SESSION I-A

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# OUT OF VACUUM ELECTRON BEAM WELDING

by

P. G. PARKS (MSFC)

Electron beam welding has been removed from its empty cocoon and made portable and applicable in atmosphere.

The 15 KV-9KW unit which weighs only slightly over 200 pounds can be considered an automatic welding head. Application studies, mechanical properties, metallurgical quality of such alloys as 2219 and 2014 aluminum as well as maraging and high strength steels have shown unscoped potentials.

Demonstrated high current densities approximately $5 \times 10^6$ watts/cm$^2$, as compared to $5 \times 10^9$ watts/cm$^2$ for hard vacuum and approximately $1 \times 10^4$ watts/cm$^2$ for GTA welding does permit a significant improvement in welding efficiency. Operational accomplishment and results todate are illustrated by mechanical properties, metallurgical quality and procedure details in welding materials to 3/4-inch thickness and at speeds to 140 I. P. M.

In the mid 50's the U. S. industries became interested and active in the application of hard vacuum electron beam welding. By the beginning of the 60's, the hard vacuum E. B. welding systems, and its chambers had become an important factor in the small and difficult welding jobs.

Pieces had to be of a reasonable size in order to fit into the ever-present vacuum chamber.

The attractive joint properties of HVEB welds and the acceptance of the fact that a weld is a defect surrounded by sound metal resulted in several organizations searching for a way to operate the gun out of its cocoon.

The first productive effort was the result of work by R. E. Kutchera of the General Electric Large Jet Engine Departments, Evandale, Ohio. This Air Force funded program was continued with the Alloyd Corporation and then Hamilton Standard Division of the United Aircraft Corporation.

During 1964, the Westinghouse Research Corporation engineers completed a study designed at developing an electron beam welder aimed specifically for non-vacuum or OVEB welding. Early tests of these development results demonstrated advantage over the conventional arc processes, i.e., GTA, and GMA.

During June, 1965, a 3-phase contract was made between Westinghouse and NASA/MSFC Welding Development Branch. Phase I of the study was to demonstrate and evaluate the experimental equipment. With successful completion of this phase, Phase II was the construction of a light weight, portable non-vacuum electron beam welding head, manipulator and radiation proof enclosure.

Present status of this NASA funded program is illustrated by the premier showing of the demonstration film "Electron Beam Out of Vacuum As An Automatic Welding Head". The film characterized by the following word description provides an up-to-date report.

This is an electron beam operating in air, concentrating 350 times more heat in a given area than does the most efficient, conventional arc welding process. Concentrated energy means more welding with less overheated material, higher welding speeds, less stress, less cracking and less warping. Until recently these advantages were only available when the workpiece could be put into a vacuum.

This is the welder that produced the beam. Twelve kilowatts of beam energy 150,000 volts. It is a welder with full vacuum to non-vacuum operating flexibility. It is being demonstrated here as a non-vacuum welder and has the same portability and adaptability to large and small workpieces as a conventional inert gas arc welding head.

This unit was specifically designed for complete vacuum-to-non-vacuum flexibility and portability. It is not an adoption of an earlier limited purpose piece of electron beam equipment. The welder conditions 220-volt 400-cycle power to 150,000 volts do within this small tank. The resulting 250 pound unit hangs from a conventional side beam welding carriage. The welder can also be positioned horizontally by rotating the supports at these points. High voltage connections to the welding gun itself are made directly. No high voltage cables are required. Electrons are emitted from a sturdy tungsten rod about the size of a pencil lead. The rod is heated by bombardment of electrons from a tungsten filament. Such assemblies regularly achieve 97 hours mean-time between failure. After passing down the differentially pumped column, the electrons exit from this nozzle. A supply of pure helium gas also exists at the nozzle to keep dirt from being sucked up into the low pressure region of the gun. The pumping of the high pressure regions near the exit is accomplished through flexible attached here and here to mechanical pumps outside of the enclosure. The high vacuum regions are maintained by this small pump and the slightly larger pump on the left-hand side of the welder.

Simple, all purpose x-ray shielding is achieved by this lead-plywood enclosure. The welder observes the process through a lead glass window. The welding controls are in a console in front of him. Start-up controls are in the panel rack at the right hand side of the picture.

The welder is now ready to fuse 1/4 inch thick 2219-T87 material. The welding speed is 140 inches a minute. The aluminum is simply laid atop two pieces of stainless steel. Clamps are not required since longitudinal distortion is small even on this 4-foot long weld. The resulting freedom from distortion is more easily shown in this weld taken from an MSFC sponsored welding program. The upper bead contour is very smooth. Transverse distortion is not evident.

When auxiliary inert gas shielding is properly applied along with good cleaning produces freedom from porosity can be achieved as shown by these typical cross sections.

This specimen was run at 3.6 kilowatts at 20 inches per minute. 6 kilowatts of power at 60 inches a minute produces a similar cross section. A considerably narrower cross section is observed at 140 inches per minute using 8 kilowatts of power.
These 1/2 inch aluminum welds were made at 50 inches using 10 kilwatts of power.

All plates in this series of welds have remained flat without the use of restraint during the welding process. The narrowest weld is 185 thousandths of an inch at the widest portion. This compares favorably with 200 to 300 thousandths of an inch for a comparable inert gas weld in this thickness of material.

Heavy welding ferrous materials can also be accomplished. This is 3/4 inch steel is being welded at 9-inches per minute using 9 kilowatts of power. Potentially, the most attractive payoff from welding with the electron beam is the intense energy concentration to minimize metallurgical effects in a welded joint-effects that offset the attractiveness of today's high efficiency structural materials when they must be welded. As the weld leaves the plate the narrow, confined character of the non-vacuum electron beam operation can once again be observed. The Westinghouse welder has been designed to bring the advantages of EB welding to the maximum number of applications.

Todate it has been demonstrated by experimental procedure development that welds can be produced by the O. V. E. B. system to existing standards of metallurgical quality and physical properties.

Problems of weld refinement through a comprehensive investigation program is now in progress.

An interim report titled "Relationship Between Weld Quality and Non-Vacuum Electron Beam Welding Procedures", as well as future reports may be obtained by directing request to Mr. Floyd Bulette, MS-T. Referencing NASA Contract NAS 8-11929 "Light Weight Versatile Non-Vacuum EB Welding Unit".

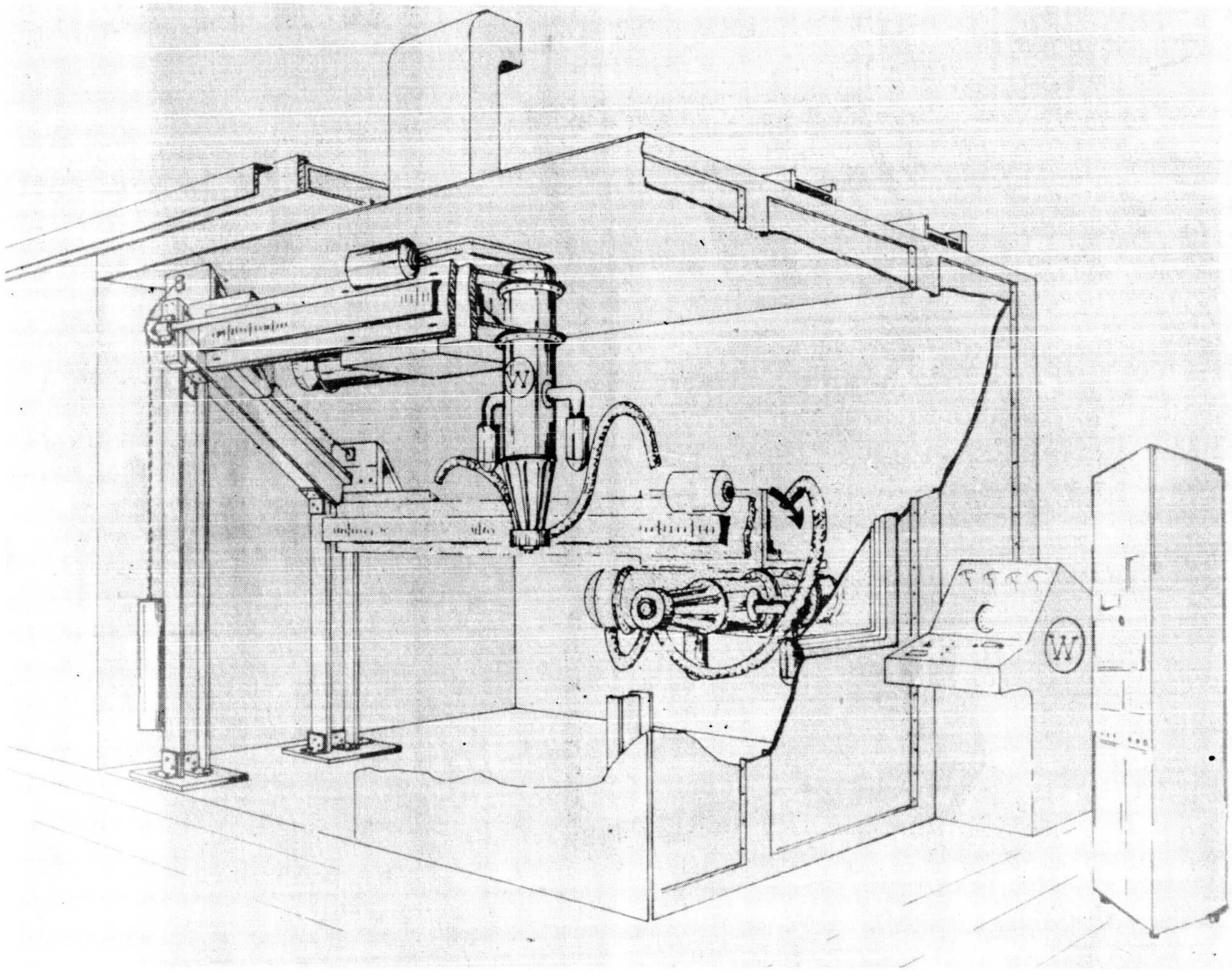


Figure 1 - Conceptual View of O. V. E. B. System

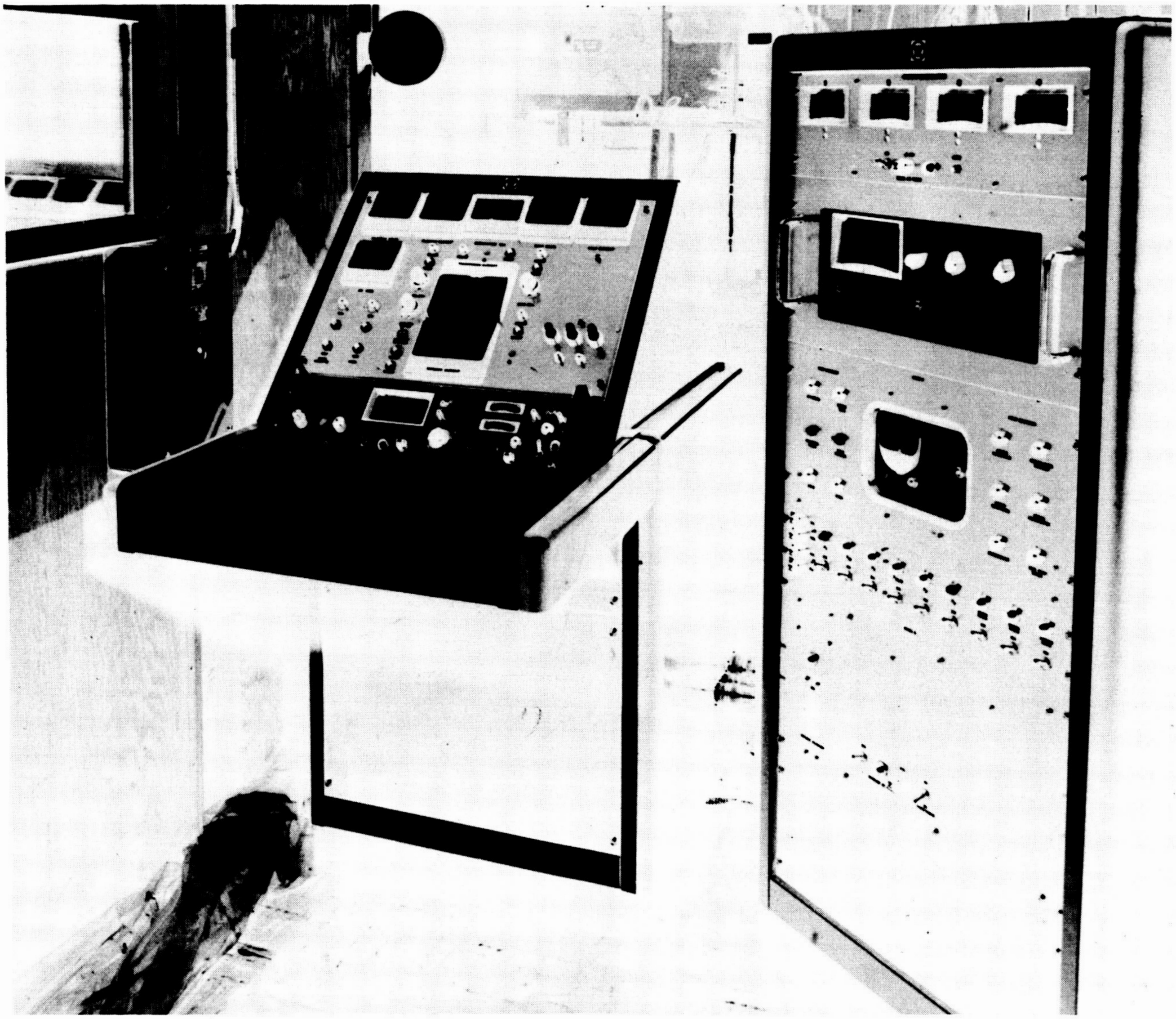


Figure 2 - Control Panels

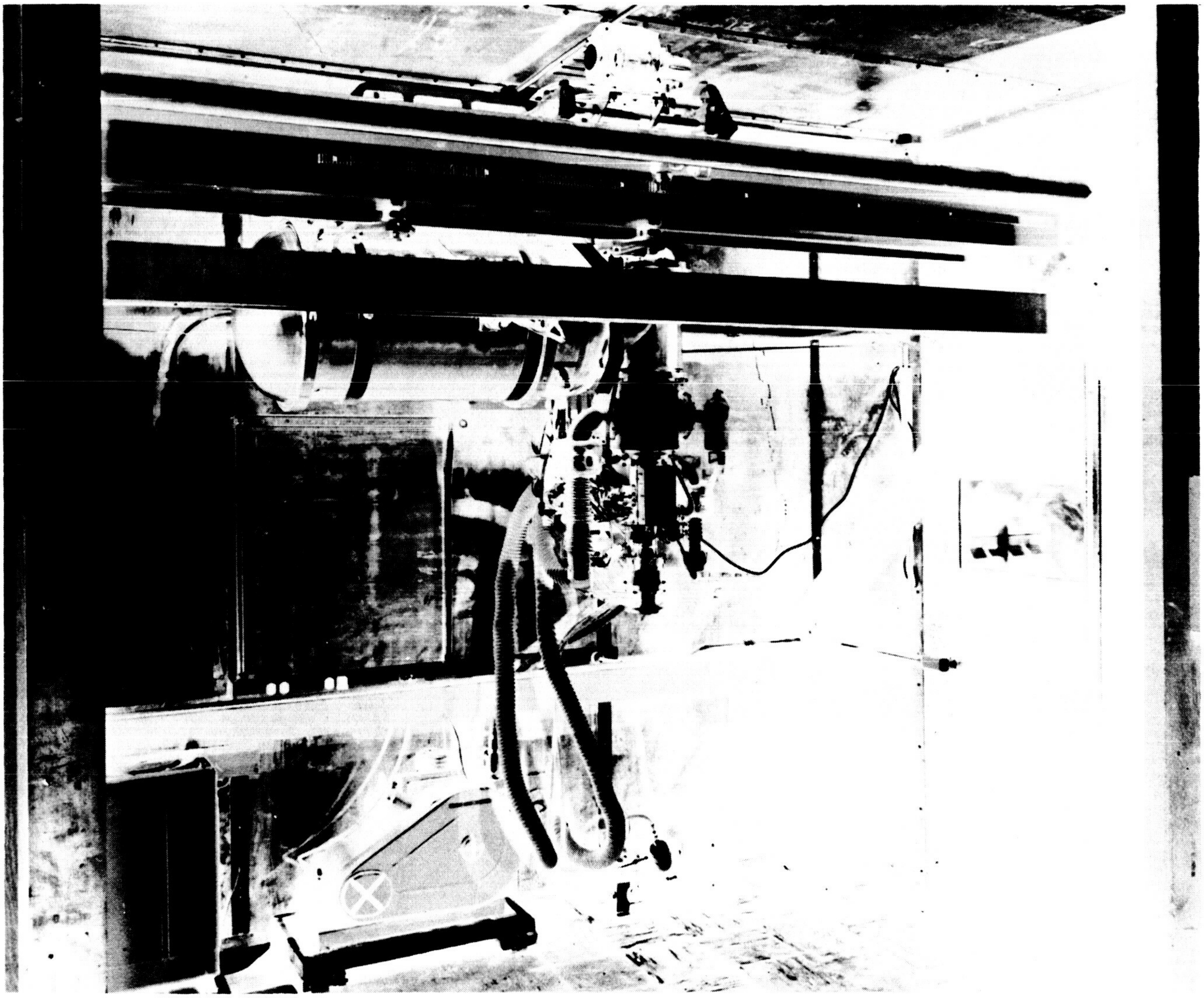


Figure 3 - Transformer and Gun

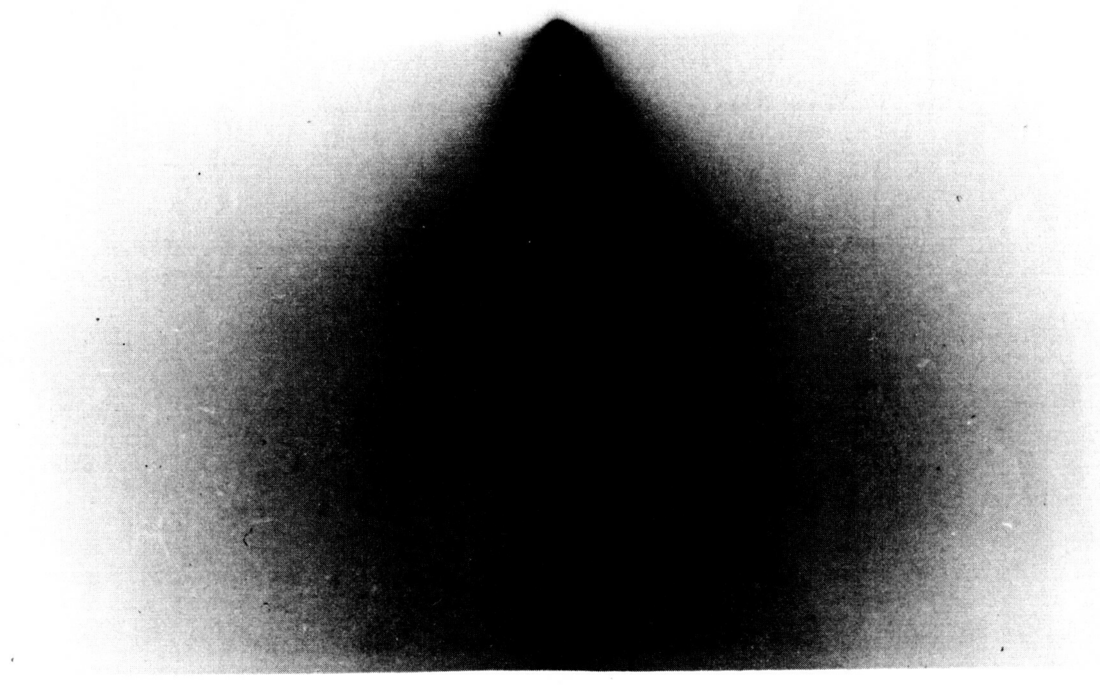
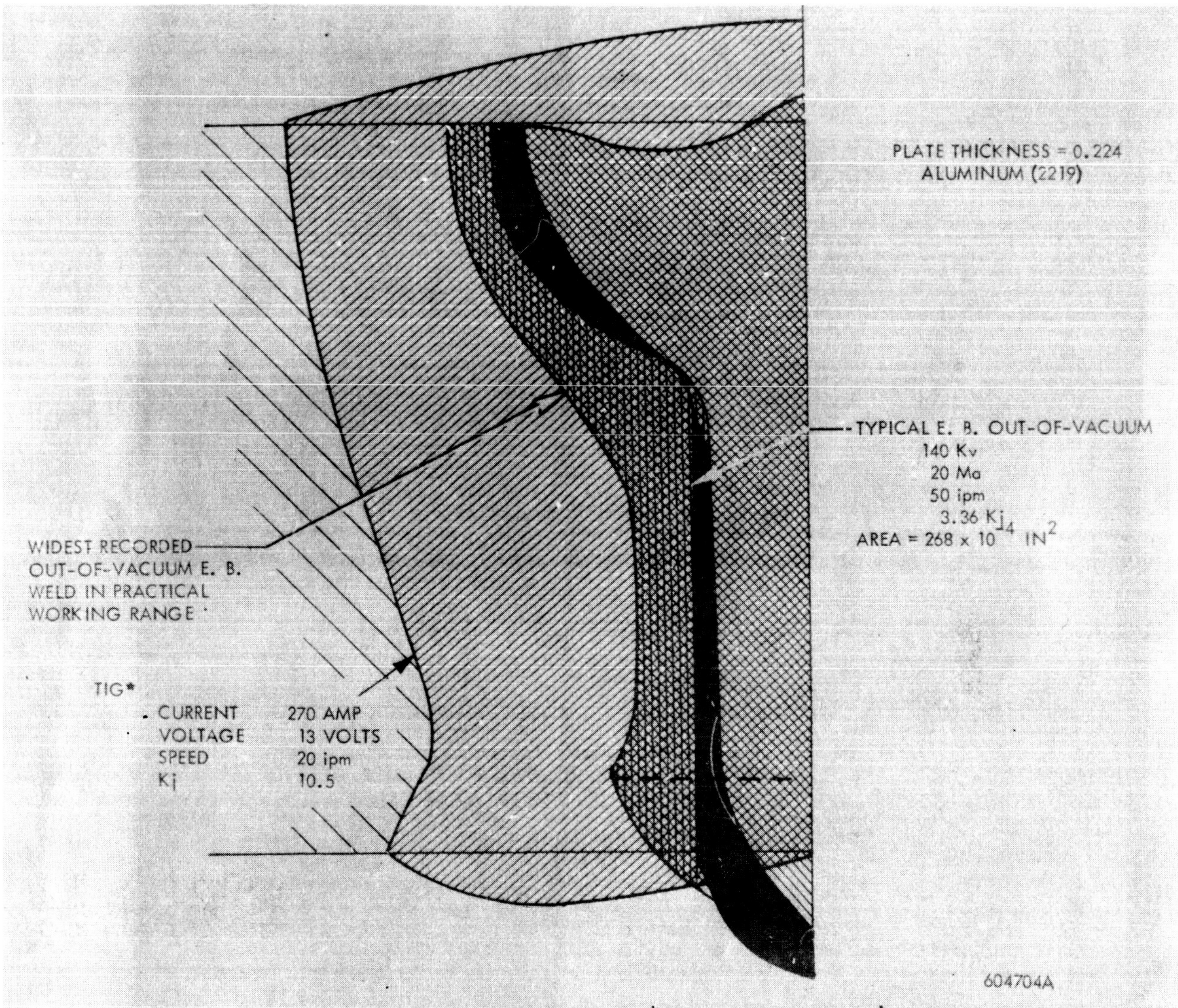


Figure 4 - Beam Stream in Atmosphere




COMPARISON WITH TIG *
IN 2219 ALUMINUM

Figure 5 - Fusion Zone Comparisons TIG, VAC, EB, and O.V.E.B.

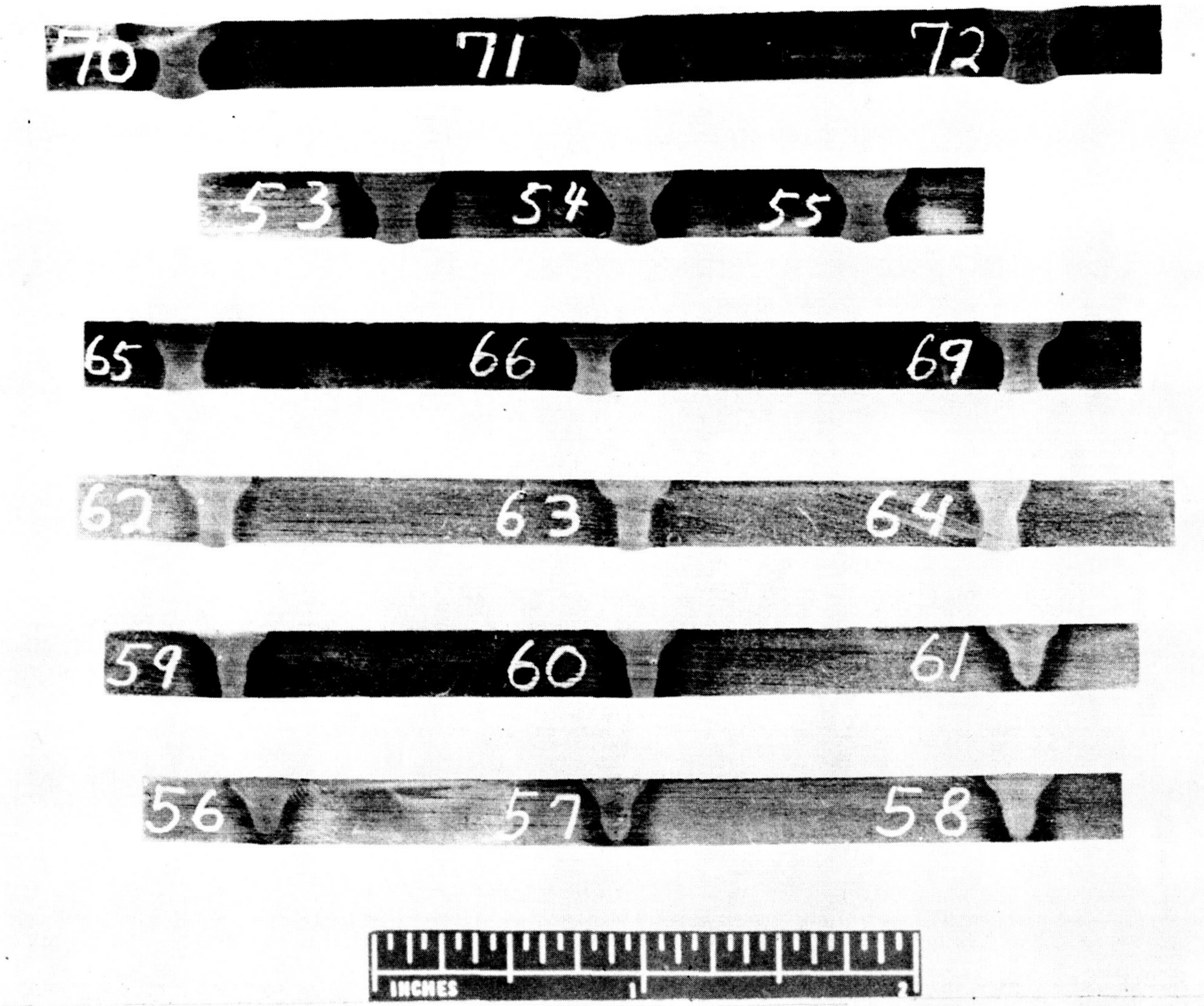



Figure 6 - O.V.E.B. Melt Patterns

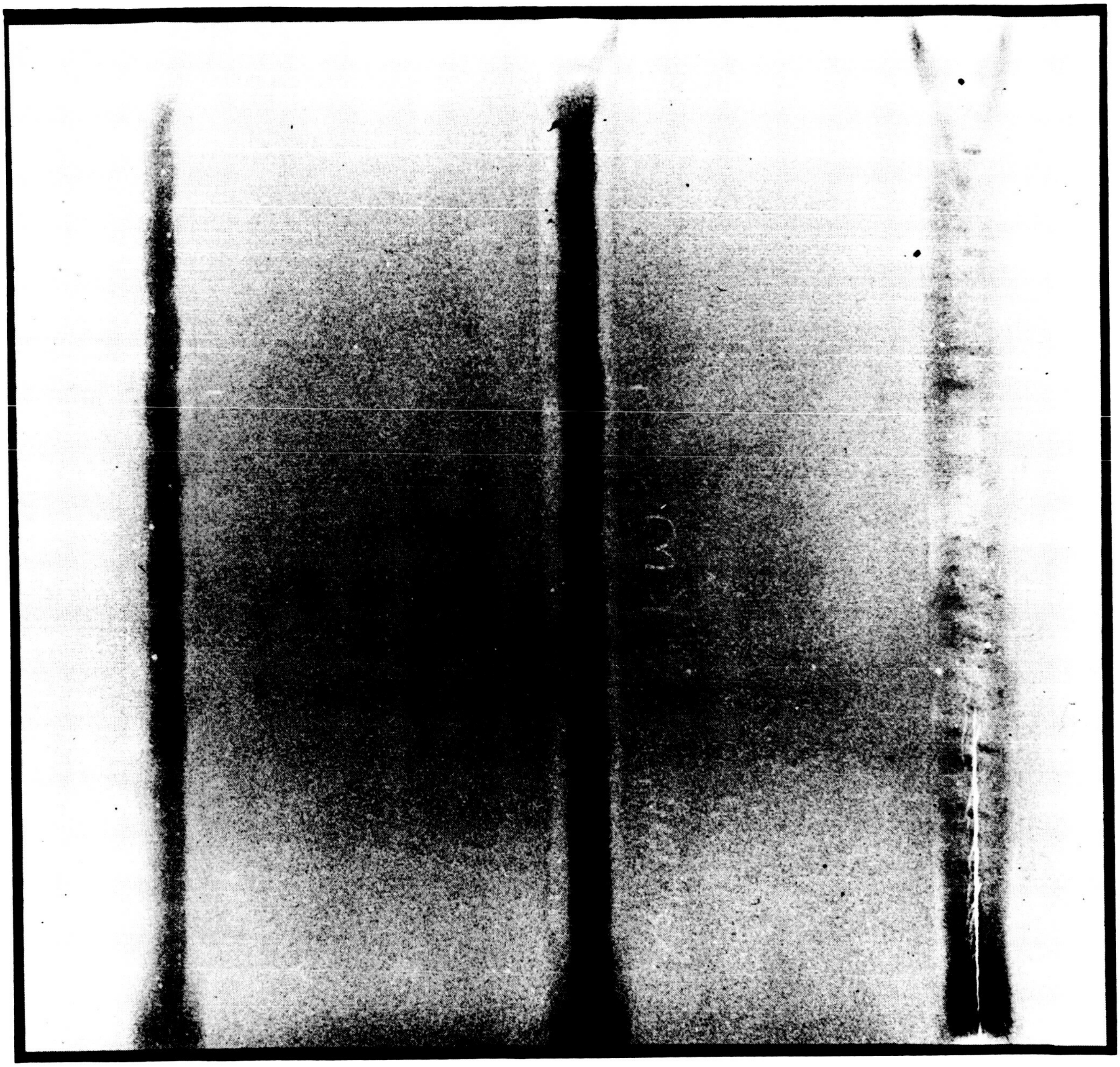


Figure 7 - X-rays of Varied Conditions

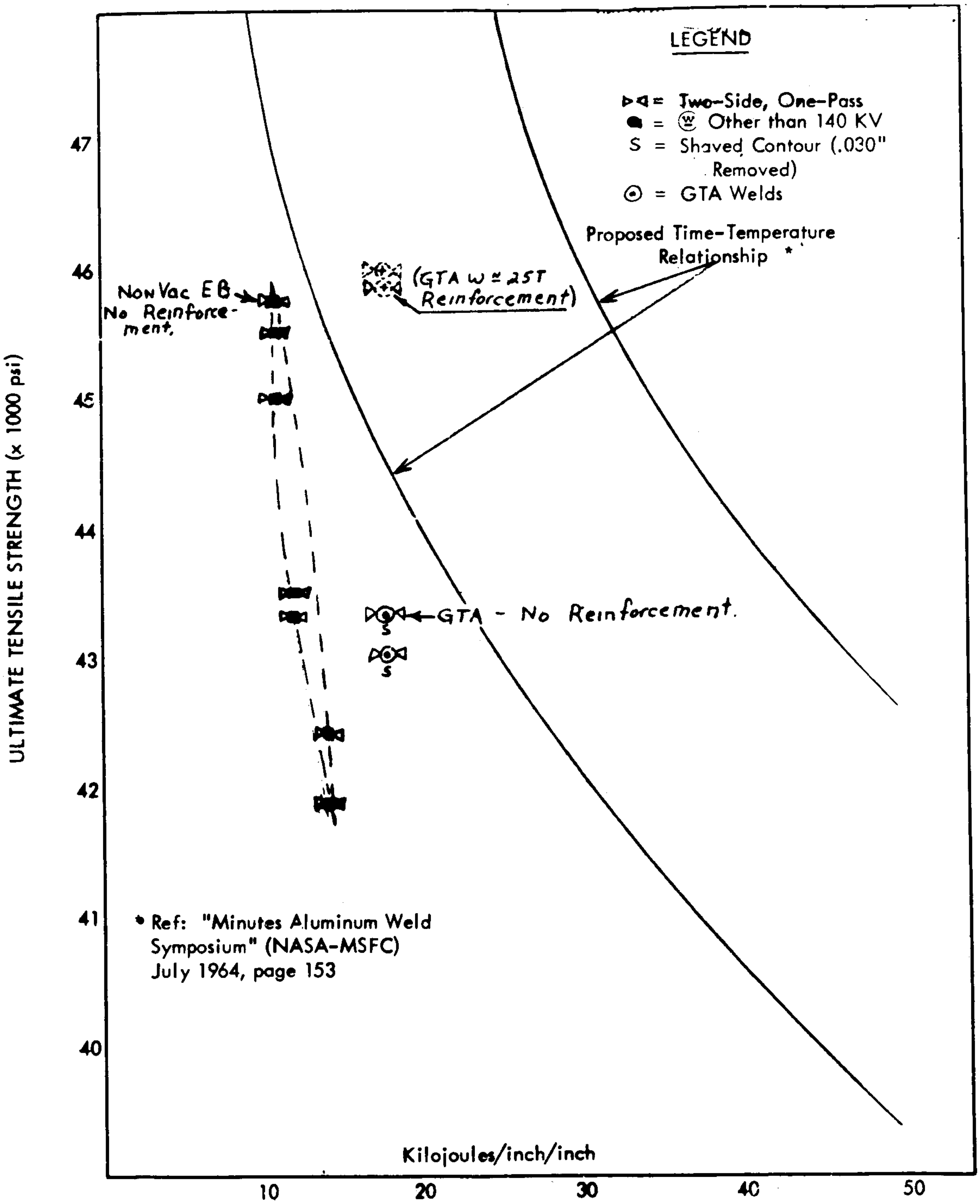



Figure 8 - Process Strength to Energy Relationships