https://ntrs.nasa.gov/search.jsp?R=19910013733 2018-03-23T03:55:21+00:00Z

N91-23046

VARIABLE POLARITY PLASMA ARC WELDING

E.O. Bayless, Jr.
Marshall Space Flight Center

Technological advances generate within themselves dissatisfactions that lead to further advances in a process that goes on and on to the benefit of all concerned. Today I intend to describe very briefly a series of advances in welding technology which culminated in the Variable Polarity Plasma Arc (VPPA) Welding Process and an advance instituted to overcome the latest dissatisfactions with the process: automated VPPA welding.

THE TROUBLE WITH GTA WELDING

Gas-shielded Tungsten Arc (GTA) was developed during World War II for welding light aircraft alloys of aluminum or magnesium. The GTA process arc is embedded in an inert gas that flows around a nonconsumable tungsten electrode as shown in Figure la. The inert gas protects the surface of the hot metal from reacting chemically with the air. This process was used to fabricate the Saturn V, and, until recently, the Space Shuttle External Tank.

One source of dissatisfaction with GTA welding is the excessive width of deep penetration welds. The force of the GTA arc isn't enough to penetrate the molten weld metal. The heat enters the weld from the arc at the surface of the puddle, and the heat spreads out from the heat source in a roughly spherical pattern. Although fluid circulation in the weld puddle can vary this, the width of a deep penetration weld bead is about the same on each side as the depth of penetration. Thus heavy welds are made with multiple beads. Each bead presents new opportunities for defects to enter the weld.

Another source of dissatisfaction with GTA welding is its sensitivity to contamination. A little grease or water can generate hydrogen, which aluminum avidly absorbs and then regurgitates as porosity upon solidification.

Reverse polarity welding, where the tungsten electrode is made positive with respect to the workpiece so that a cleaning action takes place as positive ions strike the workpiece, reduces sensitivity to contamination, but at a price.

A bit of explanation is due here. A welding arc consists of a plasma of ionized gas. There are neutral inert gas atoms, positive inert gas ions, and negatively charged electrons. The positive and negative charges balance, so the plasma is neutral. The positively charged ions drift towards the negatively charged cathode. From the sporadic flashing seen at the cathode it would appear that the positive ions charge up the surface oxide to the point of electrical breakdown and that the observed cleaning action may take place by a succession of electrical breakdown explosions on the cathode surface.

The electrons in the arc plasma drift towards the positively charged anode. They drift much faster than the heavy positive ions and carry the bulk of the arc current. They generate appreciably more heat where they enter the anode than where they leave the cathode. Consequently GTA operations are normally carried out such that the workpiece is the anode and gets the bulk of the heat. This is "straight polarity." In "reverse polarity", where the workpiece is made the cathode, the electrode receives the bulk of the heat. Therefore the penetration in reverse polarity has to be greatly curtailed to keep the electrode from burning up. Welds on the Saturn V or the Space Shuttle External Tank were generally made using straight polarity (for the sake of the greater penetration) compensated for by very stringent cleaning procedures (scraping, white gloves, etc.). The unavoidable defects were ground out and repaired.

THE TROUBLE WITH PLASMA ARC WELDING

Plasma Arc Welding (PAW) was developed in the 60's. An early application was the fabrication of steel (D6AC) rocket cases by Westinghouse. In the PAW process the arc is emitted through a water cooled nozzle surrounding the tungsten electrode as shown in Figure lb. The hot gas of the plasma expands through the nozzle in a high speed jet that easily penetrates the molten metal in the weld puddle so as to deliver heat throughout the thickness of the workpiece and not just at its surface. Deep, narrow single pass welds become feasible. In fact, in PAW practice welding in the "keyhole" mode with complete penetration of the workpiece is usual. With a high speed plasma jet continually flushing out the weld keyhole the sensitivity of the PAW process to surface cleanliness is greatly reduced.

But the PAW process is unsatisfactory when it comes to dealing with tenacious oxides. In straight polarity aluminum alloys cannot be welded. One encounters an invisible surface film that prevents the liquid metal from flowing together into a sound weld. One does not get a weld bead; one gets a crinkly mess where the metal has been melted. If polarity is reversed to take advantage of the effect of the cleaning effect of reverse polarity, this problem disappears, but penetration capability is drastically reduced.

THE TROUBLE WITH VARIABLE POLARITY PLASMA ARCH WELDING

VPPA welding was developed in the late 60's and early 70's by B.P. VanCleave at Boeing Company. This process resembles the PAW process, except that the VPPA process incorporates a variable current waveform. The system spends part of its time in reverse polarity for the cleaning benefit and the rest of its time in the more efficient straight polarity mode. For 2219 aluminum about 4 milliseconds reverse and 19 milliseconds straight polarity has been found to work well. A special power supply was developed for this process on contract by Hobart Brothers Company as existent power supplies were not up to the demands of the process for the heavier welds.

Marshall Space Flight Center (MSFC) began to develop a VPPA system in the late 70's, shortly after the emergence of Hobart's VPPA power supply, with a view towards replacing the GTA system then in use for fabrication of the Space Shuttle External Tank. In 1984 an article was published in the Welding Journal (September 1984, pp.27-35) describing the development of the VPPA system at MSFC and noting that, "Implementation of the VPPA welding technique in the production of the Space Shuttle External Tank is nearing completion." A picture of the present VPPA system at MSFC is shown in Figure 2. At present the implementation is 80% complete.

To operate the GTA system one has to set current, standoff or voltage, weld speed, shield gas flow, and wire feed rate: 5 variables. To operate the VPPA system one has to set addition reverse polarity current, reverse and straight polarity time cycle increments, plasma gas flow and plasma jet orientation: 5 more variables making a total of 10 variables. The initial system as described in 1984 was computer controlled. General Digital Industries, Inc. of Huntsville, Alabama, set up the digital control system as subcontractor to Hobart. The heart of the system was the PAL-100 computer (PAL = "Process Automation Language") operating with a Digital Equipment Corp. (DEC) LSI-11/23 micropressor. With this equipment the welding variables can be programmed in advance. The operator will still have to make trim adjustments, however, to compensate for local perturbations. The operator will also have to make seam tracking corrections and wire entry angle adjustments as needed. This can result in defects or, at least, variability of weld properties. Considering the very high cost of the parts being processed and the repair costs, this is unsatisfactory.

THE AUTOMATED VARIABLE POLARITY PLASMA ARC WELDING SYSTEM

A brief description of current efforts to automate the VPPA welding system completely and to eliminate the hand of the welder on the controls entirely has been given in the Research and Technology 1989 Annual Report of the Marshall Space Flight Center (C. Kurgan: Fully Automated Variable Polarity Plasma Arc Welding. p. 240). A schematic view of the effort is shown in Figure 3. The work comprises development of sensors to feed back information and control in real time with respect to the weld seam (tracking) and the configuration of the weld bead/puddle/keyhole, development of a mathematical model of the relation of the system parameters to the bead configuration, and special (e.g., wirefeed and torch rotation) controls as well as general system control algorithms. We envision this system as the future standard VPPA system for aerospace fabrication. It is expected to reduce defects to the extent that radiographic inspection requirements can be relaxed.

UTILIZATION OF THE VPPA SYSTEM: PRESENT AND FUTURE

Manufacturers interested in welding heavier sections (say quarter-inch and over) of aluminum alloys or other alloys with tenacious surface oxides have a potential interest in VPPA welding equipment.

For the most stringent aerospace fabrication requirements we regard computer control as essential. When it is ready we think a fully automated, top-of-the-line system will be the most economical for this kind of work.

But it is possible to acquire various versions of a VPPA welding system. A research contractor acquired a rock-bottom basic (strictly manual) system several years ago for less than $45,000. The equipment was mostly from Hobart with the MSFC special design torch from a local manufacturer (B & B Precision Machine Inc., 6762 Highway 431 S, Brownsboro, Alabama 35741). The machine is used for research, but we believe the (university) contractors can make good welds when they wish even at this primitive level of equipment. Aerospace requirements would not apply in manufacturing, say, tank trucks, for which even primitive VPPA equipment might be adequate.

CONCLUSION

Our intent in making this talk has been to spotlight an item of technology, VPPA welding, which we thought valuable for our own applications and which we chose to, develop further. It is our hope that this presentation may lead to further use and development of VPPA welding to the benefit of a growing technological capacity in the U.S.A. and in the world.

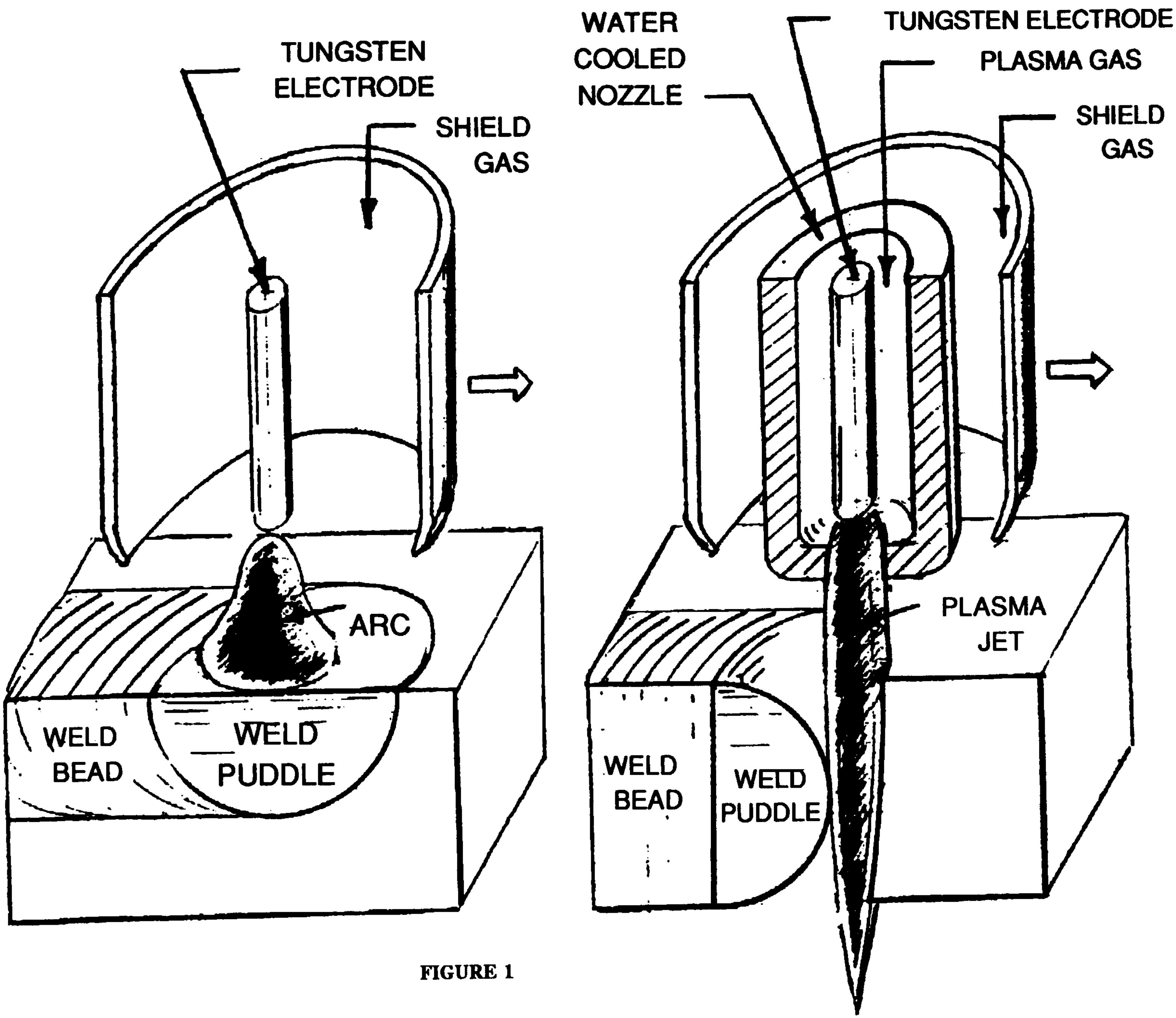

FIGURE 1

a. GTA Process

b. PAW Process(Keyholing Mode)

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

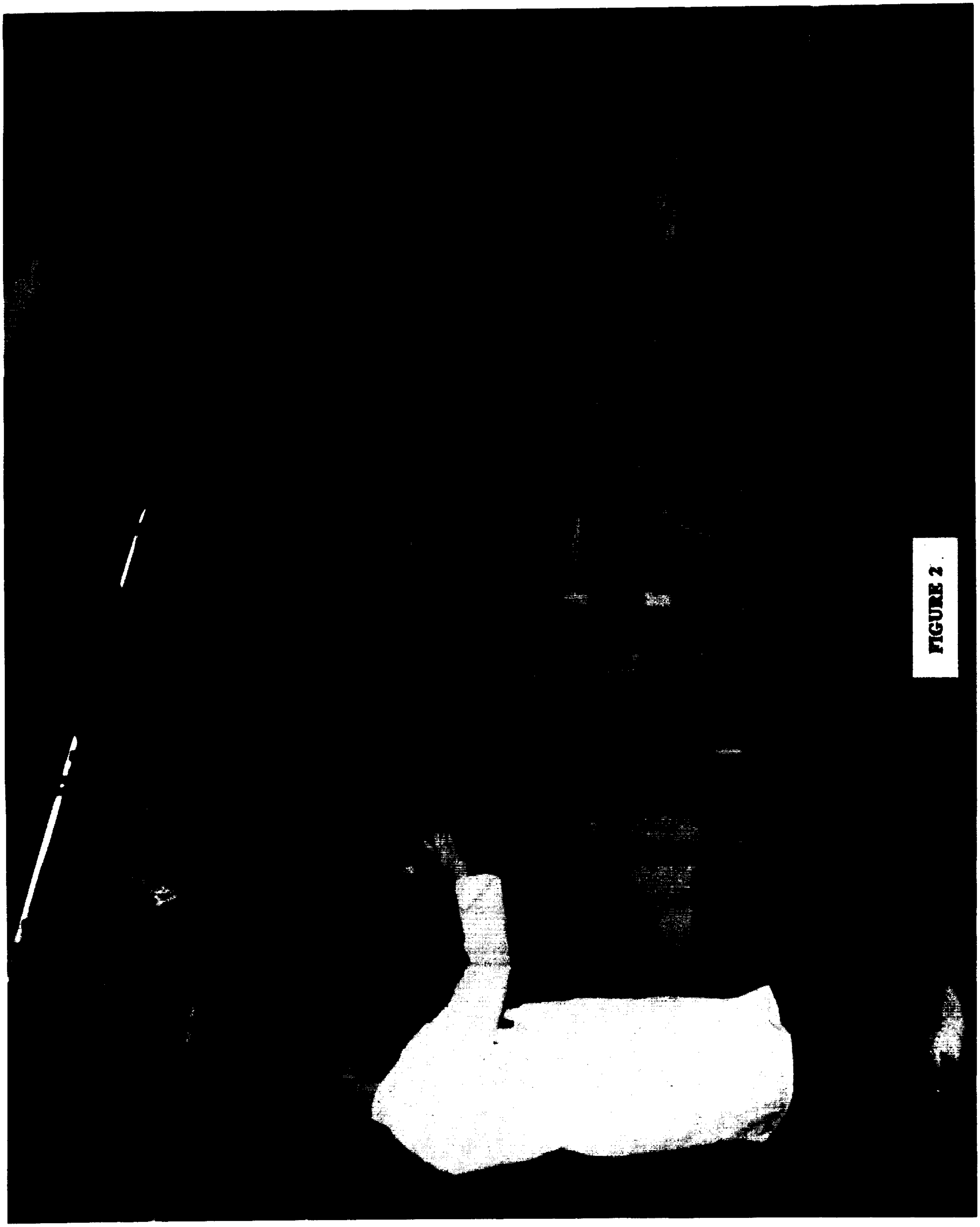

FIGURE 2

MARSHALL AUTOMATED WELD SYSTEM (MAWS)

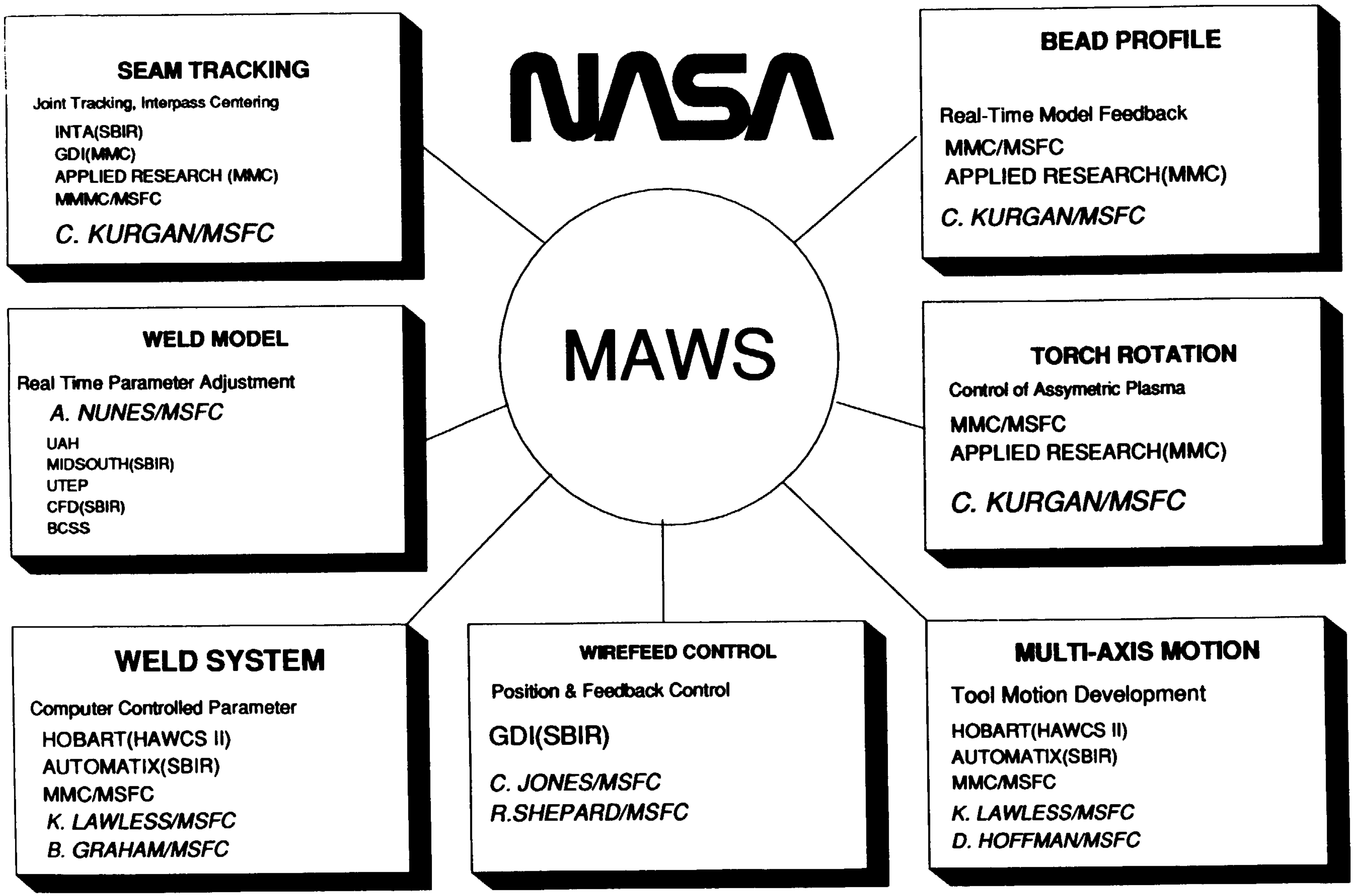

FIGURE 3