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MANAGEMENT SERVICES OFFICE

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OUR INVESTMENT IN SPACE TO BRING MANIFOLD RETURNS
First Supplement

By

Special Publications Section
Scientific and Technical Information Branch
Management Services Office

GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

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This first supplement to "Our Investment in Space To Bring Manifold Returns" discusses the general ways in which space technology influences our lives and describes specific applications of this technology. Several aspects of fabrication, fluid transfer, pressure measurement, ultrasensitive instruments, infrared technology, new materials such as pyrolytic graphite, geodesy and mapping, food and agriculture, and microelectronics are covered. author

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I. INTRODUCTION

"Our Investment in Space to Bring Manifold Returns," MS-IS-64-01, issued September 29, 1964, discussed (1) the general ways in which missile and space technology influences our lives, (2) applications of this technology in specific fields, and (3) NASA's Technology Utilization Program.

Other than the enrichment of man's knowledge about the Universe, the benefits of space research take three forms: the by-product, general transfer of technology, and economic stimulus. The by-product and the general transfer of technology require no explanation here, but the economic stimulus is a little less obvious. The space program is providing a market for many products and materials that were previously not economically feasible for use in general industrial applications; as the space program provides a market, the manufacturer can take advantage of mass production to lower the price, thereby enabling his product to reach a much larger market.

The first volume discussed the contributions that the space program has made to weather forecasting, communications, transportation, medical technology, new materials, energy sources, cryogenics, the plasma jet, computer technology, analog-to-digital conversion, packaging and shipping, and management and control. This supplementary volume covers several aspects of Fabrication, Fluid Transfer and Pressure Measurement, Ultrasensitive Instruments, Infrared Technology, Pyrolytic Graphite (as an example of a new material), Geodesy and Mapping, Food and Agriculture, and Microelectronics.

Any industry or contractor in the Huntsville area that desires more detailed information about the innovation mentioned in this document, or any other innovations derived from the space program, should contact:

Technology Utilization Office
Building 4200
George C. Marshall Space Flight Center
Phone: 876-1514

Further, any person working at George C. Marshall Space Flight Center, or with any local contractor, who knows of innovations that may have commercial applications should contact the same office.

II. FABRICATION

Chapter I of <u>Conference on New Technology</u> (NASA SP-50 15) pretty well summed up the progression of aerospace fabrication: "In the reciprocating engine days, the major fabrication problems were fine finishes and close tolerances, and both were within reach by slight extensions of existing techniques and equipment. The jet and turbine era brought with it high rotational speeds and high temperatures. Since high temperatures in the gas stream yielded high specific thrust, heat-resistant materials for combustion chambers, nozzles, and turbines were developed. These materials required new concepts of joining machining and forming, and fabrication became more difficult. With the beginning of the space age, however, those in fabrication became sure that previously men in research and engineering had only been difficult; they then said, 'Why be difficult? With just a little more effort we can be impossible.'

"Saying that the space-age fabrication problems arise because of requests to build things from unmachinable, unweldable, and inflexible materials to impossible shapes, finishes, and tolerances is only a little facetious. Seriously, progressively more difficult fabrication problems have been generated by this transition from Kitty Hawk to the Moon.

"The research centers and the aerospace industry are faced with very severe design and fabrication challenges brought about by the requirement of 100 per cent reliability of the product in both safety and operation for the time required to complete the mission, which could range from minutes to years.

"This finished product may contain such incompatible elements as liquid fluorine, liquid hydrogen, liquid metals, and radiation sources. It must operate perfectly in the hostile environment of space, which includes extremely high and low temperature, vacuum, vibration, radiation, and gravity forces. It must also provide a safe and livable environment for man. The conditions mentioned restrict the selection of materials to those few that can meet the performance requirements with small regard given for fabrication difficulty.

"The challenge to inventive engineering, precision craftsmanship, and versatile tooling is constant. A part must often be made that has never been made before; also, the machine or technique required may be non-existent."

Some techniques that were either developed or refined in the missile and space field have definite applications in traditional industries, as is shown in the following sections. (Important advancements have been made in welding and soldering, but these are not discussed in this document.)

A. CHEMICAL MILLING

Chemical milling is a process for removing metal from a workpiece in a chemical bath, either acidic or basic. Chemical etching was performed as early as the 16th century, and is still used in applications such as halftone photoengraving. Etching is a process of removing very small amounts of metal; chemical milling removes relatively large amounts over large surface areas.

When a workpiece is prepared for chemical milling, it is generally covered with a masking material, usually an elastomer (such as butyl rubber and neoprene) or a plastic (such as polyvinyl chloride). The areas to be milled are scribed, and the masking material is removed. Next, the workpiece is put into a vigorously agitated, corrosive bath and left there for a predetermined time. The chemical is neutralized after the piece is removed from the bath.

For intricate shapes, the workpiece may be remasked and remilled several times; this eliminates the conventional procedure of cutting the piece into parts, machining, and refabricating. Further, it is possible to produce contoured or tapered shapes by controlling the rate and the way in which the workpiece is immersed into the corrosive bath. Design changes are relatively easy to make and involve no expensive tooling, and for that reason chemical milling is economical when design changes are frequent.

Other advantages include:

(1) The process requires a relatively small investment in equipment.

(2) It is suited to the production of complicated parts, often eliminating the necessity of welding or riveting various components together.

(3) It is useful for the elimination of weight that is unnecessary for structural strength after an intricate part has been formed.

(4) Tolerance as close as ± 0.002 in. can be attained.

(5) Milling can be achieved without loss of properties after heat treatment of the workpiece, thereby avoiding warpage that often occurs if parts are heat treated after milling.

(6) Many alloys that are difficult to machine by conventional methods are suited to chemical milling. Various superalloys have been chemically milled successfully, along with aluminum, magnesium, titanium, tooled steels, monel; less extensive chemical milling operations have been made with molybdenum, tungsten, beryllium, and tantalum.

Disadvantages include:

(1) Scribing is not ideally suited to automation, although some progress toward automation has been made.

(2) Imperfections in the metal can affect the rate of milling in localized areas.

(3) Internal corners are rounded instead of squared, and previously locked-in internal stress may be released, causing the workpiece to warp.

(4) The process is often more expensive than ordinary machining methods.

The term "chemical milling" was coined in 1953 by Mr. Samuel Sanz of North American Aviation, who first suggested the process. In connection with the fabrication of a rocket casing, a cylinder made of sheet aluminum had to be butt welded; but welding was difficult because of the thinness of the sheet. Using a thicker sheet would have caused excessive weight, and planing a thick sheet to leave a lip at the edge was too expensive. Sanz suggested that a heavy gage sheet be masked at the edge to be welded and then placed in a corrosive bath. The idea was feasible. Since then, chemical milling has been used widely in missile and space work; in fact, many complex missile and space vehicle components would have been extremely difficult to produce without the chemical milling process.

Some component made by chemical milling has been used in almost every US airframe produced in recent years, including the Boeing 707 and 720, Douglas DC-8, and Convair 880 and 990. The process has been used to make parts for office equipment and for the automotive industry. About 80 manufacturers and processors use chemical milling, including many of the large aerospace firms and small job-shop firms, such as Chemical Milling International Corp., Chemical Contour, Strazza Industries, and Chemtronics, Inc.

(Principal Sources: The Commercial Application of Missile/ Space Technology, Denver Research Institute, University of Denver, September 1963; Conference on New Technology, NASA SP-5015 , June 4-5, 1964)

B. HIGH ENERGY FORMING

Missile and space requirements for shaping hard-to-form metals into intricately shaped parts, often in large sizes and with a high degree of precision, are largely responsible for the development of high energy forming techniques. In general, these techniques are particularly suited to shape parts that are needed in relatively small quantities, and where other metal forming techniques would require expensive tooling.

The sources of energy for these forming techniques are (1) explosive charges, (2) combustible gas mixtures, and (3) high-voltage capacitor banks.

1. Explosive Forming is the oldest of the high energy forming techniques and is the more widely used. Much of the research done with explosive forming techniques has been sponsored by NASA and other government agencies. The process, however, is not new. In the late 19th century, several patents were issued on a process to use explosive charges to emboss and form metals. Brass spittoons were actually fabricated by this method. But the process was used very little until the mid-1950's, when aerospace companies and government agencies began exploring its possibilities as a method to form difficult metals. The process works as follows:

The sheet of metal to be formed is placed over a female die. A partial vacuum is made in the cavity between the metal sheet and the die. The die and the metal are placed in a tank of water. Then an explosive charge is placed at a calculated distance above the metal sheet. When the explosive is detonated, the metal is rammed into the die.

The advantages of explosive forming are numerous, depending upon particular applications. Only one die is necessary as compared to two for most processes. Tolerances of ±0.002 in. are easily obtained because spring-back is minimized. It is particularly applicable to large shapes and unusual configurations that are beyond the capabilities of conventional tools. A major disadvantage is the associated noise and hazard problem, which seems to limit the potential in indoor assembly-line production.

At the Marquardt Corp., explosive forming has proved to be especially advantageous where a limited number of parts is desired and where tools and equipment represent a large portion of production costs. Where explosive forming techniques have been used at Marquardt, considerable savings have been realized through simplification of tooling and by the elimination of hydraulic presses, spinning machines, or similar equipment. Although Marquardt reports that most of its current explosive forming work is being done for use in the missile and space programs, some experimental work is being done for such commercial uses as the production of large water valves.

At the Martin Co., it is anticipated that explosive forming can be used commercially in forming a variety of metal shapes, both large and small. Through their aerospace work, Martin has made several contributions to explosive forming techniques. The development of scaling laws of explosive forming has allowed the results of small-scale experimentation to be applied to the production of large, full-scale parts, thereby reducing the high cost of earlier, trial-and-error methods of establishing inter-relations between shell depth and explosive charges. They developed a "plug cushion" method of distributing the shock wave of the explosion more evenly. Surface treatment techniques that impart better ductility to the metal being formed have been developed, and a new technique for the explosive forming of honeycomb structures shows promise.

North American Aviation, Inc., believing that explosive forming may have a large potential for commercial application, set up a new facility especially for such work. They are already doing some explosive forming for customers outside the aerospace industry. For instance, they made a stainless steel feed wheel to squeeze orange juice for Braun Citrus Co.; the wheel required very close tolerances and had to be fabricated from a high yield point material. Another job was for Watervliet Arsenal in connection with gun bore evacuators and cladding tubing. North American believes that non-aerospace industries most likely to use explosive forming in the future are those engaged in sheet metal forming, tank-end forming, tube forming, hole punching, automotive manufacture, and marine vessel fabrication.

According to Howard M. Gadberry, Senior Adviser for Technology, Midwest Research Institute, "A company in Kansas City wanted to make 20-ft diameter dished tank heads. The management had approved the construction of a \$4 million facility to make these heads by conventional means. Midwest Research Institute furnished the NASA report describing the production of 160-in. dished heads by explosive forming and put them in touch with the men at Marshall Space Flight Center who directed this work. The company is now enthusiastically planning toward making these heads by explosive forming, since their costs estimates show that they will save nearly \$2 million in capital costs by using explosive forming."

(Principal Sources: Conference on Space-Age Planning, May 6-9, 1963, NASA SP-40; The Commercial Application of Missile/Space Technology, Denver Research Institute, University of Denver, September 1963; Missiles and Rockets, June 8, 1964)

2. Combustible Gas Forming, a technique that was developed at the Boeing Co., is similar to explosive forming. The metal is shaped by igniting a gaseous mixture, usually hydrazine and oxygen, in a closed die. If the gas mixture can be ignited in a uniform manner, it produces a change of optimum shape because the energy source assumes the shape of the container. This method is more desirable than explosive forming when the part to be formed is thin and when rupture is likely if the pressure should be unevenly distributed.

The combustible gas forming method is sometimes used as a supplement to explosive forming when the quantity of parts to be produced is large enough to make open-tank explosive forming uneconomical.

Metals can be formed by energy from high-voltage capacitor banks by two basic methods, electrohydraulic and electromagnetic. At present, both methods seem to be more adaptable to indoor assembly line production than explosive forming, which creates a noise problem and is hazardous.

In the electrohydraulic method, an electrical discharge from a bank of capacitors sends a shock wave through water to form the metal against a die. Electrohydraulic equipment for forming titanium, colombium, stainless steels, tungsten, beryllium, and other alloys has been developed, principally at the General Electric Co. 's facilities at Schenectady, New York.

(Principal Source: The Commercial Application of Missile/Space Technology, Denver Research Institute, University of Denver, September 1963)

3. Electromagnetic Forming is accomplished by an intense magnetic field, which is created when stored electrical energy is pulsed into a coil around the workpiece, forcing a metal workpiece to expand or contract against a die or against a mating workpiece.

The use of magnetic fields to shape metals has been developed extensively here at George C. Marshall Space Flight Center in connection with the Saturn program. The first electromagnetic metal-forming machine for industrial use is in production at General Atomic Div. of General Dynamics Corp.

The electromagnetic method is particularly suited for shaping tanks and for expanding or shrinking tubes to make pressure-tight joints. For swaged fittings, magnetic pulse working shrinks metal with less springback than any other method, producing a stronger, safer joint.

A firm in Springfield, Illinois, has found magnetic swaging to be the only satisfactory way to fasten terminals and connectors onto low impedance coaxial cable without damaging the thin insulating sheath.

Another high-energy magnetic technique that could have commercial application is a "magnetic hammer" that was developed here at George C. Marshall Space Flight Center.

North American's Space & Information Branch reports that the hammer has been used briefly on the S-II static stage of the Saturn to correct contour deformities. A company spokesman said that the hammer is being tested currently to determine its effects on the tensile strength properties of 2014 aluminum.

Initial studies, he said, seem to show that the hammer has great potential in the manufacture of space hardware. Besides correcting deformities in metal, its possible uses include metal forming and blanking, or punching out metal with a die.

The tool includes the hammer, hand-held and similar in appearance to a small floor buffer, and a fast discharge pulse power unit that provides the high-energy force. The tool makes use of a magnetic repelling force: the hammer is placed over the work area and fired; this causes a repelling action that moves the affected material quite rapidly in a direction away from the hammer. There is no marring, scratching, or contamination of the part that is being repaired.

(Principal Sources: Conference on Space-Age Planning, a part of the Third National Conference on the Peaceful Uses of Space, Chicago, May 1-9, 1963; The Commercial Application of Missile/Space Technology, Denver Research Institute, University of Denver, September 1963; Space Information Digest, April 7, 1965)

C. FILAMENT WINDING

In filament winding, a resin-impregnated fiber (usually glass) is wound around a preshaped mandrel and heated or cured until the resin (usually an epoxy) is hardened. Either helical or biaxial windings are used, according to a study by the Denver Research Institute. In helical windings, a varying pattern is used to optimize strength in the hoop or the longitudinal direction; biaxial winding is basically either circumferential or longitudinal with variations to accommodate specific loads. When a combination of oriented filaments is used, a maximum advantage can be taken of the strength of the fiber material.

Filament winding was performed as early as 1947, but the process was not very successful until epoxy resins were improved. (Epoxy resins were discovered near the end of World War II, but quantity, quality, and variety were extremely limited.) By 1951, 3000-psi pressure bottles were manufactured by filament winding to replace metal air storage bottles in jet aircraft. The first missile use was in the Aerobee high-altitude research rocket, in which filament-wound pressure bottles contained nitrous oxide. Since then, filament-wound structures, including rocket chambers, have been used more and more frequently in the missile and space programs.

Filament-wound structures often have outstanding shock-absorbing characteristics and good resistance to heat and corrosion. But their most attractive property for aerospace applications is a high strength-to-weight ratio. According to The Proceedings of the NASA-University Conference on the Science and Technology of Space Exploration (volume 2, chapter 68), "Filament-wound structures offer a strength-to-weight ratio which is three times as efficient as that for titanium and four times as high as that for aluminum. In aerospace applications, this strength-to-weight ratio can lead to significant increases in final velocity and in payload weight. Filament-wound structures are considerably more efficient than metals because of the high directional strength of the glass fiber, which can be applied in the direction of load. Metals have isotropic strength properties and require additional weight in the structure to satisfy the maximum undirectional loads while only part of the strength is used for lesser loads in other directions."

The space program has made definite contributions to filament winding technology in general and also to epoxy-glass fiber materials. Several commercial applications were cited in the Denver Research Institute study, and a few examples are given below.

Experience gained in filament winding large rocket chambers enabled Lamtex Industries, Inc., to manufacture 8000-gal railroad tank cars that weigh five tons less than conventional steel tank cars. (A brochure that describes NASA's Technology Utilization Program gives an example of a filament-wound plastic tank car that weighs nine tons less than its steel equivalent.)

Attracted by the aerospace market, Lamtex developed a filament-wound reinforced plastic, called Hystran, which has been used in several NASA projects and such missiles as Polaris, Nike-Zeus, and Pershing. The firm hopes to use Hystran for boat hulls, automotive bodies, construction material, and "hot sticks" for handling high voltage lines. Negotiations have been made to market filament-wound air tanks for truck brake systems, for automotive parts and for chemical tanks. Lamtex has also developed filament-wound pipe and tubing for various applications.

As early as 1957, Black, Sivalls & Bryson, Inc., had manufactured tanks by filament winding techniques for commercial applications. In 1958, they performed research on filament-wound rocket motor chambers, and went on to manufacture motor chambers for the second stage of the Polaris missile and for the third stage of the Minuteman missile. As a result, the firm is able to draw on a much broader base of glass filament and resin technology. They now manufacture a variety of tanks, ranging from 300 to 17,000 gallons in size, for storing hydrochloric acid, phosphoric acid, wine, alum solutions, and corn syrup.

Also, work is under way to filament wind shotgun barrels, battery cases, fishing rods, and many other products.

(Principal Sources: The Proceedings of the NASA-University Conference on the Science and Technology of Space Exploration, NASA SP-11, November 1-3, 1962; Profile, Goodyear Aerospace Corp., Fall Quarter, 1963; The Commercial Application of Missile/Space Technology, Denver Research Institute, University of Denver, September 1963)

D. DIFFUSION BONDING

Diffusion bonding, sometimes called "solid-state" bonding, is a process for joining metallic parts. The atoms or molecules of one part diffuse into the atoms or molecules of another if two clean and closely fitting surfaces are joined under pressure, with or without the application of heat. No melting takes place. The proximity on a molecular level of the two parts, and the resulting intermolecular attraction, form the bond.

Although diffusion takes place in all welding processes, conventional welding is undesirable or even impossible for some applications. For instance, it is impossible to accomplish a weld between steel and tantalum by conventional means; steel vaporizes at a temperature that is 450° F below the melting point of tantalum. Other combinations cannot be welded because of the dissimilarity in the expansion of the metals when they are heated. When still other combinations are heated, the materials become weaker, or else have altered properties; refractory alloys, for instance, become brittle when they are welded.

That materials placed in ideal contact will diffuse into one another has been known for many years, but only recently has practical application of this principle been made. Possibly the earliest use of diffusion bonding was in nuclear engineering; the method saves expensive material in the process of cladding reactor fuel elements. The space programs have required much research in diffusion bonding because, for one reason, the process must be understood to prevent materials from sticking together in space.

The National Research Corp., under contract with NASA's Goddard Space Flight Center, investigated the mechanics of diffusion bonding under ultra-high vacuum, which prevents contamination and permits the surfaces of metals to join upon contact. Based on this research, the National Research Corp. suggested that the diffusion bonding process offers potential as being a vastly improved means of joining metal parts, such as electronic components.

North American Aviation, Inc., performed research in diffusion bonding because of its possible advantages to many aspects of the aerospace programs. The bond is clean, strong, and homogeneous. The original properties of the materials are not lost in the process, and the bond becomes an integral part of the piece. Also, it is possible to join metals to nonmetals by diffusion bonding. The process has been used successfully by North American Aviation's Atomics International Div., and potential applications in other areas are being investigated.

In diffusion bonding, the cleanliness of the surfaces is extremely important. Soft metals can be bonded in air, but only by deforming the surfaces to attenuate the oxide film. Protecting the surfaces from atmospheric contamination by use of an ultra-high vacuum permits bonding with very little deformation, but some deformation is necessary to insure full contact. If one or both of the surfaces are soft and clean and can be deformed, extremely smooth surfaces are not necessary. Hard surfaces, however, can be joined only if they are extremely smooth and have the same contour.

A similar process, called explosive welding, has been developed at Pratt and Whitney Aircraft's Florida Research and Development center. The metals to be welded are supported by a back-up plate. A thin sheet of ribbon explosive, about the width and thickness of a piece of chewing gum, is placed over the interface of the parts. A mating member is placed over the area to be welded. The pressure achieved during the explosion is between seven and ten million pounds per square inch. The ultra-high pressure and shock waves cause the metals, though still cold, to become plastic, and diffusion occurs at the interface. According to Dr. I. M. Levitt, explosive welding may find dramatic application in space and may prove to be a useful fabrication technique here on Earth.

(Principal Sources: Data provided by General Features Corp.; The Commercial Application of Missile/Space Technology, Denver Research Institute, University of Denver, September 1963)

III. FLUID TRANSFER AND PRESSURE MEASUREMENT

A. FLUID TRANSFER

Fluid transfer has been a major problem in the development of missiles and space vehicles. Scientists and engineers have had to perfect hydraulic equipment that could control extremely cold, noxious, highly reactive, intractable, and even self-igniting liquids in environments of high and low extremes of both temperature and pressure. Fluid transfer technology in general has benefited from the missile and space effort, particularly in the areas of reliability and weight reduction of components and in difficult applications, such as cryogenics.

1. Pumps. About one-third of the effort in a rocket engine development program is devoted to the turbopump, according to a chapter in the Proceedings of the NASA-University Conference on the Science and Technology of Space Exploration by Melvin J. Hartmann and Calvin L. Ball. "In general," they say, "the propellant must be moved from the low-pressure tank to the high-pressure engine system. The propellants are usually stored at low pressures for minimum tank weight, and boiling or cavitation may occur in the fluid system whenever the pressure is further reduced by velocity increase. The pump must be capable of ingesting such vapor and still increasing the pressure of the propellants."

The major problem in developing pumps to do the job is cavitation at the pump inlet, where the velocity of the fluid increases and the static pressure decreases. Whenever the static pressure drops below the vapor pressure of the fluid, part of the fluid can flash into an instable gas bubble. When this bubble reaches a higher pressure area, it suddenly collapses, causing fluctuation in the pump's discharge pressure, which in turn can cause thrust fluctuation or can even create oscillations serious enough to damage the rocket chamber.

Before the development of missiles and space launch vehicles, cryogenic fluids had never been pumped in large volume and at high pressure. The large amount of research and development concerning cavitation and other pumping problems in rocket propulsion systems has led to improved pump design techniques in general and to specific components that have commercial applications. A few examples follow.

North American Aviation, Inc., redesigned an ordinary centrifugal pump to deliver large amounts of rocket fuel. A screw-type mechanism, called a pump inducer, was added to the system to start the flow of the fluid before it reached the pump. The company maintains that the inducer increases the overall efficiency of a centrifugal pump and that it has large potential in commercial applications.

Sundstrand Corp., working under Government contract, developed an optimization technique to determine which type of low specific speed pump would operate best in missile and space auxiliary power systems. Applying this technique to commercial problems, Sundstrand discovered that a pump previously used only in missile applications was needed in commercial jet aircraft and in oil field applications. The pump, bearing the trade name Sundyne, apparently has broad potential for future use.

Pyles Industries, Inc., originally a manufacturer of pumps for automotive grease, oil, sealers, paints, etc., developed a number of pumps and related products to fulfill specific missile and space requirements, such as spraying epoxy coatings and ablation materials. These products are now used commercially for spraying polyether and polyester foams, for the application of polysulphides in automotive windshield sealing, for fabrication of boats, and so on.

(Principal Sources: Proceedings of the NASA-University Conference of Space Exploration, NASA SP-11, November 1-3, 1962; Transforming and Using Space-Research Knowledge, NASA SP-50 18, June 2, 1964; The Commercial Application of Missile/Space Technology, Denver Research Institute, University of Denver, September 1963)

2. Valves. How would one design a valve to be used in the liquid oxygen (LOX) supply line to the LOX pump in a missile system? This valve must remain tightly shut while the LOX tank is being filled, although thermal shock and unequal contraction of valve surfaces occur when the valve at ambient temperature suddenly is filled with fluid at -279° F. This LOX valve must be quick-opening. It must be remotely operated. It must permit high flow rates but with very low pressure drop. It must be highly reliable, in spite of the ice that collects on its external surfaces.

Such requirements have forced the development of valves that have unique characteristics. Also, pressure control and relief valves, hydraulic servo valves, and flow control valves for extreme temperatures have been designed for missile and space programs. Valve design in general will benefit from the aerospace requirement for higher reliability but less weight, and some of the new or improved designs have specific commercial applications.

A high performance safety relief valve was developed by Anderson, Greenwood and Co. for a missile launching system. This soft-seated, high-pressure valve has become a standard in the missile industry, and according to the firm, the demand created by missile and space programs provided a sufficiently large market to enable them to manufacture the valve at a commercially acceptable price. Now the valve is being used for pressure control in polyethlene plants, compressor stations, chemical and petrochemical facilities, and pipeline systems.

Kieley and Mueller, Inc., improved an existing valve design to meet requirements to load liquid fuels and oxidizers into launch vehicles. The improved valves have higher capacities and lower weight per valve, faster speed of operation, and tighter shut-off than was previously available. The improved valves have been sold, for example, to manufacturers of oxygen for the acetylene process, and the firm is making efforts to market them for low temperature helium separation processes.

At North American Aviation, Inc., a valve already in existence was re-engineered and seated with such materials as Teflon, Mylar, and Kel-F. Data were passed back to the company that manufactured the original valve, and the company in turn began producing improved valves and marketing them to the cryogenics industry.

Hills-McCanna Co. adapted for commercial application a ball valve that was developed for use in missile launchings. While developing the valve, the firm exposed it to severe mechanical and hydraulic shock tests. Shortly after completing these tests, the firm learned that a major manufacturer of tank cars was interested in a bottom unloading tank car valve that would pass similar tests, because a mechanical failure would be costly and dangerous. In addition to the tank car application, petroleum, petrochemical, pulp and paper, and other chemical process industries are using these ball valves.

Hoke, Inc., produces stainless steel valves for liquid metal service. The revival of activity in alkali liquid metal research by the missile and space programs has led to improvements in these valves for use in research on nuclear engines for space vehicles. These improved valves are being used in nuclear power stations and in research involving high temperature fluids.

NASA's Office of Technology Utilization is encouraging the commercial use of a special valve in which a conical-walled plug seals against a recessed spherical seat. This design permits proper sealing of the valve even if the stem is misaligned or forced out of its normal axis; further, this design makes it possible to obtain high mechanical advantage from the forces applied to the valve, and no deformation of the spherical valve seat or of the sealing face of the conical plug occurs because the wearing surfaces are not stretched beyond the elastic limit by unequal distribution of forces. NASA has filed a patent application for this valve, but royalty-free non-exclusive licenses for its commercial use will be available.

(Principal Sources: NASA Tech Brief 63-10341; The Commercial Application of Missile/Space Technology, Denver Research Institute, University of Denver, September 1963)

3. Seals. Extremes of temperature and pressure along with severe vibration problems in missile systems brought about seal material and design changes. For instance, North American Aviation, Inc., helped develop an improved cryogenic pump seal for handling liquid oxygen. Use of this seal is expected to increase widely within the cryogenic industry. The company developed a metal seal, called Natorq, that is suitable to operate in extremes of temperature and pressure, from -360 to 1200° F and from 0 to 10,000 psi. Natorq seals can be used in hydraulic, pneumatic, gaseous, and cryogenic systems.

Another metal seal was developed at Harrision Mfg. Co. for the Atlas missile. The seal, coated with metal materials that are particularly resistant to radioactivity, can be used where exotic fuels or gases are required. The seal has been used in deep well oil drilling, liquefaction of gases, and atomic energy applications. It has potential in the pharmaceutical, food processing, and chemical industries.

(Principal Sources: Transforming and Using Space-Research Knowledge, NASA SP-5018, June 2, 1964; The Commerical Application of Missile/Space Technology, Denver Research Institute, University of Denver, September 1963)

B. PRESSURE MEASUREMENT

An Italian physicist, Evangelista Torricelli, measured static pressure with scientific accuracy as early as 1643. He used a mercury barometer. There was little need for measuring dynamic pressure, however, until the time of the steam engine, and methods and equipment for measuring dynamic pressure were not developed fully until they were almost necessary to facilitate internal combustion engine research.

Many devices are available now for measuring both static and dynamic pressure. In most of these devices, the pressure to be measured produces a mechanical strain or displacement (as in a Bourdon tube) that is then converted to an electrical signal (as by a potentiometer). The piezoelectric principle permits the strain and conversion to take place in the same element because the material changes its electrical resistance when a force is applied to it.

The pressure range and frequency range of conventional pressure transducers and associated equipment were not adequate for aerospace requirements. Improvement was necessary to insure reliability under severe environmental conditions; but, at the same time, weight and volume had to be decreased.

The methods and equipment developed to meet these requirements are generally available now for other scientific and commercial uses, as the following examples will illustrate.

As a result of aerospace requirements, Rocketdyne developed a dynamic analog differential equation equalizer (DADEE) that virtually eliminates the undesirable "ringing" that results from the excitation of a transducer at or near the natural resonant frequency. DADEE provides a means to recover, observe, and record (in real time) accurate analog data that would otherwise be distorted by limitations of the measuring system. The device has industrial potential wherever a problem in extending the physical response of a transducer exists. Specific applications include internal combustion research and gas turbine engine development.

Ames Research Center developed a slack diaphragm differential pressure transducer to replace the liquid manometer systems that were used in wind tunnels. The transducer consists, essentially, of a neoprene diaphragm that is supported by a rigid plate; the plate, in turn, is attached to a strain gage force beam system. Commercial and scientific applications include remote reading barometers, altimeters, air speed indicators, Mach meters, pneumatic gaging and positioning, and industrial controls.

Ames also developed a capacitance pressure transducer that can be made as small as 0.13 inches in diameter to minimize the disturbance of airflow in a wind tunnel. The miniature differential pressure transducers are made by a special spot-welding technique, and they have a flat response (within five per cent) up to one-third of the resonant frequency. (Design details and a schematic diagram can be found in NASA Tech Brief 63-10502.)

Ames developed a mercury manometer with an electronic follower that will provide very accurate pressure reference with either a visual or electrical digital output. Accuracies of 0.002 to 0.005 inches of mercury are obtainable. This device is being used commercially in various liquid level and pressure measurement applications.

Microdot, Inc., developed a weldable strain gage for aerospace applications. Previous types of strain gages had to be cemented to the element being measured. One of the industrial uses for the weldable device is the measurement of internal pressure in tanks that contain corrosive chemicals.

Lockheed Electronics Co. discovered piezoresistivity in silicon carbide. Although there have been no non-space applications to date, the firm believes that the material has potential in pressure measurement applications, such as underwater transducers.

Mr. D. E. Melton at the George C. Marshall Space Flight Center has invented a fluid meter that can be calibrated without removing it from the flow line. This meter makes calibration faster, helps prevent contamination of the line fluid, increases the measurement accuracy by minimizing valve leakage, and makes remote calibration possible. NASA encourages the immediate commercial use of this invention. (A patent application has been filed; inquiries concerning license rights should be made to D. E. Melton, MSFC.)

Servomechanisms, Inc., produces pressure measuring devices to be used in small meteorological rockets that test the atmosphere before a space vehicle launch. Because of the experience gained in this and related aerospace work, Servomechanisms has developed several pressure measuring devices that the firm believes will have wide by-product potential.

(Principal Sources: NASA Tech Brief 63-10429; NASA Tech Brief 63-10502; Steel, December 23, 1963; The Commercial Application of Missile/Space Technology, Denver Research Institute, University of Denver, September 1963)

IV. ULTRASENSITIVE INSTRUMENTS

A variety of instruments has been invented in various aspects of the missile and space programs. Two examples follow.

A. PIEZOELECTRIC TRANSDUCER

Micrometeoroids are a possible hazard to manned space flight. Heretofore, the determination of the number, size, and speed of these cosmic dust particles has been an almost impossible task; the particles are so small that 25 trillion of them would weigh only an ounce or so. Clearly, an ultrasensitive detection instrument was required to measure the impact of such small particles.

Mr. Vernon L. Rogallo of the Ames Research Center, in connection with micrometeoroid studies, has invented a piezoelectric transducer that can measure the impact of 0.001 grain of moderately fine kitchen salt after a 0.38-in. fall.

In this instrument, two piezoelectric ceramic beams are cantilevered parallel to one another and are connected at the free end. Any force or impact on the target area deflects the cantilever assembly, thereby producing positive and negative charges. Electrodes one the surface of the beams collect the charges, and the voltage between them is proportional to the momentum of the impacting particle.

The instrument, in addition to its use in micrometeoroid studies, will have immediate and broad industrial applications in vibration detectors, accelerometers, and seismometers. Also, the instrument can be used in the calibration of small jets, and its high sensitivity and wide range makes it an ideal device for the calibration of laser beams. But possibly the greatest potential of the instrument lies in biomedical research.

For some time now doctors have been concerned with the effect of drugs on the hearts of unborn babies. Certain chemicals have teratogenetic effects on human beings, and it is apparent that some fetal abnormalities have occurred that were not due to hereditary influences. Some of the drugs that cause such abnormalities have been identified and, of course, have been taken off the market.

According to scientists at the Federal Food and Drug Administration (FDA), toxicological studies using animals are extremely difficult and at times yield inconclusive results. The use of fertile eggs is easier and more reliable. A chemical is injected into the yolk sac before incubation, and then the embryonic development of the chick is studied. One technique for determining the effect of drugs on chick embryos has been to monitor the heartbeat or muscular movement by inserting probes at appropriate points, but this and other techniques have not been entirely satisfactory.

Because the piezoelectric transducer can be converted into an excellent miniature ballistocardiograph, it has received much attention from FDA scientists. In fact, Dr. Jacqueline Verrett, of FDA's Division of Toxicological Evaluation, has worked directly at the Ames Research Center with Mr. Rogallo; their experiments indicate that the instrument has considerable potential in biomedical research. If an egg is placed in a cup that is attached to the stem of the instrument, the action of the embryo's heart can be monitored. Studies have revealed that life in the embryo can be detected in about three days after incubation and can be monitored from then until maturity without damage to the embryo.

Doctors have begun to suspect certain antibiotics that are sometimes given to pregnant mothers. Some of the antibiotics that have been injected into fertile eggs appear to cause malformation of the chicks. The amplitude and the frequency of the heartbeat is also altered. Ten milligrams of an antibiotic were injected into an egg after 19 days of incubation. The ballistocardiograph showed that the characteristic heart rate was 300 beats per minute before the injection. Six minutes after the injection, the heart rate dropped to 260 beats per minute, and an amplitude drop indicated a weakening of the heartbeat.

These investigations are still preliminary, but scientists hope to obtain enough information to determine whether antibiotics and other drugs have any effect on human anomalies.

The piezoelectric transducer will facilitate thorough studies of the effects of drugs, pesticides, and food additives on chick embryos, and it is hoped that the results of these studies can be correlated with the effects of drugs on the human embryo.

In time, the simple instrument that was developed at Ames Research Center to study micrometeoroids might well help prevent, or even eliminate, the malformation of children before birth.

B. GDM VISCOMETER

Another ultrasensitive instrument has been developed at the Massachusetts Institute of Technology in connection with the Polaris inertial guidance system. Originally used to test the performance of gyroscopes and gyro subunits, it is so sensitive to torque that it can measure the rotational force exerted by a small wheel making only one revolution per day.

The device has turned out to be a valuable medical research tool for studying blood and blood viscosity, according to a report by the Denver Research Institute. Medical researchers call it the "GDM viscometer," after its developers, P. J. Gilinson, C. R. Dauwalter, and E. W. Merrill. When used as a viscometer, the instrument is rigged to a small cup that contains the fluid to be tested. A rotor, turned by a torque motor, is immersed in the fluid. The motor turns the rotor with an extremely slow but constant speed; a selection of speeds is available so that viscosity readings may be taken at different flow rates. The rotor exerts shear on the fluid at a known rate, depending on the motor setting. The shear rate is analogous to the flow rate and causes a shear stress in the fluid which, in turn, exerts a torque on the cup that contains the fluid. The GDM viscometer measures the torque on the cup with extreme precision. When the torque is known, the shear stress that produced it can be computed. Shear rate (known from the motor setting) and shear stress (read as torque by the instrument) are used to compute the viscosity of the fluid.

A blood plasma viscosity test with the GDM viscometer requires only a teaspoon of blood and can be performed in less than a minute, whereas conventional viscometers require far more blood and so much time that clotting can occur before completion of the test. But the major advantage of the new viscometer is its capability of imparting minute shear rates to the fluid and of measuring the equally minute shear stress that results, thereby facilitating viscosity studies at low, previously unattainable ranges of shear rate and shear stress.

Shear, or flow, rates of fluids are measured in inverse seconds, and viscosity is measured in centipoises. Most viscometers can measure the viscosity of blood plasma under shear rates as low as 20 inverse seconds, but are inaccurate at lower ranges; going 200 times lower, the GDM viscometer can measure viscosities under shear rates as low as 0.1 inverse second.

Previous studies with less sensitive viscometers have indicated that the viscosity of blood plasma remains at approximately 1.5 centipoise under shear rates as low as 20 inverse seconds. The seemingly constant viscosity at reducing shear rates indicated that blood plasma is Newtonian. More recent studies, however, suggested the possible non-Newtonian nature of plasma, thereby causing medical researchers (Dr. R. W. Wells of Harvard Medical School and Dr. W. W. Merrill of MIT) to seek a more sensitive instrument.

Data obtained with the new GDM viscometer have shown that as the shear rate is lowered to the range of 0.1 inverse second, plasma viscosity jumps to as high as 18 centipoise. This discovery let to the conclusion that plasma is, in fact, non-Newtonian. An understanding of the non-Newtonian nature of blood plasma is an important piece of fundamental knowledge; it might well help explain some of the curious mechanics of blood circulation in capillaries, the body's smallest blood vessels.

V. INFRARED TECHNOLOGY

An English astronomer, Sir William Herschel, first studied the infrared portion of the electromagnetic spectrum in the year 1800. Because of inadequate laboratory apparatus, however, little was learned about infrared radiation for almost a hundred years. Scientific progress was rapid between 1900 and 1920, and industrial applications were not far behind. Between 1920 and 1940, the principal use of infrared was in spectrochemical instruments for qualitative and quantitative analysis of industrial chemical samples.

The potential use of infrared in military surveillance, fire control, and weapons (e.g., the sniper's scope) instigated much infrared research during World War II. This research has been continued in the missile and space programs, where infrared is useful in such applications as space navigation, the stabilization of spacecraft by means of horizon scanners, and the radiometric and spectrometric studies of other planets.

Many commercially adaptable devices have been developed in these programs, from photographic equipment to rapid-scanning monochromators. The latter are useful in the study of rapid chemical reactions. Heat-homing missiles, such as the air-to-air Sidewinder, have been responsible for the development of extremely sensitive detection devices and related instrumentation. Of more commercial significance, perhaps, is the quantity and quality of infrared devices and instrumentation that are required in the missile and space programs. More refined and more rapid production techniques have reduced the cost of infrared instruments, making them available for commercial use.

Infrared Industries, Inc., has based several commercial products on experience gained from missile and space programs. One of these products, called "Infrabeam," is used for door automation, liquid level control, area surveillance, conveyor control, machine control, and materials sorting. Unlike other photoelectric controls, Infrabeam is not susceptible to light interference problems because optical filters transmit only infrared radiation that is modulated or coded by the transmitter.

Infrared Industries also developed a telephone-like communications system, powered by flashlight batteries, that transmits line-of-sight messages on an infrared beam. The device was first marketed under the name "Infraphone" to the construction and transportation industries and to public safety workers. Later the device was marketed as a toy under the name "Astrophone."

The Eagle "I" traffic detector is another Infrared Industries product. The Eagle "I," first marketed in 1961, has been approved for traffic control and vehicle counting by the US Bureau of Public Roads. Another traffic detector, Traffitrol, is marketed by Minneapolis-Honeywell Regulator Co. It evolved largely through the application of several infrared components that were developed for the missile and space programs. Traffitrol detectors have been installed in many cities in the US and abroad.

Barnes Engineering Co. developed the infrared horizon sensors for Project Mercury and applied the same techniques in an infrared micrometer for industrial use. One application of the infrared micrometer is in the steel industry. The micrometer locates the top and bottom edges of a hot rod against the relatively cold environmental background, and then measures the distance between these edges to a few thousandths of an inch, even when the hot rod is traveling at speeds from 35 to 75 mi/hr. Sensors of this type are also being tested in a glass factory to measure glass rods as they are formed. Other applications are certain to develop; as Mr. Barnes, President of Barnes Engineering, has pointed out, many objects in industrial processes need to be measured but, for one reason or another, cannot be touched.

Possibly, infrared observation from spacecraft will be more generally beneficial to mankind than the development or application of specific devices. Infrared is a useful tool for the scientific observation and analysis of planets and other celestial objects. Heretofore, such observations were hindered by the Earth's atmosphere. Satellites facilitate not only celestial observations but also observations of the Earth and its atmosphere. Such observations, in addition to general surveillance of the Earth, will help determine water vapor and carbon dioxide concentrations, and will be valuable in meteorological and other studies.

(Principal Sources: Technology Utilization Program, National Aeronautics and Space Administration; The Commercial Application of Missile/ Space Technology, Denver Research Institute, University of Denver, September 1963; Proceedings of the Conference on Space-Age Planning, a part of the Third National Conference on the Peaceful Uses of Space, Chicago, May 1-9, 1963)

VI. PYROLYTIC GRAPHITE: AN EXAMPLE OF NEW MATERIALS

"One more example from among the dozens of space materials will suffice to demonstrate that materials, as much or more than anything else, have bridged the sometimes-easy, sometimes-difficult gulf from spaceship to industrial furnace. Early in 1958, General Electric began investigating techniques for making large free-standing shapes of pyrolytic graphite for use as nosecones... Now, 'transfer research' is underway to develop it for uses requiring thermally or chemically resistant refractory materials such as furnace parts, piping, or crucibles for coating metals or caustic solutions. Other applications exist in electronics: as frequency filters, thermistors, high temperature capacitors, and variable fuses..." according to an article in the March 1965 issue of Industrial Research.

Ordinary graphite, such as used in "Lead" pencils and in lubricants, is a soft carbon that conducts electricity. Pyrolytic graphite, made by deposition of carbon from a vapor phase onto a substrate, is highly anisotropic; its physical, electrical, and thermal properties differ on perpendicular planes.

According to an account by the Denver Research Institute, along the layer plane, pyrolytic graphite is semimetal, electrically conductive, and thermally conductive. Perpendicular to the layer plane, the carbon atoms are loosely bonded and pyrolytic graphite is a thermal insulator. Other properties include oxidation resistance and impermeability. But it has several disadvantages: It is difficult to fabricate, it is expensive, and it develops localized high stresses upon rapid heating.

Patents concerning the formation of pyrolytic graphite were issued to W. E. Sawyer and Tomas Edison during 1879-1883; Sawyer and Edison were trying to improve the uniformity and mechanical properties of carbon filaments. It was investigated for use in coating electron tube components in the 1930's, but at that time the graphite was available only in powder form or as film coatings. Apparently, its anisotropy was not considered to be very important. Some research was done during the 1950's toward using pyrolytic graphite for coating nuclear reactor fuel elements.

In 1958, the Missile and Space Vehicle Department of General Electric Co., under US Air Force contract, performed research on techniques for making large shapes of pyrolytic graphite for missile nose cone applications, as was stated earlier. The General Electric Co. has continued its work in this area. In fact, their Specialty Alloys Product Section of the Metallurgical Products Department had set up production facilities by 1960.

According to the Denver Research Institute report: "Most of their [GE's] pyrolytic graphite sales have been as an R&D material, primarily for use as a thermal shield or rocket nozzle in space applications. To date there have been only token commercial-sales of the material to determine its suitability for commercial and industrial applications.

"Much progress has been made in recent years in developing pyrolytic graphite and its new alloys for practical use. However, work remains to be done in understanding further its physical properties and in developing fabrication techniques. Also, its current high cost acts as a limiting factor except in special applications. Nevertheless, its unique properties seem to hold substantial promise for commercial as well as missile/space uses. Its potential for solving many of the difficult problems posed by nuclear propulsion in space should act as a stimulus for continued interest.

"Pyrolytic graphite has a number of commercial applications, but the Metallurgical Products Dept. believes that such applications are still some three years off. Such potential applications include uses requiring thermally or chemically resistant refractory materials, such as furnace components, or as piping or crucibles for coating molten metals or caustic solutions. There are also a number of possible applications in the electronic and electrical fields, e.g., use in frequency filters, thermistors, high-temperature capacitors, time delay mechanisms, and variable fuses."

One recent practical use of pyrolytic graphite was noted in the January 28, 1965, issue of The Wall Street Journal: "Space age smoking will be promoted by a California firm. The bowl of a new pipe it will offer is lined with pyrolytic graphite, a heat-resistant material used in rocket nose cones and nozzles. The heat reduction cuts the smoker's nicotine and tar intake, the firm claims." Presumably, the heat reduction is possible because along the layer plane pyrolytic graphite is more thermally conductive than copper.

(Principal Sources: Industrial Research, March 1965; The Commercial Application of Missile/Space Technology, Denver Research Institute, University of Denver, September 1963; The Wall Street Journal, January 28, 1965)

VII. GEODESY AND MAPPING

Not all of the ancients believed that the Earth was flat. Pythagoras, Aristotle, Poseidonius, and Ptolemy maintained that it was spherical. According to K. A. Kulikov's Fundamental Constants of Astronomy (translated from the Russian by the Israel Program for Scientific Translations), the first calculation of the Earth's radius was made by Eratosthenes at Alexandria at about 250 B.C. He approximated the length of the arc between Alexandria and Aswan from the time it took a caravan to make the journey, and he determined the difference in latitude by observations of the noon elevations of the Sun at the summer solstice. Having the length of the arc and the angle, Eratosthenes calculated that the Earth's radius was about 6300 km.

An important milestone in geodetic methodology occurred during 1614-1616, when W. Snellius, a Dutchman, introduced triangulation. But it was his method, not his measurements, that was important. In about 1670, a Frenchman, Jean Picard, refined the triangulation technique, using such instruments as the terrestrial telescope with reticules and the quadrant. Now, because of technological advantages made possible by satellites, triangulation and other methods of geodetic measurement are possible on a global basis, permitting heretofore unattainable accuracy and range.

The exact location of tracking stations is important in spacecraft guidance; therefore, NASA is undertaking to map the Earth more precisely. Discrepancies in tracking data from Cape Kennedy and Bermuda sites were caused by a mapping error; the Coast and Geodetic Survey determined from Echo I and Echo II data that the Bermuda Islands are 220 feet north and 105 feet west of their previously mapped locations. The Echo satellites are also being used to map the US mainland and Alaska.

In 1966, a Passive Geodetic Earth Orbiting Satellite, called Pageos, will be launched into an almost circular polar orbit at about 2200-mi altitude. The satellite will serve as a reference point for as many as 36 camera sites, which will link all parts of the Earth in a series of giant triangles. Calculations based on data from the camera network could establish any point on Earth in a three-dimensional coordinate system. It is expected that the distance between two points on Earth that are some 2000 miles apart can be calculated to within 32 feet. A fully global mapping program, however, will require international cooperation. Such a program was formally requested at a meeting in Paris on December 14, 1964.

In addition to Pageos, NASA will orbit two Geos satellites--one in 1965 and another in 1966. Whereas Pageos will require at least three tracking sites, Geos will require only one. (Geos can be used however, in multistation calculations.) Flashing lights, various electronic beacons, optical reflectors, and possibly radar reflectors aboard Geos will provide precise information concerning its orbit in relation to the Earth; from this information the location of a single station can be tied to other known points.

With an altitude of only 700 miles, Geos will not be as desirable as Pageos for long-distance measurement or for mapping on a global basis. But Pageos, being light and balloon-like, is limited to geometric studies; Geos, being heavy and compact, will be sensitive to the gravimetric variations, which provide important information about the shape, size, and mass of the Earth. Such gravimetric data from Vanguard I, orbited in 1958, helped determine that the Earth is slightly pear shaped.

The benefits of the mapping programs will be significant. According to The Wall Street Journal (December 15, 1964), "Experts estimate that with the help of the special geodetic satellites, the accuracy of present map measurements can be improved 10- to 100- fold. By sighting on spacecraft 2200 miles above the Earth, one can calculate distances across vast ocean areas and thus accurately relate continents to each other.

"The distance between the US West Coast and Japan is now known to an accuracy of only 400 to 500 feet out of 6000 miles, and there's sizable uncertainty, too, about the exact location of many Pacific Islands. Satellite mapmaking, it's believed, will cut the errors considerably; even a slight improvement could be important for navigating supersonic aircraft, which can miss an objective so easily.

"Furthermore, if most nations ultimately join in the international effort, boundary uncertainties could be cleared up, and dozens of other discrepancies, produced by independent, national mapping systems, done away with.

"Science will be served, too. Experts expect to reap new knowledge about the shape of the Earth. The peculiar phenomenon of 'continental drift,' the gradual movement of land masses in the Arctic, the Antarctic, and elsewhere, could be calculated more carefully with an accurate global map system."

Also, a system for precise mapping of the ocean floor is now technically and economically feasible. The system, the needs for developing it, and possible methods for establishment are discussed in the February 1965, issue of the Battelle Technical Review; the author is A. George Mourad of the Columbus Laboratories of Bàttelle Memorial Institute.

He observes that surface coordinate points have been generally established on land by the US Coast and Geodetic Survey. These points are identified by permanent markers called "bench marks." Distances or angles, or both, are measured between the bench marks. A grid is thus formed that is the base for establishing accurate charts, maps, property lines, and other similar engineering operations.

Precise maps do not exist for the oceans because past difficulties associated with establishing permanent markers on water and the lack of stable platforms precluded precision measurement of distances and angles necessary for the construction of accurate ocean maps.

Now, however, because of the advancement in electronic surveying and the use of satellites for geodetic purposes, it is possible to measure long distances precisely in the oceans. The progress achieved in sonar techniques and the invention of underwater acoustic devices also make it possible to establish permanent marine bench marks similar to those on land.

"Although some difficulties may still exist," Mourad says, "the establishment of an oceanic geodetic system is technically and economically feasible. Such a system, of course, would be available for navigational purposes; but of equal or even greater importance would be its usefulness in making possible the mapping of the ocean floor."

Geophysical exploration for petrochemical and hard mineral sources is in progress today, and such exploration is already handicapped because of the lack of proper facilities for surveys and mapping. Some of the recurring problems are those of correctly locating specific areas and of relocating specific points when necessary.

Among the activities cited that would benefit from an ocean geodetic grid system are spacecraft recovery; ocean engineering; open ocean tide measurement; calibration of inertial and electronic navigational systems; and seismic and magnetic mapping.

VIII. FOOD AND AGRICULTURE

Food presents extremely difficult problems in manned space flight. Astronauts cannot take large stores on Earth orbital or lunar missions. Long voyages of the future, which may last for months or even years, will probably require a completely regenerative, closed, and balanced ecological system capable of producing food. Information gained in research related to these problems could have a profound influence on food and agricultural processes. The growth and use of synthetics or new foods, and the process of compressing large numbers of calories into pill-sized packages, could prove to be invaluable as the world's population mounts and the demand for food multiplies.

Bio-astronautic research is being performed to discover methods of growing higher plant life capable of surviving environments that man may create on Mars and Venus in the future. Life scientists at Republic Aviation have designed a greenhouse, to be used by lunar colonies to grow vegetables, in which sunlight and darkness can be simulated during the lunar week when either is missing. Such studies could well contribute to the growth of better crops on Earth, and could originate a strain of inexpensive foods to supplement farming in countries that are at present suited to the growth of only one or two crops.

One of the more unusual applications of meteorological satellites was reported by the London headquarters of the Desert Locust Information Service. Data from Tiros satellites made it possible for meteorologists to project with great accuracy the course and direction of insect swarms over wide areas in Africa and Asia, where insects are a threat to agriculture.

Better understanding of the weather, which will depend in part on satellites and sounding rockets, will be extremely valuable to agriculture. By taking advantage of long-range forecasts, farmers could obtain maximum yields and reduce risks and losses from crop damage. It has been estimated that accurate prediction of the weather just five days in advance would result in annual savings of 2.5 billion dollars to agriculture, and the savings will be even more impressive if ever man learns to control or modify the weather.

Improved soil conservation could turn out to be the greatest long-range benefit of weather understanding and modification. It is noteworthy that the two leading nations in space research, the US and the USSR, are among the countries that are most affected by soil erosion. The Russian steppes of Kazakhstan are a large contemporary dust bowl, reminiscent of the middle 1930's when dust from the American Great Plains stretched from Texas to Saskatchewan. In the future, it might be possible to control the wind and the rain in a manner that will preserve the soil. If so, meteorological satellites and space research will play an important role. In a more remote vein, it has been conjectured that knowledge gained from a first-hand study of the Moon and the planets will eventually contribute to the conservation of soil on Earth.

Many utopian books of the past have predicted mechanized farming, which is fast becoming a reality. In 1836, an American writer named Mary Griffith published a book called Three Hundred Years Hence, in which all agricultural work was performed by machinery that was driven by some magical internal power source. The internal combustion engine fulfilled the requirements of mechanized farming fairly successfully, but the Earth's supply of petroleum can't last forever. It is quite possible that the fuel cell, solar cell, or some other energy source developed for spacecraft will become the "magical internal power source" for farm machinery.

Although the major benefits to agriculture are yet to come, it is certain that the space effort is providing new or better tools and methods for agriculture. Infrared food blanching, for instance, is highly effective in preparing goods for canning and freezing. The Boeing Co., as a result of space experimentation with algae, has developed a process for making flour of high nutritive value. A new forage harvester has been designed on principles of aerodynamics that were discovered in space research. Nonlubricated, dry-film bearings that were developed in the space effort are now being used in farm machinery. A weld seam tracker and proximity control unit, developed at the George C. Marshall Space Flight Center, is being investigated for use in the manufacture of farm equipment. The Caterpillar Tractor Co. installed a telemetering system that monitors piston operating temperatures in experimental engines. The space effort has enabled Black, Sivalls and Bryson, Inc., to manufacture storage tanks for corn syrup and animal feed by filament-winding techniques. Hundreds of similar examples are bound to occur as the transfer of innovations and know-how from missile and space technology to industrial applications becomes more complete. What's more, agriculturalists of the future may well welcome all the technological improvements that they can get, in spite of current surplus in the United States. According to an article by Gunnar Myrdal in a recent issue of The New Republic, "The Food and Agriculture Organization [FAO] has calculated that close to one-half of the world's population suffers from sheer hunger or crippling malnutrition or both. The masses of the underfed are in agriculture. Taking into account pending increases in population, the FAO calculates also that in order to provide a reasonable level of nutrition for all people, total food supplies must be doubled by 1980 and tripled by 2000."

As the population increases, the shortage of water is likely to be more critical than a shortage of food. It is already a problem in some areas. It might be a major world problem as early as 1970. According to statistics published by the Caterpillar Tractor Co., the demand on the water resources in the US will have doubled by 1980 and will have tripled by the year 2000. By 1980, industry alone will probably require as much water as is currently required for all industrial, domestic, and agricultural uses.

Clearly, ways to conserve and reuse water, together with economical desalting of sea water, will be essential in the future. Space research may help provide the methods and the technical ability necessary to meet these demands, and meteorological satellites and sounding rockets could be invaluable in devising the implementing methods of controlling the amount and distribution of rainfall.

The space program includes studies on how water can be used and reused to best advantage by astronauts in flight. A number of possibilities are being investigated, including the vaporization of volatiles in biological wastes. One such program is being carried out by General Dynamics/Astronautics under the direction of the Office of Advanced Research and Technology (NASA). A closed ecological life-support system that will enable an initial supply of only 29 gallons of water to serve the needs of a four-man space station crew for one year is being built. The water regeneration equipment, one of many subsystems in the complete life-support system, will recover and purify water from several sources, including urine and excess moisture in the cabin air.

The Marquardt Corp. is developing an astronaut waste management system for NASA's Manned Spacecraft Center; in this system, distillation at low temperature and pressure will be employed to provide potable water from wastes.

Research of this nature could provide the technology, and even complete systems for home or community use, to help meet the water shortage on Earth. Already city utility and urban planners are casting a hopeful eye toward NASA's life-support programs.

(Principal Sources: Missiles and Rockets, June 29, 1964; Missiles and Rockets, September 28, 1964; The Practical Values of Space Exploration, Report of the Committee on Science and Astronautics, US House of Representatives, Eighty-Seventh Congress; Water Crisis, USA, the Caterpillar Tractor Co., 1962; Space, The New Frontier, Office of Educational Programs and Services, National Aeronautics and Space Administration; Proceedings of the Conference on Space-Age Planning, NASA SP-40, May 6-9, 1963; The New Republic, April 24, 1965)

IX. MICROELECTRONICS

Missile and space demands for less weight and volume and higher reliability have greatly accelerated the development of microelectronic circuitry. Besides performing and sponsoring a great deal of research and development in this field, the missile and space programs have provided a market for microelectronic circuits.

Up until 1964, almost all the production of microelectronic circuitry was used in missile and space projects. Now manufacturing costs have been reduced and production is rising rapidly. About 136,000 microelectronic units were produced in the first half of 1963; about 2,000,000 were produced in the first half of 1964; and a rate of 10,000,000 per year was estimated for the last half of 1964. Microelectronic circuitry is currently being used in some commercial computers, and will be used in such consumer products as portable television sets, automobile radios, and high fidelity sets during 1965.

Mr. Frank Leary, in an article in the January 1965 issue of The Exchange (an organ published by The New York Stock Exchange), defined microelectronics in this way: "Conventionally, electronic circuits are made up of tens or hundreds or thousands of individual components: tubes or transistors, diodes, resistors, coils, capacitors, and others. Your TV set or radio has these components packed about a hundred to the cubic foot. Microelectronics means that the equivalent of a million or more components will be packed in a cubic foot."

According to a report by the Denver Research Institute, microelectronic circuits can be divided into three categories: semiconductor integrated circuits, thin-film circuits, and modular circuits (although there is widespread confusion as to terminology and hot disagreements as to which is best).

Semiconductor integrated circuits are formed on an active substrate, such as silicon or germanium. With this technique, it is possible to place a complete circuit that contains both active components (transistors, diodes) and passive components (resistors, capacitors) in a case that would previously have held only one of the transistors.

Thin-film circuits are formed on an inactive substrate, such as glass or ceramic. The passive circuit elements are formed by vacuum deposition; the active elements are added separately as discrete components.

Modular circuits consist of discrete, minute active and passive components that can be connected by wires, printed circuitry, or thin films. These are packaged in tiny modules.

Although the reduction in size and weight is extremely important in some applications and is definitely an improvement in terms of production, housing, and transportation costs, by far the greatest merit afforded by microelectronics is in increased reliability. As Mr. Leary said, "A system with 1000 electron tubes used to have a probable time-to-failure of a day or so; early computer users can tell you how often the repairmen were inside the old computing systems replacing tubes that had gone bad. The same systems, transistorized with probably 1500 or 2000 transistors, had a much better reliability figure--perhaps two or three weeks to failure. With microcircuits, engineers are talking about systems with a probable time-to-failure of three and four years."

Perhaps the ultimate (but futuristic as to commercial application) in miniaturization is molecular circuitry. According to Standard & Poor's Compendium of American Industry, "This concept envisages the entire circuit in a single solid block of material, with the various circuit functions introduced through diffusion and machining techniques. One estimate of the theoretical packing density, which is limited only by atomic interaction, is 5×10^{12} parts per cubic foot. By comparison, the human brain has about 5×10^{11} parts per cubic foot..."

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