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NONAEROSPACE USES OF CHEMICAL ROCKET TECHNOLOGY

by Walter T. Olson
Lewis Research Center
Cleveland, Ohio

Presented to the NASA Office of Advanced Research and Technology at the Lewis Research Center
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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INTRODUCTION

This report presents some examples of nonaerospace uses of chemical rocket technology. Three guidelines were used in the selection of the examples.

The first of these guidelines is that a complete picture of the nature and extent of the uses of chemical rocket technology does not exist, nor can it be acquired readily. In fact, it often happens that the uses are closely guarded or are kept secret by the user! The principal tasks of the Lewis Technology Utilization staff are to find new technology that may have nonaerospace applications or uses and to make it known to the nonaerospace world through a variety of techniques. The sampling presented herein has been done by that staff because they are interested in the subject; there is no formal continuing procedure for finding the particular use of any piece of technology.

The second guideline is that for the "technology related to chemical rockets" presented herein, there is no assurance that the dollars spent on these items were "chemical rocket dollars" and only "chemical rocket dollars." In general, the technology related to chemical rockets is defined for this report as work funded by, or inspired by, or at least justified by the chemical rockets field. Currently, there are more than 3000 items that NASA's Technology Utilization program formally publicized through <u>Tech Briefs</u>; a <u>Tech Brief</u> is a one-page flyer that advertises the existence of an individual item of technology with a view to stimulating interest and use for the item. Of these 3000 items, about 750 can be identified as having derived from work done with chemical rockets in mind.

A third guideline is that, although the piecemeal presentation of specific examples, such as in this report, seems to be a way to put a note of reality into the idea that advances in one field can produce useful advances in another field, we may nevertheless

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*Based on a briefing prepared by members of the staff of the Lewis Technology Utilization Office and presented to members of the staff of NASA's Office of Advanced Research and Technology on December 11, 1968.

miss the forest for the trees this way. New technical strengths have been created in our country as a result of the research and development in the space program. These strengths are represented by such things as the ability to orient and navigate precisely spececraft at enormous distances, the high reliability of complex equipment like the chemical rocket propulsion system, the ability to handle and interpret by computer huge quantities of data, and the coordination of hundreds of thousands of people and thousands of organizations toward a single goal. Things such as these represent new levels of capability in technology and its management in our Nation. It is just such capability, or capacity, that is moving this Nation into what J. J. Servan-Schreiber (author of the best seller The American Challenge) calls a "post-industrial society." He finds about four countries that are capable of moving into this new level - a level in which such fundamental changes will occur that by the year 2000 life in our country will be as different from life for us today as our life today is from life in Egypt or Nigeria.

NASA-Lewis has tried to communicate some sense of this total development of technology on a number of specific occasions - namely, through conferences on new technology. For example, a conference was held for Cleveland industry in 1964 (ref. 1), and one was held in 1967 for small businessmen in industry and commerce in Lewis' general geographic area (ref. 2). A conference on Selected Technology for the Petroleum Industry met in 1965 (ref. 3), and there was one for the electric power industry in 1968 (ref. 4). These last two conferences in particular were unique in that teams of technical personnel were brought from these industries to the Lewis Research Center, were briefed on what the Center was doing and learning, and were asked to stipulate what was new and potentially useful to their industry. These conferences were structured on the basis of industry telling NASA what they thought NASA had accomplished that would be good for them. Finally, those conferences were organized with the objective of communicating the total development of technical areas or subjects that could transfer from the aerospace field to some other field, such as electric power.

To look more specifically at chemical rocket technology, particular examples will be examined under a number of obvious rocket headings, or topics. The first topic is propellants. Here entire areas of chemistry have been moved ahead significantly from the search for high energy propellants.

PROPELLANTS

Free radical research, for example, was sponsored generously, if only for a short while, at the National Bureau of Standards in a search for trapped, high-energy, metastable species that might be useful for increasing rocket performance (ref. 5). The results of this work amount to advances in the techniques of producing, trapping, analyzing, and determining the energy states of free radicals of various species. Now this information is useful in research that continues today on reactions pertinent to polymerization, biology, combustion, spectroscopy, astronomy, and chemical synthesis.

A second item is fluorine. Fluorine was in commercial use because of the Atomic Energy Commission's needs for fluorine to make uranium hexafluoride for uranium separation. Production reached the order of 1000 tons of elemental fluorine a year in World War II. The contribution from chemical rocket research was largely engineering and techniques in the handling and use of liquid fluorine. For example, materials, both metal and nonmetal, that could be used with fluorine were selected, and advanced equipment, such as fittings, disconnects, valves, pumps, instruments, etc., was created. The additional operational use of fluorine stimulated further toxicity studies. The first fluorine used in the rocket work at Lewis was delivered in 6-pound quantities at 400 psi in little gas cylinders. Today it is hauled in tank trucks in 5000-pound lots as liquefied gas. Reference 6 is a résumé on the handling and use of fluorine and fluorine oxygen mixtures in rocket systems. More than 3000 copies of this résumé have been sold to other than space industries, which gives some idea of the extent of interest.

Another item is boron chemistry. It has been added to, in almost all aspects, by millions of dollars spent from 1955 to 1960 in the United States in research and development activities mostly for a super fuel, but also for rocket fuels. Figure 1 gives a résumé of the chemical uses of boron (refs. 7 to 10). The main use is as borax or borates, where the glass and enamel and the cleaning industries are the big users, but it is also used for leathers, fire retardants, cosmetics, and so on. Compounds of boron with halogens, such as boron trifluoride, are used for catalysts and chemical intermediates. Boron alloys are used mostly in toughening steel or in making spring copper. The refractories, carbides and nitrides, are for abrasives and armor. Boron hydrides is a field which was not invented for the chemical rocket program by any means. This field was started by Stock, a German chemist, in 1912 and developed by him until 1936. But this field, revived and pushed by aerospace research and development money, expanded so phenomenally that the American Chemical Society had to establish a special committee just to handle the nomenclature of the new types of compound being discovered (ref. 11)! Boron hydrides were of interest because they yielded as much as 60 percent more heat of combustion than the conventional hydrocarbon fuels. Their properties made them rather awkward to handle, however, since the boranes decomposed, were toxic, and were spontaneously flammable. Thus, a lot of chemistry was performed to try to make tamer boranes even at the cost of some heat of combustion. As a result of that effort, the whole borane field blossomed into many subfields: boron hydrides, hydrocarbyl boranes, aminoboranes, carboranes, and borazines. And now Chemical Abstracts lists, under boron chemistry, column after column of papers on these many subfields derived from them. No attempt has been made in figure 1 to list them all.

A technology survey on handling hazardous materials treats chemical propellants such as pentaborane, liquid hydrogen, chlorine trifluoride, and ozone (ref. 12); about 3000 copies have been sold.

Another propellant item, polysulfide binders made for solid rockets by Thiokol, turned out to have good quality for printing press rolls for the publishing industry. Thiokol's licensee on this application reportedly sells about 20 000 to 25 000 pounds a month of these polysulfides for printing rolls.[1]

VALVE TECHNOLOGY

A subject related to propellants is advanced valve technology. More than 1000 copies of a survey (ref. 13) on this subject have been sold. Here is an instructive incident. The vice president of a leading manufacturer came to Lewis' Petroleum Conference a day early and said he was there to see what new information was available. He mentioned that he had picked about 3 or 4 items out of reference 11 and that his company is now making money on them. To the query, "What are they?", he replied, "I'm not going to tell you; I don't want the competition to find out." The incident typifies a common response to an effort to pin down a specific application. But here are some examples of valve technology that have moved from the chemical rocket field to others (ref. 14). A company developed a soft-seated, high-pressure, safety relief valve which is a standard of the missile industry. Production for rocket uses led to reduced costs, and now this valve is used commercially to control pressure in such places as polyethylene plants, compressor stations, pipelines, and chemical and petrochemical facilities. Another company developed a high-capacity, fast-acting, tight shutoff valve for loading propellants. The valve proved commercially desirable to a company producing oxygen for an acetylene process and to others. Another company developed a special ball valve to pass severe mechanical and hydraulic shock tests. The valve was subsequently sold to tank car manufacturers, petroleum and petrochemical companies, pulp and paper processers, and other chemical producers and process industries. An aerospace manufacturer put Teflon, Kel-F, and Mylar seats on a standard valve that one of their subcontractors manufactured. The engineering information was given to the subcontractor and he now markets these valves in the cryogenics industry.

CRYOGENICS

The propellant work for chemical rockets has largely helped the entirely new industry of cryogenics into existence just in the last 15 years. Of course, liquid oxygen was

[1]Telephone conversation: Mr. Paul Foster to Thiokol, December 2, 1968.

used in the steel industry. But during the first few years of rocket research, valves, lines, tanks, and similar equipment were only available on rent from the primary suppliers of liquid oxygen. As a direct result of the needs for chemical rocketry, production and handling equipment improved technically, became widely available for purchasing, and, with competition, its cost reduced greatly. In addition to liquid oxygen, liquid nitrogen is being used increasingly: for example, in the frozen foods industry liquid nitrogen is used for quick freezing foods such as strawberries, turkeys, fish, etc. Also, designs are going forward to use liquid nitrogen in aircrafts to refrigerate the foods on board (ref. 15).

Liquefied gases are used for cryoforming soft or annealed metals. A metal such as 301 stainless steel can be work hardened with only modest stretching if it is at a very low temperature; stretching or working such metal by a few percent at 320° F hardens it as much as 30 to 40 percent working at room temperature does.

Advances have been made in transfer lines, tanks, valves, instruments, and insulations for liquid hydrogen and liquid helium. One of the important things that has come out of dealing with large structures to carry these cryogenics is the development of a whole new technology called fracture mechanics. This subject has to do with understanding how materials fail because of flaws or cracks in them. A metal structure of any size can be expected to have a flaw or crack in it. When metals with cracks in them are tested as small specimens in the laboratory, some of them are brittle: They break abruptly when stressed in tension. Other metals are ductile: With a crack in them, they only tear when pulled. That same ductile metal, though, when used in a large cross section, can rupture, or crack, just as if it were brittle, even though it is made out of metal that a small-scale test showed to be ductile. An understanding of this kind of problem is developing out of the field of fracture mechanics and is being applied to more than just chemical rockets and propellant tanks.

Then, there are new insulations for large storage vessels. They comprise multiple alternate layers of thin sheets of aluminized mylar and fiber glass cloth with a vacuum applied to the resulting multilayer sandwich. Such an insulation is 1000 times more effective than conventional insulation. Figure 2 shows a 200 000-gallon storage vessel and 35 000-gallon freight cars for liquid hydrogen; the boiloff rate in the storage vessel is only 0.05 percent per day. The foregoing techniques and materials are adding to the know-how and economy of storing and shipping cryogenic gases of commercial value such as liquid methane. In addition, this same aluminized mylar sheet is on sale as a rescue blanket.

Research on superconductivity is stimulated by the increasing availability of liquid helium and liquid hydrogen. For example, figure 3 shows a cryomagnet. Research on cryomagnets leads to their use for MHD power generation among other things. Also, Edison Electric Institute, the association that supports research for the electric power industry, is sponsoring research on transmission lines made of superconductors cooled with liquid helium; for example, figure 4 shows one idea for the construction of such a conductor. A very fine superconducting wire can carry an electric current that would otherwise require a copper conductor 1 inch or more in diameter.

It is interesting to note that the demand for liquid helium rose 1000 percent from 1962 to 1967, and it reached an annual rate of about one-half million gallons (ref. 16) due to the impetus of cryogenic research. Cryogenics has also been used for surgery - for example, in treating Parkinson's disease. A tiny thermocouple (0.006-in. diam.) was developed for research at Lewis on ionized gases (fig. 5); this same thermocouple was incorporated in the surgical cannula used to freeze tissue. For the first time now, the surgeon has quantitative control over the use of his instrument (fig. 6). Cryogenic surgery is now being extended to surgery of the eye, pitituary, prostate, and tonsils. Even painless and permanent branding of animals with a brand at -70° C has been reported (ref. 17)!

BEARINGS, SEALS, AND LUBRICANTS

Technology created in this area relates to rocket turbopumps and appears in numerous publications. Some of these publications get wide publicity as Tech Briefs. For example, a recent Tech Brief (ref. 18) describes a lubricant-impregnated bearing suitable for service in liquid hydrogen; 50 inquiries for more information have been received on this one example. Of 19 Tech Briefs from Lewis alone on this topic, more than 1400 inquiries have resulted. Of these 1446, 885 were on lead oxide as a solid lubricant, about 100 were on the use of an oriented, hexagonal crystal structure in metals to improve bearing friction at extreme loads, and 90 were on the improvement of ball bearing fatigue life by controlling the hardness of balls to a specified amount greater than the hardness of the race.

TABLE I. - INQUIRIES FOR INFORMATION FROM LEWIS RESEARCH CENTER ON SELECTED TECH BRIEFS ON BEARINGS, SEALS, AND LUBRICANTS

NASA Tech Brief	Inquiries
68-10340	16
68-10270	16
68-10249	28
68-10176	13
68-10165	52
68-10134	35
67-10364	4
67-10009	8
67-10007	29
67-10006	34
66-10678	23
66-10373	97
66-10165	3
66-10087	14
66-10005	4
65-10251	90
64-10116	885
64-10042	79
63-10337	16
	1446

[a]Source: Technology Utilization Office, Lewis, December 2, 1968.

RELIABILITY AND QUALITY CONTROL

The total practices of the Lewis Center in design criteria and practices, design review, reliability analysis, failure mode analysis, testing, and qualification of pieces, components, subsystems, systems, and combined systems were presented, by request, to the representatives of the electric power industry. Reliability and quality assurance has also been the subject of a course at the B.S. and M.S. level at the University of Arizona, and Lewis staff members, in addition to lecturing in this course, have presented lectures on the subject to technical societies such as the Institute of Reliability Engineering and Management. Also, Martin-Marietta offers automatic checkout and control systems like that on TITAN to commercial accounts, for example, in the petro leum industry.[2]

CONTROLS, INSTRUMENTS, AND MEASUREMENTS

Several Tech Briefs from Lewis are considered in which nonaerospace firms have taken a strong interest and received more detailed information on controls, instrumen and measurements. For example, a strain-wire flowmeter with a fast response time (ref. 19) developed to measure both variable and steady flow rates of propellants has received 28 inquiries (fig. 7). A turbine-type flowmeter in liquid hydrogen (ref. 20) h received 18 inquiries. A liquid hydrogen densitometer based on the resonant frequenc of microwaves in a cavity filled with liquid hydrogen has been devised (ref. 21). A mi crowave enters the wall of a cavity that is closed at the ends to microwaves with thin open cylinders (fig. 8). Radii of these cylinders and the distance between them determine whether this cavity will resonate or not; the frequency is observed at resonance. The frequency depends on the dielectric constant of the cavity contents, and the dielec tric constant depends on the density, so the instrument can indicate density. There ha been 40 inquiries on this densitometer. Figure 9 shows another way of continuously measuring the density of flowing fluids; 50 inquiries have been received here on this o (ref. 22). The propellant flows through a tube with flexible bellows at each end. A driver oscillates the tube in the transverse direction. The force of oscillation and the inertia of the system are measured. The total force in that oscillating system is, of course, proportional to the mass; the mass is proportional not only to the hardware, but to the density of the liquid in it. This is another way of measuring density.

Liquid crystals can be used to detect voids in fiber glass laminates (ref. 23). It i hardly an instrument, but it is a measurement technique. Ninety-eight inquiries have been received on it.

COMPUTER PROGRAMS

NASA is investing a lot of time and money in computer programs for propellant chemistry, fluid behavior, combustion and heat transfer, optimum design of tanks, tur bines, compressors, pumps and nozzles, and all kinds of systems. Copies of these computer programs go to COSMIC, a NASA-sponsored dissemination organization at th University of Georgia. COSMIC sells them to the public at the cost of reproducing

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[2]Telephone conversations, Martin-Marietta in Denver.

them. Thus, work that the taxpayer has supported through NASA does not have to be done over again. All one has to do is to pay for the cost of making the copies. This program of COSMIC started in July, 1966. There are 2000 programs in the inventory, about 70 percent of them from NASA and most of the rest from the Atomic Energy Commission. In fiscal year 1968, COSMIC sold over 3000 copies and descriptions of the 400 of these programs that are available "off-the-shelf." About 25 percent of the inventory relates to chemical rockets; for example, programs on thermodynamic properties of ideal gases and their chemical equilibrium in complex systems have been devised by the Lewis Research Center. These programs have been distributed by COSMIC and Lewis to about 52 different industries and universities. The design practices for high performance pumps and turbines have been reduced to computer programs. An examination of three programs from Lewis on these topics shows that they have been sold by COSMIC to users, such as General Motors, General Electric, Rohr, Dresser and Clark, Engineering and Scientific Computer Center, Pratt & Whitney, and Avco, on numerous occasions. Because COSMIC has sold at least once every program that has been made available to it, Lewis has decided to send them a copy of every program. For example, using the Technology Utilization clause in its contract at General Dynamics/Convair, Lewis is now in the process of obtaining 96 different programs from the Centaur Project to be added to COSMIC.

The idea that a computer program seems to be specific to aerospace apparently is no bar to its use in other fields. For example, consider a particular program from North American Rocketdyne prepared for the J-2 engine project on a contract with the Marshall Center. The object of the computer program is to determine the optimum spacing of the slots in the fuel injector plate that admit coolant along the walls of the J-2 engine. Minimum film coolant for maintaining wall temperatures below a set value is sought. In a more general way, this computer program for sizing and locating film cooling slots finds the values of several independent variables which minimize the dependent variable, coolant flow. Because there are many different ways to put the slots in the injector, there are many independent variables. But the important thing is that the program can be generally applied. It was transmitted to COSMIC in 1966, and by 1967, 325 copies had been sold. Figure 10 shows 32, or about 10 percent, of the firms that got copies of that program. What do they use it for? Westinghouse is using the program to optimize the design of synchronous electric motors. Eastman Kodak is using it to optimize the design of lenses. Bonneville Power Dam is using it to optimize the efficiency of their power generating systems. The University of North Carolina is using it to study trends in public health and to optimize the data by which to combat diseases. United Aircraft is using it to design optical guidance systems. General Foods is using it to optimize the variables in food processing and canning, and so on. We are just beginning to see the profitable application of these NASA computer programs beyond the space field, and this should be a most valuable area because these programs, once transferred to one of these companies, can be used over and over again.

COMBUSTION, HEAT TRANSFER, AND FLUID FLOW

The technology consists largely of substantial amounts of new scientific data and knowledge in addition to just techniques or inventions or gadgets. Much of this knowledge moves outside the aerospace field through meetings and journals of the learned societies.

NASA has been experimenting with a pilot program at Oklahoma State University for assisting the transfer of information by means of the creation of teaching aids at the college level. The staff at Oklahoma State University selects topics that come out of NASA technologies or new knowledge that has been created, and they then prepare a monograph to explain and to illuminate this new knowledge. They have written about 20 of these so far. If it turns out that visual material, that is, a movie, or something of that sort, is more useful for instruction than something written, then a visual brief is prepared; about 21 of these have been prepared. Table II listed the monographs and visual briefs based on chemical rocket technology. As the next step, Oklahoma State University arranges for the review and use of this material. Figure 11 shows how much action there has been already in the pilot program in terms of numbers of instructors and students. Also, it is noted that industries are borrowing this material and using it for their in-plant seminars.

TABLE II. - CHEMICAL ROCKET RELATED MONOGRAPHS AND VISUAL BRIEFS PREPARED BY OKLAHOMA STATE UNIVERSITY UNDER NASA CONTRACT

Monographs
A Generalized Correlation of Vaporization Times of Drops in Film Boiling on a Flat Plate. Source: NASA Lewis Research Center.
Formulas for Radiant Heat Transfer Between Nongray Parallel Plates of Polished Refractory Metals. Source: NASA Lewis Research Center.
Pool Boiling Heat Transfer at Reduced Gravity. Source: NASA Lewis Research Center.
The Method of Zones for the Calculation of Temperature Distribution. Source: A. D. Little under NASA contract.
Calculation of Complex Chemical Equilibria. Source: NASA Lewis Research Center.
Critical Flow of Real Gases Through Nozzles. Source: NASA Lewis Research Center.
Thermodynamic Consistency of Vapor-Liquid Solubility Data. Source: NASA Lewis Research Center.
Enthalpies of Co-existing Equilibrium Vapor and Liquid Mixtures from Solubility Data and Equation of State Calculations. Source: University of Michigan under contract to NASA Marshall Space Flight Center.
Visual briefs
Hydrodynamic Rotating Shaft Seals. Source: NASA Lewis Research Center
Visual Observations of Cavitation in Rotating Machinery. Source: NASA Lewis Research Center.
Bubble Dynamics for Nucleate Boiling in Reduced Gravity. Source: NASA Lewis Research Center.
Investigation of Impinging Sheet Injectors. Source: The Jet Propulsion Laboratory.
Pool Heating of Liquid Hydrogen Over a Range of Accelerations. Source: NASA Lewis Research Center.
Visualization Studies of Combustion Instability in a Hydrogen-Oxygen Model Combustor. Source: NASA Lewis Research Center.
Experimental Observations of Transient Boiling in Subcooled Water and Alcohol. Source: NASA Lewis Research Center.
A Visual Study of Two Phase Flow in a Vertical Tube with Heat Addition. Source: NASA Lewis Research Center.
A Visual Study of Velocity and Buoyancy Effects on Boiling Nitrogen. Source: NASA Lewis Research Center.
Evaporative Cooling and Freezing of Propellants in Injector Manifolds Vented to Space. Source: NASA Manned Spacecraft Center.
Hypergolic Propellant Research. Source: NASA Manned Spacecraft Center.
Propagation of Char During Ablation. Source: NASA Manned Spacecraft Center.
Journal Bearings in Laminar and Turbulent Regimes. Source: NASA Lewis Research Center.
Fluid Cavitation at Pipe Bends. Source: NASA Marshall Space Flight Center.
Saturn Radiation and Convection Base Heating. Source: NASA Marshall Space Flight Center.
Low Gravity Fluid Behavior in Tanks. Source: NASA Marshall Space Flight Center.
Fluid Cavitation Caused by Vibration. Source: NASA Marshall Space Flight Center.

MATERIALS

The materials field offers a very fruitful area for nonaerospace uses, of course. One major contribution from the chemical rockets field has been the development of and the techniques of winding very strong, lightweight vessels made out of glass fibers impregnated with a resin; figure 12 shows such a vessel being wound. Figure 13 shows an application of these filament-wound vessels to a tank truck; the reduction in weight is very appreciable. Figure 14 presents an application of a plastic tank for underground storage of gasoline. A big virtue is that it is corrosion-resistant; also, it is lightweight, so it installs easily. Figure 15 is a tank car in the experimental stage; the 9 tons of weight potentially saved by using this filament-wound tank are worth pursuing. United Technology Laboratory is in pilot production with pipe wound of glass in diameters up to 48 inches (refs. 24 and 25). This pipe is one-sixth the weight of comparable steel pipe and one-tenth the weight of concrete; thus, handling costs are reduced. It is also nonbrittle, corrosion and decay resistant, and is therefore useful for irrigation pipelines in places such as California where earthquakes might shift a concrete or steel pipe around and break it.

Another materials item is HYSTL plastics, a new class of thermosetting plastics (ref. 26). They were developed by Thompson Ramo-Woodridge (or TRW) for the Lewis Research Center in the search for possible new ablative liners for rockets. It turned out that HYSTL is not a desirable ablative, but is good for many other uses. It is a new class of thermosetting plastic with a high strength and good thermal and chemical stability. It is based on high vinyl content polybutadiene glycol. After a market survey, TRW set up arrangements with Commonwealth Oil Company and others to manufacture and market this material on a fairly large scale. They have filled more than 120 applications for foreign and domestic patents, including covering uses in moldings, laminates, adhesives, and coatings. This plastic is also being evaluated for its compatibility with living tissue with a view to its biological use.

Space-originated materials can also meet biological needs. Pure, high-strength carbons and graphites, which were developed for such rocket applications as thrust chamber liners (graphite cloth) and nozzle throats (pyrolytic graphite), can apparently serve as replacement parts for the human body. Figure 16 identifies several stipulated uses of graphite materials from North American Rockwell Corporation (ref. 27). It is very interesting to note that this extension of the uses of carbon was directly stimulated by the NASA Technology Utilization program at North American. Replacement such as heart valves and bone joints are self-explanatory as are implanted splints. Dialysis parts and circulatory bypass implants are a matter of using a carbon part and removable plug in a vein for use with an artificial kidney or for tempory circulation assistance. Myoelectrodes are little probes for taking the electric signal from the nerve of a particular muscle with a view that this signal would then "work" some other part of a prosthetic device. Cosmetic replacement is self-explanatory. Epithelial bone extension means bringing the load carrying member out of the body in the case of an amputation.

Table III compares some aerospace related parameters, strengths, temperature tolerance, chemical compatibility, and galvanic compatibility for classes of materials.

TABLE III. - PARAMETRIC COMPARISON

Parameter	Metals	Ceramics	Carbons
Aerospace and biomedical			
Strength	High	High	Fair to high
Temperature tolerance	Fair	High	High
Chemical compatibility	Low	Fair	High
Galvanic compatibility	Low	Fair to high	High
Biomedical only			
Tissue acceptance	Low	Low to fair	High
Nontoxic	Low	Fair	High
Body fluid resistance	Fair	High	High
Density matching	Low	High	High

Carbons are almost as good as or even better than metal and ceramics for several aerospace uses. In biomedical parameters, such as tissue acceptance, nontoxicity, body fluid resistance, and density matching, the carbons are superior to the ceramics and metals.

Another item in the materials field relates to die-casting. Die-casting is a low-cost automated process for mass producing precise, metallic parts, usually of a low melting metal like zinc or aluminum which are cast at about 800° to 1300° F. It would be of great economic importance if iron or steel could be commercially die-cast. The use here has been restricted by lack of mold material that will stand repeated use from 2200° to 2800° F. The low thermal expansion and the high heat conductivity of tungsten and molybdenum appear to make these materials ideally suited as molds for die-casting iron or steel. Figure 17 shows some stainless steel die-castings, and figure 18 illustrates some metal die components. Now, literally thousands of ferrous alloy experimental castings have been made in tungsten and molybdenum dies to date. This work is conducted by aerospace firms, for example, General Electric, using private funds and using refractory metals technology, which is another field brought into bloom by the nourishment of aerospace requirements and aerospace money.

The stainless steel skin of the Apollo spacecraft was made of precipitation-hardened stainless steel. That is a stainless steel that is harder, stronger, and more corrosion resistant even at high temperatures than ordinary stainless steels. The maker of that steel, Armco Company of Ohio, has found uses for the whole family of these precipitation-hardened stainless steels, and they make parts for racing cars, chemical processing equipment, boat propeller shafts, protective soles in military boots, and electric razor heads (ref. 28). These steels are also coming into use in commercial aircraft, like the B-747 and the SST, and in military aircraft, like the C-5, C-141, and F-4.

Another kind of steel is marging steel (ref. 29). This high nickel content steel fills the need for strength and resistance to brittle fracture, and it can be heat treated at moderate temperatures. Although this steel was not invented for aerospace uses, chemical rocket requirements pushed its development to the point where maraging steel became commercially available, and now it is used in high pressure chemical processing equipment and in pressure hulls for deep-submerging vessels, like the one called "Deepquest." It is also used for die-casting molds for aluminum and for extrusion tools for zirconium, beryllium, and high nickel content alloys. Maraging steel is also used for parts of hydrofoil ships.

FABRICATION

Space requirements place unusual demands on the metal working industry. New methods used to make difficult-to-form aerospace parts out of tough or difficult-to-handle materials have evolved slowly and did not move into general industrial use very rapidly because of the initial expense and the complexities of initiating these new methods. But just in the last few years they have come into much wider use; magnetic forming, electron beam welding, and electric discharge machining are now becoming standard production practices.

In magnetic forming, a surge of electricity through a coil produces a magnetic field, and the mechanical force of that field can crimp, expand, or form a conducting metal (see fig. 19). For example, when the magnet shown in figure 20 (on the ground in the foreground) was placed inside the large pipe (in this case, a propellant line for a Saturn rocket) and activated, it expanded stiffening rings into the pipe. The technique is now in use as a production method in the automotive industry where a major company uses it to crimp a copper ring around a plastic seal on a dry joint. They also crimp a steel ring around a rubber boot, put a ring on a shock absorber, and seal the hose to the gas tank with an aluminum ring by this method. They even use it to crack the stator laminations in electric motors. The steering gear division of this company has more than a dozen machines in operation on production. Another firm uses magnetic forming on shock absorbers and for connecting axle housings to the differential. One automobile manufacturer recently ordered an 84-kilojoule machine, which is the largest one in the industry. This machine will be used to make a variety of automotive, marine, and appliance parts. More than 1000 copies of a NASA technical survey on high velocity metal working (ref. 30) have been sold to nonaerospace industries.

Figure 21 shows electron beam welding. Electrons generated from a hot filament are accelerated to the work piece to be welded by a high voltage. The high-velocity electrons are focused into a beam by magnets, so that a very sharp beam impinges on the work piece. The process is usually conducted in a vacuum. The result is a very clean, deep weld, with a minimum of thermal distortion to the exterior. Electron beam welding has been used for many kinds of space and chemical rockets parts, and now, as described in some detail by the trade press, it is used by General Motors and Ford to weld steering columns. Ford is also using it to weld ring-gears, commutators, and other distributor parts. Others are using it in aviation, electronics, and office machinery; typewriter carriages are also welded this way. Ball valves, ball joints, band-saw blade teeth, spark plug rings, and servopistons are just a few further examples of the use of electron beam welding. It is expected that sales of electron beam equipment will be up 50 percent in 1968 over 1967.

Figure 22 shows an electron beam welder that X-rays its own welds (ref. 31). Because electron beam welding is done in vaccum, it is very time consuming to take the work out of the vacuum, move it to another spot to get an X-ray, and then replace it in vacuum for further welding. This innovation uses the electron beam itself to produce an X-ray of the weld that is being made. The X-rays which are read on polaroid film, are produced by impinging the electron beam on a tungsten target. Since 1967, 150 non-aerospace companies have been provided complete technical details on this technique. Owing to the initiative of a member of the Lewis staff, the three manufacturers of electron beam equipment have distributed 2000 copies of the Tech Brief on this innovation (ref. 31) to their customers; this ought to generate further inquiries and broaden the use of the technique.

In electric discharge machining (ref. 32) 50 volts produce an arc between a very carefully shaped tool and a work piece (see fig. 23). The arc may occur at 250 000 cycles per second. Each arc etches away a little bit of the work piece; the dielectric fluid washes these burned cuttings away. The tool advances slowly as it "cuts." It is used to machine injectors for rockets and also for fine work on delicate parts, because there is no tool pressure exerted on the work. For example, the method has been used at Lewis to cut holes near the thin cooling tubes on chemical rocket engines. This method is currently in extensive use in the automotive industry, especially for cutting stamping dies. IBM uses it to make dies, to make tooling, and for stock removal in production. The market for this kind of equipment is estimated at about $25 million in 1969.

SUMMARY

About 750 of the 3000 items that NASA has so far identified and published as potentially useful outside of the aerospace field can be identified with chemical rocket technology. A number of technical fields can each be shown to contain examples of chemical rocket technology that is actually used for other than aerospace purposes. These uses range from broad advances in the technical field to smaller applications, such as gadgets and inventions. Some of these fields are chemistry, fluid systems (pipes, valves, tanks, etc.), cryogenics, rotating machinery (turbines, pump, bearings, seals, lubricants), instruments and controls, computer software, metals, nonmetallic materials, and fabrication. In effect, chemical rocket technology has turned out to be technically productive for the nonaerospace as well as the aerospace field.

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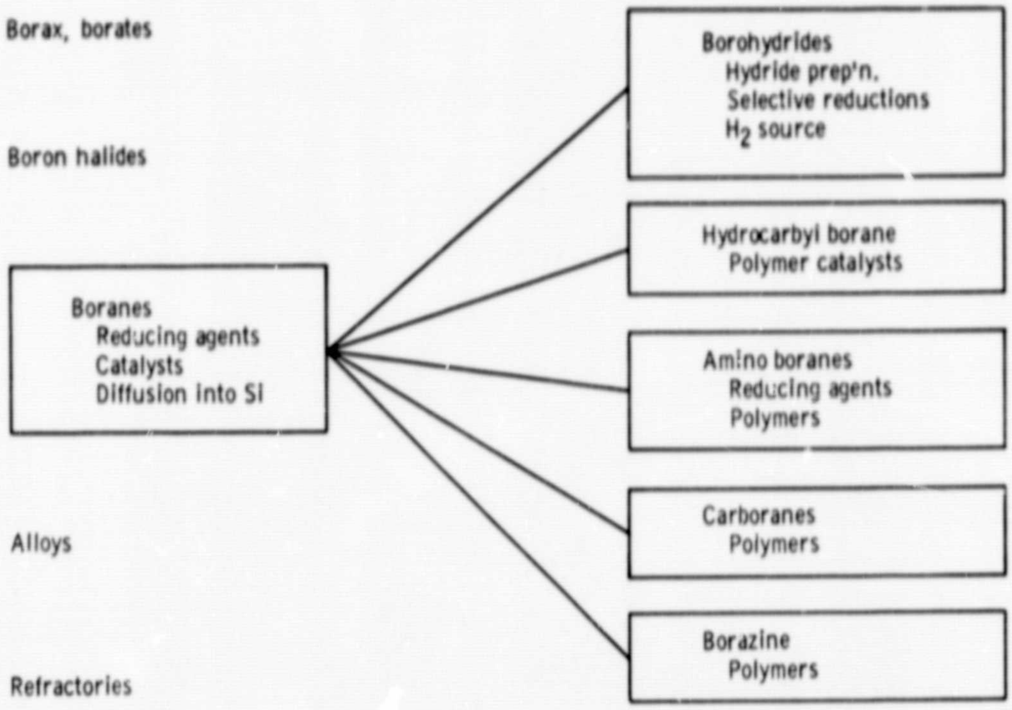


Figure 1. - Chemical uses of boron.

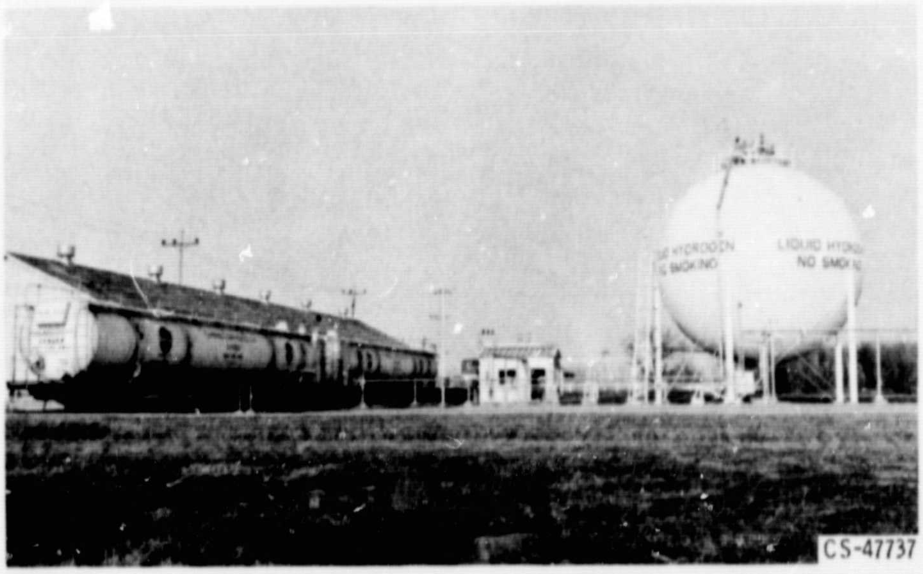


Figure 2. - Liquid hydrogen storage facility.

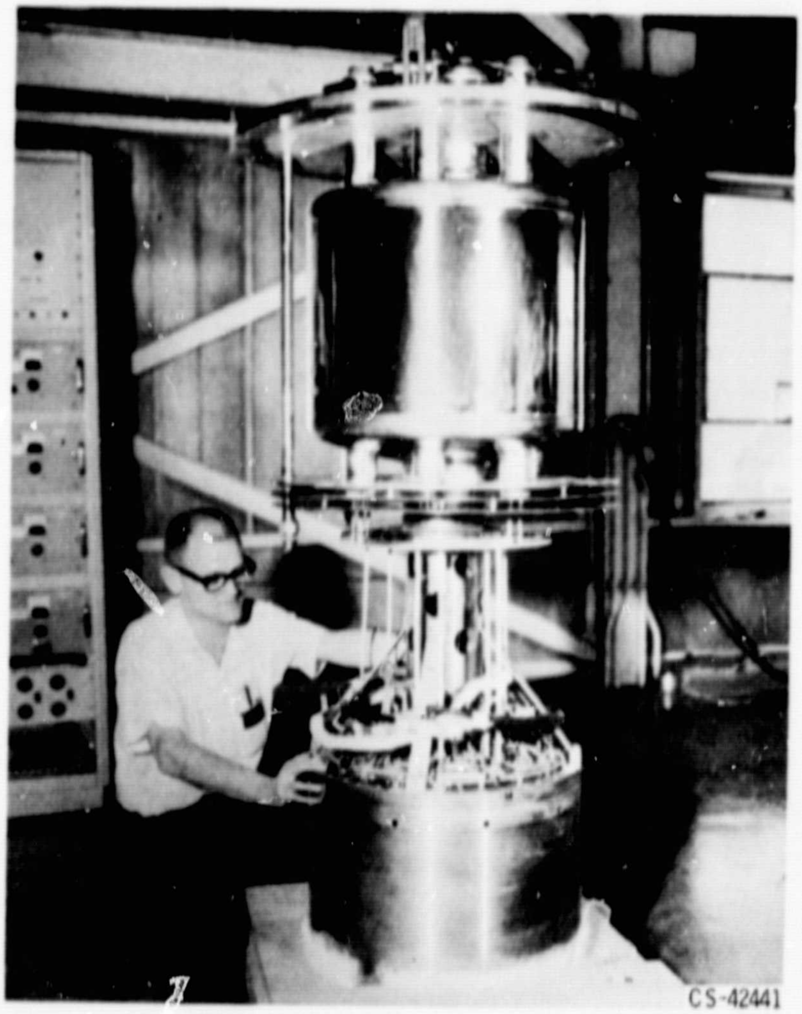


Figure 3. - Cryomagnet.

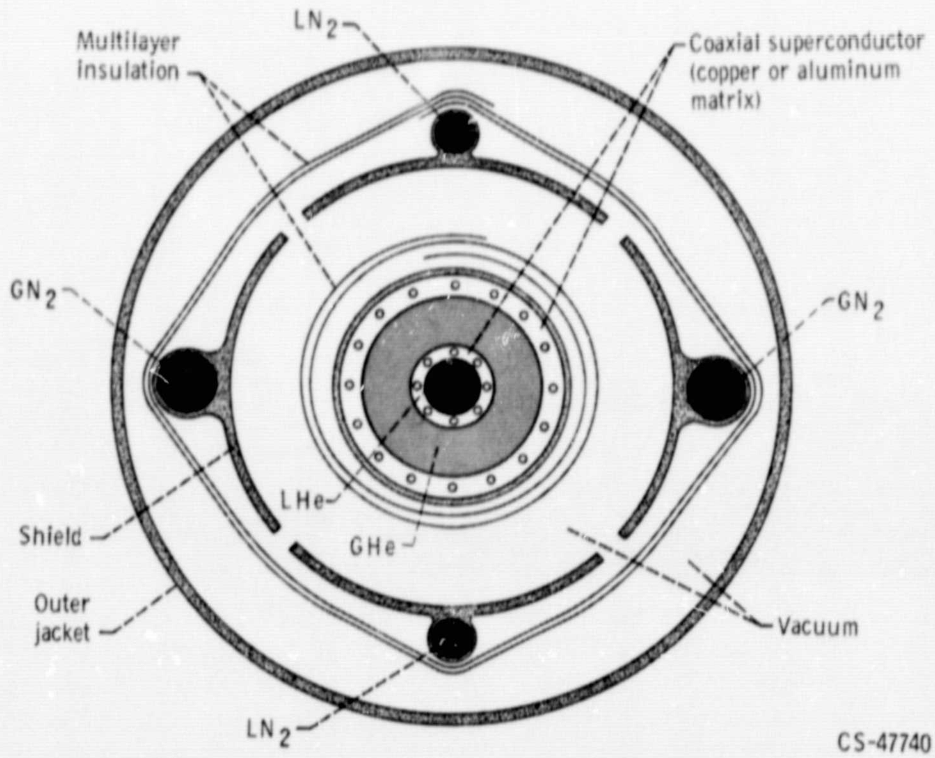


Figure 4. - Conceptual model of superconducting power transmission line.

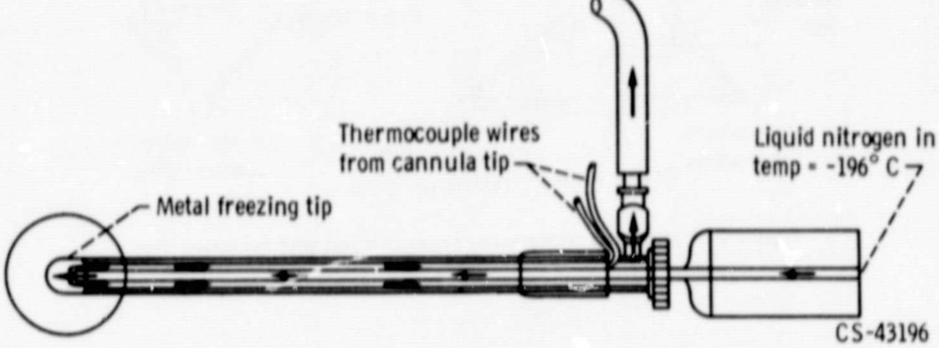


Figure 5. - Vacuum insulated cannula.

Figure 6. - Use of vacuum insulated cannula in cryogenic surgery.

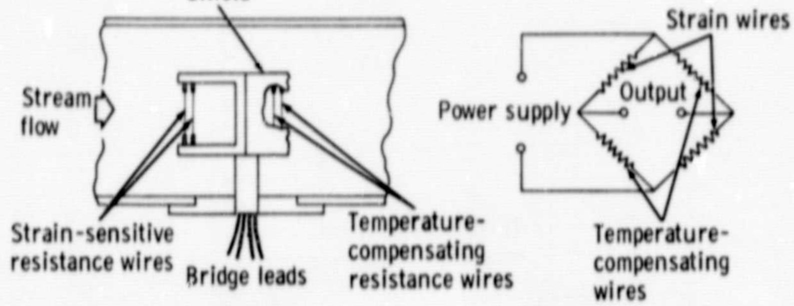


Figure 7. - Improved strain-wire flowmeter has fast response time.

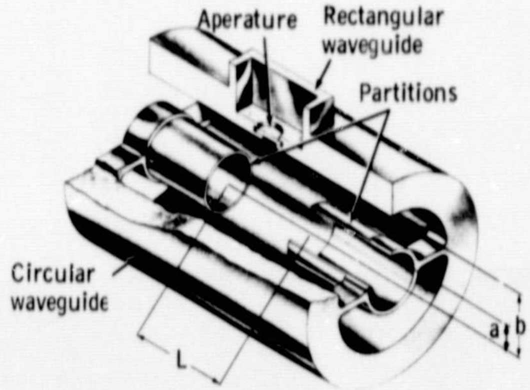


Figure 8. - Liquid hydrogen densitiometer utilizes open-ended microwave cavity.

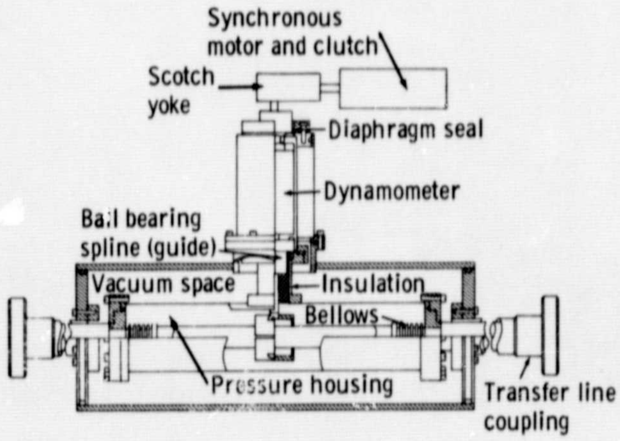
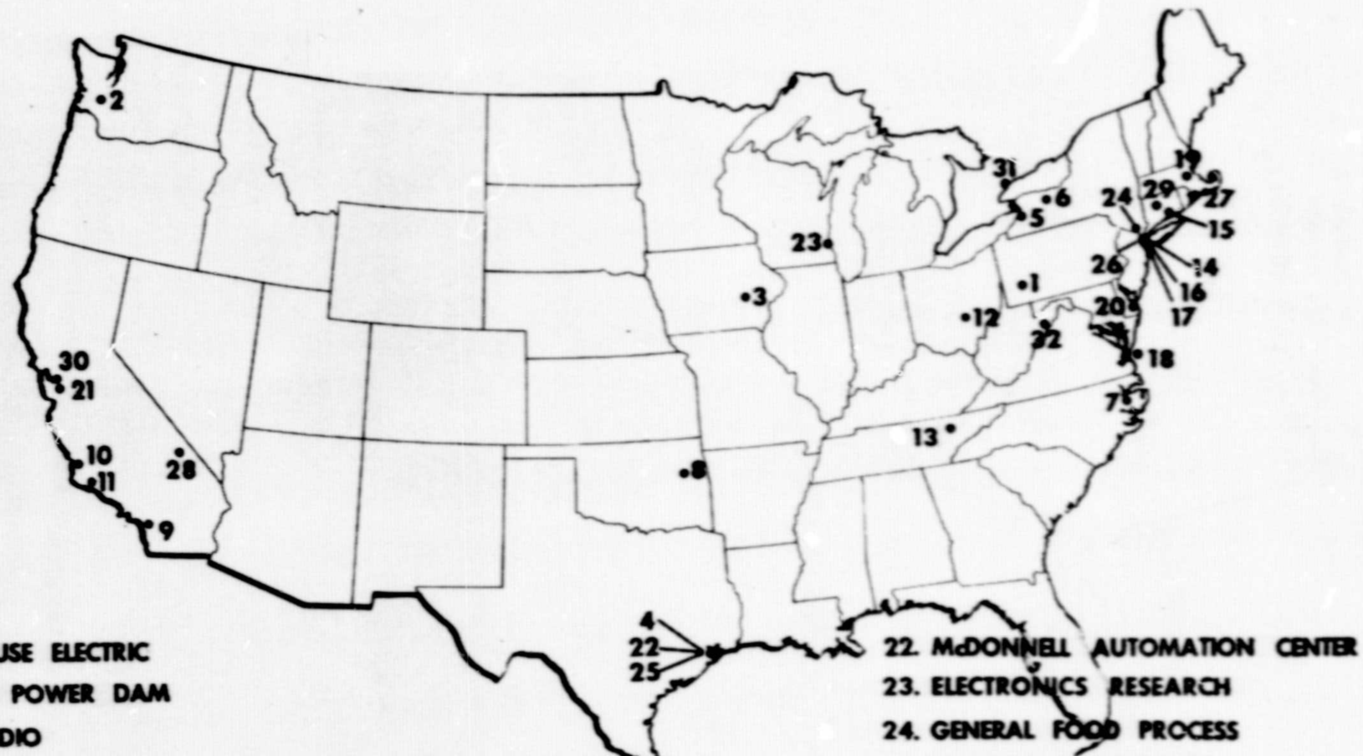


Figure 9. - Instrument continuously measures density of flowing fluids.



1. WESTINGHOUSE ELECTRIC
2. BONNEVILLE POWER DAM
3. COLLINS RADIO
4. SHELL OIL CO.
5. CORNELL AERO LAB.
6. EASTMAN KODAK
7. UNIV. OF NO. CAROLINA
8. PAN AMERICAN PETROLEUM
9. RYAN AERONAUTICAL CO.
10. AEROSPACE CORP.
11. PHILCO FORD AERONUTRONICS
12. UNIV. OF OHIO
13. UNION CARBIDE CORP.
14. ENGR. & RESEARCH SERVICES
15. UNITED AIRCRAFT
16. IBM
17. UNIVAC
18. NASA WALLOPS IS. STATION
19. NASA ELECTRONIC RESEARCH
20. HERCULES POWDER
21. STANFORD RESEARCH
22. McDONNELL AUTOMATION CENTER
23. ELECTRONICS RESEARCH
24. GENERAL FOOD PROCESS
25. HUDSON ENGINEERING
26. REALTIME COMPUTER SYSTEMS
27. SCIENTIFIC RESEARCH
28. U.S. NAVAL ORDNANCE
29. SIKORSKY (HELICOPTER)
30. IBM
31. KATES, PEAT, WARWICK CO.
32. CHEMICAL CO.

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Figure 10. - Actual applications of the optimization computer program.

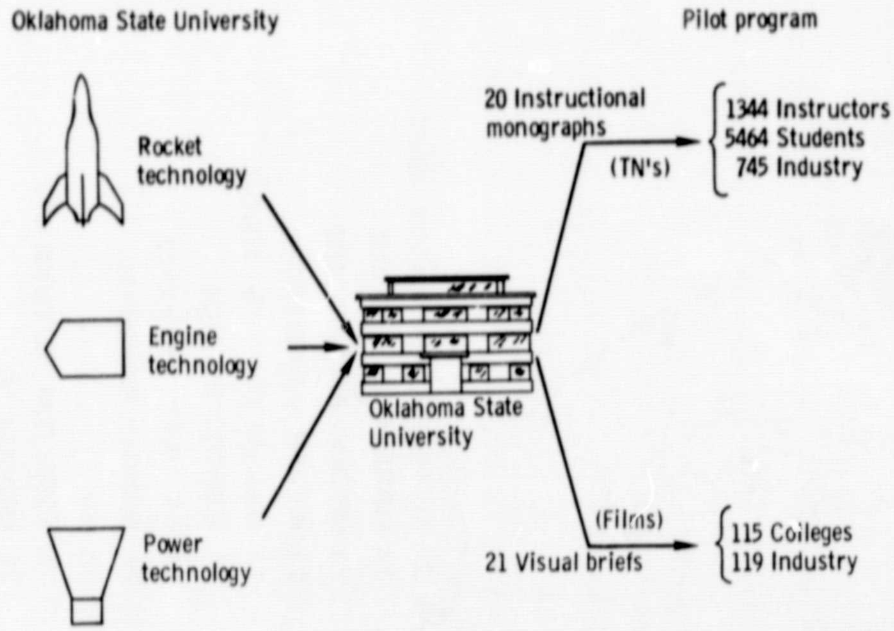

Figure 11. - Educational supplements.

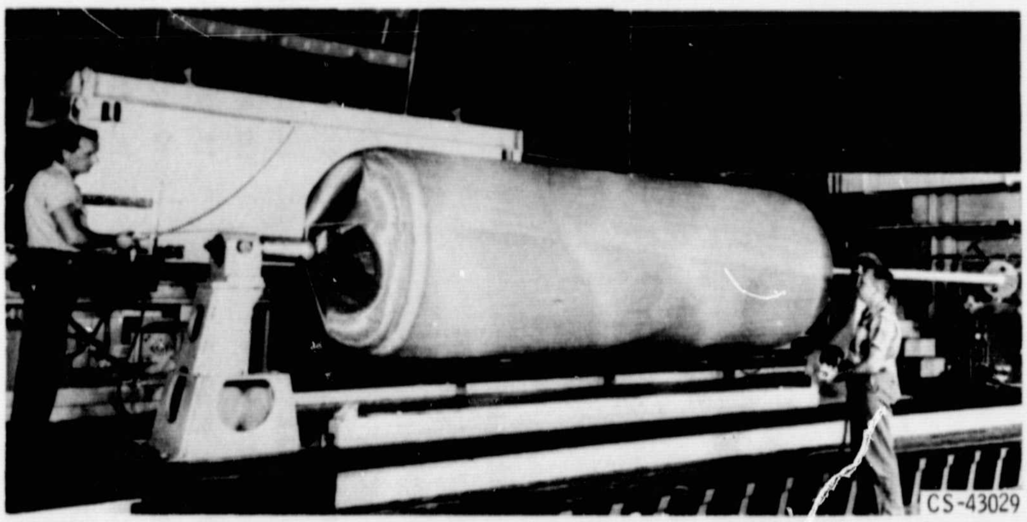

Figure 12. - Vessel being wound with glass fibers.

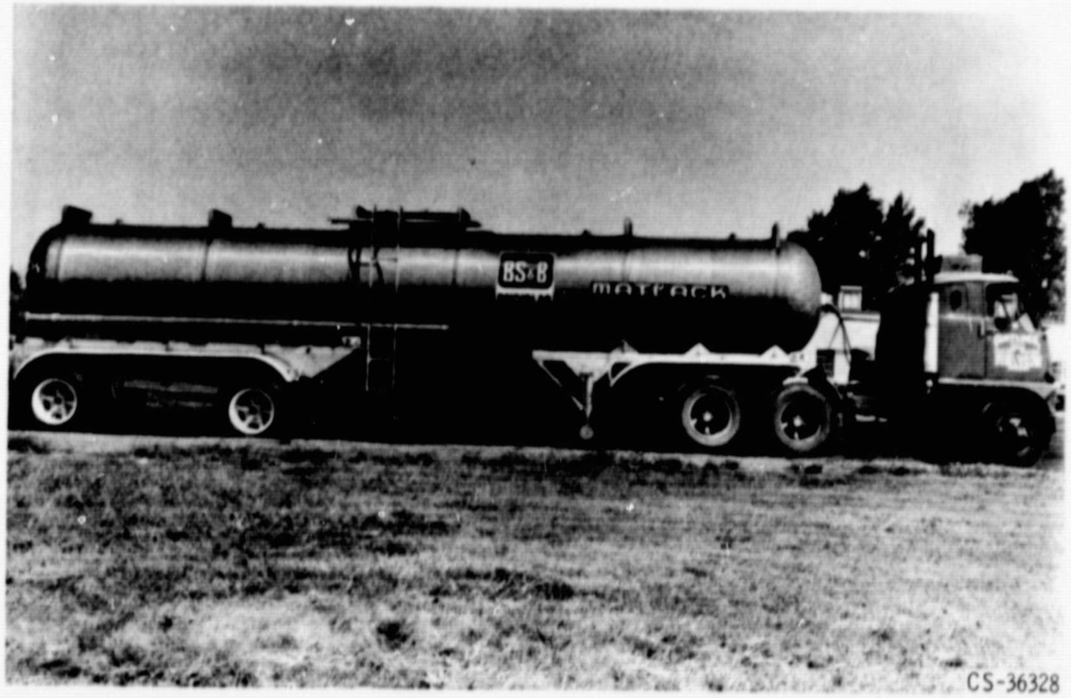

Figure 13. - Fiber glass reinforced plastic tank on tank truck.

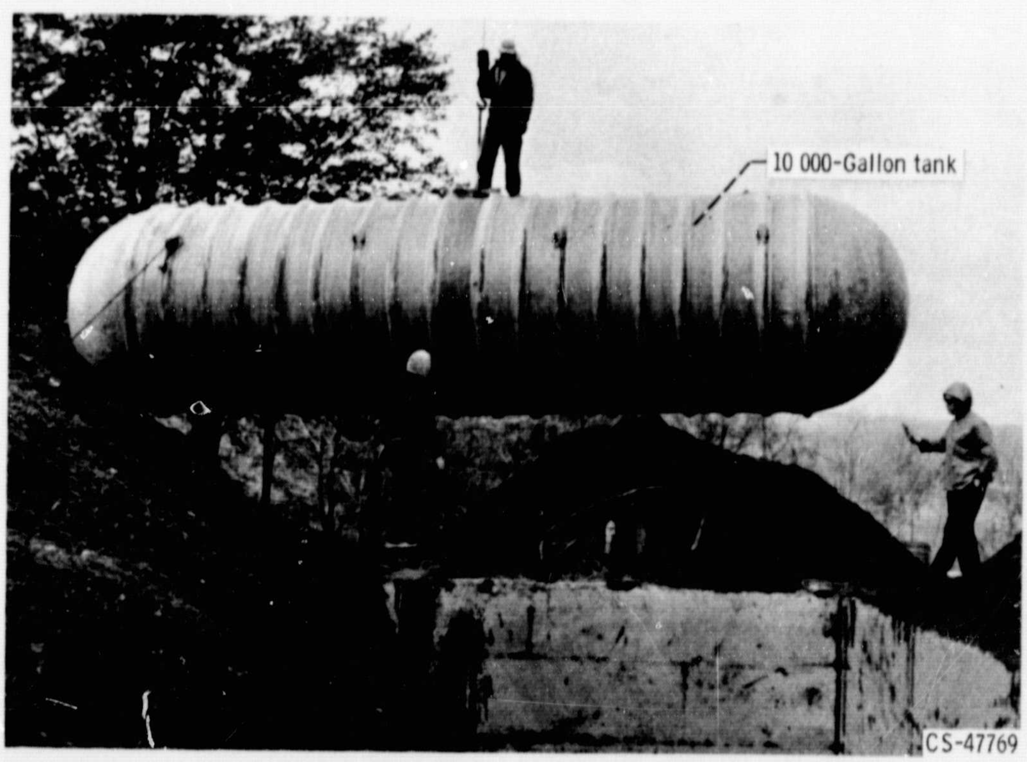

Figure 14. - Fiber glass reinforced plastic tank for underground storage.

Figure 15. - Experiment fiber glass reinforced plastic tank on railroad car.

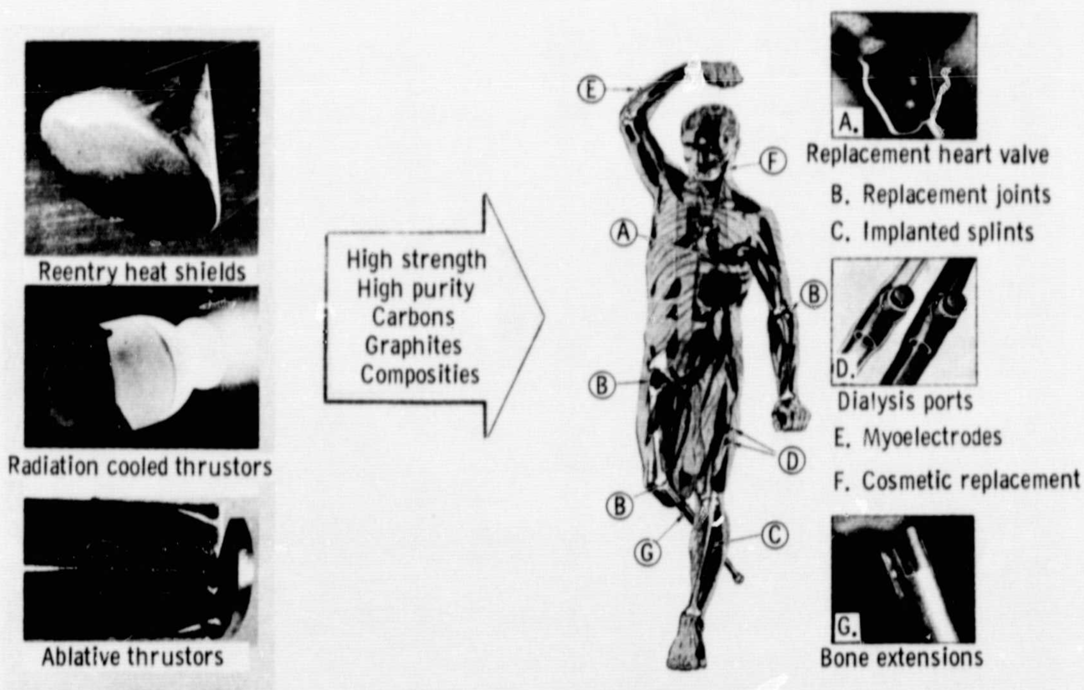

Figure 16. - Aerospace development and biomedical potential.

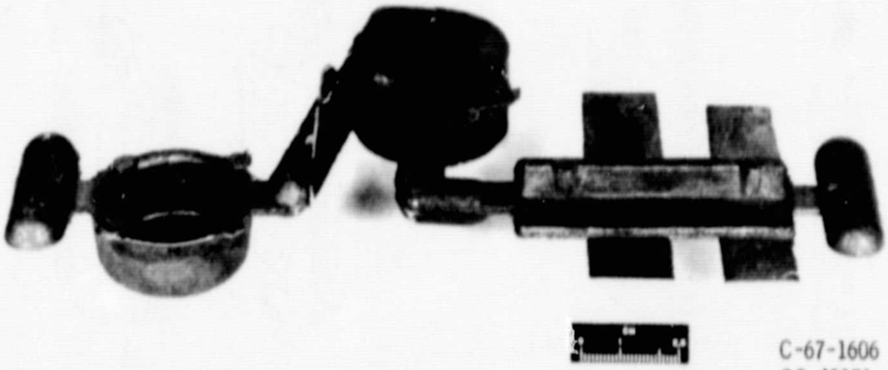

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Figure 17. - Stainless steel die casting produced from refractory metal dies. (Courtesy of the General Electric Company.)

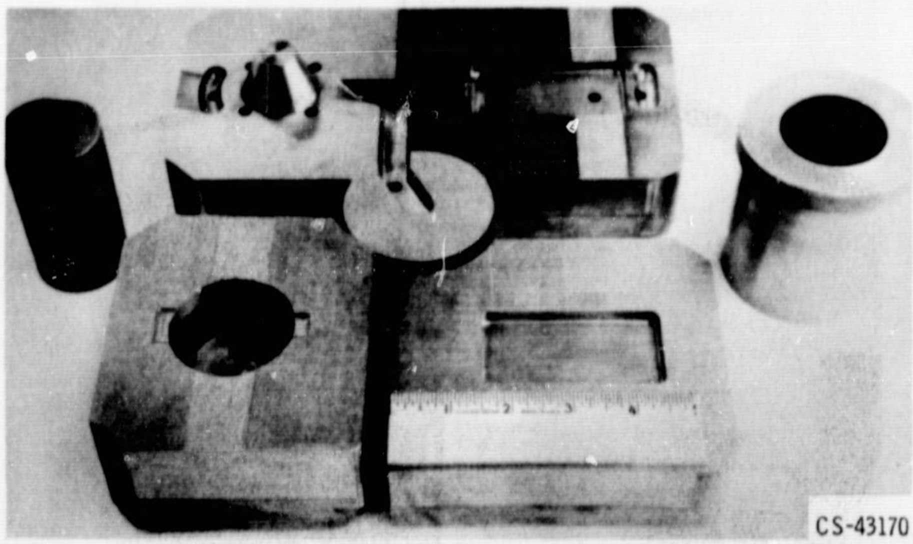

Figure 18. - Refractory metal die components. (Courtesy of the General Electric Company.)

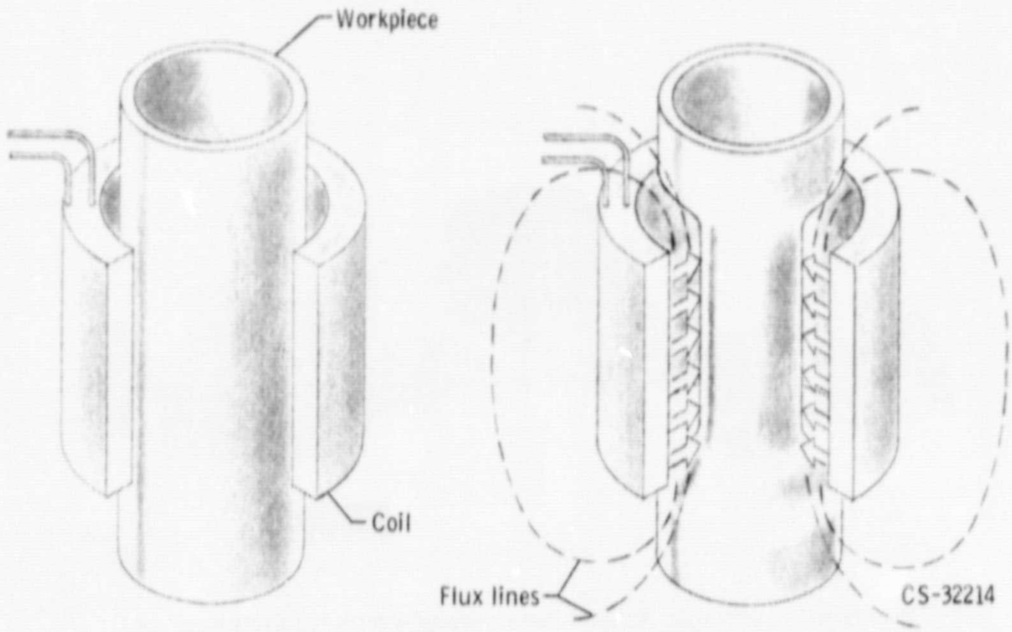

Figure 19. - Magnetic forming.

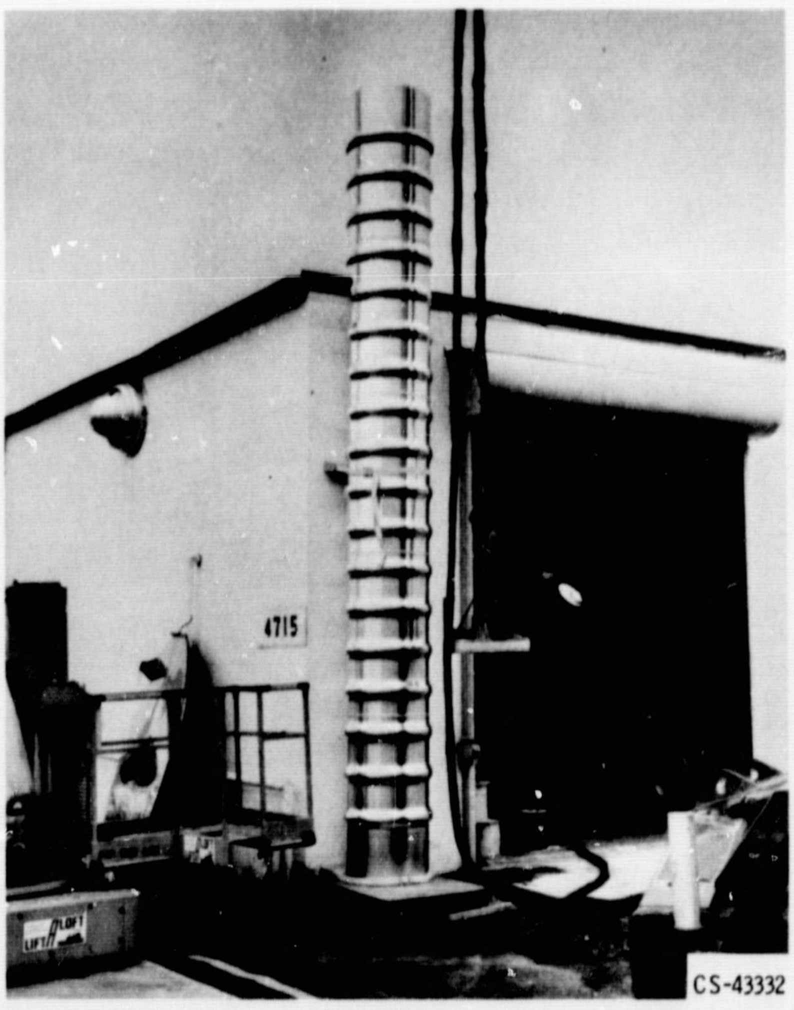

Figure 20. - Magnetically formed corrugations in pipe.

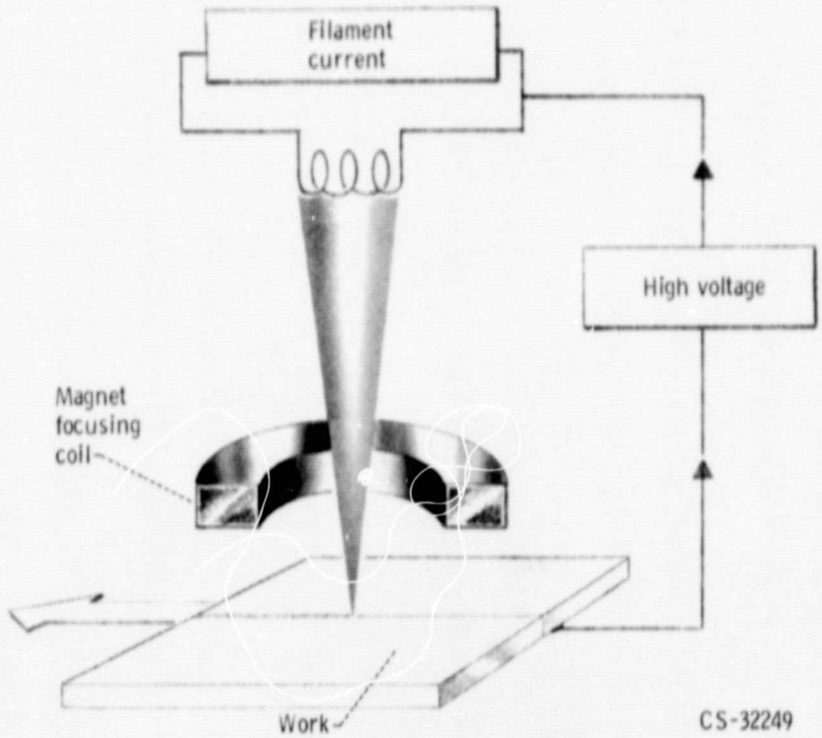

Figure 21. - Electron beam heat source.

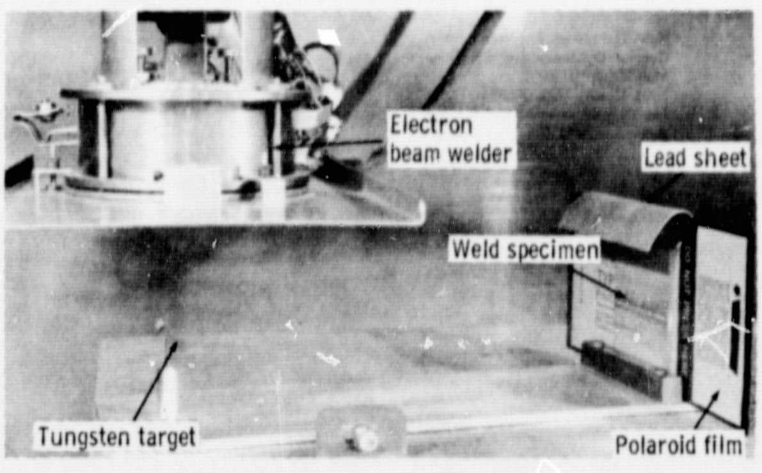

Figure 22. - Electron beam welder x-rays its own welds.

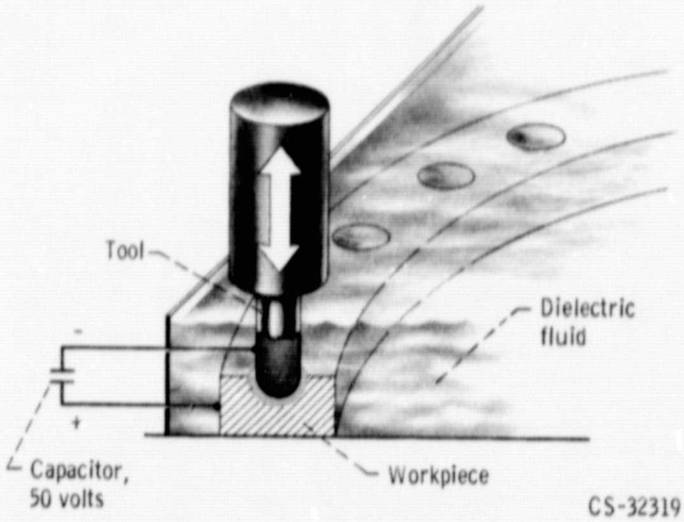

Figure 23. - Electric-discharge machining.