide for each possible welding process. Dr. Mitsubuchi has also made such recommendations in the past.

Mr Lee Wilbur of UTC/Advanced Systems proposes that the Shuttle C, in orbit would make an excellant manufacturing/welding facility. Mr. John Bobo, same organization, also states that this type of activity shouldn't die, as did Harold Conoway from Rocketdyne.

Other working groups proposed by the attendees include:

Automation and Sensing for Welding (M. Abidi)
Tooling Requiements for space Welding (A. Lang)
Testing and Inspection (J. Jones)
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