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WELDING/BRAZING FOR SPACE STATION REPAIR

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Fabrication and Repair Candidates

Throughout the 30 year operation of Space Station Freedom, it is reasonable to assume that structural and operating system damage and deterioration will occur through normal use, operations accidents, and/or collision with debris. It is likely that some of this damage will be of immediate urgency without the availability of identical replacement parts. "In situ" repair will become mandatory.

Three primary bonding assembly methods have been identified as candidate techniques for "In situ" repair or this damage. These techniques include adhesives or adhesive bonding, mechanical fasteners, and welding and brazing techniques. Typical examples of each of these techniques as repair candidates will be presented.

FABRICATION AND REPAIR CANDIDATES

THREE PRIMARY ASSEMBLY METHODS

0 ADHESIVES

0 MECHANICAL FASTENERS

0 WELDING AND BRAZING

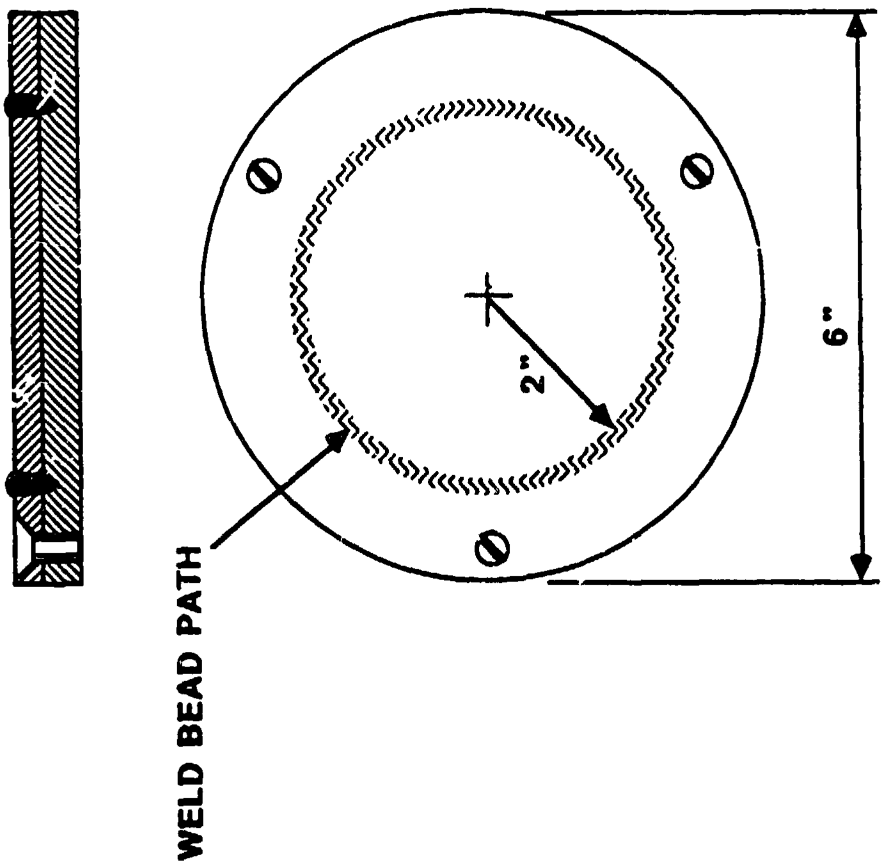
Debris Penetration of Module Panel

A penetration impact to the 1/8 inch 2219 aluminum shell grid panel of a module is simulated in this figure. The use of an "adhesive tape system employed from the inside of the module to effect a repair was investigated by a major aerospace company. This system may provide some immediate relief from the damage but the long term viability is questionable. This is rather like "applying a band aid to a pressure vessel leak."

Ground base welding repair techniques have been developed and have been successfully used in almost every major industry. Welding alternatives need to be developed for space module vessels.

Welded Repair Patch

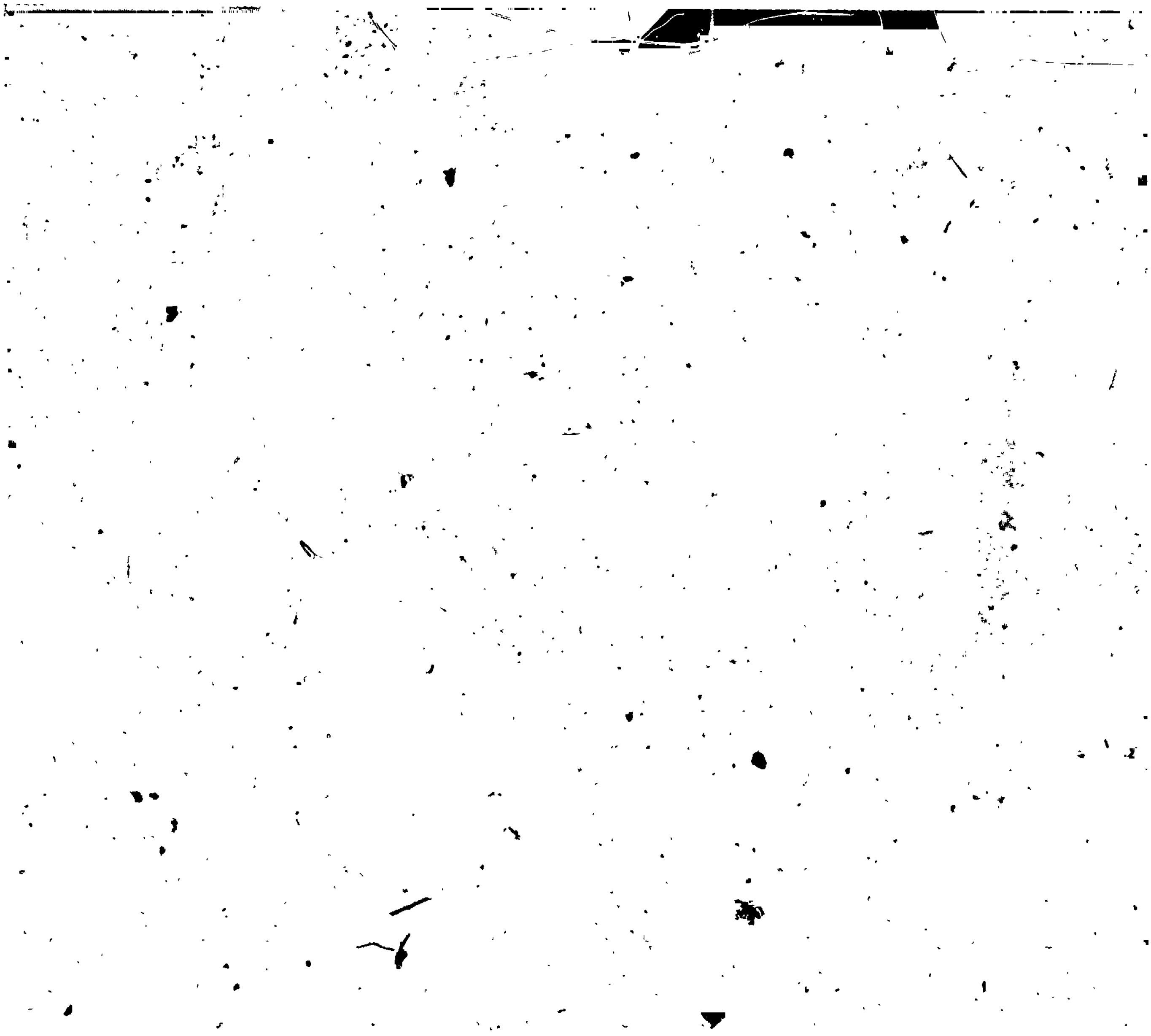
The Martin Marietta Company has proposed a weld repair patch technique for module repair as illustrated in this figure. The patch, ideally also made from 2219 aluminum, could be affixed over the damaged area and a circular weld bead repair made through the patch and into the module wall to seal off the damaged area. The welded patch would provide a reliable, long term, leak tight repair which could be made from either the outside or inside of the vessel with equal reliability. The welding process under development by Martin Marietta to bond this patch will be described in more detail below.



Panel #1 2219 ALLOY

Mechanical Assembly of Utility Fluid Line

A second example where repair may be required might be on a broken fluid line. The current repair procedure might consist of cutting the damaged fluid line and installing a "quick disconnect" mechanical coupling.



Space Station Utility Systems

The 1989 proposed operating fluids and operating pressures for thermal, propulsion and other fluid lines are presented in this figure. The relatively high operating pressures should be noted. The long life reliability of many mechanical disconnects at these operating pressures is uncertain.

However, welded tube and pipe assemblies operating at these pressures are routinely used on earth base construction in chemical producing plants, nuclear reactors, refrigeration and other critical facilities.

SPACE STATION UTILITY SYSTEMS

SYSTEM	OPERATING FLUID	PRESSURE (psi)
Thermal	Ammonia	65 and 130
Propulsion	Hydrogen/Oxygen	500 to 3000
Fluids	Nitrogen	600 to 6000
	Waste Gases	30 to 1000
	Water	10 to 60

Welding Has The Most Potential

In earth base construction, welding and brazing has traditionally proven to be a reliable and cost effective means of fabrication and repair. With appropriate development, it could prove to be an enabling technology for in-space repair and construction, as well.

OF THE FABRICATION AND REPAIR CANDIDATES -

WELDING HAS THE

MOST POTENTIAL

NASA has had some successful in-space welding/brazing trials, primarily on space lab. These trials, however, have been of limited extent and have not caused a modification of the opinion in NASA Standard-3000. That opinion remains: "Soldering, welding, brazing, and similar operations during maintenance shall be minimized."

NASA-STD-3000/VOL IV

PARAGRAPH 12.3.1.1

Item t.

Soldering, Welding, and Brazing -

Soldering, welding, brazing, and similar operations during maintenance shall be minimized.

Soviet Aerospace Fabrication - An Overview (In-Space Welding)

On the other hand, the Soviets have made an "all out" commitment to in-space welding. Beginning as early as 1964, they have investigated a large number of different fusion welding processes and, despite some narrowly avoided disasters, they have intensified their efforts in welding in space developments.

Soviet Aerospace Fabrication — An Overview

In–Space Welding

- Soviet welding–in–space project dates to 1964 when an overall evaluation program was adopted
- Fusion welding processes evaluated included GMA, GTA, plasma arc and electron beam
- First actual welding in space occurred in October, 1969 with the E.B., plasma and GMA processes
  - During this first E.B. experiment, a rotating table malfunctioned and the electron beam burned thru the container into the space ship wall
    - Did not penetrate because in Mr. Paton's opinion, earth's magnetic field caused beam to curve
  - Despite this narrowly avoided disaster, Soviets standardized on E.B. as the one process to use

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Soviet Aerospace Fabrication - An Overview (Background)

In order to obtain first hand knowledge of the Soviet In-Space welding efforts, the American Welding Society arranged for a visit to Soviet aerospace facilities by delegates from several U.S. aerospace companies. The Paton Electric Welding Institute in Kiev served as the host institution, and Mr. Boris Paton, Director of the Institute, served as the official host. Mr. Paton is a high ranking member of the Soviet Academy of Sciences and has been charged with coordinating advanced materials development for the Soviet space effort, thus he provided an effective link to Soviet technology.

Soviet Aerospace Fabrication — An Overview

Background

- Soviets invited a delegation of U.S. aerospace representatives to visit Soviet Union to learn first-hand Soviet fabrication techniques for their space program
  - The invitation, extended from the Paton Welding Institute, came through the American Welding Society (AWS)
  - The delegation consisted of:
    - Dr. Dave Dickinson, Chairman, Dept. of Welding Engineering, Ohio State University
    - Dr. Hank Babel, McDonnell Douglas, Huntington Beach
    - Mr. Bill Hooper, Martin Marietta, Michoud Division
    - Mr. Jim Walker, Past President, AWS
    - Mr. Hal Conaway, Rocketdyne

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Soviet Aerospace Fabrication - An Overview

The American Aerospace Delegation spent two weeks in July 1989 visiting five prominent Soviet Aerospace related facilities in Kiev and near Moscow. In many instances, this was the first Western Delegation to visit previously restricted areas. Discussions on materials, structures, instrumentation, training, and fabrication techniques for ground base and in-space operations were held.

Soviet Aerospace Fabrication — An Overview

- The U.S. delegation spent two weeks (2–14 July 1989) in the Soviet Union visiting:
  - The Paton Welding Institute, Kiev
  - The Cosmonaut Training Center, Star City
  - NPO "Komposit," Moscow area
  - NPO "Energija," Moscow area
  - NIITM Research Institute of Mechanical Engineering, Moscow area

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Process Under Consideration - Electron Beam Welding ...

From the discussions held in the Soviet facilities, and from developmental activities within the American Aerospace Companies (and other companies throughout the world), it is obvious that a great number of welding and bonding processes are under consideration for in-space construction and repair. The list presented in this figure is by far not exhaustive.

Process experience in some of these areas will be highlighted below, starting with several examples of electron beam welding, some of which have been space demonstrated while others are under development.

PROCESSES UNDER CONSIDERATION

0 Electron Beam Welding/Cutting/Brazing

0 Arc Welding

0 Laser Welding

0 Explosive Bonding

0 Induction Welding/Brazing

0 Microwave Bonding

0 Thermit Welding

EVA Electron Beam Welding System

A significant portion of the Soviet in-space welding equipment development effort has been directed at producing and demonstrating the viability of the EVA Electron Beam Welding System illustrated in this figure. This system is called the "Universal Versatile Hand Tool". This 1 KW electron beam devices has been designed for manual cosmonaut use with welding, brazing, cutting and vapor deposition of coating capability. The varying processes are obtained by focusing or de-focusing the beam and by directing the beam on a crucible containing coating materials.

The 2.2 kilogram gun obtains its 1 KW of power from the spacecraft (the primary is 27 volts DC with and invertor). The gun voltage is only 18,000 volts, maximum, and the maximum beam current is 70 MA.

Lt. Gen. Djanibekov Demonstrating Gun

In this figure, Cosmonaut Vladimer Djanibekov is demonstrating the use of the "Universal Versatile Hand Tool" for welding. The samples to be welded are mounted in a "flip up" tray in the rear of the power supply unit. Manual welds are made with the gun assembly.

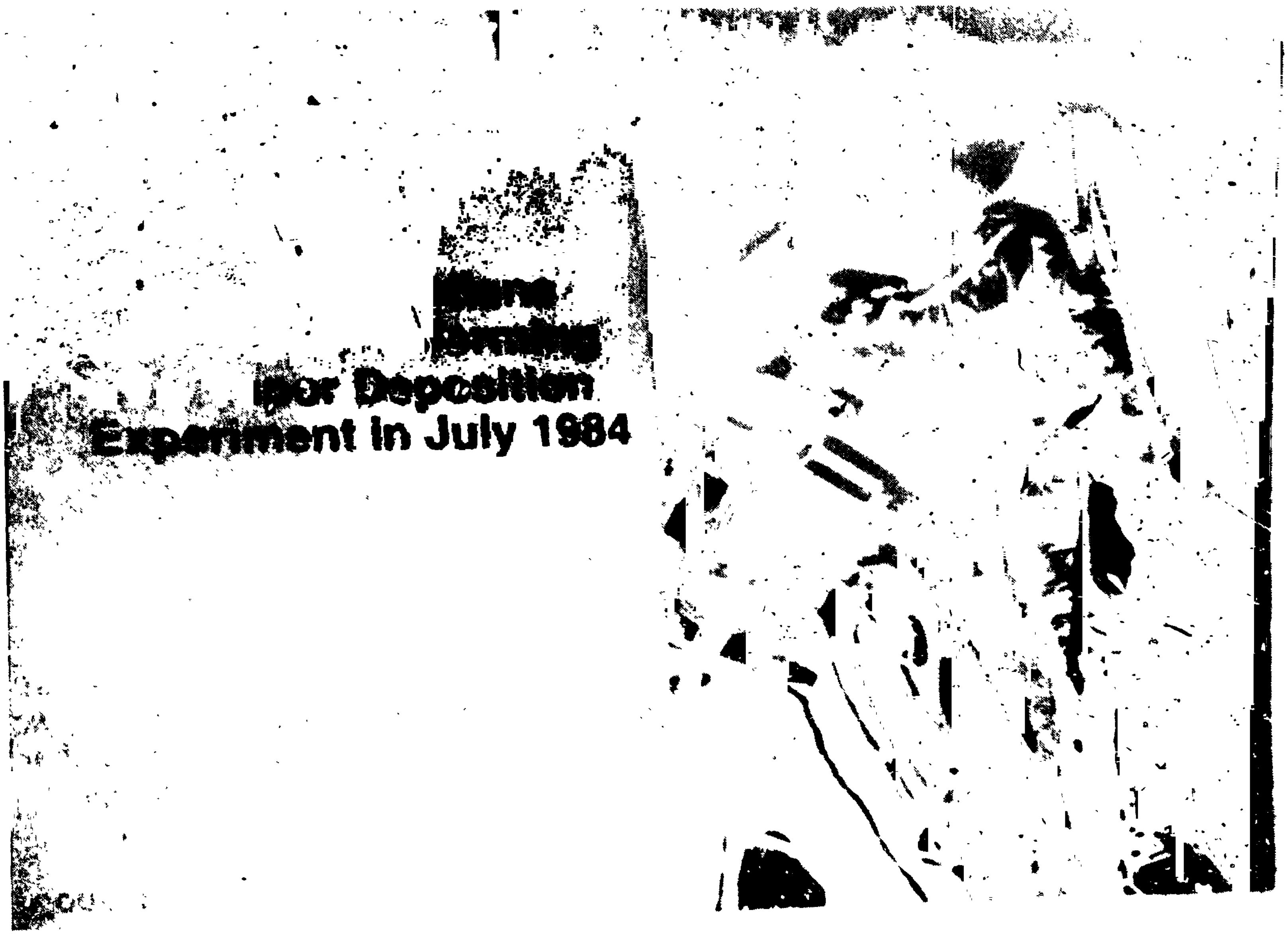
In space experiment were performed by Cosmonaut Djanibekov which demonstrated the feasibility of cutting and welding steel, aluminum, and titanium alloys up to 3 mm (0.120 inch) thick in the butt weld configuration. This should be sufficient for most of the current U.S. material design thicknesses.

The Soviets are currently working on a unit which will provide 2 KW of power and have wire feeding capability for welding thicker materials in a weld overlap or prepared groove configuration. This will open considerably wider space construction options.


During Space Welding

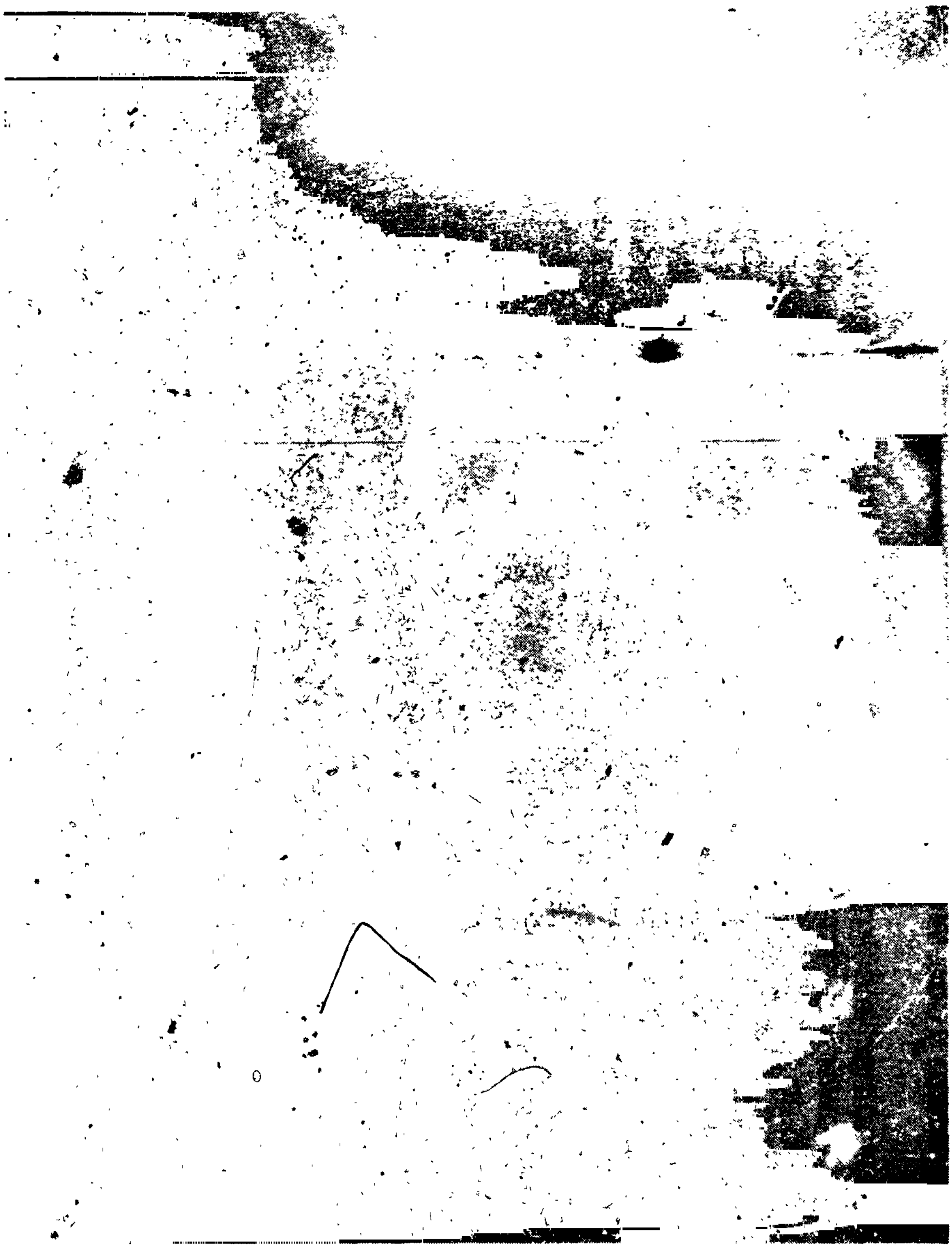
Cosmonaut Svetlana Savitskaya Performing EVA Vapor Deposition

Cosmonaut Savitskaya performed an EVA experiment in July 1984 to put a vapor deposition coating on a sample mounted on the "flip up" holder. Vapor coatings of gold, silver, and copper have been demonstrated in space. Ground base experience with electron beam vapor deposition is much more extensive.


Deposition
Experiment in July 1984

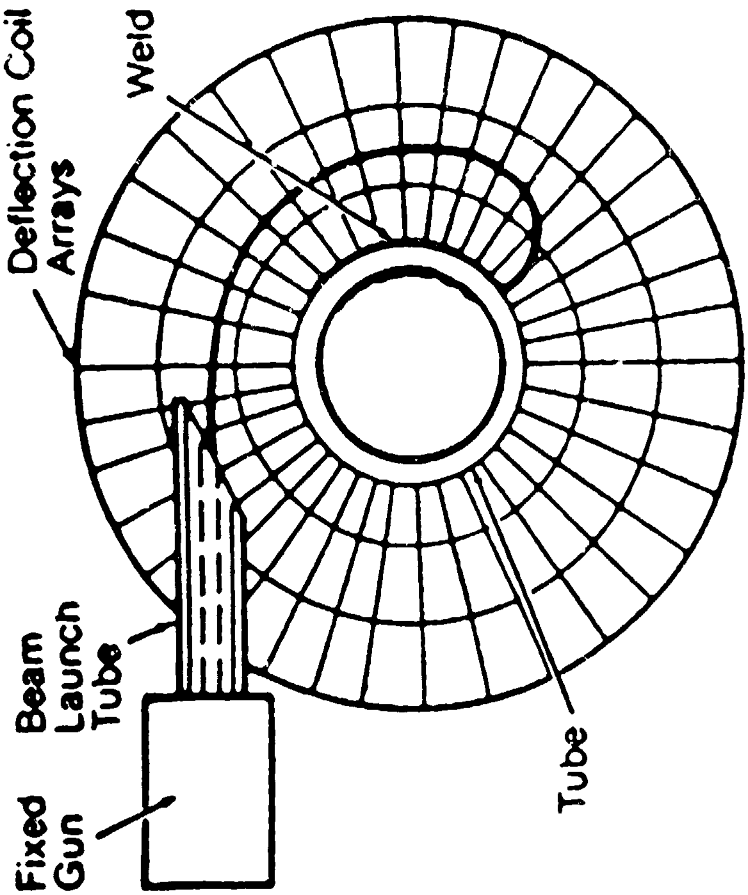
Concept of EB Welding Trusses

In addition the Soviets have developed several concepts for the original construction and repair of space trusses. Here is shown a concept for joining legs of metallic tubular trusses. Development of a deployable triangular truss with electron beam welded or brazed nodes has been performed and ground tested.



Electron Beam Tube Weld

In another electron beam development efforts, a European firm, Babcock Power Ltd., is developing an electron beam welding device for in-space welding of tubes as illustrated in this schematic. The electron beam is controlled and deflated through 360 degrees around the tube by an array of deflection coils. Unwrapping the beam will produce a butt weld around the circumference joining the two tubes. Note that this system is ideally designed for automated welding which could reduce some EVA time. In addition, the beam is completely enclosed thus reducing any risk of generated x-rays during electron beam welding.

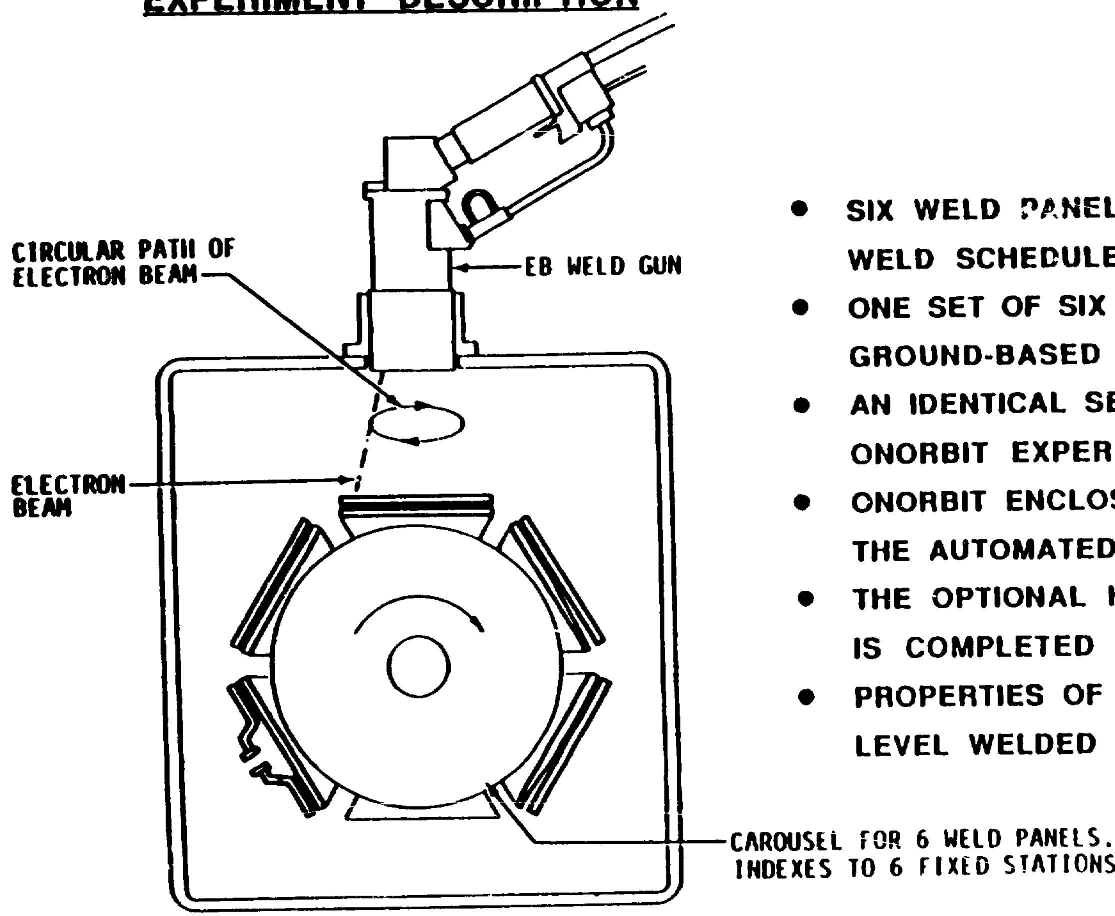


Deflection Coil Arrays
Weld
Beam Launch Tube
Fixed Gun
Tube

On Orbit Electron Beam Welding Experiment

As part of an Outreach Experiment, Martin Marietta has performed an experimental definition to develop an on orbit electron beam welding gun which can be used as an automated system or as a hand held unit. The gun power will meet or exceed those of the Soviets and contain safety features not found in the Soviet unit. The experimental demonstration calls for the evaluation of multiple welded panels to evaluate varying welding parameters and panel configurations.

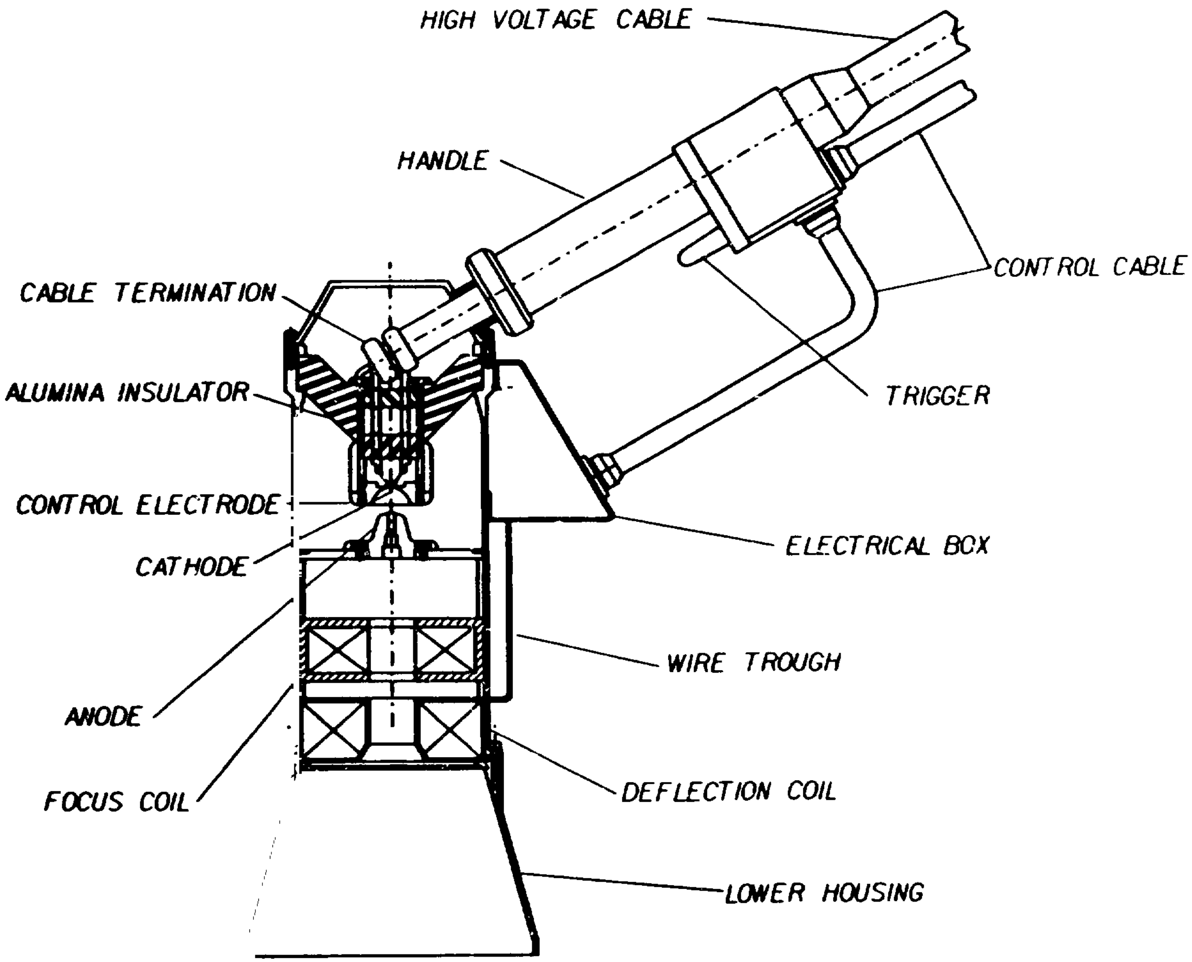
EXPERIMENT DESCRIPTION



- SIX WELD PANEL CONFIGURATIONS AND WELD SCHEDULES ARE DEVELOPED
- ONE SET OF SIX PANELS IS WELDED IN GROUND-BASED EXPERIMENT
- AN IDENTICAL SET IS MOUNTED FOR ONORBIT EXPERIMENT
- ONORBIT ENCLOSURE IS PORTED TO SPACE: THE AUTOMATED CYCLE OF WELDS IS REPEATED
- THE OPTIONAL HAND-HELD WELDING EXPERIMENT IS COMPLETED
- PROPERTIES OF ONORBIT WELDED AND GROUND-LEVEL WELDED PANELS ARE COMPARED

On Orbit EB Gun

This frame is a cut away schematic of the Martin Marietta On Orbit electron beam gun showing internal components. The deflection coils are used to automatically rotate the beam in order to make the repair weld as illustrated earlier for the space station module panel weld repair. Note that the lower housing on the gun completely encloses the welding beam thus providing safety.



On Orbit EB Gun

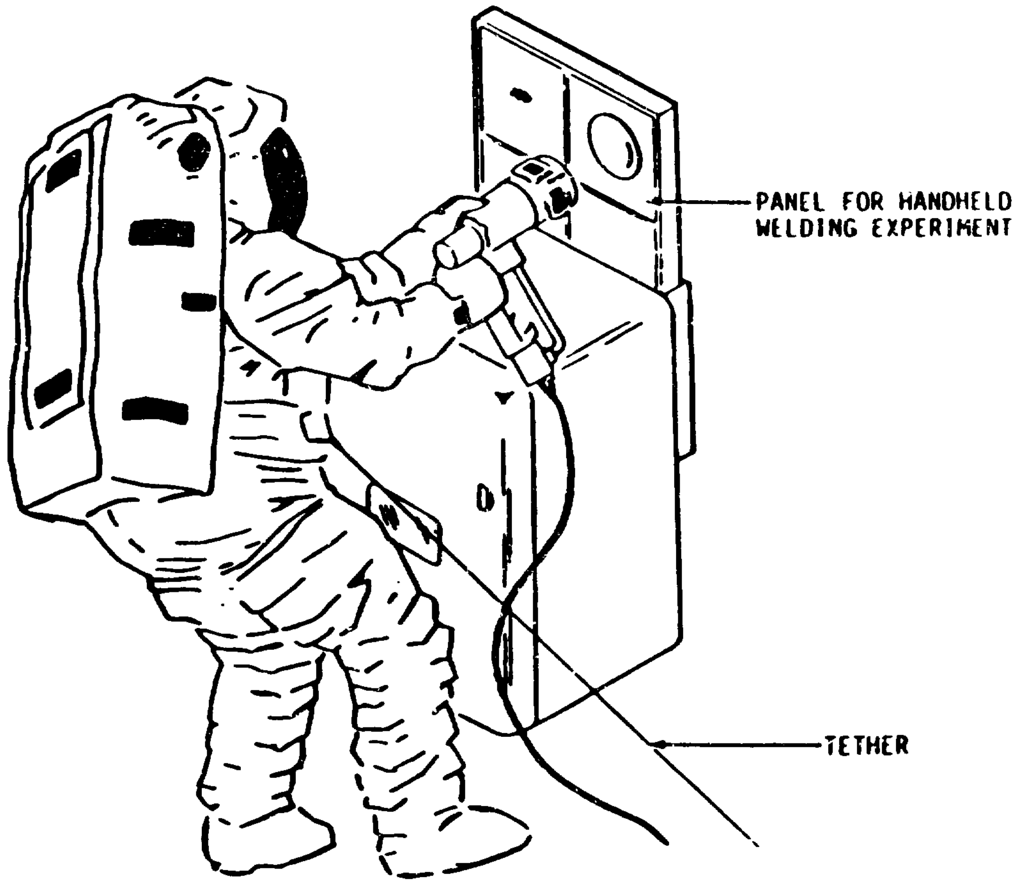
MARTIN MARIETTA PROPRIETARY

MARTIN MARIETTA
MANNED SPACE SYSTEMS

On Orbit Electron Beam-EVA

This figure illustrates the use of the Martin Marietta electron beam gun in a hand held welding configuration.

ONORBIT ELECTRON BEAM WELDING EXPERIMENT DEFINITION PROPOSAL



Processes Under Consideration- Arc Welding

The Soviet Union has performed extensive research on conventional arc welding processes including gas metal arc, gas tungsten arc, and plasma arc welding before deciding to concentrate the majority of their effort on electron beam welding. In each case they demonstrated the viability of arc welding in space, but felt that better control was available through the electron beam route. A recent process modification of gas tungsten arc welding by Rocketdyne has demonstrated remarkable promise in ground base testing which could lead to advantages unforseen by the Soviets.

PROCESSES UNDER CONSIDERATION

0 Electron Beam Welding/Cutting/Brazing

0 **Arc Welding**

0 Laser Welding

0 Explosive Bonding

0 Induction Welding/Brazing

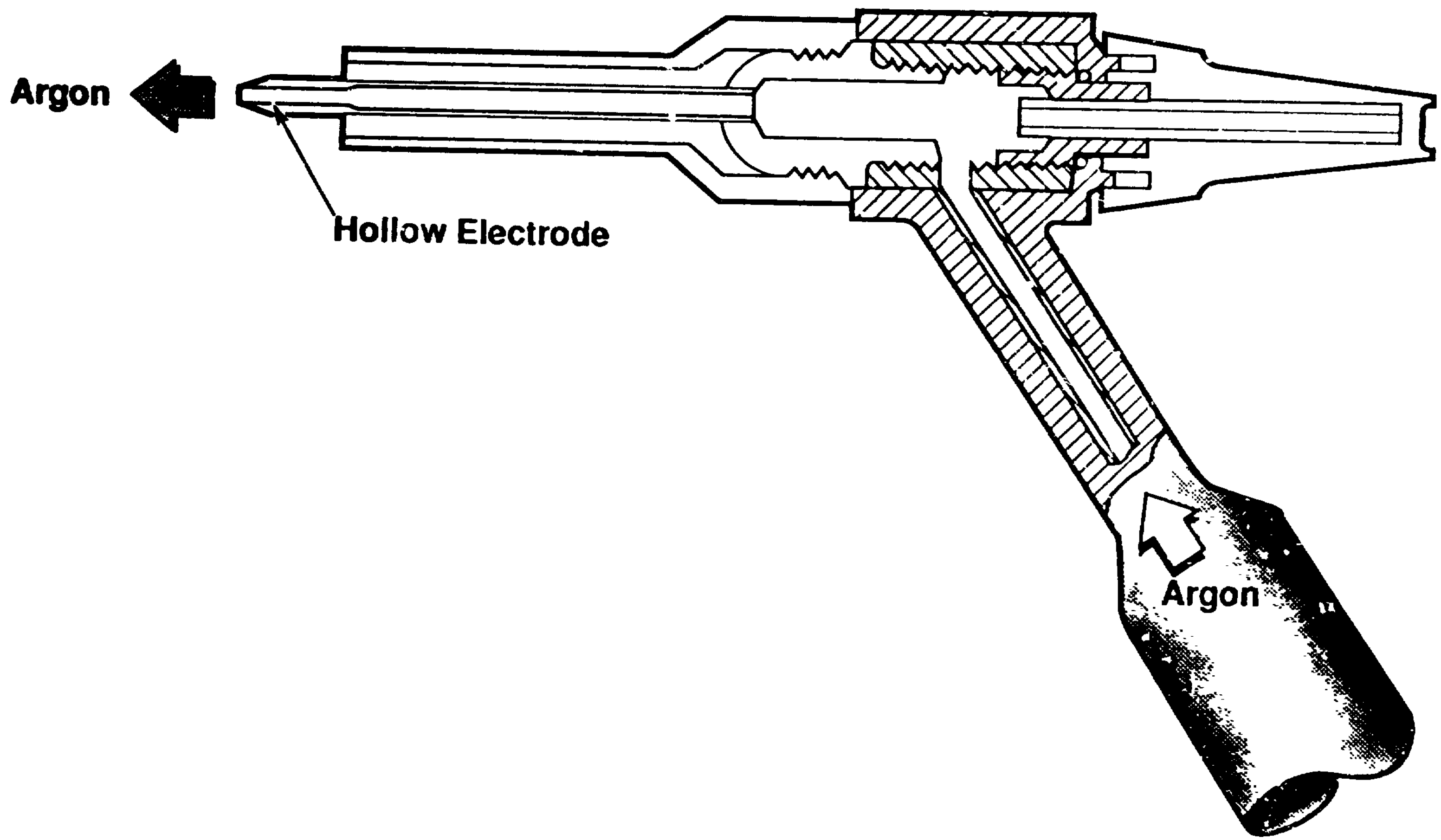
0 Microwave Bonding

0 Thermit Welding

Rocketdyne Vacuum GTAW Torch

A schematic of this modified gas tungsten arc welding torch developed by Rocketdyne is presented in this figure. In this modification, the normal solid tungsten electrode is replaced by a hollow tungsten electrode. The argon gas used for the arc plasma is fed through this electrode in conventional gas tungsten arc welding. This arrangement provides positive arc stabilization in vacuum environments. No shielding gas is required.

Rocketdyne Vacuum GTAW Torch



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Vacuum Gas Tungsten Arc System

Using the modified system with a 0.020 inch hole through the electrode and an extremely small gas flow rate of only 1 cubic foot per hour for arc maintenance, excellent arc welds produced in vacuum have been demonstrated. Arc starting and control were excellent. And the vacuum was observed to purify the weld and generally produce a better weld than available in conventional arc welding.

Vacuum Gas Tungsten Arc System

- Rocketdyne developed hollow electrode concept
  - Small (0.020 in.) hole through an 0.093 in. dia tungsten electrode
  - Gas flow less than 1 cfh
  - Welds are "deep/sound"
  - Welds larger than conventional GTAW welds with same energy

- Advantages of hollow tungsten concept for space based welding
  - No differential pressures
  - Excellent arc starting capabilities
  - Vacuum purifies the weld
  - Vacuum helps clean parts

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Rocketdyne Division

Processes Under Consideration - Laser Welding

The laser welding process on earth is becoming a maturely developed technology offering advantages of speed and control. However, only a small amount of space laser welding research is underway.

PROCESSES UNDER CONSIDERATION

0 Electron Beam Welding/Cutting/Brazing

0 Arc Welding

0 **Laser Welding**

0 Explosive Bonding

0 Induction Welding/Brazing

0 Microwave Bonding

0 Thermit Welding

Current Solar Collector Experiments

The University of Alabama in Huntsville is proposing the use of solar Collectors, similar to those proposed for solar dynamics furnaces, for supplying the energy for pumping in-space lasers. It is proposed that the laser beam would be distributed through a fiber optics system to a hand held welding gun or an end effector on a robotic weld repair unit. Laser welding devices such as these can provide all the advantages and options available on the Soviet electron beam system without as great a concern about secondary x-ray generation.

LASER WELDING IN SPACE

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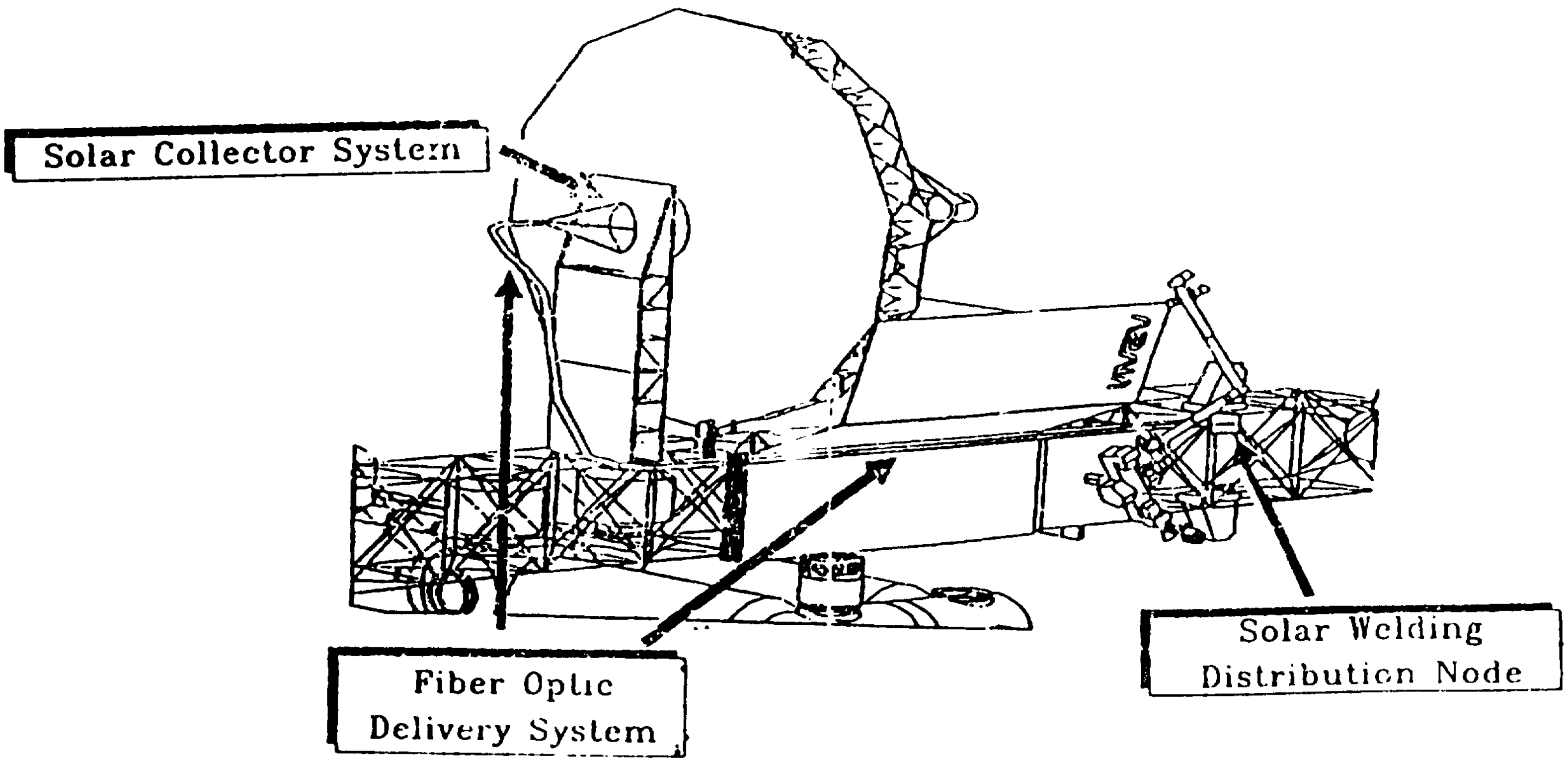
CURRENT SOLAR COLLECTOR EXPERIMENTS CAN ASSIST IN DEVELOPING SOLAR PUMPED LASER TECHNOLOGY



Current concepts being developed for the Solar Dynamics Furnace and the Large Deployable Reflector Assembly will also provide a testbed for applying solar pumped lasers to repair and/or assembly operations.

CO Lasers for Space Applications

In an independent effort, a program definition to develop a Carbon Monoxide laser is underway. This unit would provide high power at high efficiency while maintaining lighter weight and more compact design than other types of lasers.

CO LASERS FOR SPACE APPLICATIONS

* **CO AS HIGH AS 45% EFFICIENCY**
  CO_2 10 - 20% EFFICIENCY
  ND:YAG 1 - 5% EFFICIENCY
* **CAN HAVE VERY COMPACT DESIGN**
* **CAPABLE OF VERY HIGH POWER**
  (MITSUBISHI - 10 kW)
* **5 um WAVELENGTH GOOD FOR WELDING AND CUTTING**
* **BEING DEVELOPED IN GERMANY, JAPAN, AND USSR,**
  (PROPOSED PROJECT AT OSU ONLY U.S. PROGRAM)

OSU

Processes Under Consideration - Explosive Bonding

The use of ribbon explosives or small detonation charges appropriately located on or near parts to be joined can produce a running shock wave at the bond joint. This wave provides both interruption of the interface oxide layer and intimate surface contact under pressure sufficient to produce an inter-atomic bond (cold weld) across the interface.

PROCESSES UNDER CONSIDERATION

0 Electron Beam Welding/Cutting/Brazing

0 Arc Welding

0 Laser Welding

0 **Explosive Bonding**

0 Induction Welding/Brazing

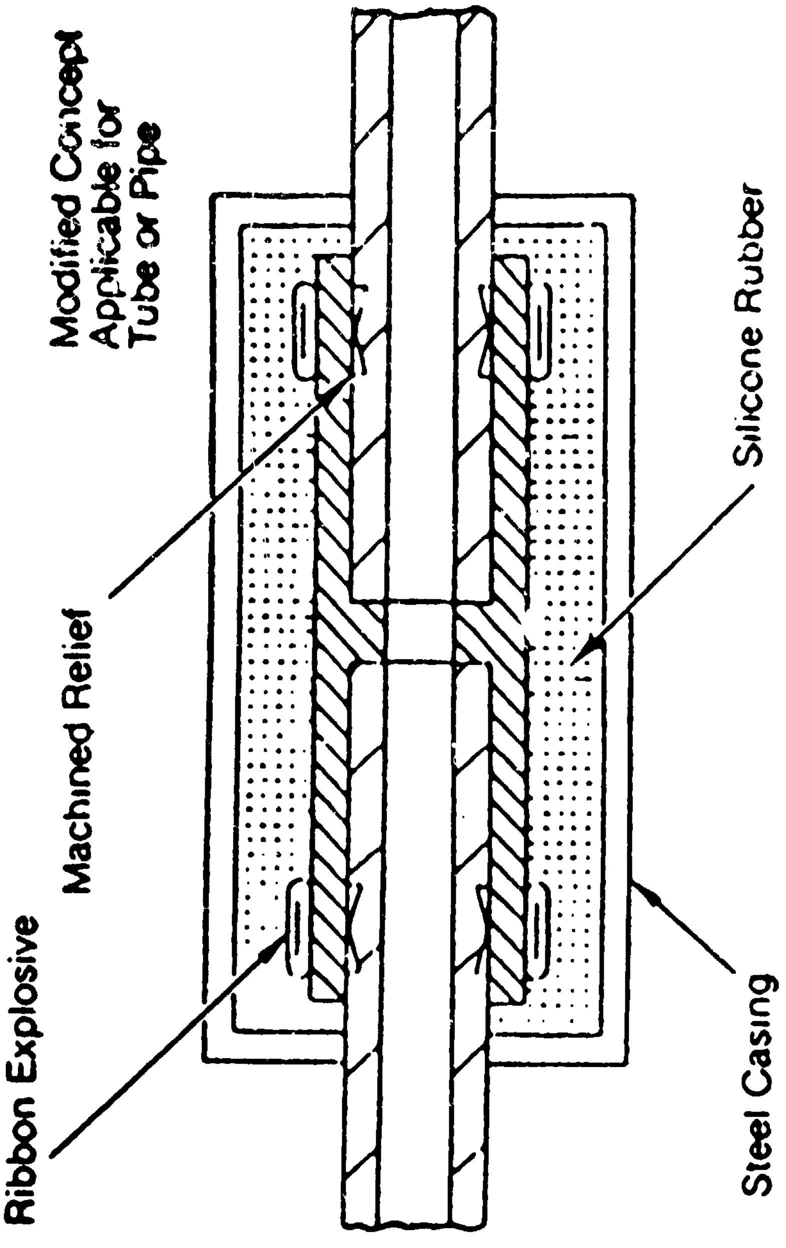
0 Microwave Bonding

0 Thermit Welding

Explosive Welding Setup Appropriate for Tubing

This figure shows a McDonnell Douglas modification of an explosive bonding process developed at NASA-Langley for bonding of tube sections. The tubing to be bonded is inserted into a sleeve around which the explosive ribbon is wrapped. Welds are made rapidly on each side of the tube within a fully enclosed container to avoid and contamination of the space atmosphere. The advantages for emergency repair of damaged truss structural tubing, rather than waiting for replacement parts, is obvious.

A similar explosive bonding system is under development by the Soviets for attaching all the tubes at a nodal point in one operation.


Modified Concept
Applicable for
Tube or Pipe
Ribbon Explosive
Machined Relief
Silicone Rubber
Steel Casing

Processes Under Consideration

In addition to the processes described above, a whole series of other welding and bonding processes are in various stages of development. These include induction welding and brazing for metallic and doped polymer and polymeric composite materials. Microwave bonding for ceramic materials. Transient liquid phase diffusion bonding for metal matrix composite materials. And thermit welding for hard to bond metals and large cross section materials.

PROCESSES UNDER CONSIDERATION

0 Electron Beam Welding/Cutting/Brazing

0 Arc Welding

0 Laser Welding

0 Explosive Bonding

0 Induction Welding/Brazing

0 Microwave Bonding

0 Thermit Welding

Boris Paton Statement

In the decades following the first world war, applications where welded construction proved to be more reliable, more cost effective and better than conventional construction and repair techniques were continually identified. To meet the demand for welded construction, a whole series of welding processes were developed during this period.

Now that we are entering a new age of space exploration and development, a fabrication and repair challenge again is occurring. The need for welding applications in repair and original fabrication is appearing. This demand must be met by appropriate process development for the space environment.

As Mr. Boris Paton, Director of the Paton Institute in the USSR says, "In the not too distant future, welding in space will become not an experiment but general practice - as is welding for earthly construction.

"In The Not Too Distant Future, Welding In Space Will Become Not An Experiment But General Practice - As Is Welding For Earthly Construction"

B. Paton
USSR, 1970

Conclusions

The challenge is up to us. The need for welding and brazing for space station repair and construction during station evolutionary phases is clear. Process developments to meet these needs are underway. The time is right to consider welding and brazing for improved fabrication and repair reliability.

CONCLUSIONS

WELDING/BRAZING SHOULD BE CONSIDERED FOR IMPROVED FABRICATION REPAIR RELIABILITY