NOVEMBER 23, 1959

SPACE AGE MATERIAL—
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missiles and rockets

MAGAZINE OF WORLD ASTRONAUTICS

SPECIAL ISSUE

Missile/Space Materials

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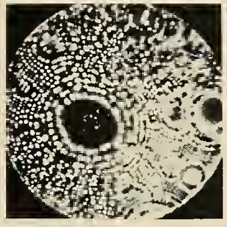
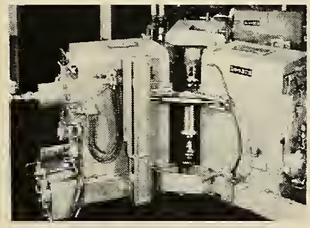
COVER: Braiding stainless steel wire on flexible hose made of du Pont Teflon and fiber glass at the Titeflex Inc. plant in Springfield, Mass. See Story on p. 52.



ATOMS OF tungsten in first photo of single atoms. Taken by field emission microscopy, it is a magnification of 4,300,000 times. A survey of the revolution in materials starts on p. 13.

STEEL CASING made for Aerojet-General by Kaiser Metal Products, using the Hydrospin process. Rockets must be made more reliable and lighter. See story beginning on p. 21.



FLOTURN machine at Pratt & Whitney plant in East Hartford, Conn., turns out seamless cylinders whose freedom from weaknesses affords a major advantage for use in rocket cases.

missiles and rockets

MAGAZINE OF WORLD ASTRONAUTICS

31,000 copies of this issue printed

NOVEMBER 23 HEADLINES

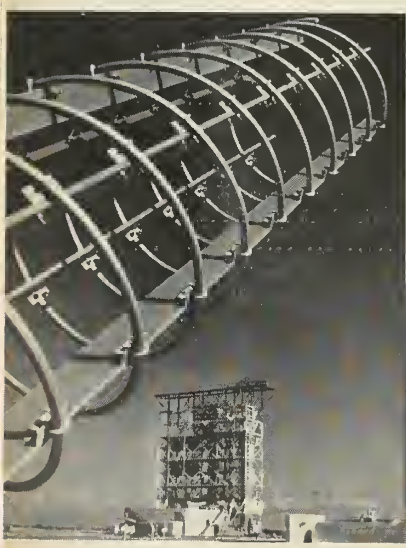
FIRST SPECIAL SPACE AGE MATERIALS ISSUE

THE MISSILE WEEK

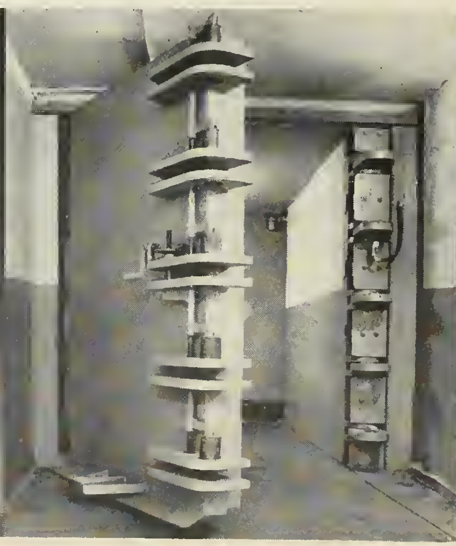
U.S. Reg. Pdg.

DEPARTMENTS

About the earthly side of Canaveral—Only recently, it spawned little more than snakes and other crawling creatures. Today, high flying birds are poised there, and because they can't jump off from sand, most of the Canaveral manpower and materials go into ground support equipment. And virtually all the steel material required can be purchased from one source—United States Steel. Whether we're talking about carbon steel, high-strength low-alloy steel, constructional alloy steel, or stainless steel, steel fence, electrical cable, wire rope or cement,



On this vertical oscillating radar tracking unit, every nut, bolt, and insulator collar is Stainless Steel. To the right, is a Stainless Steel fuel tank, and beyond that rises the U. S. Air Force Thor gantry tower, with a structural steel frame similar to a nine-story building.



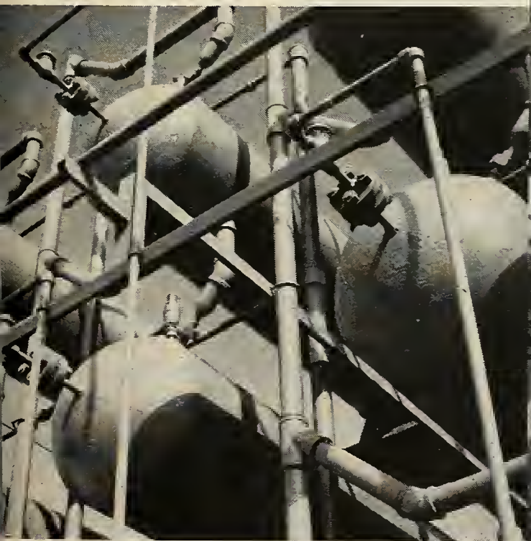
The door to the U. S. Air Force Atlas blockhouse weighs 24 tons. It is solid manganese steel about eight inches thick. At X minus 15, the door automatically locks and it is blast-proof and vapor-proof.

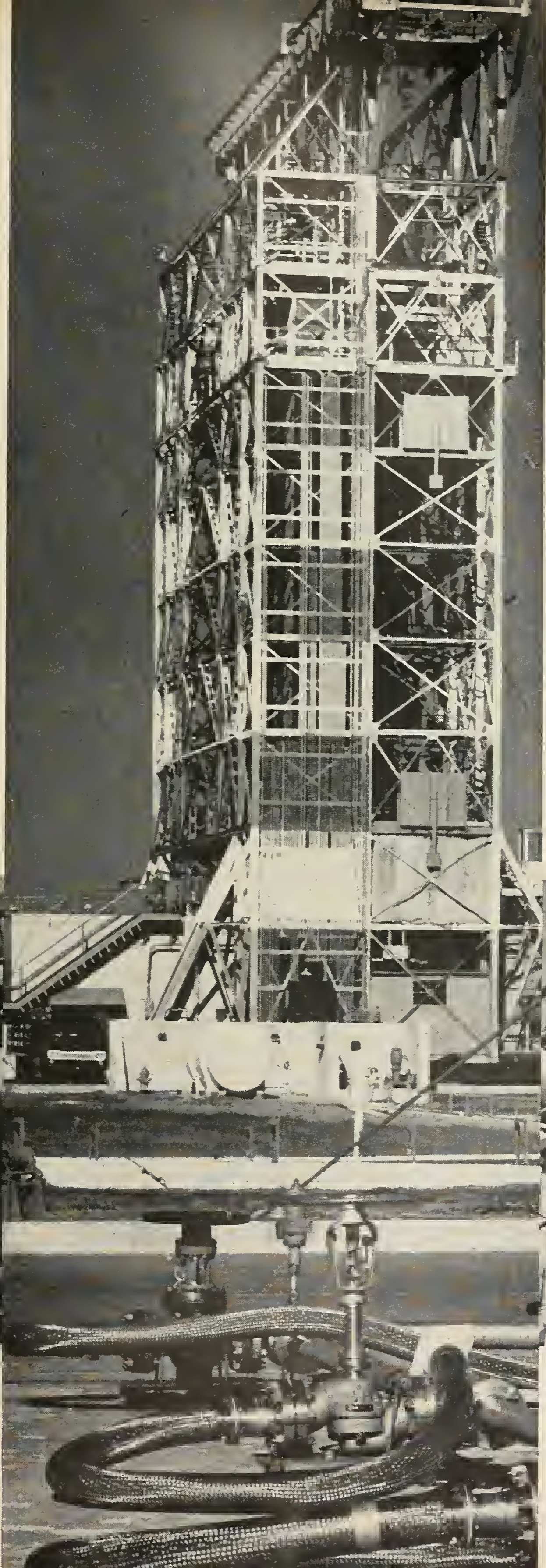
The mobile transporter for the Thor is strong but light on its wheels because it was designed with weight-saving high-strength steels. Slanting to the left is the steel umbilical tower which carries Stainless Steel fuel lines and control lines.

United States Steel maintains the technical services to provide the proper assistance to cope with any problem on these materials for ground support. When a ground support program is still on the drawing board, consult

United States Steel

USS is a registered trademark





hese pressure vessels for the U. S. Air Force Bomarc A system e seamless steel cylinders about 20 inches in diameter and 26½ et long. The cylinder walls are slightly more than an inch-and-a-alf thick and will contain gas at pressure up to 4500 psi.

tainless Steel pipes and Stainless Steel flexible tubing carry the el for the Thor complex. Fuel lines must be almost surgically clean prevent explosions and assure proper flow. Inspectors check the ies with everything from microscopes to ultraviolet lamps. ▶

Washington Countdown

IN THE PENTAGON

The coming Missile Gap . . .

may be preceded by a Bomber Gap as a result of the tight defense budget being planned for FY 1961. The Air Force may have to cut some SAC bomber wings in order to make ends meet.

• • •

Trouble in NATO . . .

also is expected to result from other proposed cuts—these in foreign aid. The cuts would delay the flow of U.S. Army tactical missiles to NATO troops.

• • •

The number of *Polaris* subs . . .

in the new budget may hang on whether the Navy insists on construction of a second nuclear-powered carrier. With the carrier, the Navy would get only three of the missile-launching subs. Without the carrier, the Navy might get five.

• • •

The next generation ICBM . . .

after *Minuteman* may be *Midgetman*—a far smaller, lighter, easier-to-handle bird. *Midgetmen* might also be used as an anti-missile missile.

• • •

One million pounds . . .

of thrust appears to be the Air Force goal in calling for industry to come up with designs for a huge new solid rocket motor. Such a booster would have a number of military applications. Powering *Dyna-Soars*, for instance.

• • •

A second giant test stand . . .

planned for Edwards AFB may be built to accommodate rocket engines exceeding 1.5-million pounds of thrust. Air Force and NASA funds will be used. One stand for 1.5-million-pound-thrust boosters already is under construction at the aero-space base.

• • •

Special 'mole pay' . . .

for "molemen" manning hardened ICBM bases is under consideration by the Air Force. The extra money for servicemen spending a specified number of hours underground each month would be comparable to flight pay.

ON CAPITOL HILL

Space patent law . . .

will get a going-over early next month before the House Space Patent Subcommittee. Hearings on whether the patent provisions of the National Space Act should be revised are scheduled to open Nov. 30.

• • •

Tithe for science . . .

legislation is expected to receive new attention when Congress opens for business in January. The proposal would call for adding 10% for basic research to all military and space R&D appropriations.

AT NASA

Sodium vapor tests . . .

being conducted with sounding rockets at Wallops Island will provide information for both Project *Mercury* and *Dyna-Soar*. The tests are yielding data on wind velocities between 50 and 150 miles above the earth.

• • •

The *Mercury* Astronauts . . .

are undergoing heat chamber tests in their space suits at the **Air Crew Equipment Co.** in Philadelphia. Temperatures exceed 150 degrees.

AROUND TOWN

Some of the reports . . .

being passed around the nation's capital:

. . . The Air Force is considering construction of ICBM bases on sparsely inhabited Pacific islands.

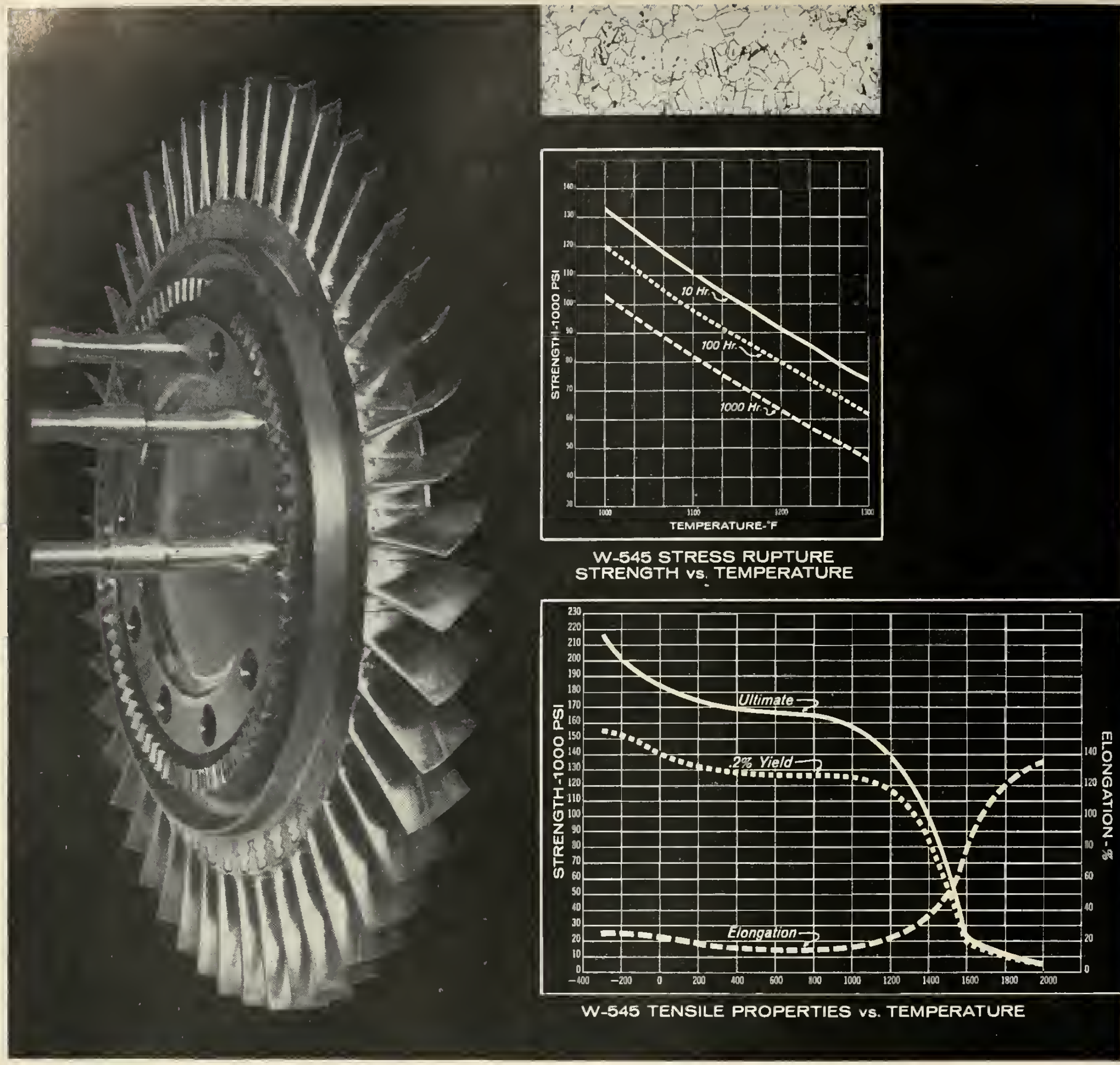
. . . The Defense Department is having a rough time finding a top man to head ARPA for only the Administration's last year.

. . . The Senate Space Committee will hold its fire on the Administration space program until early next year.

• • •

Five Soviet scientists . . .

attending the American Rocket Society's annual meeting in Washington received only nine-day visas from the State Department because that was all the time they requested. If they had asked for a longer stay for more extensive travel, it would have been given consideration.



W-545 STRESS RUPTURE STRENGTH vs. TEMPERATURE

W-545 TENSILE PROPERTIES vs. TEMPERATURE

NEW HIGH-TEMPERATURE ALLOY W-545 HAS 20% MORE STRENGTH

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WATCH "WESTINGHOUSE LUCILLE BALL-DESI ARNAZ SHOWS" CBS TV FRIDAYS the missile week

Industry Countdown

MANUFACTURING

Less work for industry???

The fund-pinched Army reportedly is circulating a memo directing that as much ordnance development and production as possible be retained in-house to keep its arsenals busy. Several prime missile contractors are said to be worried that follow-on contracts may be diverted to arsenals—particularly in the propulsion field. Cut-down on private contracting would be gradual, and it would be felt next year. The memo, according to industry sources, was put into circulation one month ago. However, the Army denies such a memo exists.

• • •

AF will spend $6 million . . .

on developing process for producing very high temperature graphite for leading edges of re-entry vehicles and for nuclear reactor applications. One of the leading contenders for a share of the program is **Raytheon Co.**'s new "pyrographite"—manufactured from deposits of carbonaceous vapor at temperatures above 3632°F.

• • •

Huge plastic "bubbles" . . .

are being proposed as means of solving problems of assembling either platforms in space or constructing lunar bases. The bubbles would have self-contained atmospheres . . . removing the requirement for workers to wear special space suits.

• • •

'Profit for performance' . . .

The largest Air Force cost-plus-incentive-fee contract ever awarded—$100 million—has gone to **General Electric**'s Missile and Space Vehicle Division for *Atlas* and *Thor* re-entry vehicles. The contract is a new type and may signal a break in DOD's tough position on incentives.

PROPULSION

Only three more . . .

of **Grand Central Rocket Co.'s** LKS 54,000 pound thrust *Mercury* escape motors remain in development phase before they enter qualification (99.9% reliability). Roughest chore is in aligning the three nozzles to vehicle where the tolerance is 1/186,000 of a millimeter.

• • •

Largest mixing machine . . .

in the solid propellant industry also is claimed by GCR. The 350-gallon container can mix 5000 pounds in one batch—only two mixes are needed to fill the 7000-pound *Nike-Zeus* sustainer.

• • •

For field loading . . .

of solid boosters, **Rocketdyne** has come up with a "QuickMix" process where dry and liquid ingredients are blended in a liquid carrier at high speeds, with no appreciable heat build up. Mobile pilot plant with 500 pounds-per-hour capacity indicates 5000 pound-per-hour plant is feasible.

• • •

Plasma buffs . . .

can't always agree. Two papers at last week's American Rocket Society meeting backed plasma propulsion for inter-orbit lunar missions—but a third paper contended that plasma accelerators aren't well enough understood yet to determine if they are practical for space usage.

ASTRIONICS

First space trajectory . . .

symposium to develop a centralized source of information and reference is being held Dec. 14 and 15 at Orlando. Sponsored by **Radiation Inc.**, ARPA and the American Astronautical Society, the meeting will survey the current state-of-the-art in astromechanics, trajectory computation and optimization, space maneuvers, ascent and re-entry, and fundamental astronautical constants. Proceedings will be printed in book form.

• • •

New TV rocket . . .

is being developed by **Atlantic Research Corp.** Expendable camera would be boosted to 200,000 ft. and descend via parachute while transmitting a continuous picture of lower atmosphere and earth's surface over standard meteorological radiosonde frequencies down to 70,000 ft. System reportedly would be cheaper than one requiring a motion picture camera and recovery.

WE HEAR THAT—

Rocket jump belt . . .

for infantrymen may be bought soon by the Army from **Thiokol** . . . Anti-ICBM guidance techniques evaluation is underway at **Boeing Aircraft** . . . Series of minor mishaps have been plaguing **The Martin Co.** *Titan* program—delaying current test shots at Cape Canaveral . . . Britain's *Black Knight* re-entry vehicle (powered by the **Bristol Siddeley** Gamma engine) has had five successful flights at Woomera . . . also "Down Under" the **de Havilland Propellers Ltd.** *Blue Streak* is nearing flight test.

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Materials: a New Era Begins

All elements, all compounds will be used to meet stern demands of space and nuclear technology; hundreds of millions spent on materials research

by Jay Holmes

WASHINGTON—The materials with which men work characterize the epochs of history. In describing ancient times, we speak of the Stone Age, followed by the Bronze Age and the Iron Age. Ours has been the Age of Steel. But this age is coming to its end.

Spurred by the demands of space flight and nuclear technology, man is entering an era in which he will use not just a few but all the elements in the periodic table. And with the aid of chemistry, he will use not just the compounds found in minerals but every possible combination and permutation of the elements.

A century from now, historians assessing the accomplishments of man's first 100 years of exploring space may well decide that the most important was the introduction of new materials on earth—liberating him from restriction to a few metals, wood and a dozen kinds of stone.

Already, metallurgists are working with such hitherto unlikely elements as molybdenum, niobium, tantalum and the rare earths. New alloys announced recently include a steel including yttrium, aluminum with added lithium, nickel mixed with a dozen different elements. And in chemistry, there seems to be no limit at all to the number of possibilities.

Why introduce new materials? Because those in existence won't do the job in space. Missile and space vehicle designers today are in a situation like that of a small boy at a party where unlimited amounts of ice cream, cake, candy and soda pop are served. He can ingest the goodies but his stomach cannot digest them.

Similarly, the designer often must swallow more of a space mission than the materials at hand can digest. In propulsion and space flight, the materials must contend with extremely high temperatures, pressures and vacuums. Particle erosion, radiation and micrometeorites add to the difficulties. And, to top it all, the entire system must have minimum weight.

To develop the materials, government, industry, universities and independent laboratories are spending hundreds of millions of dollars annually. But despite this grand scale, not enough is being done. The programs are not touching all bases. The reason for this is simple. No one agency is responsible for a comprehensive program of materials research for space.

• **Exponential curve**—But an even more pervasive problem is communication. The sheer volume of research is staggering. If a design engineer were to read all the reports on materials research even in one narrow area, he would have no time to design. The amount of research in the United States since World War II is greater than all that was performed between 1776 and that time. And the curve is exponential. It may take only a few years before this quantity is doubled again.

How is materials research information distributed? In many ways. Scientists doing similar work often communicate privately. Papers are given at professional meetings and published in journals. Periodically, such organizations as Wright Air Development Center, Air Research and Development Command, Office of Naval Research and Stanford Research Institute conduct special symposia on materials. Nevertheless, only part of the information filters through to the engineers who must use it.

But even if they received all the necessary facts, the engineers probably would be unable to absorb them. For the problem is not simply one of adding a few new items to an existing technology, as for example in the case of new information about steel. In this case, the engineer already has learned the basic information in college and in his previous experience.

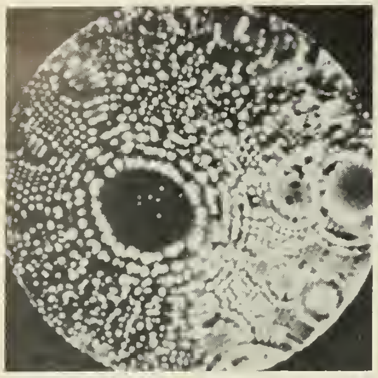
The new materials create entirely new technologies. There is no underlying experience. The engineer did not learn about their properties in college. Even as recently as five years ago, many materials in wide use today were laboratory curiosities or had never been made.

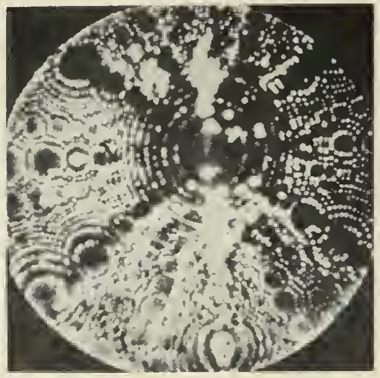
• **Clearing-house activities**—One current approach to solving the problem is by centralizing information, if possible on punched-card files, and establishing materials information centers. The Army is establishing a plastics center at Picatinny Arsenal, N.J. The Solid State Directorate of the Air Force Office of Scientific Research is circulating a proposal for a central national materials research laboratory. The National Bureau of Standards expects to increase its clearing-house materials information activities.

In an effort to gauge the amount of Space Age materials research, MISSILES AND ROCKETS undertook a survey of projects sponsored by government agencies. It soon became apparent that even so modest an objective is extremely difficult to attain. For only the Air Force centralizes its research and development. In the Army and Navy, it is attached to each technical service and bureau. Furthermore, all services have separate research activities attached to every major weapons system.

In the National Aeronautics and Space Administration, materials research is centralized to some extent. But separate activities again are carried out in connection with major programs. The Bureau of Standards has materials research in progress in all of its sections. The Atomic Energy Commission was not included in the survey because, although much of its materials research will be of value in the space program, the activity obviously is aimed in another direction.

John Garrett, materials specialist in the Department of Defense, estimates that the military is spending several





TUNGSTEN ATOMS, enlarged 4,300,000 times at left and 2,750,000 times on right, photographed in 1956 by E. W. Muller of Penn State under Air Force research contract, gave man his first look at individual atoms.

hundred millions this year on materials research, most of it aimed at developing missile and space materials. The research ranges from the most fundamental studies of the nature of matter to extremely practical programs for sheet-rolling metals such as molybdenum and titanium.

• **More scientists needed**—In a program, Project *Pontus*, the DOD's Advanced Research Projects Agency is seeking to get at the root of the matter by increasing the supply of scientists capable of materials research. ARPA expects to obligate about $15 million this year to establish materials research centers in three to five universities. Dr. John Kincaid, ARPA scientist in charge of the project, said he expected to complete a preliminary screening this month of about 20 universities that have expressed interest in taking part.

The centers will work in such areas as high-temperature physical chemistry, organic chemistry, solid state physics, metallurgy, ceramics and engineering. The aim is to uncover new information in these areas, while training graduate students and increasing the supply of materials specialists with advanced degrees. Thus some of the government money may go for stipends, he added.

The three services are spending about $70 million on materials research this year, most of it much closer to the end product. However, this sum also includes $12 million for fundamental studies, about $4 million for each service. Of the rest, the Air Force is spending almost $28 million, the Navy $23½ million and the Army almost $18 million.

• **Space room**—A large item not included here is a multi-million-dollar Navy Bureau of Aeronautics program for sheet-rolling titanium, molybdenum and other new metals. BuAer is sponsoring construction of an 80'x40'x20' argon-filled "space room" at the **Universal Cyclops Steel Co.** plant in Bridgeville, Pa., with a rolling mill, forge and facilities for welding and brazing reactive metals. The room is expected to be completed by the end of the year.

Other programs are the research associated with each weapon system and an ARPA applied materials research program.

• **NASA research**—The space agency is spending something over $5½ million on materials research, about 55% on high-temperature materials, 10% on high-strength materials, 20% on space environment effects and the remainder on fundamental studies. Most of NASA's research is in-house.

In addition, the space agency has a sizeable program in connection with its nuclear propulsion program, Project *Rover*, which it sponsors jointly with the AEC.

The Bureau of Standards devotes between 25% and 30% of its $36 million budget to fundamental materials research. The Bureau is considering establishment of a center for information on preparation of pure crystals, in addition to some increase in its materials research activity. Dr. Irl C. Schoonover, associate director for planning, says all basic research in materials is of value in some phase of the space program.

Schoonover said the nation needs more centralization of materials information than exists now. One solution, he said, might be a central clearing house of materials information. He said such an institution would have to be staffed by research specialists but it should not itself attempt to engage in research. Instead, he said, the level of activity at existing institutions should be increased.

• **Central laboratory**—Charles Yost, director of solid state sciences in the Air Force Office of Scientific Research, is circulating a proposal for establishing a central national laboratory for basic studies in the properties of crystals and preparation of specimens for study. Such a laboratory would be a leader in the field, he said.

The Missiles and Rockets survey disclosed that many agencies are hard at work developing and learning to work with high-temperature metals, coatings, ceramics and cermets. The same is true of high strength structural metals and plastics. Vacuum research is getting increased attention—so that materials are available for use in space.

But many scientists feel that the level of effort is too low. Last summer, the Materials Advisory Board, of the National Academy of Sciences conducted an ad hoc study of materials research. Although its recommendations have not yet been published, it is known that the consensus is that the level is too low, chiefly because there is no comprehensive program of developing materials for space.

For example, the scientists who took part felt more activity is needed in such areas as vacuum research, surface effects, very low density structural materials and temperature control by emissivity and absorption.

Like many other aspects of the space program, it appears that materials research needs someone in charge.

GE Reveals Process For Making Diamonds

Schenectady, N.Y.—The process for producing man-made diamonds—covered until recently by U.S. Government secrecy order—has been revealed here by **General Electric** Research Laboratory scientists.

The essential breakthrough involved in transforming carbon into diamonds was the use of a molten metal catalyst, which acted as a thin film between the carbon and the growing diamond crystal. The molten film and the development of new superpressure and high-temperature apparatus made possible the long-sought transformation.

Without the catalytic action, it is estimated that pressures of 3,000,000 psi and temperatures of over 7000°F would be necessary to transform the carbon into diamond. No equipment presently exists that could produce such a combination of sustained pressure and temperature.

The catalyst metal can be chromium, manganese, iron, cobalt, nickel, ruthenium, rhodium, palladium, osmium, iridium, platinum or tantalum.

Temperature Barrier Slows Progress

Refractories need oxidation-resistant coatings; ceramics too porous or brittle; cermets unreliable; Air Force bets $6 million on graphite.

John F. Judge

WASHINGTON—High temperature constitutes a phase of the current space effort on which all lines of progress converge—and slow to a crawl.

The immense and complex problems caused by the temperatures encountered in every mission through and beyond the earth's atmosphere are the most unyielding obstacles to the advancement of our space program.

Every solid known to man has a definite limiting temperature, beyond which it is either a liquid or a gas. But some problems become acute long before this limit is reached. There are phase changes, oxidation and other conditions which affect the operation of the material.

Thus the broadest significant term applicable in this field is resistance—resistance to high temperatures, to thermal shock, to thermal conductivity, to erosion, corrosion and oxidation.

Finding the material is only part of the picture. We must learn to work it—to forge, sinter, cast or machine it into usable shape. We find ourselves in a situation similar to the legend of the inventor of the universal solvent—how was he going to get his product to market?

But there is no one high-temperature problem. Each application is different. The temperature ranges themselves are created by man. They are determined by passage in and out of the atmosphere and the conditions in the reaction chamber of the vehicle itself.

In the last four years the search has broadened to include an extremely large number of materials. The substances explored range from the familar to the unexpected.

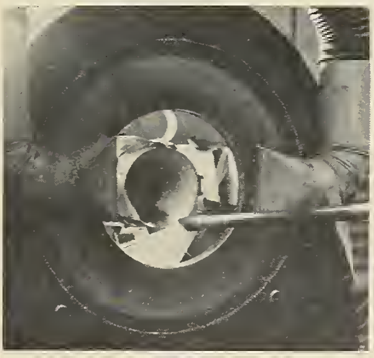
• **Refractory metals**—The classic area of refractory metals is probably the largest and most comprehensive source of high-temperature substances.

Roughly taken as all those metals whose melting point either equals or exceeds that of chromium, the refractories have an inherent deficiency—their low oxidation resistance. This difficulty is overcome to some extent through alloying, but the area thus far explored is a minute part of an unknown whole.

This disadvantage of oxidation points up the fact that refractory metals are characterized by good retention of strength at high temperatures rather than high strength per se. Robert I. Jaffee of the **Battelle Memorial Institute** says that, as a first approximation, the potentialities for high-temperature strength increase as the melting point increases.

The metals that seem to be of the highest interest are in groups V-A and VI-A of the Periodic Table. For an extended discussion of the advantages and shortcomings of each of these metals—such as the low modulus of niobium and its high rate of oxygen diffusion, the high density of tungsten and its high ductile-to-brittle transition and the high thermal conductivity of molybdenum and tungsten and their low expansion coefficients, see M/R Aug. 31, 1959, pages 13-15.

Some of the companies that specialize in refractories are: **Astrometals, Cleveland Pneumatic Industries, Wah Chang, Titanium Metals Corp. of America, Firth Sterling Inc., Beryllium Corp., Brush Beryllium Corp., Nuclear Metals, Union Carbide Metals, Fansteel Metallurgical, Sylvania, Nuclear Corp.,** and **Alloyd.**



CERAMIC COATING applied to inside of combustion chamber and exit cone for Thiokol pre-packaged liquid engine.

The recent applications of refractory metals are in two major categories. There are the sheet applications for leading edges of hypersonic vehicles and the large, heavy forgings of the more refractory metals such as molybdenum, tantalum, and tungsten.

The major problems in the forgings are in obtaining sufficient ductility to withstand fabrication and the more severe thermal shock conditions of actual use. The stress problems are much less severe in leading edge applications.

• **Surface films**—Besides alloying, protective coatings can be used to enhance the oxidation resistance of the refractory metals. Many experts feel that coatings will have to be used regardless of the quality of the alloy.

Experience in the coating of refractories is strongest in the area of molybdenum. **Linde** LM-2 and Chromalloy W-2, based on molybdenum disilicide, are among the best. Ceramic coatings for molybdenum have been developed which are satisfactory for conditions of low stress and high temperature.

Currently, the major means of consolidation of refractory metals are powder metallurgy and arc melting. Electron beam melting is rapidly developing as a third large method.

Refractory metals will advance on many fronts in the near future. Powdered metal alloys will compete with large arc-cast alloys—tantulum-base alloys will develop high-temperature strength—self-healing coatings for oxidation protection will be found—oxidation resistant colombium base alloys will be used for leading edge application without protective coatings, and fabrication methods will improve.

• **Ceramics**—Oddly enough, the

fact that a material has a high melting point is usually of secondary importance. In most cases it is the ability to resist oxidation and thermal shock that counts the most. Ceramics, being characteristically brittle, would seem to be out of the picture. This is not the case. Ceramics are actually competitive with metals at some of the elevated temperatures.

Generally, ceramic coatings are either too porous or brittle. Since they depend on mechanical bonds for adhesion, they usually fail because of poor bonding, lack of ductility and poor matching to the base metal. They are not reliable for systems where the base metal deforms appreciably.

Nevertheless, ceramics offer a great deal in the elevated temperature ranges as a structural insulator, and as protective coatings. In a stiffness, Young's modulus, to weight-ratio comparison, ceramics such as pyroceram and alumina are actually superior to many metals. Characteristics such as this lead many to believe that ceramics cannot be ruled out since further research may well provide breakthroughs.

Firms such as **Minnesota Mining and Manufacturing, Haynes Stellite, General Electric, Kearfott Co., Carborundum Co., Corning Glass, Haveg Industries, Motorola, Norton Co., National Ceramic, Gladding, McBean & Co.,** and many others are hard at work in this area, improving and developing new combinations.

Cermets, a combination of ceramics and metals, have been the object of intensive research in the last decade, especially leading to aircraft applications. However, no cermet of sufficient reliability has yet been found.

The recent production of cermets based on the refractory metals such as molybdenum and tungsten—instead of cobalt and nickel—has increased the likelihood of their use at high temperatures. Cermets' mechanical properties are somewhat better than ceramics'.

Many of the applications for high-temperature materials may not involve oxidizing environments. Then the susceptibility of cermets to oxidation will not be a problem and their high strength can be utilized. For example, a silicon carbide-molybdenum material cermet has a transverse rupture strength of about 42,200 psi at room temperature, but at 1830°F the strength increases to 71,900 psi.

The development of a special flame spraying process by the American Electro Metal Division of Firth Sterling, Inc., has lead to the coating of many base metals and shapes with $MoSi_2$, Cr_2NiB_4, NiAl, and $MoAl_2$. This technique also permits the building up of coatings on an expendable pattern.

• **Oxides**—At elevated temperatures, the excellent chemical stability and corrosion resistance of oxides open another field in materials. As with ceramics, the oxides have the disadvantages of poor resistance to impact failure, low-temperature fracture and poor thermal shock properties.

In single-crystal configurations or dense solids, these materials exhibit their best combination of high-temperature qualities. There is substantial room for improvement through control of composition and structures by better methods and fabrication techniques.

There will be further developments in this direction in the near future. The effect on high temperature applications is bound to be considerable.

• **Plumbago**—The oldest nonoxide super refractory in current use today is graphite. This material has a unique property in the high-temperature field. Its strength increases with increasing temperature until it has almost doubled at about 4300°F.

Not very impressive at room temperature, graphite is stronger than most of the known high-temperature materials, except some of the refractory carbides, above 2900°F. It holds considerable strength as high as 5500°F. The biggest problem with graphite is oxidation, and this has been the object of a great deal of attention.

Minnesota Mining and Manufacturing Co. has developed a siliconized-silicon carbide coating for oxidation protection. **National Research Corp.** deposits molybdenum carbonyl on it followed by a coating of an aluminum-silicon eutectic. After treatment, the graphite winds up with molybdenum disilicide, then an alloy of molybdenum, silicon and aluminum and finally an outer coating of alumina. This protective coating held up for a half hour at 3450°F.

The **Vitro Corp. of America** has developed a technique of depositing either carbide, silicide or metal-alloy coatings on graphite by an electrophoretic process.

The extent to which graphite has been considered in space applications is difficult to estimate. However, the Air Research and Development Command allotted 10% of its present applied research budget of $20 million to R&D on this material and an additional $4 million will be funded in the near future from other sources. If they were given the choice now, Air Force materials officers would use graphite as the leading edge of *Dyna-Soar*.

Another problem is the grade of graphite. The best available has a 25% possible variation in properties. But this must be brought down to at least 5% for space use. Such a grade is possible but it is not commercially produced at present.

• **Ablative materials**—One of the most surprising developments in recent year is the progress made in the use of plastics for high-temperature applications. Focused on the re-entry problem, where temperatures are such that no known material is stable, research revealed that for short-period exposures, certain reinforced plastics were amazingly durable.

The concept of ablation is often defined as the orderly removal of material from a surface in a hyperthermal environment by interaction between the surface and the applied heat and velocity. It is primarily a method of heat absorbtion. While the factors affecting ablation are to a significant degree unknown, the superiority of reinforced plastics has been demonstrated.

Generally, it is agreed that organic plastics are better than inorganic materials and the phenolic resins include the best class of plastics tested to date. But GE scientists feel that it is possible that the superiority of certain phenolics may merely be a reflection of the large amount of development effort that has been expended on them.

The ultimate criterion for selecting materials for high-temperature application is weight loss, but other considerations have proven useful in understanding the mechanics of ablation. Studies at GE of ablated configurations have provided some insight into the operation of the phenomena in terms of steady-state damage, uniformity and freedom from impurities.

An example of the effectiveness of plastics is the *Discoverer* nose cone heat shields. Developed by the **Aviation Products Division of B. F. Goodrich,** the shield is composed of several combinations of fabrics impregnated with phenolic type resins.

Machine tape winding under controlled tension and heat forms the shield which is then vulcanized for days at high pressures. Temperature increments are controlled throughout the process, resulting in a fine degree of regulation of the resin content, specific gravity and dimensional stability.

Some of the many firms involved in the development and supply of materials for these purposes include **Taylor Fibre Co., Johns Manville, Union Carbide, Durez Plastics Div.** of **Hooker Chemical, Du Pont, Selas Corp., H. I. Thompson Fibre Glass, Continental Diamond** and **Owens-Corning Fiberglas Corp.**

for space flight . . .

Structural Strength Is Major Hurdle

Flaws in building materials cause many missile failures; poor industry communication often a factor; objectivity, research in materials needed

by Edward W. S. Hull

WASHINGTON—If paper could fly or designs carry payloads it would be the U.S., and not Russia, that is "two to five years ahead" in spaceflight accomplishments.

We have no dearth of detailed systems in the proposal, design and R&D stage. What we lack is the ability to readily and reliably translate dreams into reality—concepts and designs into hardware.

Sooner or later, the problems reduce themselves to structures—materials and how to put them together. Sometimes a big bird fails due to human error, such as the last-minute failure to close a valve or somesuch.

But more often than not, it fails because some piece of hardware did not stand up under the rigors of its intended operational environment. A motor case blows up because of an undetected flaw in the basic material. A missile skin melts under aerodynamic heating. Thermal shock fractures a nozzle insert. Vibration separates the inseparable components of a printed circuit. A missile frame buckles under high acceleration. Radiation changes the chemical structure of a plastic. The dead cold of liquid oxygen embrittles critical aluminum welds.

Take your choice. The causes of missile and space vehicle failure are legion. Sometimes it's a matter of design, but usually it's the inability of a structure to do the job it was intended to do. Structures and materials are rapidly becoming the most critical area of research and development in the entire missile field. This becomes evident when you realize that combustion chemists, propulsion engineers, frame designers, systems engineers and program directors all have stated, financed goals and projects, which in nearly every instance exceed the current capabilities of structures and materials to fulfill the requirements.

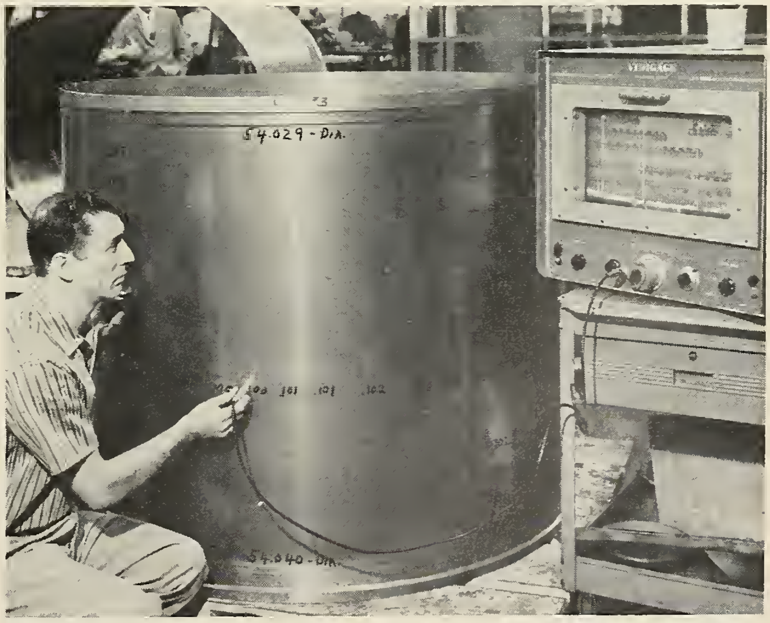
• **Poor communications**—This incapability is due only in part to lack of advancement in the state of technology. Just as often, the blame falls on poor communications within the industry and on the vested-mindedness of people working in one materials field —who refuse to consider the applicability of other materials technologies.

Eight months after unclassified publication of technical papers on notch sensitivity of high-tensile steels, project engineers writing specifications for solid-propellant rocket motor cases in some of the nation's most critical projects had never heard of the phenomenon. They were calling for minimum yield strengths of 220,000 psi in cases where the maximum calculated stress was 165,000 psi *including a 25% safety factor*. When asked why, they replied: "Because it's fashionable!"

Increasingly it is becoming apparent that no single material and no single structural concept is going to be the best answer for all applications of a particular rocket component. Yet pride of authorship, combined with the enthusiasm of a sales pitch and the habits of years, lead one rocket engineer after another to push his technology to the exclusion of all others.

These are customs of the now-dying age of casual technology, which are slow to fade away. Fading they are, however, and the quicker the better. For an increasingly precise and unforgiving requirement in structures and materials is to "let the punishment fit the crime."

• **Varying environments**—The materials of space technology run the gamut from thin mylar films to 500,000 psi music spring steel wire. These



TESTING MOTOR CASE section produced at Kaiser Metal Products Inc., Bristol, Pa. Structures must be strong, light.

must withstand ambient and self-induced environments ranging from 4° to 20,000°K; from zero gravity to hundreds of *g*'s; from the hard vacuum of outer space to the extreme pressures of ballistic re-entry; from zero radiation to the intense "atmosphere" of the radiation belt during a solar flare or the hot innards of a fast reactor; from dry to high humidity.

Lives of missile and space structures range from a few seconds to years. One day, a requirement will call for an extended space probe out to where the sun is a star—years out and years back, enduring sequentially the entire range of conceivable environments. Another specifies the active life of the rocket-powered missile in terms of seconds—birds such as *Hawk, Redeye, Eagle*—but calls for storage lives running into years, often under the inconsiderate conditions of unprotected fields.

In the final analysis each of these requirements boils down to a problem of structures and materials. Design 'em we can. But building 'em is a bird of another color.

The two critical requirements in structures and materials today are:

Informed, imaginative open-mindedness, an ability and willingness to compare requirements with *all* available materials/structures capabilities. Read "Missile Suppliers Speak . . . on Materials." Even applying a discount factor for the inevitable pitchmanship that creeps into such a piece, you'll find capabilities you probably didn't know existed.

A secret in selecting the right materials/structure combination for the job is in comparing operational environmental requirements with the elemental physical capabilities of a materials concept—without initial regard to the traditional applications of that concept. The fact that it's normally used for unbreakable toys doesn't mean it won't be good for re-entry. Look at nylon, for example. It shows off milady's legs. It also will protect a simple steel nose cone from the full rigors of atmospheric re-entry.

Research and more research. One writer in "Missile Makers Speak . . . on Materials" deplores the custom of some materials suppliers of pushing a new material on the market without really knowing either its limitations or its capabilities. He yearns for the day when we'll tailor-make materials, knowing beforehand that they will fulfill the stated requirements.

In a word, we know very little about the basic structure and behavior of materials—about the interfacial characteristics of a metal's granular structure; about the influence of trace elements in metals; about the molecular, chemical and mechanical bonds that hold all kinds of materials together; about why, in elemental terms, one material gives way under a particular environment, while another, which is but little different, rides through without strain.

Such research is just now beginning to be undertaken. Until it begins to produce tangible results we will continue to "muddle through" in a marginal manner. In time, however, operational requirements will demand that we also get efficient. That time is not far off.

One important concept now coming into popularity is the composite structure—utilization of different materials in mixed configurations to do a specific job. This is tailor-making a structure, the next best thing to tailor-making a material.

For example, take the skin of one of tomorrow's manned space vehicles designed to exit and re-enter the earth's atmosphere repeatedly, yet also designed for protracted flight in outer space.

• **Hazards in space**—The erosive effect of the constant bombardment of molecular-sized particles encountered in extended space flight will eventually sputter away the vehicle's surface. Small meteorites going perhaps 100 miles a second have an intense penetrability. Radiation is a menace to both men and instrumentation within the vehicle. Heat balance—absorption vs. emission—is a unique requirement of outer space, dependent on both surface color and texture. Many materials in a vacuum have a vapor pressure such that in due course they will evaporate away. Temperature of re-entry is always a problem.

Thermal shock is yet another problem. So is coefficient of thermal expansion under repeated cyclical heating and cooling. High accelerations are encountered, even assuming the system as designed and built is completely vibration-free. The skin structure may require that a circulation cooling system be incorporated. On top of it all, the structure must both carry heavy loads and maintain its dimensional stability within very close tolerances, particularly when subjected to aerodynamic phenomena during re-entry and flight within the atmosphere.

Obviously, no one existing material designed into a simple structure will fulfill all these requirements and get off the ground. For, above all, it must be light in weight. How then do we design an operational structure? The only existing answer is composites. They would incorporate metals, nonmetallics, plastics and ceramics, and would utilize the advantages of both solid and hollow core construction. One might look something like this:

The basic concept would be a double single-"V" hollow core—three layers of sheet separated by two "V" corrugations. The outer sheet might be inconel (high-temperature strength); outer "V" of copper (strength plus heat sink); middle sheet of stainless steel (moderate temperature strength); inner corrugation of high-temperature plastic laminate; inner skin of plastic laminate. Filling the outer core might be a foamed ceramic heat sink, insulation, meteor barrier; filling the inner core a foamed plastic meteor barrier. Running through either the inner or the outer core might be a circulatory cooling system. Laid on the outer surface of the outer sheet would be a hard high-temperature coating of tungsten carbide. The whole structure might be 1½"-2" thick.

• **Innards stop bullet**—The tungsten carbide's primary job would be wear resistance—against the sputtering action of long-term particle bombardment. It is also a temperature barrier. Inconel is another temperature barrier—also the first in a series of defenses against meteoric penetration. The "V" web of the outer core is also a meteor barrier, presenting a slant surface to the incoming projectile—a principle used to protect the backs of fighter pilots.

Both the foamed plastic and the foamed ceramic offer additional resistance to meteor penetration—just as a man's innards, rather than his bone structure, stop a bullet. The ceramic and the outer metallic structure constitute a high-temperature heat sink. All the bulk acts to stop radiation. For purposes of this discussion we have assumed compatibility of thermal coefficients of expansion and the existence of high-temperature bonding techniques for the plastic.

Whether such a structure will ever be made precisely this way is doubtful, but NASA has determined need for hard outer coating; effectiveness of widely-spaced parallel sheets as impact barriers; need for temperature and radiation protection; etc. It's a far cry from the simple riveted structure of the conventional aircraft, but it's just a hint of what's to come. Note that it employs each of the known basic materials technologies in the manner most suited to its physical characteristics. It's a straightforward, unprejudiced approach, making best use of available technologies. This is the philosophy of doing it now. For the future, as we said, research, research, research.

MISSILE MAKERS SPEAK

In this section, Missiles and Rockets *is proud to present for the first time in trade publication history a symposium on needs in missile/space materials now and over the next decade.*

To gather information for this special issue, Missiles and Rockets *went to the men who must know the problem best—those who live with it every day. Prime and propulsion contractors on every major missile and space vehicle system were asked to outline the demands that foreseeable missions will place on the materials of which the structures must be made. The authoritative replies from spokesmen for a dozen major contractors are presented in this section, MISSILE MAKERS SPEAK.*

Stating the needs is but half of the problem, of course. The question is how they will be met. Beginning on page 38 is a second special section, entitled MISSILE SUPPLIERS SPEAK. Here spokesmen for 47 other companies outline the state of technology in their areas of specialization.

Structural Materials Face Tough Demands

by A. A. Watts

Cincinnati—Operating conditions of solid rocket propulsion systems impose very stringent and widely variant requirements on structural components. Temperatures vary from near-ambient in the combustion chamber walls to about 6000°F in the nozzle. Operating pressures may vary in the range of 500 to 2000 psi.

Gas velocities may reach several times the speed of sound in certain parts of the system. High-temperature corrosion is experienced to different degrees because of the widely variant propellant compositions.

The missile industry imposes three very stringent criteria on solid rocket structural components. These may be defined briefly as (1) maximum reliability, (2) minimum possible weight, and (3) minimum cost. Short-range compromises on weight and cost are possible, but little compromise can be tolerated on reliability. High quality is of paramount importance, and a high degree of precision engineering and design must be associated with very careful control of materials processing and manufacturing operations.

• **Rocket cases**—There are two principal problems in the fabrication of solid rocket motor cases: selection of optimum materials, and selection of optimum manufacturing methods. There are many available materials for fabricating solid cases. These may be classified broadly as: low and medium alloy martensitic steels; hot work martensitic tool steels; martensitic stainless alloys; cold-worked austenitic stainless alloys; precipitation-hardenable stainless alloys; aluminum alloys; titanium alloys; reinforced structural plastics; and metal laminates.

After thorough and exhaustive examination of all of them, it appears that the low-alloy steels are best suited to meet the requirements of the three basic criteria, at the present time.

Of the many available low-alloy steels, compositions based on the AISI-4300 class (or modifications of AISI-4340), appear to have the best combinations of properties from the point of view of strength, ductility, notch sensitivity, workability, weldability, machinability, heat-treatment response and distortion; of available commercial compositions of this type, Tricent Steel (300-M) seems to have the best combination of properties.

• **Design demands**—Steel quality is quite important, and high-quality vacuum-melted steels must be employed to minimize inclusion content, to achieve maximum weldability, and to obtain adequate ductility at design strength levels in excess of 200,000 psi. At lower design strengths, good grades of airmelted steels give adequate performance.

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The basic criteria also establish that a simple manufacturing process is inherently best adapted to solid case requirements. Theoretically, a homogeneous, seamless case represents the ultimate in reliability and weight requirements. Although this design is not possible with the present state of technology, it is recognized that preferred approaches must minimize welding or joining. Cost reductions should be achieved without compromising component performance. Of the many manufacturing methods available, roll-forming (shear-spinning, spin forging, etc.) appears best suited as a simple manufacturing process for the cylindrical portion.

A new hydrospin machine, being built for **General Electric** by **Cincinnati Milling Machine Co.,** is capable of roll-forming cylindrical components up to 75 inches diameter by 100 inches long. This will be available early in 1960 for manufacturing solid rocket cases. Other equipment presently installed at GE includes two 47-by-50-inch hydrospin units and one 68-by-60-inch roll-forging machine.

Tricent steel and roll-forming have been combined in the manufacture of high-quality, large-diameter solid rocket cases. One such case is 44.5 inches in diameter; has a single girth weld; a roll-formed cylindrical section, and machined forward and aft closures with integral skirts, bosses, and ports (no welding). Variable wall thicknesses have been used throughout the design to obtain minimum weight for optimum performance, especially on end closures. Several cases have been hydrostatically tested to 190,000 psi hoop stress. Other work indicates that 230,000 psi hoop stresses can be achieved reliably. Welding techniques have been developed that provide joints with properties approaching those of parent metal.

• **Barrier falls**—We are now convinced that the so-called 200,000 psi design barrier is fictitious. Advanced programs are under way to study the mechanical behavior of metals under complex and combined stresses, so that adequate and accurate design stresses can be established. Other work under way shows promise of providing 300,000 psi design stresses with alloy steels for the near future, and perhaps as high as 400,000 psi ultimately.

This potential is provided by the deformation of steels in the metastable austenitic condition. The process is known as aus-spinning. In this process, the spinning preform is austenitized at about 1700°F., cooled rapidly to a temperature in the deep-bay region (800°F—1000°F), roll-formed to desired reductions, quenched to room-temperature, and tempered to develop suitable strengths and ductilities.

Work to date has been conducted on many experimental steels and on commercial compositions such as Super-Tricent, Halcomb 218, and LaBelle HT. A wide variety of strengths and ductilities can be obtained by varying the amount of reduction, the spinning temperature, holding times, and tempering cycles. Ultimate tensile strengths have approached 400,000 psi in some cases, and 0.2% offset yield strengths approach 360,000 psi.

The properties of aus-spun Super Tricent are especially attractive. At the 300,000 psi yield strength level, tensile elongations are about 15% in 2 inches. Normally, in conventional heat treatment of steels, strength is increased only at the expense of ductility. Work on other materials have produced tensile elongations as high as 20% with 0.2% yield strength of 320,000 psi.

• **Solid rocket nozzles**—The performance of present nozzle components is limited seriously by the lack of structural materials. Work during the last 10 years has centered principally on using ceramic, metalloid, and cermet materials. These materials have generally proven inadequate because of lack of thermal and mechanical shock resistance.

CASTING OF a truncated, cone-shaped portion of a re-entry vehicle thermal shield of new GE ablation material.

Work in the U.S. during the last three years has concentrated on development of refractory metals for components that are in contact with hot exhaust gases. These metals include molybdenum, tantalum and tungsten. Although the oxidation resistance of such metals is poor, high-temperature oxidation is often not a problem since exhaust gases present neutral or reducing conditions. The advent of aluminized propellants has presented some serious problems because of deposition products which react catastrophically in some cases with the structural component. With other propellants, highly localized oxidizing conditions can result in serious deterioration of nozzle walls.

The melting point of the structural material is an important design criterion for uncooled nozzles where minimum weight is desired. Since tungsten has the highest melting point of all metals (6170°F), it promises the greatest potential for designing solid rocket nozzles. However, the high density and high thermal conductivity of tungsten prevent the use of all tungsten nozzles. Rather, nozzle designs must employ thin shells or liners of tungsten which are backed up by lightweight, thermally insulating materials. Such backup materials may include constituents such as ceramic oxides and graphite.

• **Work hot**—The ductility of tungsten and molybdenum is quite low at room temperature, but even this limited ductility is still several orders of magnitude higher than that possessed by refractory non-metals. Above the ductile-brittle transition temperature (400-600°F), tungsten and molybdenum are quite ductile and fabricability increases with increasing temperature. However, fabrication of these metals presents very serious problems where complex shapes are involved.

Metallizing processes for coating components with refractory metals are quite attractive. Components of complex geometry can be fabricated easily and economically within certain limitations. Until recently, conventional metallizing processes used hot combustion flames, obtained by burning suitable fuels with oxygen or air, to melt and carry molten particles to the work piece being coated.

Two other methods have been developed in the past two years. One method employs the generation of very high-temperature plasmas (up to 30,000°F) for spraying metallic powders. The other method involves melting metallic wires in a high-intensity electric arc; molten particles are carried to the work by cold gases. The latter Libby "arc-spray" gun was developed in our laboratories.

A wide variety of configurations can be processed with the versatile arc-spray gun. Parts can be built up easily by depositing molten particles onto appropriately shaped expendable mandrels. Mandrels can be removed later by machining, solvent dissolution, or other suitable means. Parts can subsequently be heat treated, fabricated, machined, etc. Metals can be deposited on a wide variety of materials including graphite, other metals, ceramics, and plastics.

• **No "stick"**—It is desirable to coat internal surfaces of graphite nozzle bodies directly to minimize processing costs. However, tungsten deposited directly on graphite does not have adequate adherence to withstand the high-velocity, high-temperature gases in nozzles, because of the formation of brittle tungsten carbide. Accordingly, rhenium plating and processing techniques have been developed to deposit thin bond layers of rhenium onto graphite, on which tungsten is subsequently deposited. Rhenium does not form a carbide, and also acts as a particle barrier to retard diffusion of carbon into tungsten.

This W-Re-Gr system has proven very successful as nozzle bodies in high-performance solid propulsion motors. Early design and processing problems limited performance, but recent modifications have justified this system completely.

nuclear needs to be even stiffer . . .

Rockets Must Be Lighter, More Reliable

by L. L. Gilbert

L. L. Gilbert is the head of the Materials and Process Department, Azusa Operations, Aerojet-General Corp.

AZUSA, CALIF.—The most critical materials and processes fabrication problems facing the missile industry today and for the next decade are dictated by:

1. Operational environments,
2. Design specifications (which are primarily a function of a specific mission for which a particular system is designed), and
3. Increasingly stringent reliability requirements.

The problems of the next one-to-three years are those based predominantly on chemical rockets and the problems of the next ten years will be a combination of chemical rocketry and more advanced types of propulsion systems, such as nuclear, plasma, ion and photon engines.

In chemical rockets today, two basic problem areas exist; improved reliability and reduced inert weight—particularly propellant tanks, nozzles, controls and electronic components, pumps, gears, and turbines. The most critical and immediate need is to devise solutions for reliability and reduced inert weight in the distinct functional areas (1) solid motor cases or liquid engine tankage (pressure vessels), and (2) thrust chamber nozzles.

• **Pressure vessels**—The ultra-lightweight requirements for solid motor cases have opened a completely new field of problems in the high-strength materials such as aluminum, titanium, stainless and alloy steels. Recent studies have emphasized that the reliable use strength level is limited by the inherent toughness or notch sensitivity of the material and that toughness decreases as strength is increased. Thus, reduced weight (increased strength) and increased reliability (increased toughness) are opposing requirements. Present alloy steels, for example, are notch sensitive above about 200,000 pounds per square inch yield strength. Notches or flaws can be reduced by utilizing ideal fabrication techniques. But the small improvements achieved by improved fabrication do not satisfy the ultimate requirement of still lower weight vessels.

The question of what makes high-strength material behave in a brittle manner must be answered. Studies, many of them of a basic research nature, are necessary to provide answer to this question. Rapid and economical laboratory tests to predict pressure-vessel behavior must be devised. This knowledge is needed to develop new materials and new processes of making, shaping, and treating alloys to achieve the maximum theoretical combination of strength *and* toughness.

Environmental conditions complicate the solution. Cryogenic propellants require tank materials of high strength and toughness to temperatures of –420°F. Materials useful at room temperature may not be useful below room temperature because strength and toughness are temperature-dependent. Corrosive propellants require compatibility with tank material.

The use of glass filament-reinforced plastics for pressure vessels offers a potential extremely high strength-density-ratio material. However, the necessity of local reinforcing when the process is applied to complex configurations often results in a drastic reduction in strength-density ratios. Further research and development to extend the processing technology of glass filament-reinforced plastics to complex pressure vessel configurations offers a potential solution to the solid-rocket chambers and liquid-engine pressure vessels where environments are compatible with this composite material.

STEEL CASING fabricated for Aerojet by Kaiser Metal Products using hydrospin process.

Lightweight insulations must also be developed to protect pressure vessels from detrimental effects of aerodynamic heating or to prevent external heat effects detrimental to the propellant.

• **Nozzles**—The present combustion temperatures of solid and liquid propellants are approximately 5500°F. Within the next several years propellant temperatures will range from 6500°F to 8500°F. Uncooled nozzles are already operating near the maximum temperatures for solid materials. Increases in firing time are also expected. This combination of time and temperature requires development of liquid film cooling and endothermic cooling methods—the latter possible employing composite materials consisting of refractory skeletons "married" to ablative materials having high specific heats, heats of fusion, dissociation and vaporization.

Composite materials studies would include means of protecting graphitic materials from erosion and oxidation—something more than a coating since most refractory coatings to date exhibit lack of reliability when subjected to impingement of entrained particulate matter in the propellant stream under extended firing durations.

• **Next decade's problems**—The problems of the next decade will be dictated primarily by the extension of missions to include intraplanetary space probes requiring long firing times, start up in flight, and extremely reliable thrust control for soft landings. Future propulsion systems will include nuclear rockets operating at very high temperatures, plasma engines of low thrust and very long firing times, ion engines of equally low thrust, and—possibly at the very end of the next decade—photon engines.

Nuclear fuels are essentially limited to uranium, plutonium, and thorium. The more desirable propellants would include hydrogen, helium or other light gaseous materials. The major problems appear to be those of compatibility of the fuel material and its accompanying radiation with container, heat exchanger and the structural materials at ultra-high temperatures, and the development of fabrication techniques for providing complex fuel element shapes of

photon engines in ten years?

reasonable economy and high reliability.

• **Reliability needs**—It might be said that the reliability requirement of nuclear propulsion systems is one order of magnitude greater than that of chemical systems. Abortive missions induce considerably greater hazard to terrestrial ecology and can completely inactivate firing stands and launch areas in case of catastrophic failure. The necessity of careful selection of materials with respect to nuclear cross-section, nuclear economy and high-temperature capability seriously limits the materials choice.

The use of beryllium, its alloys and compounds, graphite, the reactive metals and in some cases thin sections of the refractory metals, implies development of fabrication techniques and materials properties beyond the present state of materials technology. For very long missions, it is conceivable that propellant storage tanks of very large dimensions (30 to 40 ft. diameter, 100 to 200 ft. long) would be required to provide propellant for round trip flights.

The ion, plasma and photon engines are still mainly theoretical. However, corrosion problems presented by the highly reactive propellants (cesium, lithium, etc.) and the sputtering erosion or radiation damage inherent in ion or plasma engines require extensive investigation to make them operational.

The Growing Role of Materials Engineer

by N. J. Hoffman and D. E. Roda

Canoga Park, Calif.—Rocket engine technology has begun to edge out from the domain of the mechanical engineer, chemical engineer, and stress analyst.

Exotic propellants, daring propulsion concepts and unique environmental conditions are pushing rocketry into some of the physicists' ivy-covered realms, such as the solid state, nuclear, and plasma technologies, into the chemists' research laboratories and directly into the province of the materials engineer. The only limitations of the rocket engine are the limits of man's imagination and the limits of the materials from which the hardware is constructed.

The problems associated with materials for this generation of liquid-fuel rockets are rapidly being solved. The most pressing problems are concerned with the joining of high-strength, corrosion-resistant alloys in the heat-treated condition. There are many obvious problems requiring study by liquid rocket engine materials engineers, such as compatibility, anti-galling characteristics, high-temperature physical and mechanical properties, and fatigue life.

Other areas requiring study are not so immediately obvious. These include such items as cleaning and passivating procedures; physical and mechanical properties at cryogenic temperatures, especially relative thermal contraction data; safe utilization of low-ductility materials, lubricants, bearings and seals that must work under very extreme environmental conditions; and catalytic properties of materials.

• **Very low temperatures**—In advanced liquid rocket engines, exotic propellants, such as liquid hydrogen fuel and liquid fluorine oxidizer, accentuate the materials problems present with conventional propellants. Materials for seals, lubricants and cleaning procedures are two areas that do not allow the materials engineer to rest easy when he handles liquid fluorine. The lack of cryogenic property data around −423°F and safe use of brittle materials loom darkly on the horizon while he contemplates liquid hydrogen.

Solid propellant rocket engines of high specific impulse present several rather difficult problems to the materials engineer. Demand for very light casings of high strength-to-weight ratio has led to the use of extremely high-strength steels fabricated with new techniques. This technology is so new that the background for designing and fabricating with these very-high-strength steels is still not on a scientific basis.

Nuclear heat transfer rocket engines are around the corner, according to nuclear physicists and mechanical engineers. If the nuclear heat transfer rocket is going to employ an epithermal or thermal reactor made from graphite and uranium carbide, the materials engineer is going to have to hustle. Today, although the black art of making graphite in the United States is in rapid transition, the lack of an adequate graphite technology is a major obstacle to this type of nuclear propulsion. Variation of mechanical properties from lot to lot, major joining problems, and the general unfamiliarity of private industry with this material as a structural member, are part of the graphite picture. The most important step, dissemination of knowledge on the processing technology of graphite, will have to begin.

N. J. Hoffman is a Research Engineer and D. E. Roda, a Group Leader, both of Rocketdyne, a Division of North American Aviation, Inc.

• **Nuclear radiation**—Effects of radiation on materials, especially plastics and electronic equipment, are another major problem. Suitable materials for moderators, shields, and reflectors, will have to be studied.

The ion rocket engine system radiator will present some of the knottiest materials problems: in the field of selective spectral surfaces; long-time creep properties of the refractive metals; and the many problems inherent with proximity to a nuclear pile power source.

Any propulsion system operating in outer space will tax the materials of its construction in rather unusual ways. The high vacuum of outer space may alter surface properties of the metal hardware. Protective oxide films may disappear, causing metal surfaces in contact with each other to weld together. Materials containing dissolved gases may release these gases with serious results. Corpuscular radiation from the sun may cause hardware to sputter away over long periods of time. Cosmic radiation may drastically affect plastics and the ability of some metals to withstand triaxial stress.

• **Space sandblasting**—Meteoroid damage to materials will be a very large headache. Solid particles of rock or iron-nickel alloy will impinge on the hardware at velocities in excess of 30,000 feet per second. At such speeds,

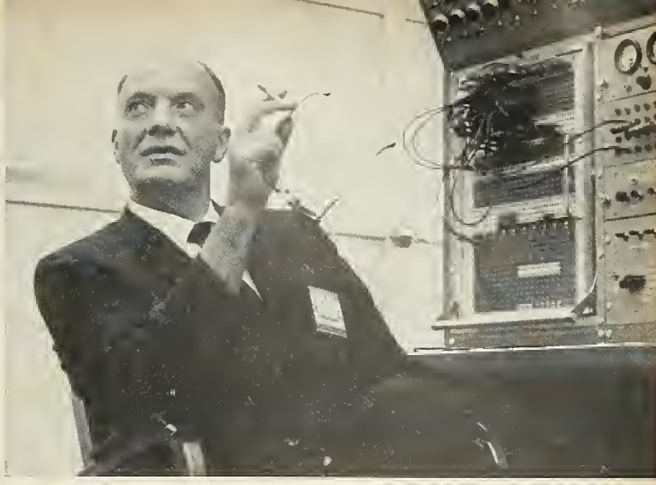
SEASONED IN THE SERVICE

William Wheeler, vice president in charge of Motorola's Military Electronics Division discusses participation role in the B-70 project being developed for the Strategic Air Command at North American.

"North American's pre-award analysis and evaluation, before awarding the contract for the Mission and Traffic Control System of the B-70 Valkyrie to Motorola, was one of the most thorough and extensive ever made."— North American Aviation, Inc.

On the next two pages: Motorola's Seasoned Military Service Record.

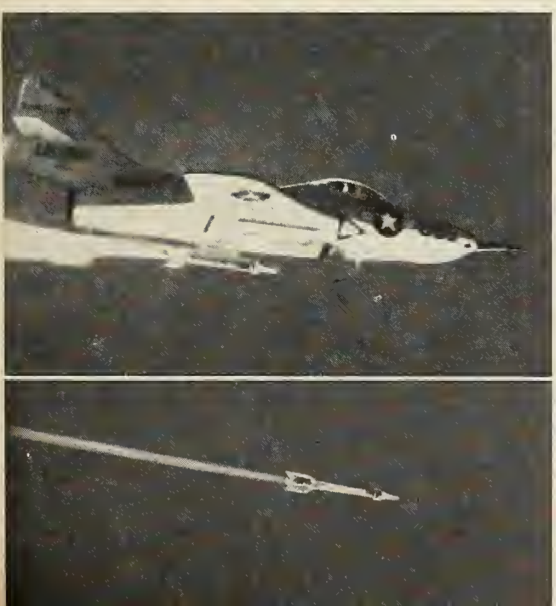
Joe Chambers, Motorola vice president and general manager of the Western Military Electronics Center, directs Phoenix laboratories concerned primarily with work on sophisticated airborne and spaceborne electronics.



John Byrne heads highly classified advanced study and developmental work on a wide variety of military contracts at Motorola's Systems Research Laboratory, Riverside, California.

Development of passive seeker by Motorola, Riverside, is under contract to the Signal Corps for use with U.S. Army drones capable of performing night, day, and all-weather surveillance.

Motorola's surging capabilities in the solid state electronics art is achieving new dimensions in complexity, performance and reliability for new electronic concepts.



Inspection, the eyes of quality control, helps convert experience into reliability at Motorola.

AN/SSQ-23 Sonobuoys for the anti-submarine warfare program in volume production at Motorola Chicago.

Motorola is making significant design contributions to advanced guidance head for Sidewinder air-to-air missile which is under fabrication at Phoenix laboratories.

diamonds where none should be . . .

HUGE TEST STANDS such as this one at Rocketdyne's Propulsion Field Laboratory in Santa Susana mountains, hold engines captive during ground firing tests.

new phenomena may possibly occur. Mineralogical investigation of meteorites have shown diamonds present in structures which were apparently under pressures too low for diamonds to have been formed. Perhaps the pressures resulting from fantastically high-velocity small meteoroid particles colliding with large meteoroids changed carbon into diamonds.

The phenomena resulting from such collisions should be studied by the materials engineer in the hope that some method, such as "bumpers" of some material may alleviate damage. The relationship of alloy structure or material properties to meteor damage alleviation is one of the major problems of the future for the space vehicle materials engineer. At present, the problem looks very difficult, but a few short years ago, the re-entry problem seemed completely insoluble.

Today, the materials engineer acts as consultant on complex materials problems that tend to limit severely the design engineer. Tomorrow the materials engineer will have to supply the very launching pad before the preliminary designer's imagination can soar into tomorrow's tomorrow. A greatly expanded research effort will be required.

Missile 'Innards' Must Take Space Rigors

by Frank McGinnis

GREAT NECK, N.Y.—If we hurled nothing but nose cones into space the materials research people could go back to their golf.

The cone may glow, peel, and erode but the material retains shape, most of its body, and all of its function. This materials problem has largely been solved. But behind the nose cones lies a host of seething components, instruments, and payloads which must live and function in a hostile environment of extreme temperatures and caustic radiation. Using available materials we are in the position of sending boys to do men's jobs.

Anticipated temperatures in uninsulated compartment areas of reentrant manned space vehicles run to several thousands of degrees F. Many materials, which shrug off radiation fail dismally when faced with heat. Beyond 300°C the elastomerics, so perfect for gaskets and seals, must be discarded. Less than perfect rigid materials must be used.

Long term stability is a necessity for materials used in satellites and in missiles maintained in readiness over long periods. With the exception of a few non-polar compounds (polyethylene tetrafluorethylene) the thermoplastics must be eliminated. There are substitutes for the thermoplastics but most of these are susceptible to temperature extremes.

Guidance systems employing floated gyros demand a flotation fluid that remains fluid. The fluorovinyl chloride family, often used in inertial components, solidifies at room temperature. This can cause internal damage and also requires long warm-up time. To alleviate this particular problem we at Sperry have developed a bromo-derivative fluid, Gyrolube Flotation Fluid, which remains in a plastic state to –65°F. This is not the ultimate answer.

The heart of many guidance systems is a grouping of gyros and accelerometers coping with vast distances and extreme accuracies. Measurements on the order of 5 to 10 millionths during fabrication are hardly sufficient. Stability of material after measurement is imperative. Closest to the ideal structural material—combining weightlessness, infinite modulus of elasticity, and dimensional stability—is beryllium. Unfortunately this material presents a health hazard in handling. It is also brittle, difficult to fabricate, fusion weld and braze. In its favor is a melting point of 2345°F making it useful structurally when aluminum (1200°F) and magnesium (1100°F) are liquid.

Mr. Frank McGinnis is the Director of Reliability and Quality Control at Sperry Gyroscope Company, Great Neck, N.Y.

• **Friction question**—Figuring prominently in inertial guidance problems are ball bearings. It has been found that, during fabrication and sizing, minute contaminant particles are introduced into the bearing. When marginal lubrication, necessary for design application, provides a film thickness of merely 1/10 of a micro-inch, the particles of aluminum oxide or other abrasive material can easily be larger than the oil film. During rotation these particles are associated with a release of heat or electrical energy causing a chemical change in the lubricant. Operational usefulness becomes marginal and a new lubricant desirable.

In rotating electrical components, slip ring assemblies add woes to the picture. Organic materials in the air can cause polarization of materials on the slip ring surfaces forming a varnish resulting in open circuits. Wear of brushes and rings seems to be perpetual. A protective coating is needed to prevent varnish formation and minimize wear without harming the electrical function. We are endeavoring to develop materials which are compatible wear-wise and will provide good electrical continuity.

Printed circuit boards suffer under Space Age heat and radiation. Dimensional stability is affected by expansion and contraction. The physical structure (fibrous) prevents subminiaturization by limiting placement of holes. Glass epoxy materials are good only to 150°C and solder techniques must change with solder being liquid at 361°F. Bare copper oxidizes at 500°F. For the board itself, glass or ceramics may be future hopes but machining and fabrication are difficult. Ceramics may well prove to be a rich field for many materials research problems.

• **More study needed**—A long-range view would seem to indicate need for accelerated research in the field of solid and liquid state physics. Recently we have seen ferrites, transistors, cryotrons and MASERS developed. Other components presently under study, and dependent for their operation upon the physics of materials, are nuclear resonators, non-reciprocal circuit elements such as gyrators, and passive elements whose impedances vary with fractional powers of frequency.

In its present form the cryotron is limited to low-frequency operation but a number of generic forms being developed promise great size reduction and higher frequency capability. Noteworthy are the cryotrons made by vacuum deposits of successive layers of superconducting and insulating materials on a dielectric substrate.

This statement of requirements represents a shopping list for the American industry super-market. It has been said that materials are not everything. The reverse is true for missiles and space travel.

Materials Will Have To Outdo Themselves

by Dr. George J. Mills

Dr. George J. Mills is manager, Materials Department, Space Technology operations, of the Aeronutronic Division, Ford Motor Co.

NEWPORT BEACH, CALIF.—The availability, production and application of materials is far behind our capability in systems and component design. This is due, in part, to the physical and technological separation of design, development, and testing on the one hand and materials research and development on the other.

What the limiting materials performance capabilities may eventually be are not now easily defined. We are still uncovering or distinguishing environmental conditions at a far faster rate than materials technology can satisfy.

The great variety of material performance requirements have directed attention to composite structures in which each component performs a function for a prescribed time period. The future is not as easily satisfied since we are asking of materials things that presently appear to be beyond their inherent nature. For example:

• **Ceramics**—Some of the more critical problems facing the missile industry in ceramics are: (1) tailoring combinations of ceramics with other types of materials to withstand environments of increasing severity; (2) improving or creating fabrication processes to produce structural ceramics possessing optimum and reliable physical properties; and (3) improving the understanding of the fundamental behavior of ceramic and allied types of materials.

Of the materials for rocket liners and nozzles, re-entry nose cones and leading edges, no one possesses all the required properties—such as thermal shock resistance, thermal insulation, high strength, corrosion resistance, etc. This establishes a need for composite structures.

The fabrication of large ceramic structures is a relatively new requirement calling for original creative thinking. Ceramics that are structurally sound and reproducible are required for engineering applications. Techniques must still be developed for nondestructive testing of ceramic structures.

From a long-range viewpoint, better understanding of the fundamental behavior of ceramics is needed so that the knowledge can be applied to practical problems. Theories based on atomic dislocations which can clarify such areas as deformation and diffusion are an example.

• **Metals**—Steel is the most important high-strength structural alloy. However, the technical evolution of modern high-strength steels has not kept pace with aircraft and missile design requirements for higher strength-to-weight ratios.

Another important problem is protection of refractory metals against oxidation. Tungsten, tantalum, niobium and molybdenum give promise as ultra-high-temperature structural materials. Unprotected, however, catastrophic oxidation occurs at temperatures as low as 1500°F. For molybdenum there have been developed some coatings that give a significant measure of protection in the 2000-2500°F. range. However, these silicide-containing layers suffer disqualifying instability in the 1200-1700°F range. A stronger integrated attack on this problem through basic research is vitally needed.

In recent years there has been great progress in mechanical properties testing. Ultra-short time and ultra-high-temperature creep-rupture data is available for most well-known engineering alloys. Hot hardness testing is a common metallographic tool. Modulus-of-rupture data are published for many materials, at least up to 1500°F. However, a serious problem is the lack of a definitive test for pressure-vessel failure synthesis. Neither impact nor notch-sensitivity tensile tests can duplicate stress biaxiality. Correlative data are lacking to explain either the mode or the manner of premature failures in pressure vessels.

• **Plastics**—The demand for plastic materials with improved properties has increased from the range 200°F to 650°F, such as encountered in high-speed aircraft, to 5000°F to 10,000°F, such as required in modern space vehicles. Particular emphasis has been stressed on materials with superior properties of ablation, thermal insulation, and high strength-to-weight ratios.

Although only satisfactory as compromises, ablation plastics have been obtained through utilization of improved phenolics, phenolic-silanes, and nylons, in combination with reinforcements of high-silica content, asbestos, and graphite fiber. However, there is still considerable research and development necessary in ablating materials in order to attain the goal in ablation plastics, i. e., the largest amount of heat absorbed per unit weight of ablator.

Probably the greatest area for future research and development will be in knowledge of plastic materials' behavior for long time periods under extreme vacuum and space environments. But first the design engineer must provide information on the operational requirements of space vehicles and their effects on plastic materials.

Pushing Up I_{sp} Brings Fresh Problems

by Dr. Morris A. Steinberg

SUNNYVALE, CALIF.—The most critical immediate materials problems facing the missile industry today concern propulsion and motor casings. Problems in these areas are going to become even more horrendous.

With the aim for higher specific impulse and with the development of better solid propellants, fuel compositions tend toward higher metal content additives. This helps increase specific impulse but also raises a large number of additional problems.

The high temperatures associated with these systems cause vaporization of normally solid reaction products. Their dissociation can also produce finite rates of side reactions. If condensation recombination, and re-establishment of equilibrium is not achieved in the nozzles of high-performance engines, associated energy losses will cause a significant reduction in propellant performance. Chemical kinetics and supersonic flow in nozzles must be explored both analytically and experimentally in order that propellant systems can be optimized to yield the greatest specific impulse.

New schemes of nozzle construction must be rigorously investigated because of the tremendous materials problems that will be associated with the next generation of solid propellants. These include film cooling, ablation, transpiration cooling, etc.

• **New approaches**—The development of ultra-high-strength motor cases consistent with operational pressures and structural integrity, and the development of lightweight plastic-type motor cases are a prime necessity for both missiles and boosters for spacecraft. New approaches, such as shear-spin forming, improved steels and improved welding techniques are of paramount importance.

New concepts in plastic laminate structures, consistent with reproducibility and high strength, should be investigated rigorously. New concepts in refractory metal-organic laminate structures, and methods of laminating refractory oxides with materials that will insure structural integrity for some of the inert components in the propulsion system, are of major interest today. Finally, insulation materials better than those presently available must be developed.

Dr. M. A. Steinberg is Manager of the Materials and Propulsion Research Division of Lockheed Missiles and Space Division.

Although there have been significant advances in overcoming the atmospheric re-entry problem, much more remains to be learned—use of ceramics as refractory coatings for other refractory metallic materials, for instance.

The inherent brittleness of ceramic materials—and the difficulty of producing large shapes of complex design—limit their usefulness in certain critical applications. However, we are counting on new fabrication techniques to yield products that can be used. For example, metal-reinforced ceramics: filaments of the refractory oxides fabricated by filament wrapping techniques and bonded with inorganic materials, capable of withstanding higher temperatures than present resin-bonded fiberglass structures.

As concerns re-entry bodies, a better understanding of the ablation process would seem one of the major research activities that must be undertaken. We should investigate the potential use of *inorganic ablators* to absorb larger amounts of heat, with these ablators having very high "Q" stars (BTU/lb).

• **Vacuum effects**—One final major area of activity that I would like to stress is that of surface effects in spacecraft materials. Surface phenomena are among the least understood of reactions involving materials and their interaction with their environment. The affect of prolonged exposure of materials to the vacuum of space presents a large new field of endeavor necessary to navigation in space.

Low vapor pressure alone will not assure permanent dimensions, particularly with sufficient heat input to materials. Absence of gas films will permit sizing and galling of sliding or contacting parts. Lubrication in space will present greater problems and will be more generally required than in the earth's atmosphere.

The effects of ascent heating, solar ultraviolet radiation, vacuum, micrometeorite bombardments, Van Allen radiation, and molecular bombardments should be investigated so that proper preparation can be made of these surfaces to assure temperature control being exercised at all times. In addition to flight environment effects on surface emissivities, the shop environment must be taken into account. It is needed to determine manufacturing controls.

Coping with High Flame Heat

by Eugene L. Olcott

ALEXANDRIA, VA.—In general the hardware on solid-propellant rockets has gone through three historical phases of development.

Solid propellants employed in the barrage rockets of World War II burned with high flame temperatures. Heavy hardware and the accompanying heat-sink effect were employed to obtain endurance of materials in these flames.

Eugene L. Olcott is director of the Materials Division of Atlantic Research Corp.

The next stage of development saw the use of propellants with lower flame temperatures so the hardware could be lightened, thus increasing missile performance.

The latest phase of development is a return to high flame temperatures to increase propellant performance, maintaining light hardware to retain its missile-performance advantages. It is this combination of high flame temperatures and light hardware—together with other advances, such as increased burning time and pressure—that presents challenging materials problems.

Considerable progress has been made. It is interesting to note that designers of liquid-propellant rocket

motors are considering materials applications used for solid-propellant motors in lieu of regenerative cooling.

The most critical problem areas in a solid-propellant rocket motor are (1) the motor case, (2) the motor-case insulation for high-performance end-burning motors, and (3) the nozzle insert. For nominal operating conditions, some of these problems are readily solved with current materials technology.

• **Motor case**—The problem of minimizing motor-case weight (while containing the high internal pressure) has been partially solved by the use of high-strength alloy steel. Alloy steels have poor resistance to crack propagation when heat-treated to an ultimate tensile strength above 240,000 psi. However, this fault can be overcome by heat-treating below this strength level.

• **Motor-case insulation**—Motor-case insulation in an end-burning rocket is a particularly severe application for materials. Parts of the insulation are in contact with hot combustion gases for the full burning duration. The steel motor case must be insulated to maintain a temperature below 600°F. The insulation must form with the motor case without cracking under internal pressure. In the *Iris* sounding rocket, for example, motor-case insulation weight is only 5% of the propellant weight. Even further weight reductions are planned by using less of an improved modified-epoxy system.

• **Nozzle insert**—The material problem encountered in designing a nozzle insert is a particularly difficult one. Here exist all the complications of chemical reactivity, erosion, thermal shock, differences in thermal expansion of mating parts, and fabrication. The surface of the nozzle insert closely approaches the gas temperature, since it must be insulated from the structural parts of the rocket motor. Refractory metals and alloys have limited applications.

In these instances, design problems are further complicated by the poor thermal shock resistance of ceramics. On the other hand, high-temperature strength has not been a critical factor when adequate support of the nozzle insert is possible.

We will have to use brittle and difficult-to-fabricate materials. The highest attainable strength-to-weight ratio for structural parts will continue to demand attention. Hopefully, continuing advances in materials technology will furnish further improvements in materials performance before we will be forced to resort to cooling or other involved means of alleviating the materials problem.

Call for Scientific Approach

by Coleman Raphael

FARMINGDALE, N.Y.—In the evolution of the aircraft and missile industry, the development of materials to meet specific needs has generally been treated as an art, rather than as a scientific branch of a technical industry. Now, with the sudden rapid strides of missile and rocket development, and the advent of a new technological field, astronautics, the need for a more scientific approach to material development is clearly indicated.

One of the critical shortcomings associated with today's materials is the lack of information concerning their properties. A typical example of this was evident recently with the sudden popularization of titanium, the "wonder" metal. Everybody "wondered" how it could be used efficiently. The manufacturers who were producing titanium alloys (at premium prices), while publicizing their light weight and high static strengths, had essentially no information concerning their properties in fatigue, impact, creep, and various thermal environments.

A much more desirable approach to the materials problem is one in which the requirements are first specified, and then the combined talents of the chemist, metallurgist, and physicist are directed toward the development of a material to satisfy these requirements.

Many techniques are available for production of desirable mechanical and physical properties. The organic chemist, for example, is able to select radicals and form molecular chains that will synthesize compounds having specified characteristics. The metallurgist knows the effects of small amounts of alloying elements on crystal structure, the way that grain size and distribution affects properties, and the variations of grain size with heat-treatment and cold-working techniques. By directing a concerted effort toward the utilization of these techniques, it should some day be possible to design a material "to order," to meet the requirements of manufacturing simplicity and reliability in withstanding its environment.

Coleman Raphael is Manager, Advanced Projects, for the Missile Systems Division of Republic Aviation Corp.

• **Temperature barrier**—Most of the major obstacles to astronautical development in the next decade fall within a single category: the need for withstanding sustained high temperatures. For example, the performance of a rocket engine is critically dependent upon the specific impulse of its fuel. Today we are using specific impulses of about 240 in solid motors with the ability of making a sizeable increase by the addition of suspended aluminum particles to the fuel. In the future, with the use of lithium and other high-energy fuels, it will be possible to make tremendous increases in rocket performance.

However, specific impulse is proportional to the square root of chamber temperature. To make efficient use of lithium fuels, it will be necessary to bring chamber temperatures to over 6000°F (with proper oxidizers chamber temperatures could reach 8000°F). The problem will then be the development of rocket engine liners, nozzles, and launching platforms to withstand these temperatures. Today, using ablating Refrasil liners, the maximum chamber temperatures which can be withstood satisfactorily are in the range of 2000 to 3000°F.

Vehicles that are to fly within the atmosphere at high supersonic or hypersonic velocities will be subjected to external skin temperatures as high as several thousand degrees. It is, therefore, necessary to have materials that can withstand these temperatures, simultaneously carrying air loads and being able to deform with the structure. The most promising materials for resisting temperature over 2000°F are the refractories and their alloys—tantalum, molybdenum and tungsten. However, these materials are at present too brittle to be worked or machined. One of our major problems will be to increase their ductility and adaptability to aircraft and missile manufacture.

To find solutions to these problems, we should abandon our present custom of developing new materials, marketing them, and then investigating their properties. Instead, we should begin to seek *an understanding of the fundamental characteristics of materials on a molecular and submolecular basis, so that it may someday be possible to tailor the design of a new material to its specific requirements. A major research program in this direction will probably require government support, but the results should be well worth the investment.*

No Magic Materials in Sight

by John L. McDaniel

John L. McDaniel is assistant technical director of the Ordnance Missile Laboratories Division, Army Rocket and Guided Missile Agency.

HUNTSVILLE, ALA.—The most critical materials problems facing the missile industry today and upcoming in the next decade in the area of field Army weapons may be broken down into three major categories:

1. Missile structures that achieve adequate compressive strength with minimum weight.

2. Solid-rocket motor cases that attain a very high strength-to-weight ratio within a moderate temperature environment.

3. Lightweight materials to withstand the environment of the exhaust products of solid-propellant rocket motors.

In the case of the solid-propellant rocket, the motor cases must withstand the loads from the internal pressure of the combustion and those from aerodynamic loads. To reduce the weight of the casing materials, designers have allowed for stresses that just about equal the maximum yield strengths that can be realized with steel.

It is with these high-yield-strength steels that the problem of brittle failures has become paramount. While this brittle nature of the steel may be tolerated in a motor case, it is a limiting factor in dome ends that contain thrust reversal mechanisms or ports, thereby setting up areas wherein the stresses cannot redistribute themselves because of the brittle nature of the steel.

• **Material limits**—The combustion products from the rocket motor are exhausted through a nozzle carefully designed to control the thrust. The greatest gains in performance and economy for future field army weapons will be realized through higher gas temperatures. The gains are limited today by the strength of structural materials at high temperatures.

A major challenge in the next decade is to provide structural materials to use in a nozzle exhaust environment of 7000°F for durations up to 100 seconds. In addition to withstanding the high thermal flux from the exhaust gases, the nozzle divergent section is also the structural member to which a variety of vector control devices may be attached, so this member must also have adequate section modulus and strength at the elevated temperature.

The most critical materials problem facing the missile industry today is one of *engineering*. No magic materials are likely to appear overnight; therefore, systems must be designed around existing materials.

Effects of Environments

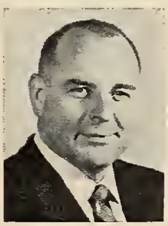
by John Van Hamersveld

HAWTHORNE, CALIF.—To evaluate the most critical materials problems facing the missile industry today, and enigmas with which the industry will be faced during the next decade, it is desirable to review some of the environments under which rocket, missile and space capsule materials must operate with a high degree of reliability.

The following four general environments may drastically effect the behavior of the present and future materials:

1. Severe conditions imposed by liquid-propellant, solid-propellant, and nuclear-powered rockets.

2. Conditions imposed by natural hyperenvironments.



John Van Hamersveld is general supervisor of the Design Support Branch of Norair Division, Northrup Corp.

3. Conditions imposed by induced hyperenvironments.

4. Conditions imposed by a combination of natural and induced hyperenvironments.

Developers and producers of rocket powerplants should be more intimately acquainted with materials problems in their field than the rocket, missile or satellite systems developer. Although solid- and liquid-propelled rocket motor materials are subjected to extremely high temperature and highly corrosive fuels, the exposure is usually very short.

Conditions imposed by induced hyperenvironments with which rocket, missile and space capsule builders are faced include the following items: temperatures ranging from about –420 to +6000°F; thermal shock of an entire vehicle caused by re-entry and of components; mechanical shock; acceleration effects; acoustic vibration; mechanical vibration; explosive decompression; and nuclear radiation.

To envision how numerous possible combinations of natural and induced hyperenvironments could affect rocket, missile, and space capsule materials systems requires little imagination.

A study of possible environments reveals that the most critical materials needs now facing the industry include:

• **Optimum materials** system—development of materials that, when combined structurally, act as an optimum integral unit.

• **Structural** metallic, non-metallic, and composite materials that resist temperatures ranging from –420 to +6000°F and that are relatively immune both to electromagnetic and energetic particle radiation.

• **Ductile protective coatings** capable of resisting a wide range of temperatures, and radiation for periods of time ranging from three hours to a year.

• **Low-density** materials that can be utilized in the design of lightweight vehicle structures and payloads.

• **Fasteners** capable of satisfactory service at temperatures of at least 3000°F.

• **More economical** methods for forming metal components. This includes precision explosive forming of super alloys and refractory metals.

• **Techniques** for improved similar and dissimilar metal joining. This includes explosive forming and electron beam welding.

• **Wrought beryllium** products such as sheet, tube, forgings, and extrusions.

• **High-strength, high-temperature** metallic sandwich structures made from refractory and exotic metals or alloys such as molybdenum, tantalum, columbium and beryllium.

• **High-strength, high-temperature non-metallic** fabrics, such as woven quartz fibers for parachutes and insulating blankets.

• **Plastic forming methods** enabling forgings and extrusion of refractory metals to be accomplished while the materials are in their most plastic solid condition.

• **Sealing materials and systems** wholly compatible with a materials system.

Future Temperature Problems

by Harry A. Campbell

NIAGARA FALLS, N.Y.—Although much publicity is given to the effects of aerodynamic heating of missile nose cones, it appears that designs employing ablation-type materials are suitable for present requirements. The major problem remains that of discovering materials possessing the greatest possible strength-weight ratios over wide ranges of temperature.

Among the metals, molybdenum, tungsten, niobium and their alloys are under extensive investigation. High-strength steels in the 300,000 pounds per square inch range are needed for rocket engine chambers, especially for solid propellants. Means of fabrication of these materials remain problem areas because of the high costs. Welding is of special importance here.

Molybdenum, tungsten and niobium oxidize rapidly at temperatures of 1500°F and above. This could be catastrophic. Search for oxidation-resistant coatings is active. A few promising coatings have appeared but experience is needed with a full-scale structure under load. A reliable method of inspection for the integrity of such coatings is seriously needed.

H. A. Campbell is the Director of the Engineering and Research Laboratories, Bell Aircraft Corp.

Still another set of problems is presented by beryllium, a metal with attractive structural properties.

• **Fabricating problems**—Although beryllium has a low density/modulus ratio, it is difficult to recover and to produce; it is inherently brittle and must be fabricated with great care. Extensive efforts are being made to obtain suitable shapes and develop better methods of working and joining it.

Some astronautical materials problems visible to the next decade can be summarized somewhat as follows:

• **Overcome** the brittleness problem in beryllium.

• **Produce** ductile ceramic materials in large shapes.

• **Find** means to raise the recrystallization temperature for heat-resisting alloys.

• **Improve** resistance to oxidation of heat-resisting alloys with or without coatings.

• **Improve** the strength properties of existing alloys by at least 25%: preferably 50%.

• **Develop** non-metallic large strength-weight ratio materials for continuous service at 1000°F or higher.

• **Develop** light-weight nuclear shielding materials.

Materials To Fit The Needs

by E. J. Dofter

DETROIT—The phenomena surrounding the brittle-fracture of pressure vessels fabricated from high-strength steels constitute the material problem requiring the greatest attention in the missile industry today.

A satisfactory solution that can predict the behavior of steels, particularly at high hardness levels under complex stresses, is still not available. Such a theory is needed. Also, we need a simple laboratory test, results of which will correlate well with service failures of pressure vessels.

E. J. Dofter is the Assistant Chief Engineer, in the Missile Division of Crysler Corporation.

Most other critical missile material problems have their roots in the behavior of the material as it is affected by its environment. By far the greatest volume and tonnage of materials in use today eventually finds its way into a product which is used in ambient environment. As a result, a great amount of data and experience is available in the behavior of materials in these environments.

Materials in the missile industry require that they be used at extremes of environments which were not common even five years ago.

Two courses of action have been pursued in fulfilling missile material requirements. The first has been to develop new materials and alloys to cope with these environmental extremes. The second has been to obtain better data on commercial materials so that they can be better understood and intelligently employed in these new environments. I recommend the latter course of action as being the most productive on the short haul.

• **Common materials**—The majority of materials used in the missile industry are not new. It is their use that is new. It is possible to use common materials in new applications after their properties are well known and correlated with the requirements of the surrounding environment.

The propellants used in the missile industry are, of necessity, materials with great chemical activity, which creates problems of corrosion and explosion in storage and handling. There is a great need of improving nonmetallic polymers, adhesives, and sealants which must come in contact with high-energy propellants such as chlorine-trifluoride, hydrazine and hydrogen tetroxide.

In the next decade, progress undoubtedly will be made in the solution of the above problems; but new problems will arise as the frontiers of space flight are extended. One of the major impending problems about which very little is known is the behavior of ordinary materials when subjected to the hard vacuum of outer space.

The effects of radiation that occurs in space must also be studied. The predicted problems of the next decade, as we see them from our present vantage point, will undoubtedly have to be revised as our space program continues. The VanAllen radiation belt, for example, was not even included in the problems of ten years ago. We must be prepared to face new difficulties as our knowledge of outer space increases, and we should also expect to solve these problems as this knowledge increases.

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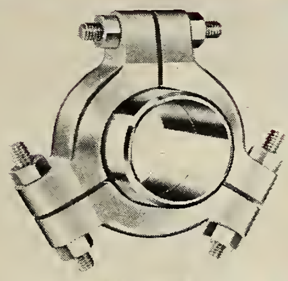

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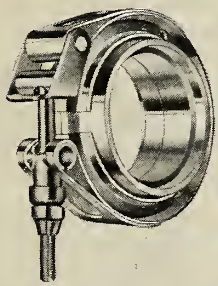

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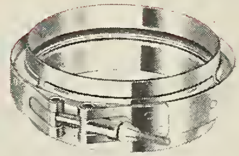

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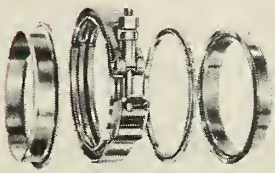

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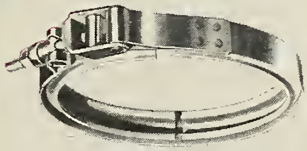

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Hot-nose Missiles Need Better Radomes

Super ceramics are being developed and new fabrication methods make alumina promising for high-temperature uses replacing plastics

by **Hal Gettings**

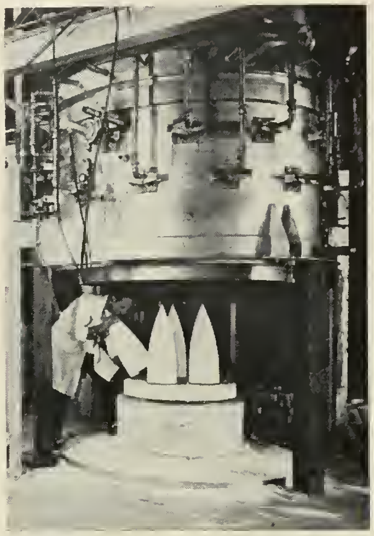
WASHINGTON—Hot-nosed hypersonic missiles pose demands for ceramic materials far superior to those available at present. Air friction heat generated by the high-speed birds practically eliminates conventional plastic noses. Metals, obviously, cannot be used since they are not transparent to radio waves. Much research is in progress.

The radome serves as a protective covering and window for the radar antenna. Its shape—a projectile ogive—is a compromise between aerodynamic and electromagnetic ideals—with electromagnetic considerations the loser. The resulting configuration poses problems in both transmission characteristics and fabrication processes. These problems, not too severe with plastic structures, become especially troublesome in ceramic construction.

First major work in ceramics was by **Corning Glass** which developed Pyroceram radomes now used on the *Tartar* surface-to-air missile. Now considerable research is being done with alumina (aluminum oxide), a metal oxide that produces a ceramic with all the required characteristics of missile radomes. Both Corning and **Raytheon** have apparently ironed out most of the problems in producing noses of the required shapes and sizes with this new material.

Alumina is attractive for radome application for a number of reasons. Primarily, its most important attribute is a stable dielectric constant over a wide temperature range. Some trouble has been experienced with dielectric homogeneity, but research shows no insurmountable problem.

A second vital characteristic is resistance to thermal shock. Aerodynamic heating causes temperature changes of several thousand degrees within a few seconds. This tends to weaken the structural properties of the radome material. In addition, thermal gradients in the structure cause thermal stresses which can fracture the material. Alumina has successfully demonstrated its resistance to these shocks and stresses up to more than 4000°C.



ALUMINA nose cones for *Sparrow III* missiles are mass-produced at Gladding, McBean & Co.

• **Rain erosion**—In general, alumina is one of the most satisfactory refractory oxides for a wide variety of environments. It is unaffected by air, water vapor, vacuum or common atmospheric chemicals up to temperatures above 1700°C. It is much harder than glass and many metals, a factor extremely important due to the rain-erosion problem in high-speed missiles. Water droplets hit the surface of the radome like bullets with impact pressures high enough to fracture most materials.

The big problem with alumina radomes is in fabrication. Both Raytheon and Corning use the "slip-cast" method of forming. The nearly liquid alumina slip is cast in molds and, after hardening, is fired at high temperatures in much the same manner as conventional pottery. In the "green" stage, large castings have a tendency to slump, or deform, if not handled properly. Techniques have been perfected only recently to minimize this characteristic.

Research is aimed at producing a finished casting that needs no further work. This has not been successfully done to date, however. The rough casting must be machined to provide the critical wall thicknesses and smooth outside contour required. Due to its hardness, the alumina must be finished down with diamond tools. This process is one of the more critical operations and is expensive and time-consuming.

Gladding, McBean & Co., Los Angeles, has produced ceramic radomes for the *Sparrow III* by forming alumina on steel mandrels. (M/R, 3/16/59). Alumina, in the form of slurry, is sprayed on the steel forms and, after drying, subjected to pressures of over 30,000 psi to obtain a uniform density. The radome receives a preliminary firing and is then machined to the final thickness and contour. Final firing is at 3000°F. The company is presently working on a WADC contract for study phases and delivery of radomes for unspecified missiles.

The necessity for precision techniques is easily understood when a radome is considered as a lens that must be transparent to the outgoing and returning radar signals. It must not attenuate the signal nor bend the beam and yield false target information.

Basic optical laws apply and the slightest imperfection or varying thickness will produce undesirable refraction and aberration. Happily, due to the frequency (wavelength) of the radar signals and the scan pattern, the point of the nose—which would apparently present an optically impossible configuration—is not important.

Engineers working with alumina feel there is no practical limit to the size of domes that can be built. Corning has made alumina units as large as three feet in length and has bid on 12-foot units. Raytheon has produced radomes approximately four feet in length and 20 inches in diameter. Both companies feel that alumina domes can be mass-produced in quantity at reasonable cost.

Mercury Needs Based on Safety

NASA and capsule contractors pick laminated glass fiber and resin for heat shield, nickel cobalt for outside skin, titanium for inner vessel

by C. Paul Means

WASHINGTON—The materials to be used in the final *Mercury* capsule design that will take man on his first flight into space are laminated glass fiber and resin for the ablation heat shield, nickel cobalt for the outside skin, and titanium for the inner pressure vessel.

These materials were selected after extensive research conducted by the National Aeronautics and Space Administration at the Langley Research Center, by the *Mercury* capsule's prime contractor—**McDonnell Aircraft**—and by the **B. F. Goodrich Co.**, the **Cincinnati Testing Laboratories**, and **General Electric Co.**

Most important to the welfare of the astronaut is the heat shield, which must withstand temperatures of about 2600°F upon re-entry if he is to survive.

• **Tests satisfactory**—The laminated glass-resin ablation shield was picked because of its ability to withstand temperatures of 3000°F. One of this type made by B. F. Goodrich Co., worked perfectly recently when boosted 100 miles down the Atlantic Missile range by an *Atlas* booster.

During this test, the capsule reentered the earth's atmosphere at an altitude of about 250,000 feet, traveling 14,000 miles an hour. The blunt shape of the heat shield plowing into the atmosphere slowed the vehicle to approximately 500 miles an hour.

Maximum temperatures on the outside skin of the shield reached about 3000°F during the critical minute or two of re-entry, and resisting air only a few inches ahead of the plunging capsule hit a temperature of about 10,000°F for a few seconds.

The laminated glass-resin ablation shield dissipated heat to the extent that temperatures stayed below 150°F within the titanium pressure vessel during the critical moments of re-entry. Throughout the rest of the trip, about 1400 miles down the Atlantic Missile Test Range, temperatures were kept between 80 and 100°F by an air conditioning system.

Detailed specifications for this heat shield and material were developed by the General Electric Co. The work of laminating the materials and forming the shield was done by B. F. Goodrich, and the shield was then sent back to GE for final machining and installation of sensing devices.

The favorable properties of the laminated glass-resin type of ablation heat shield include high liquid viscosity at high temperatures, low thermal conductivity, high energy of vaporization; and good thermal stress characteristic.

The plastic-like substance formed by the laminated glass and the epoxy rosin forms a liquid film rapidly, which being a poor conductor of heat, protects the shield against the initial thermal shock preventing sudden boil-off.

• **Structure material**—Behind the heat shield is the capsule's structural skin made out of nickel-cobalt. This material was picked for the capsule because of its strength, light weight, and ability to withstand heat.

Nickel-cobalt has been used with great success to solve the aerodynamic heating problem in high-speed airplanes and missiles. It has proved to be sufficient in the early capsule tests.

RE-ENTRY HEAT shield of abradable plastic by CTL is used in McDonnell's development of *Mercury* capsule.

Principal reason that titanium was picked for the inside pressure vessel is its ability—demonstrated in missilery—to withstand high temperatures without buckling.

Research into the problems of aerodynamic heating is difficult because it is almost impossible to simulate the extreme heat conditions of re-entry on the ground.

The Langley Research Center has been able to solve this problem by simulating the time and chordwise temperature variations with the use of radiant heat lamps. During tests, the radiator is lowered so that it is parallel to and only a few inches above the capsule. Structural temperatures of 2500°F can be produced on the model by this method.

For the space vehicles to follow after Project *Mercury*, NASA is working on two newer types of heat shields that withstand greater heat and allow the capsule to have a greater angle of re-entry.

One type under investigation uses an insulating material which is held in place on the load-carrying structure by a thin metallic outer skin. The outer skin is corrugated to provide a means for absorbing thermal expansion and to provide sufficient stiffness to prevent flutter. This design will be fabricated from a refractory metal such as molybdenum, niobium, or tungsten, and will reducing the temperature of the load carrying structure to 1200°F when the heat shield surface temperatures are 2500°F.

Another type of heat shield under investigation has an added heat-absorbing capacity in the form of water which is stored in a light absorbent material in channels formed by the stiffeners on the structure. This type of shield provides protection to the entire capsule structure and can hold the structure's temperature to that of boiling water. A more complicated structure design will be needed because of the difference in temperature between the shield and the structure.

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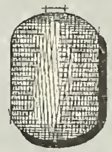

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MISSILE SUPPLIERS SPEAK

Here is a partial answer to the questions posed in the preceding section. MISSILES AND ROCKETS *asked leading materials suppliers to outline the state of technology, advances and limitations, and detail the applications to missile, rocket and space vehicle requirements of their special fields.*

Contributors also were asked to project the future trends of the technology and give their estimates of relative importance. Replies were received from 47 companies. Their statements are grouped in these categories: refractory metals; ceramics, insulation and coatings; plastics; tubing; metals; metalworking.

Refractory Metals

Machining Molybdenum Alloys

by George H. Waldeck

CLEVELAND—Vectoring nozzles which direct extremely hot and erosive solid rocket exhaust gases require utilization of new materials and introduction of new fabrication techniques.

The old concept of "high temperatures," such as 200°F to 1600°F, has given way to new working ranges of 1500°F to 5000°F. No engineer concerned with design or performance can disregard the inevitable conclusion that even higher temperatures—approaching 7000°F—will be standard factors with which to contend in the construction of future missile and rocket systems.

Of the refractory metals, molybdenum, tantalum, and tungsten maintain reasonable structural integrity at elevated temperatures. Molybdenum, with a melting point of 4760°F, is the most readily available of the three. Although rapidly and extensively eroded at high temperatures (a factor shared to varying degrees by all the refractory metals), molybdenum retains—for short duration–appreciable mechanical properties at temperatures approaching its melting point.

Experience in the successful fabrication of molybdenum nozzle components proves that cold molybdenum responds to most machining processes in much the same way as cast iron. But it is more brittle and offers considerably more resistance to drilling and cutting, with a resultant increase in tool attrition. Moderate heating of molybdenum stock improves machinability characteristics without impairing tool life. Correct tool geometry is essential but all machining can be carried out with minor refinements in existing conventional processes.

George H. Waldeck is Assistant Project Manager at the Systems Engineering Division of Cleveland Pneumatic Industries Inc.

Molybdenum's suitability quickly diminishes when the exhaust flame temperatures equal or exceed its melting point. Its useful temperature range can be extended somewhat by resorting to heavy "heat sink" designs; however, this would mean a prohibitive weight penalty. In a nozzle intended for use with the new high-performance grains where flame temperatures may exceed 6000°F, protective coatings might be a help. However, their reliability is still questionable. The next step is to look at tungsten or tungsten alloys.

• **Hot working**—Extensive experimentation has been carried out on a 50-50 W-Mo alloy to determine its machinability and to develop improved cutting techniques. Brittleness is accentuated to such an extent that cold processing results in extensive chipping and flaking. Tool attrition, in a cold process, is increased over the wear encountered in drilling pure molybdenum by at least 600%. By raising the temperature of the alloy during processing to 400°F-600°F, both drilling and cutting were vastly improved, and tool attrition and flaking and chipping were substantially reduced.

Since the temperatures necessary for proper handling of the alloys fall well below the critical temperature of recrystallization, repeated heating and cooling have no deleterious effect on the tensile strength or structural integrity of the material.

Experimentation indicates that comparable heating will permit successful machining of pure tungsten. Both tool material and geometry are very important in all cutting operations and major departures must be recognized in the cutting processes on both pure tungsten and its alloys.

There are several areas in which additional research is urgently needed before the refractory metals can be handled by either engineers or shop personnel in a wholly satisfactory manner. Three of these are: (1) Specifications for ultrasonic testing of the refractory metals. (2) Research in hot working and die forging processes at higher temperatures and in inert atmospheres. (3) Determination of mechanical and physical properties of the refractory metals in the region of 5000°F.

Moly Gains Point the Way

by Charles W. Brunstetter

HAWTHORNE, N.J.—The refractory metals are now being seriously considered for leading edge and other structural applications in advanced air and space vehicles. One reason is that re-entry frictional heating will subject the leading edge of a hypersonic vehicle to temperatures approaching 3000°F.

The refractory metals promise a solution to the temperature-strength-weight problem posed. Until now, however, these metals defied fabrication into sound structures, using conventional metal fabricating techniques. In addition, molybdenum was found susceptible to destructive oxidation at temperatures far below its maximum, desirable temperature limit.

In the past year **Astrometals Corp.** has developed a joining technique, on an experimental basis, for the successful fabrication of molybdenum. Information gained could conceivably lead to development of fabricating techniques for the other members of the group. In addition, molybdenum's susceptibility to high-temperature oxidation has been reduced through development of a protective coating.

Working with the National Aeronautics and Space Administration for the past year fabricating structural components from both coated and uncoated welded thin molybdenum sheet, we have developed resistance-welded sandwich structures with unusually high ductility and weld strength, which shows great promise.

Of the available refractory metals, the following appeared to have the most promise as structural material: molybdenum 0.5 Ti **(Universal Cyclops Steel Corp.)**, niobium 10Ti. 10 Mo. **(E. I. duPont de Nemours & Co.)**, and tungsten **(General Electric Co.)**.

- **Coating stable**—We can now successfully fabricate structural components of 0.5 Ti molybdenum coated with **Chromalloy Corp.** W-2. They are formed at room temperatures and spot welded together. A special coating provides stability at temperatures up to 2800°F, compared to 2000°F formerly.

Sheet preparation and welding have yielded finished structures with good physicals. Longitudinal strengths of welded samples are approximately 80-90% of solid, extruded forms. In addition, the ductility of the resistance-welded molybdenum structure permits repeated flexing and straightening.

Molybdenum's well-known loss of ductility at sub-zero temperatures has also apparently been overcome. Plastic deformation can now be induced at below −100°F in treated material.

Evaluation of these structures on the basis of molybdenum's high thermal conductivity, low co-efficient of thermal expansion, high modulus of elasticity and high mechanical strength at elevated temperatures, promise a good, "hot" leading edge.

A structure with molybdenum as the skin and niobium as a supportive sub-structure seems to show promise, if anti-oxidation coating problems can be solved. A composite welded structure of this type can be made but the coating that gives the molybdenum good protection now embrittles the niobium.

- **Up to 4200°**—The future of "refractory metals" appears extremely promising. Design engineers should soon be able to fabricate structures capable of withstanding temperatures as high as 4200°F for one hour.

Under a NASA contract, we are researching the potential of *all* refractory metals and their coatings. Emphasis is on fabrication of structures from thin sheet and their oxidation protection at high temperatures. Metals used in this investigation are molybdenum, niobium, tungsten, tantalum, beryllium (not classified as a refractory metal) and their alloys.

Tests will be made on methods of joining: resistance welding, electron-beam fusion, welding, riveting and ultrasonic welding. Work already started on molybdenum has resulted in good fusion welds, with good ductility, using the electron-beam welding techniques. Fabricated structures will then undergo protective coating evaluations for different environments. Structure types will include: primary load-carrying structures, radiation and heat shields, leading edges and nose cones for hypersonic vehicles.

Advances in refractory metal technology are assured by the R & D work being carried on by both NASA and the Wright Air Development Command, the molybdenum sheet-rolling program of the Bureau of Aeronautics, and the U.S. Navy-Universal Cyclops Steel Corp.'s "In-Fab" project. **Du Pont** is building a new, experimental refractory metal processing plant in Baltimore. General Electric Co. has a new type of molybdenum sheet (HD), which demonstrates a room-temperature ductility five times that of ordinary molybdenum. **Climax Molybdenum Co.** issued on Aug. 26, 1959, Specification Bulletin # CMX-FB-1, covering improved vacuum-arc-melting forging billets of molybdenum. Universal Cyclops is currently writing a specification for 0.5 Ti molybdenum sheet. **Bell Aircraft Co., Boeing Airplane Co., Pratt & Whitney Aircraft** and others are also working with refractory metals.

One observation is now justified: the super alloys of the jet engine age can not withstand the extreme temperatures anticipated in a manned hypersonic global plane's re-entry. The refractory metals provide us with the best current answer to these requirements, assuming that fabrication and service problems can be overcome. The good start, with molybdenum, points to the possibility that we will be able to utilize all of the refractories in the space program.

Charles W. Brunstetter is vice president of Astrometals Corp., formerly T. R. Finn & Co., of Hawthorne, N.J.

Tungsten Shapes Now on Hand

by John C. Redmond

PITTSBURGH—Heretofore virtually impossible to fabricate, pure tungsten and alloys such as tungsten-molybdenum and tungsten-tantalum are now available in hollow conical and cylindrical shapes, up to 8" diameter and 4" long. Billets 4½" diameter and 12" long are also available and can be forged into finished pieces.

By vacuum sintering techniques, we are currently producing tungsten metal of 99.9% purity with densities exceeding 90% of theoretical, which makes this material suitable for forging at 3400°-3500°F. Preliminary tests indicate that tungsten produced in this way has remarkable machinability characteristics at room temperature, after forging.

Equipment is now being designed and constructed to produce ingots of pure tungsten 10" in diameter and up to 18" long, weighing 900 pounds. By shaping before final sintering, special conical and cylindrical shapes are produced to relatively close tolerances, thereby greatly simplifying the forging operation for the finished end product.

Tungsten, twice as heavy as iron, has a melting point of 6170°F, the highest of the refractory metals. When weight is a critical factor, tungsten may be combined with other lighter metals of comparable metallurgy such as molybdenum, one-half the weight of tungsten, whose melting point is 4748°F. **Firth Sterling** is presently producing an alloy of 50% tungsten and 50% molybdenum with a melting point close to 5300°F in preformed shapes, requiring minimum forging.

Because of its excellent high-temperature properties, tungsten is a most desirable material for components in jet aircraft and engines, missiles and space vehicles. It also has important potential for radiation shielding, counterweights, gyro rotors, and many other commercial applications.

John C. Redmond is director of Powder Metals Research & Development for Firth Sterling Inc.

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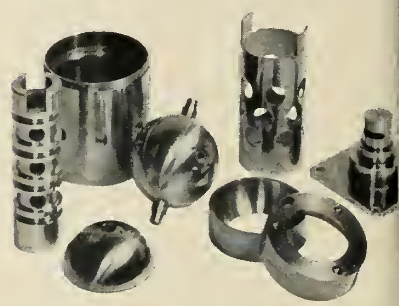

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Refractory Metals

Tantalum Easy To Fabricate

by Dr. James H. Gardner

CAMBRIDGE, MASS.—For all applications over 3000°F, tantalum is an extremely interesting alloy base because of its combination of high melting point (5430°F) and extreme ease of fabrication.

Tantalum-tungsten alloys are now being investigated for missile applications because of their remarkable high-temperature stress-rupture properties and because of their relatively high workability.

Applications for tantalum and tantalum-tungsten alloys in the missile field include exhaust nozzles, engine parts and other structural components subjected to very high temperatures. Possible skin and structure applications include leading edges and hot walls in boost-glide or other vehicles which must spend appreciable times in re-entry and maintain their structural and aerodynamic properties. *Dyna-Soar,* for example, will require a reusable leading edge material able to withstand 2500° to 3000°.

Dr. James H. Gardner is General Manager of the Metals Division, National Research Corporation.

The prime disadvantage of both tantalum and tungsten is their high density (Ta—16.1; W—19.3). Strength-weight ratio at operating temperature is the limiting design criterion in most cases. On this basis, tantalum alloys become competitive or are preferred well below 3000°F. Tantalum-tungsten alloys are more oxidation-resistant than either element alone, but coatings will be needed in oxidizing atmospheres.

Ceramics, Insulation and Coatings

Alumina Kilns in Operation

by R. C. LeMay

DRESHER, PA.—Effective heat treating is vital in producing and testing missile and rocket components. Representative critical heat-treatments include firing of ceramic radomes, heat-treating of metal casings, and exposure of electrical components to accelerating temperatures and velocities to stimulate re-entry conditions.

Prominent among high-temperature materials being developed and employed in radomes and other critical missile parts is high-alumina ceramic. Its firing temperatures approach practical maximums for both air-gas flames and for the better known lining materials. But, alumina kilns have been built and are now operating satisfactorily, and still larger kilns will be constructed to turn out the larger missile components anticipated. Kilns of still higher temperature capability can now be produced by using oxy-fuels for combustion and stabilized zirconia linings.

R. C. LeMay is Manager, Contract Sales Research and Engineering, Selas Corp. of America.

For simultaneous overall heat treatment of metal casings (normalizing, hardening, tempering, annealing, etc.) the vertical drop-bottom furnace has become generally well established. As missile cases become progressively larger, simultaneous heat treatment becomes impractical. When such cases are generally free of attachments and of uniform cross-section, the heat treating requirement may well be filled by using a progressive treatment during horizontal travel through a relatively short "barrel" or "ring" type furnace with integral quench, such as we have successfully employed for continuous heat treatment of small and large pipe.

Of particular interest is the recent successful use, by a missiles components manufacturer, of an effective and much simplified device for inexpensively testing components through exposure to simulated re-entry conditions. The natural gas, enclosed combustion, "Superheat" jet-type burner has been scaled up and fitted with a wide range of "turndown" (from maximum to minimum burning rates); a high-velocity-high-temperature jet blast results, into which samples are advanced on a controlled moving "target" to match specified heat adsorption curves.

It has already been well demonstrated that as improved physical properties are required in materials by missile and rocket manufacturers, new formulations and heat treatments are developed to provide them.

Beryllium Oxide's Big Role

by Donald C. de Gruchy

NORTH BERGEN, N.J.—A remarkable combination of properties is creating a major role for beryllium oxide ceramics in three areas of missile and space vehicle progress: in missile borne and ground-support electronics; in nose-cone, nozzle, and wing structural applications; and in lightweight nuclear reactor design.

Beryllium oxide has a melting point of 4650°F, nearly 1000° above the melting point of aluminum oxide, and in ceramic shapes it retains useful

Donald C. de Gruchy is sales manager of the National Beryllia Corp.

tensile and compressive strength to unusually high temperatures. Tensile and compressive properties of beryllium oxide at normal temperatures are lower than those of aluminum oxide, and thorium oxide has a higher melting point. But, in the range of 1000° to 2000° no other known ceramic material possesses the average strength of beryllia.

The electrical insulating properties of high-purity beryllium oxide ceramics are comparable to those of aluminum oxide. Thermal conductivity is superior to that of silicon carbide and approaches that of brass. Thermal shock resistance is the best of all known ceramics.

Beryllium oxide is the second hardest known oxide—9 on the Mohs scale. The excellent abrasion resistance of high-fired beryllium oxide is of importance in many missile applications. Beryllium oxide is essentially unaffected by heavy nuclear radiation and is an excellent nuclear moderator—reflector material.

Beryllium oxide is highly transparent to microwave frequencies. It is free of outgassing, and thus is suitable as an envelope for, or component of, hermetically sealed equipment.

A major application is for heat dissipation from electronic assemblies, particularly where the ceramic can conduct enough heat away so that a blower is not required. Another electronic use is as a radar or microwave radiation window. The ceramic allows transmission of appropriate energy but seals against micrometeorites, pressure differential, moisture, etc

Two former limitations of beryllium oxide ceramics need no longer represent problems: safety of personnel has been a problem, since the inhaled dust of beryllium oxide is extremely toxic, but this ceramic is now produced with a hard-fired surface absolutely free of dust; limitations on beryllium oxide product configuration are removed by new production methods.

Size and cost are still limitations. However, increased use of beryllium oxides and of beryllium metal are reducing raw material cost, and advances in production know-how are reducing fabrication costs.

A much more varied range of beryllia-based materials is within sight. These include compounds of other oxides with beryllia, ceramo-metallic combinations, beryllium oxide foam, and beryllium oxide fibers.

Foam can be made; no applications have as yet appeared. Monocrystal and multi-crystal fibers have been produced in the laboratory and their properties are being investigated. Ceramo-metallic combinations among other potentials, offer the possibility of integral structures with properties deliberately varied from point to point within the structure.

Insulation Systems Foreseen

by E. F. Briggs

New York—Insulation materials now being used in the missile industry fall into the following basic categories: felted insulation; molded fibrous or porous insulation; fiber-reinforced plastic materials insulation.

Utilizing the most advanced techniques in the fabrication of thin foils of stainless steel, inconel, and titanium, a variety of products have been made available for protection of jet engine internal components including flexible insulated tubing, integrally insulated duct systems, and even complete encasement of engines

Similar applications are in common usage in missiles and rockets to protect surrounding structures and instruments from the heat of combustion of rocket engines.

Those applications involving minimum space requirements are best solved by utilizing newly developed Min-K, a molded insulation material whose conductivity (lower than that of still air) is the lowest of any formed insulation material.

Fiber-reinforced plastics are ideally suited for transient applications because of their high resistance to transient heat flow (low diffusivity) for moderate temperatures, excellent short-time resistance to elevated temperatures up to 10,000°F, and high heat absorption during ablation at extreme temperatures. Micro-Quartz has proven to be exceptionally successful as a reinforcement for reinforced plastic nose cones.

To protect temperature-sensitive instruments and permit the use of lightweight and economical metal structures, low-conductivity insulation is often required as a backup for low-diffusivity reinforced plastics. Thinner erosion-resistant or ablative reinforced plastic materials, backed up by low-conductivity insulating materials, provide the required protection with considerable weight savings.

E. F. Briggs is sales manager, aviation insulation products, for the Johns Manville Sales Corp.

To meet the demand for an integrated insulation structural material, we have just completed the development of Min-Klad Interlok, an integrated structural material combining the advantages of reinforced plastic with the low conductivity of Min-K. This is the first successful insulating system locking all components together in a single structure. Prototype applications include heat shields, component housing, instrument capsules, and erosion-resistant skin structures for missiles.

Just as the weapons system became the answer to the production of today's more complicated aircraft and missiles, we believe *insulating systems,* rather than insulating materials, will become a major factor in the design of future aircraft and missiles.

The missile insulating systems of the future will in all probability utilize the advantages inherent in both heat absorption and thermal shielding materials, irrespective of subsequent advances in either aerodynamic cooling or refractory structural materials.

Plasma Jet Aids in Coating

by Ben Lohrie

Culver City, Calif.—The softening, or melting, of materials and propelling them to a molten, or plastic state to a substrate, there to serve as a coating, is a common technique. However, usual processes begin to have a difficult time in the region of 4700° to 4800°F. Other material processes in and above this area normally are limited to sintering and hot pressing techniques.

More recently, a completely new and different electric device, operating on a constricted, gas stabilized arc principle, has been introduced. This is popularly referred to as a plasma-jet. The noble gas plasma offers pure heat at temperatures up to 30,000°F. This temperature not only exceeds the melting points, but also the boiling points of the elements. Inasmuch as the plasma is inert, no chemical change to the material transpires, as is possible in the combustion processes. Moreover, since the heated particles are being propelled at high velocity, the resultant impact assures improved porosity characteristics.

In the initial development stages of the Plasmatron (Giannini's trade name for the plasma-jet) it was evident that a very promising area of investigation was in the materials fabrication and processing realm.

Of the present uses, hyperthermal wind tunnels, ablation studies, cutting, and spraying, the latter holds the widest interest. Through this medium new worlds of material processing are now attainable. Spraying as performed by the plasma-jet can be classified into four groups: corrosion barriers; erosion barriers; heat barriers; self-supporting shapes. Within this classification it is possible to spray a very broad range of materials.

Ben Lohrie is president of the Plasmakote Corp., an affiliate of Giannini Plasmadyne Corp.

Considerable success can be expected with the oxides, including thoris and urania. Magnesia seems to be the exception and does not handle easily. Performing equally well are the borides, carbides, and to a limited degree, the nitrides. The stainless alloys are particularly easy to manage. Most of the elements and rare earths are manageable. Exceptions are aluminum and copper, whose melting points are too low for the prevailing temperatures.

Today plasma-sprayed materials are utilized in an impressive number of different applications for rockets and missiles: lining large combustion chambers; fabrication of high temperature-high velocity nozzles; fabrication of radomes and other structural components; hard facing the working parts of accessories and equipment; application of coatings to molybdenum alloy structures; employment of the rare earths such as niobium, iridium, and rhenium for classified applications.

Ceramic Coatings Beat Heat

by Roland J. Westerholm

WORCESTER, MASS.—Ceramic coatings are materials which ideally "do" nothing. They don't change state, they don't move and they have nothing to do with the theoretical operation of a rocket. However, this property of "doing nothing" is exactly the reason for their importance.

These coatings consist of hard adherent crystalline refractory oxides which protect the underlying material from high temperatures and abrasion. The coatings are both thermally insulating and electrically insulating. They can be applied to a variety of materials and are particularly adaptable to metals.

In the reaction motor field, coatings have these general properties and characteristics: very high melting point; extreme hardness; relative chemical inertness; good mechanical strength; applicability to a large range of sizes and shapes; high resistance to corrosion; dimensional stability; maintenance of close tolerance; low coefficient of expansion, and resistance to mild impact

Roland J. Westerholm is product engineer in the Refractories Division of the Norton Co.

From the above information alone, it would appear that the coatings are the answers to all sorts of high temperature problems, but there are some limitations. Ceramic materials are nonductile at room temperatures. Their compressive strengths are about 10 times greater than their tensile strengths. Coatings on concave surfaces such as the inside diameter of a tube will withstand many more cycles of heating and cooling than will the same coating on the outside of a tube or cylinder

At times, another limitation of the coatings is their slight permeability. In some cases, with time as a factor, corrosive agents will permeate the coatings and attack the metal, although such attack will be much slower than for uncoated metal.

One coating, made of alumina, will provide heat protection up to 3600°F. Another made of zirconia, will protect up to 4500°F. A third, of zirconium silicate, has less permeability than the former two, but will protect only to 3000°F.

Since they were first made available in 1955, Rokide coatings have been used in development work on the *Polaris, Hawk, Terrier, Sergeant, Recruit, Minuteman, Aerobee, Sparrow, Vanguard, Titan, Bomarc, Genie, Lacrosse* and *Explorer* rockets. These coatings are also in the *X-15* rocket aircraft.

Plastics

Re-entry Vehicles Use Ablation Plastics

by L. R. McCreight

PHILADELPHIA—Reinforced plastics are the predominant material for protecting ballistic missile types of re-entry vehicles from the extremely high temperature environment.

In a few small areas such as the nose cap or possibly on the leading edges of fins for such re-entry vehicles, there is a desire for materials that resist volumetric erosion better than the current plastics.

In the case of manned re-entry vehicles or other vehicles where small re-entry angles and long re-entry times are specified, refractory materials that will reradiate the heat at some high equilibrium temperature appear competitive with the ablating plastics. In this category, we include niobium, tantalum, molybdenum, and tungsten and their alloys as well as graphite and graphite base materials.

TRENGTH-TO-WEIGHT RATIO TOPS ALL STRUCTURAL MATERIALS

*Strength/weight and other exclusive properties result from stomized orientation of continuous, non-woven glass filaments**

What's the big difference between "SCOTCHPLY" and other pre-impregnated reinforced plastics? Only "SCOTCHPLY" BRAND Reinforced Plastic has contin-uous, non-woven glass filament* reinforcement.

Here are the superior properties that result:

★ **UNMATCHED INDIVIDUAL PLY STRENGTH**—each ply consists of *continuous straight* filaments in parallel alignment, not crimped or woven.

★ **HIGHEST DEGREE OF TAILOR-ABILITY**—individual plies may be oriented to meet specific stress requirements; reinforcement (weight and bulk) is not wasted in directions or regions of low stress. This *degree* of tailorability is not possible with other reinforced plastics using woven cloth or short strand reinforcement.

This duo of exclusive advantages combines to give "SCOTCHPLY" an unequalled strength-to-weight ratio and superior fatigue properties.

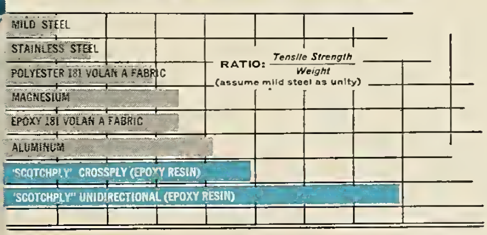
Sold in uncured rolls or sheets, "SCOTCHPLY" Reinforced Plastic is a moldable, laminated plastic consisting of a mechanically controlled ratio of resin to reinforcement*. Heat and low pressure in matched metal dies, vacuum or pressure-bag molding cure it into rigid form.

For complete information and technical service, write on your letterhead to Dept. XAC-129, Reinforced Plastics Division, 3M Co., 1210 University Ave., St. Paul 4, Minn.

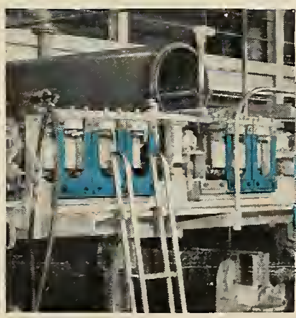
**Other available filaments: nylon, asbestos and other ablation materials. Epoxy, phenolic and other resin systems are available.*

EXTREMELY HIGH TENSILE STRENGTH and light weight are essential in this battery case by Prewitt Aircraft for a classified missile. By proper orientation of reinforcing filaments, "SCOTCHPLY" provides maximum strength where strength is needed to withstand tremendous acceleration loads.

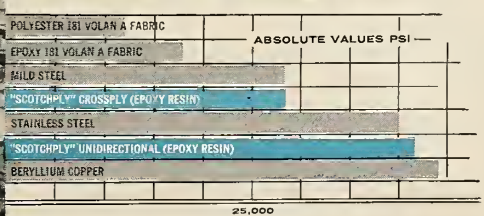
Tensile strength-weight ratios



FLEXURAL FATIGUE failure of metal Fourdrinier springs resulted in costly breakdowns on this paper machine manufactured by Rice Barton Corporation. Now Fourdrinier springs of "SCOTCHPLY"—tailored to the application—do the job.



Flexural-fatigue strength @ 2×10^6 cycles



MINNESOTA MINING AND MANUFACTURING COMPANY
...WHERE RESEARCH IS THE KEY TO TOMORROW

Recently our laboratory developed a castable or low-pressure moldable ablation material at a small fraction of the cost of currently used thermal shield materials. Phenolics are the principal resin used for ablating thermal shields. Phenolics, however, are relatively difficult to fabricate in large pieces because the released water of condensation must be carried out slowly or maintained dispersed under pressure. While these materials have been successfully fabricated and used, development of more easily fabricated materials that would perform at least as well thermally is desirable.

L. R. McCreight is Manager, Materials Studies, in the Aerosciences Laboratory, Missile and Space Vehicle Department, General Electric Co.

• **Carbon surfaces**—We have accomplished this by studying the course of the degradation of plastics when exposed to high temperatures and concluding that, among other things, a carbonaceous surface layer is needed—a layer that must be of high quality, hard, and tenacious. Experiments with various additives to easily formed plastics, such as epoxies and polyesters, resulted in discovery of some that provide a hard, tight carbon layer when polyesters and epoxies were heated to extreme temperatures. These, as well as many other "pure" resins, do not normally give a carbonaceous surface when heated.

The next step was the study of other additives to provide other properties such as even lower thermal conductivity, lower thermal expansion, and a wide variety of physical properties, without any serious loss of ablation resistance.

While there are further developments to be made, we now have made clear, unfilled, cast materials to give properties as follows: thermal conductivity, 3×10^{-5} Btu-ft-sec-ft^2-°F; thermal diffusivity, 1.3×10^{-6} ft^2-sec.; heat of ablation, 5400-12,500 Btu-lb. depending on test facility (eg. air and water stabilized arcs, rocket motors); ultimate tensile, 3500 to 10,000 psi; modulus of elasticity in tension, 30,000 to 600,000 psi; elongation, 1 to 12%.

These resins can also be filled or reinforced to give other thermal and physical properties comparable with other widely known reinforced plastics.

More and Varied Uses Seen

by John H. Lux

WILMINGTON, DEL.—Plastics have made possible operating temperatures much higher than those possible in metals. Propellant burning temperatures of up to 6000°F are common in plastic blast tubes, nozzles, and exit cones. At this time they are available in any size up to 12 feet in diameter on a production basis.

Nose cones used on re-entry vehicles are subjected to temperatures up to 20,000°F. Plastic re-entry vehicles have been recovered. Here again, there is no limit to the size that can be manufactured.

Filament-wound motor cases give the highest possible strength-to-weight ratio and will enable large plastic motors to function with a much higher mass ratio. Future propellant grains may be cast, X-rayed, and then have the plastic motor case built around them rather than in the opposite sequence as is done now.

New high-pressure equipment results in higher temperature and higher ablation resistance. We have, for example, 1500 and 2000-ton presses with over 12 feet of daylight. Large scale equipment formerly characteristic of only metals fabrication is now in our plants—for example, our giant lathe with 36-foot bed and 12-foot swing.

Two 14-foot autoclaves, 12 feet in diameter, enable large parts to be pressure molded with practically no mold cost. Large 80-inch boring mills do precision turning of nose cones and exit cones to tolerances closer than those now common for metals.

Another major breakthrough in the field of ablation resistance has been the use of edge-wound or edge-oriented plastics. We have process equipment to manufacture mechanically wound, reinforced tape, at any angle from 0° to 90° from a longitudinal axis.

In a nozzle made using **Haveg** Planeton IV—edge orientation followed by pressure molding—ablation rates were about 1/20th of those normally achieved with molded plastic parts, and, in most instances of large-size nozzles, ablation rates were lower than those of graphite.

Future thinking certainly leads us to believe that a high proportion of the materials for construction of the new rockets, missiles, and space vehicles will be plastic. This will include nose cones, motor cases, nozzles, and exit cones.

We can look forward to huge liquid-fueled rockets that will use plastic insulation, instead of cooling the motor by fluid circulation. This would decrease total weight and provide increased reliability.

John H. Lux is president of the Haveg Industries, Inc., Wilmington, Delaware.

New Idea for Thermal Barrier

by J. C. Siegle and P. H. Settlage

WILMINGTON, DEL.—To cope with the excessive thermal energy generated at hypersonic speeds, a thermal barrier is required.

The union of a plastic to a metal having good mechanical properties is a new and exciting concept for use as a thermal barrier. At temperatures associated with aerodynamic heating, the plastic layer will decompose rapidly with absorption of considerable quantities of heat, providing protection for the metal substrate. Generation and diffusion of large quantities of gaseous decomposition products into the boundary layer are also advantageous; they will interfere with the convective transfer of heat to the surface, increasing the utility of the plastics as thermal barriers.

Of the large number of plastics available in industry today, the "Teflon" TFE-fluorocarbon polymers, which have an unusual combination of physical and thermal properties, are particularly suited for use as thermal barriers. In addition, the thermal and thermodynamic properties and kinetics of thermal decomposition are available and can be adopted to calculations pertaining to their performance.

J. C. Siegle and P. H. Settlage are in the Polychemicals Department of E. I. du Pont de Nemours & Co.

• **All-gaseous products**—The "Teflon" TFE-fluorocarbon resins are particularly suited for ablative application since they are converted upon pyrolysis entirely to gaseous products. Injection of these products into the boundary layer can contribute to additional heat absorption through mass transfer. The major product of decomposition is the monomer tetrafluoroethylene. The composition of the gaseous decomposition products remains constant over the entire range of conversion.

Calculations of the extent of thermal decomposition are simplified since the reaction follows first-order kinetics.

When the temperature dependence of the rate constant in which the logarithm of the rate constant is plotted versus the reciprocal of the absolute temperature, a steep slope results. This indicates a sharp change in the rate of decomposition with temperature which appears to be a desirable attribute of the "Teflon" TFE-fluorocarbon polymers for use as thermal barriers.

The slow rate of thermal conduction through coatings of TFE-fluorocarbon resins is important in their use as thermal barriers. As a result, the incident heat energy is almost completely consumed by thermal decomposition of the external surfaces.

Retention of mechanical properties at elevated temperatures is extremely important to the performance of plastic materials as thermal barriers. The "Teflon" TFE-fluorocarbon resins are unusual among plastic materials since fabricated sections do not melt flow, crack, spall or completely lose their mechanical properties, even at temperatures far in excess of their melting point of 327°C (620°F). This is confirmed in experiments both in a solar furnace and a plasma jet.

In summary, the union of plastics with metal substrates for use on aerodynamic surfaces at high velocities offers a new and unique approach to the problem of heat dissipation. Although many plastic materials are available, coatings of "Teflon" TFE-fluorocarbon resins can be utilized advantageously as thermal barriers. Availability of thermal and thermodynamic data for "Teflon" TFE resins allows accurate calculation of the thicknesses required to provide thermal protection.

Utilization of minimum quantities of plastics to meet specific thermal requirements offers advantages in weight savings and power requirements of propulsion systems. And the excellent electrical properties of the "Teflon" TFE-fluorocarbon resins extend their utility to other applications in which thermal protection is not the dominating criterion of performance.

Aid from Silicone Rubbers

by Robert Treat Jr.

PHILADELPHIA—Only two years after their introduction, RTV (room temperature vulcanizing) silicone rubber compounds continue to extend the usefulness of conventional heat-curing silicone rubbers by eliminating the need for heat or pressure in the curing systems.

RTV provides excellent abilities for: protection of today's electronic and electrical assemblies; encapsulating electronic components, such as aircraft transformers; and protecting delicate electronic components from the effects of shrinkage when encapsulated in epoxies.

Robert Treat Jr. is a rubber specialist in the Silicone Products Department, General Electric Co.

RTV silicone rubber offers a number of unique characteristics to offset the disadvantages of both rigid and conventional mold materials, thereby enabling prototype parts to be cast more easily, accurately and economically than ever before. Some of the primary characteristics of RTV that contribute to its usefulness as a mold material are: low shrinkage, elimination of parting agent, superior surface and fine detail, high temperature resistance, and quantity model production from a single mold.

Missile applications for RTV include bonding gages while loading LOX; ablative compounds for nose cones and re-entry vehicles; binding for solid propellants; and insulator for propellent grains.

Demand Grows for Astrolite

by W. E. Benke

LOS ANGELES—Astrolite, a combination of virtually pure vitreous silica fibers (known as Refrasil) and a resin binder, is in tremendous demand for extremely high-temperature insulation and high gas velocity ablation applications on missiles.

Temperatures where Astrolite is used satisfactorily range from 5000-6000°F to several times this figure. It has proven itself an excellent material in a large number of missiles for nose cones and rocket engine components, such as nozzles and blast tubes.

Why does this material work? Although the high-temperature resin binder carbonizes at approximately 500 degrees F, the Refrasil has a melting point above 3000°F. Upon melting, the viscosity of the Refrasil is extremely high, preventing it from being easily blown away. Also, the melted Refrasil vaporizes, which tends to cool the surface of the material.

W. E. Benke is vice president for sales engineering of the H. I. Thompson Fiber Glass Co.

As with all materials, the maximum performance of Astrolite fabricated parts for any particular service requirement can be achieved only by proper design considerations. For example, fiber orientation of the reinforcement is important to the success of most applications.

All of the regular methods of molding fiber glass phenolic parts are applicable to Astrolite—vacuum bagging, autoclaving and press molding. Densities obtainable range from 80 to 110 pounds per cubic foot.

Machining of Astrolite can be done on post-cured parts as well as on parts which have not been post-cured. Our experience indicates that machining can best be accomplished by use of diamond-tipped bits, saws, and grinding wheels.

Old Items Find Space Uses

by F. William Jahns Jr.

NEWARK, DEL.—Non-metallic shapes and structures are being used on an increasing scale for missile applications, including some of the oldest established items such as vulcanized fiber and conventional phenolic laminates.

Space Age products cover vulcanized fiber, a wide range of laminates, rods, tubes, fabricated parts, molded parts, post-formed items, flexible insulation, and laminates for printed circuits.

Raw materials used include different types of paper woven and non-woven fabrics, and mica. Woven fabrics are made from cotton, nylon, asbestos and glass. Special constructions based on glass mat and felted asbestos are also used. The resins used are conventional phenolics, special types of heat resistant phenolics, melamine. epoxy, silicone, polyester, and **duPont** Teflon.

One of the most active areas of interest for our high-temperature materials is in connection with solid propellant engines. In a typical use, the plastic is used as thermal insulation and is exposed for a short period to temperatures in the range of 5500°F.

F. William Jahns, Jr. is in the Technical Service Department of the Continental Diamond Fibre Corp., a subsidiary of the Budd Company.

Production parts are being supplied for exit cones and also for the quality control tests and improvement of the solid propellant.

Some of the properties that have been responsible for the adoption of plastics for high temperature use in missile applications are:

Retention of a large percentage of mechanical strength after exposure to elevated temperatures and when tested at high temperatures; good dimensional stability; thermal properties (low thermal conductivity); high strength-to-weight ratio; resistance to moisture; resistance to hot gas erosion and ability to stand direct exposure to burning rocket propellants; longer burn-through time than metals.

Typical future trends follow: flame retardancy; fungus resistance; higher impact strength; paper base epoxy laminates; and composite structures.

Areas requiring further investigation include: fatigue properties; exposure to nuclear radiation; effect of cryogenic temperatures; development of higher melting points; high-temperature adhesives: weight reduction; correlation of the laboratory test methods compared to the service conditions; effect of post-cure on ablation; extremely high noise level; high-temperature retention of bond strength of metal clad laminates; infrared detection characteristics; effect of vibration and severe environmental conditions; and thermal conductivity in the temperatures range of 1000°F to 5000°F.

Filament Winding for Cases

by Richard E. Young

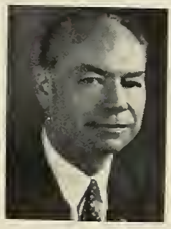
Rocky Hill, N.J.—Initial research in the application of filament-wound structures to missiles followed closely on the commercial availability of continuous drawn glass fibers and 100% reactive thermo-setting resins.

Ultimate strengths in hoop have been demonstrated in pressure cylinders greater than 135,000 psi, yielding a strength-weight ratio of slightly over 1.8 million inches. As all primary load is carried by the glass fibers, the resulting tensile stress on the glass fibers averages 300,000 psi.

Early research was devoted to development of design and fabrication techniques for simple cylinders: later work has resulted in cylindrical structures with essentially closed ends. Recent developments include rocket cases with cutouts for nozzle and terminator ports, cases with integrally-formed nozzles, and cases with integrally-formed skirts.

Principles to be followed in designing cases to be formed by the process are not yet broadly understood. As knowledge of these structures was gained from experience, it became evident that they should be regarded as resin-less nettings of high-strength filaments operating in tension only. In properly designed structures, the entire netting system should be in complete balance, with no stress evident except tension in the fibers. In practice, however, there is compression across the fibers resulting from internal pressure communicated from layer to layer.

To form rocket cases with closed ends, two winding systems are combined in the cylindrical portion of the vessel: one oriented in a low helix angle that is nearly axial, the other in a circular direction. The low-angle helical



Richard E. Young is director of the Young Development Division, Hercules Powder Division.

filaments can be passed over an end shape, leaving only a small polar opening and returning to a helical path on the opposite side of the vessel. The term "ovaloid" has been applied to the special end profile which is the natural shape for the corresponding system of terminal windings. With the entire structure designed with all fibers continuous and in tension only, the system is always geometrically similar to the unloaded unit, for thin-shelled structures eliminating secondary bending.

In theory, it is exceedingly undesirable to cut openings in pressure vessels such as rocket cases. It has proven feasible, however to provide multiple openings by special techniques. Openings, both in cylindrical and ovaloid surfaces, have been used in cases having from zero to 1000 psi internal pressure. In the same way, much has been learned in accommodating special requirements for mechanical attachment of closures and other devices.

As requirements in the missile field have advanced, the size and complexity of filament-wound cases have increased. Where initially only small tubes were used, complete chambers of considerable girth are now fabricated regularly.

Versatile Laminated Plastics

by Dr. Carlisle M. Thacker

Norristown, Pa.—Laminated plastics—also known as reinforced plastics—are the surprise material of missile-rocket technology. What makes them uniquely suitable for many rocket-missile applications is their ability to stand up under extremely high temperatures for short periods of time. Metals quickly heat through and lose their strength or even melt; laminated plastics, on the other hand, have low heat conductivity so that heat damage is confined to the surface.

Laminated plastics have other properties that contribute to their usefulness in rocket applications. One is their high strength-to-weight ratio. Some grades of laminates are as strong as metals and they retain their strength at extremely high temperatures. Because the destructive effect of heat is limited to the surface they retain more of their original geometry and hence more strength.

Laminated plastics have high resistance to thermal shock and are lighter. They are also easy to fabricate. They machine more easily than metals and they may be molded into a wide variety of shapes.

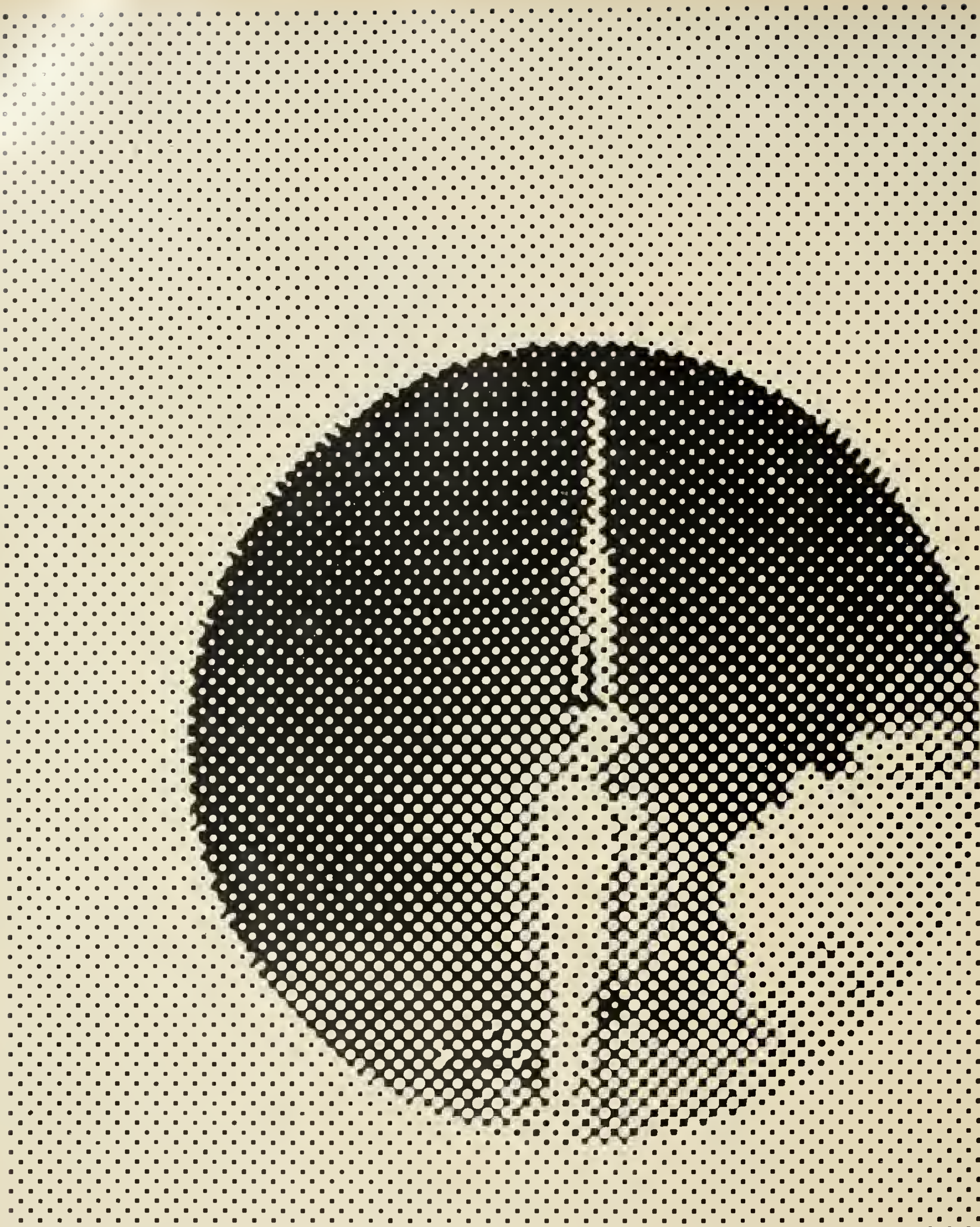
Already laminates are supplied for use in nose cones, exit cones, blast tubes, insulators, insert bulkheads, jet vanes, motor cases, rupture disks and throats—with more use reported almost daily.

A factor that has limited to some degrees the use of laminated plastics in missiles and rockets is their published property values—usually the standards of the National Electrical Manufacturers Association (NEMA standards). Since these standards are primarily for electrical applications where strength is secondary, the published data are usually below the actual tensile strengths of the materials.

Dr. Carlisle M. Thacker is Technical Director of the Taylor Fibre Company.

Wider use of laminated plastics may also be expected with continued progress in combining them with metal. Because they combine the strength of metal with the superior insulating properties of laminated plastics, these composite materials hold great promise in rocketry engineering.

One of the most pressing needs is to develop a wider variety of simple and inexpensive laboratory methods and equipment for research and for testing laminates for particular properties required in rockets and missiles. The availability of simplified, *inexpensive* testing equipment will accomplish two important goals: (1) permit development and adoption on an industry-wide basis of laminated plastics specifications tailored to the rocket and missile field; and (2) expedite research by savings in time and cost in evaluating new developments.



Phenolics Gain In Missile Uses

by Minert E. Hull

NORTH TONAWANDA, N.Y.—Use of phenolic plastics in missiles and rockets has opened a new field of technology.

This family of plastics has given outstanding results in nose cones and rocket motor insulation, primarily due to their inherent properties. Another reason is their long-time use with a well developed technology, particularly in replacing metal with plastic parts.

The thermosetting phenolic materials are designed for molding in matched metal dies at pressures of 500-5000 psi at 250-350°F.

Selected Durez heat-resistant phenolic resins modified with minerals, finely divided or as reinforcing fibers, have shown excellent insulation and erosion resistance in solid propellant rocket motor exhaust nozzles and internal parts. Two of these materials are Durez 16771, glass roving impregnated with phenolic, and Durez 19387, a quartz fiber-filled phenolic material in free-flowing granular form.

Exit nozzles of these materials were fired in a high-impulse **Thiokol Chemical Corporation** solid-propellant motor and exposed to 5000°F gas velocity of Mach 3.0 for 40 seconds. Durez 16771 eroded at a rate of 4-5 mils per second, while 19387 showed virtually no erosion. Both materials showed about ⅛" depth of char. A ½" thick phenolic-asbestos insulation was completely destroyed under these conditions.

These materials are intended primarily for insulation of metal components. They would have specialized limited use for pressure vessel applications and would require reinforcement by metal or a laminated plastic structure.

To obtain optimum strength and erosion resistance in a rocket or missile, uniform density of a molded part is imperative. High-density plastic parts are best produced in matched metal dies by the compression molding method. Some reinforced plastic materials do not flow readily in thin sections due to their bulky fiber fillers.

Minert E. Hull is supervisor, molding compound research and development, for the Durez Plastics Division of Hooker Chemical Corp.

Mold design and molding techniques determine success or failure in the application of such materials. Thus the plastic raw material supplier, the custom molder, and the rocket design engineer must cooperate very closely on mold design.

Durez 16771 is unique in being the only known commercial phenolic molding material with zero molded shrinkage. Molds can be built with no draft or taper and finished parts molded directly to size, making it possible to mold true cylinders, blast tubes and other missile parts to close tolerances.

To obtain high quality plastic parts, rocket engineers must find an experienced custom molder with suitable equipment and a sound engineering staff, perhaps difficult since only a few concerns will invest the money and effort to make a few precision missile parts on a research basis without reasonable assurance of a production run.

Super-phenolics in missiles hold great promise. Their excellent strength-to-weight ratio, insulation value and erosion resistance have been established. Their use should grow as the design engineers gain knowledge and confidence in the technology of their use in missile systems.

Strength Levels To Double

by Howard Meinke

COPIAGUE, N.Y.—The field of non-metallic structures for spaceflight and missiles is still in its infancy. Even so, composite structures of plastic in combination with high-tensile glass, quartz, ceramics, etc., have already surpassed the best metallic structures for many high-strength, high-temperature applications.

One of our latest developments has achieved a workable hoop tensile strength in the pressure chamber of a large solid rocket motor case (test motor, U.S. Naval Propellant Plant) of 200,000 psi. This is achieved by tape-winding new high-modulus Houze glass with epoxy resins. The bulkheads are tape layups, match die-molded. These are attached to the cylindrical body by a specially prepared proprietary joint. Final wraps are then applied. Considering the density of this configuration (0.070), compared with that of steel (0.283), strength-to-weight ratios for the non-metallic structure are superior by a factor of four-to-one.

The future of this technology depends jointly on the ability of glass filament developers to produce still-higher-strength filaments, tapes, mats, etc., and on the ability of the composite-structure development engineer to utilize it to its utmost effectiveness. There is no reason to assume that current strength levels of non-metallic structures cannot be doubled within a reasonable period.

Howard Meinke is chief engineer of the Plastics Branch, Fairchild Engine & Airplane Corp.

Tubing

Fiber Glass Toughened Teflon

by Titeflex Inc.

SPRINGFIELD, MASS.—Flexible hose is necessary in every liquid-propelled rocket engine. The *Thor*, *Jupiter*, *Redstone* and *Atlas* missiles make wide use of flex hose of various kinds during testing and in operation. It is also used in the *X-15* rocket aircraft.

Thermal expansion, engine vibrations and the necessity to thread pipe around obstacles make flex hose necessary for delivering gas and liquid fuel at varying temperatures.

We have just introduced a hose capable of operation between —65 and 400°F, with a bend radius about three times its inside diameter, which may run as much as 2". The hose, called Springfield 400 is made by braiding stainless steel wire about a hose made of **duPont** Teflon and fiber glass. Until now, there had been no Teflon hose that retained flexibility when it exceeded 1" in outside diameter.

Springfield 400, unlike most Teflon hose, does not have an extruded inner core. Instead, unsintered Teflon tape and Teflon-impregnated fiber glass tape are wrapped and fed into a die that forms the laminated structure into helical convolutions. The inner core is thus a convoluted Teflon core reinforced with fiber glass, offering maximum flexibility as well as outstanding resistance to corrosive fluids.

Swage Fitted Teflon Tubes

by R. C. Ramé

ROSELAND, N. J.—Flexible plumbing used in the stratosphere and beyond must be of material that is chemically inert over a wide range of temperatures, is non-contaminating, has limitless life, and is light in weight.

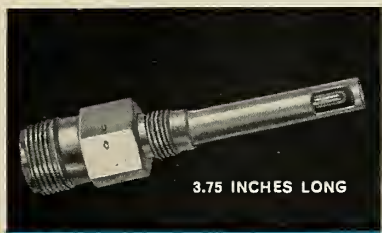
Teflon, the **du Pont** fluorocarbon resin, properly fabricated, is the only flexible hose material that meets all of these basic requirements. The reliability required for use in jet aircraft and hydraulic and fuel lines in missiles and rockets is dependent upon the fabricator's techniques and experience.

No one characteristic of a fluorocarbon hose plumbing system can be considered of primary importance to the success of its missile application—each unique quality has a relationship with the next. It must be completely non-contaminating; withstand severe vibration and g forces; be capable of intricate fittings in a highly restricted space; be chemically inert; be lightweight, have high strength, and have a long shelf life. Fluroflex-T hose assemblies with swaged fittings and made of Teflon meet all these rigid requirements.

For the future our research department has developed and is testing specially constructed lines for almost indefinite use at much higher temperatures than the 623° to-650°F now considered the limit of 100% reliability.

R. C. Ramé is Manager, Field Engineering of the Fluorocarbons Division, Resistoflex Corporation.

THIS HIGHLY ACCURATE TEMPERATURE CONTROL



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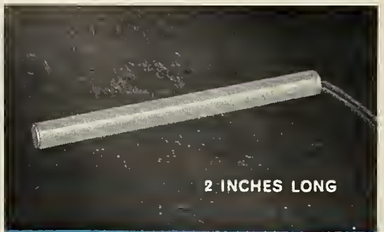
Surface type thermostat. For surface "area contact" temperature sensing. Employs the latest in high heat resistant materials for adequate ambient temperature isolation and excellent shock and vibration characteristics. (Used by Northrop Corporation for controlling critical mass temperature in a sub-miniature accelerometer.)



Well type thermostat. Cylindrical shape —suitable for "blind" well applications for sensing case temperatures. (This type thermostat being used by Sperry Gyroscope Company to sense and control accelerometer housing temperature.)

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Materials Research Called Inadequate

by John N. Dick

WASHINGTON—Availability of necessary materials for spacecraft will depend largely on the emphasis placed on materials research.

We are still spending dollars on weapons and space systems sophistications, while spending mills for the materials research and development required to make them in quantity and put them into usable configuration. Unless this point is recognized we are likely to create a configuration of fantasy, one that cannot be built except at excessive cost.

New and more complex processes will require better and more expensive equipment. In some cases, automation and numerical control must be adopted on a wide scale. Handling and testing equipment must be improved and new standards of quality control and data evaluation must be developed.

So that the metals of a decade hence, or even five years from now, will be capable of meeting the greater demands outlined here, we should begin today to give greater emphasis to materials research through the production stages. Also, we should give greater metallurgical guidance at each level of systems development from the predesigner, to the design engineer, to the fabrication developer and finally to the production unit.

A good start in helping to solve the problem would be for civilian and military agencies to raise men in their organizations responsible for materials guidance to greater prominence.

Our spending of monies for advanced material development for the long haul—research on materials to be used 20 years from today—seems to be improving. Where there is a need for more research assistance is in the more immediate area on development of volume of materials that will be used five years from today.

Col. John N. Dick (USAF, Ret.) is the Washington district manager of the Allegheny Ludlum Steel Corporation.

While the basic research metallurgist has come up with a new alloy and in his laboratory has made ten pounds of the material, he still doesn't know how to make ten tons of it. There is need here for some research to move this production knowledge faster than industry today is capable of doing by itself.

It is one thing to create a new metal, an alloy or other type material, it is another to produce it in volume. Here then is the area wherein assistance is required and a unified approach is essential—not only in financial assistance but also in the areas of supervisory guidance, improved administration and raising the status of the materials engineer or production metallurgist to a person with equal authority on the team.

Republic Reduces Impurities

by J. A. Rinebolt

MASSILON, OHIO—The rapid advancement in missile and rocket design has increased the need for metals that have high strength per unit weight at flight temperatures.

Such factors as transverse ductility and cleanliness are vital. Fatigue strength is closely related to these characteristics. Therefore, considerable attention has been focused on the benefits derived by vacuum-melting steels. Steels being melted range from low-alloy steels to high-temperature steels such as A-286.

Ultra-high strength, high-temperature alloys are melted in our new 30", 24", and 18" consumable vacuum arc melting furnaces. Ingots weighing between 4000 and 16,000 lbs. are being produced at pressures of less than 20 microns. In this process, segregation and center porosity are minimized. The non-metallic inclusions are reduced in number and size, primarily because of the absence of contaminating effects of atmosphere, furnace and ladle lining, slags, etc. Hydrogen, oxygen, and nitrogen content are materially reduced, making the steel less susceptible to flaking after forging.

Alloys melted in these furnaces include AISI 4340, M 300, and a special grade containing .45% carbon, ½% nickel, 1% chromium, and 1% molybdenum.

J. A. Rinebolt is the Supervisor of Alloy Research and Development at Republic Steel Corp.

Specifications for missiles and rockets requiring 15% average and 10% minimum reduction of area at these high-strength levels are successfully met by the alloys produced by the vacuum-arc process. At these levels, the strength-to-weight ratio equals or exceeds that of other materials used in aircraft and missile applications.

Vacuum-consumable, arc-melted steels have helped meet the demand for premium quality materials for rocket and missile applications. In the future, alloys such as the 5% chromium or die steels, which have inherent low ductility in the air-melt condition, may be applicable to missile design if the ductility can be improved through this new technique in melting steel.

VascoJet Can Be Roll-formed

by Dr. John C. Hamaker, Jr.

LATROBE, PA.—Several years ago we introduced Vasco Jet 1000—an ultra-high-strength steel for landing gear, bolts, and fasteners, high-speed turbine rotors, and critically stressed airframe parts.

Shortly after its introduction, a demand arose for this material in the form of sheet, plate, and welding wire for pressure bottles in liquid-propellant rockets, and cases for high-performance solid-propellant rockets. Several major producers have obtained burst stresses in excess of 300,000 psi on VascoJet 1000 rocket cases, and of liquid nitrogen bottles for the *Hawk* missile guidance system are in production.

Test problems during the initial learning period of applying ultra-high-strength steels to thin, high-performance motor cases instigated a number of notch-strength or crack-propagation test programs in government and industrial laboratories. Results of these investigations indicate that all materials possess a similar, increasing degree of notch sensitivity with increasing strength.

The results show the necessity for eliminating mechanical and metallurgical notches if higher strength levels are to be used for rocket cases. Vacuum melted material together with improved design, fabrication and inspection, have permitted the 240,000 psi uniaxial yield level to be successfully used in full scale VascoJet 1000 cases at **Pratt and Whitney** aircraft. Significant improvements have resulted from replacement of the roll formed and longitudinally welded sheet, by girth-welded continuous cylinders. The cylinders are produced by deep drawing, roll ring forging, machining, roll spinning, or similar methods.

In both present and future planning of missiles and space vehicles, a 5% chrome air hardening steel like VascoJet 1000 offers a number of advantages. Tempering at 1000°F or above to 260-300,000 psi ultimate gives maximum stress relief, freedom from retained sustenite, and hot strength. Weld ability is excellent with structure indistinguishable from the parent mold.

New steels, such as Vasco X5, are currently being produced with 330,000 psi ultimate and 270,000 psi yield strength. Greater strengths would be available from high-speed steels or their modifications having yield strengths in the vicinity of 390,000 psi, if designers and fabricators become accustomed to working with decreased ductility and increased notch sensitivity.

New material manufacturing methods are intriguing. For ribbon-wrap construction, good ultra-high-strength in steel strip has been obtained by austenitic warm working experiments.

Among heat-treated steels, capable of being formed and welded in the soft condition, better ductility and notch toughness at higher strengths are being obtained from new consummable electrode vacuum, induction vacuum, or electron gun melting.

Dr. John C. Hamaker Jr. is director of research and metallurgical engineering for Vanadium-Alloys Steel Co.

Better Steels from Research

by J. J. Heger

PITTSBURGH—The **U.S. Steel Corporation** is engaged in a continuing program to extend the usefulness of products of steel and its alloys for the challenging, often changing and novel requirements for high-performance aircraft and ground support equipment.

Current emphasis is in the temperature range from −420°F up to 1200°F. One of the results from this program was X-200, an air-hardening steel in sheets and light plate sections with a minimum yield strength of 230,000 psi. X-200 and other alloy steels, having capabilities of being heat treated to yield strength levels over 200,000 psi, are being tested in the form of small pressure vessels. The results of these hydrostatic burst tests of small bottles will be correlated with laboratory tests of fracture toughness.

An important part of the program embraces extensive studies of the capabilities to convert novel and high-strength alloys developed in our research laboratory into the forms, sizes, and qualities required by the fabricators and designers. The development of new production methods is as important as development of the alloys themselves.

An interesting program is the sandwich rolling of wide sheets. Sandwich rolling consists of placing several plates or sheets of the desired alloy between two heavier carbon steel plates. Side or closure bars of carbon steel are inserted and welded to the edges of the carbon steel plates to make a "composite" slab. In the rolling operation, the slab is rolled in one direction to develop the width ordered and then cross-rolled to develop the length.

J. J. Heger is the Chief Research Engineer, Stainless Steel, at United States Steel Corp.

The composite plate may be further processed by annealing and flattening; the assembly is then sheared around all four edges to eliminate the frame of carbon steel, releasing the internal sheets. Such shearing may be performed after rolling and the individual sheets annealed and flattened, if a rapid cooling rate is required in annealing the alloy.

Significant quantities of sandwich rolled sheets in such compositions as 4340, H-11, AIRSTEEL X-200, and 300M have been produced for development purposes in the fabrication of large cases for high-performance solid-propellant missiles. Recent interest in sandwich-rolled sheets of stainless steel as cover sheets for honey-comb panels has resulted in the intensification of development of sandwich rolled sheets of precipitation hardening stainless steel.

Austenitic Alloys Stronger

by J. Bulina

PITTSBURGH—During the last few years, outstanding advances have been made in the development of alloys for high-temperature applications. Only one important class of alloys is generally referred to as the iron-nickel-chrome austenitic type.

Techniques such as induction vacuum melting, consumable electrode vacuum melting, extrusion and addition of minor elements such as boron, zirconium and rare earths are now common and standard production methods. The improvements realized have been rather substantial.

A good example of how these technology advances have improved an alloy can be shown by comparing the properties of W-545 with other alloys of its class. This alloy has properties essentially equivalent to other high-nickel-content alloys. Consumable electrode vacuum melting improved the cleanliness and quality and made possible additions of more titanium, thus increasing the ability of the alloy to precipitation-harden. The addition of boron to enhance both ductility and strength made it possible to develop W-545 as an improved iron-base austenitic alloy for higher strength and higher temperature applications. The properties are comparable to other higher alloyed materials which would, no doubt, cost more. It is, therefore, reasonable to assume that one may purchase more strength per dollar.

J. Bulina is a Product Development Engineer for the Westinghouse Development Corp.

These alloys are generally used for high-temperature, high-strength applications in steam turbines, gas turbines, missiles, rockets, etc. Another use for these alloys are for high-strength, nonmagnetic applications in electrical apparatus. More recently, they have been used at extremely low temperatures, −50 to −300°F, due to their stability of maintaining an austenitic structure.

Structural Aluminum Lighter

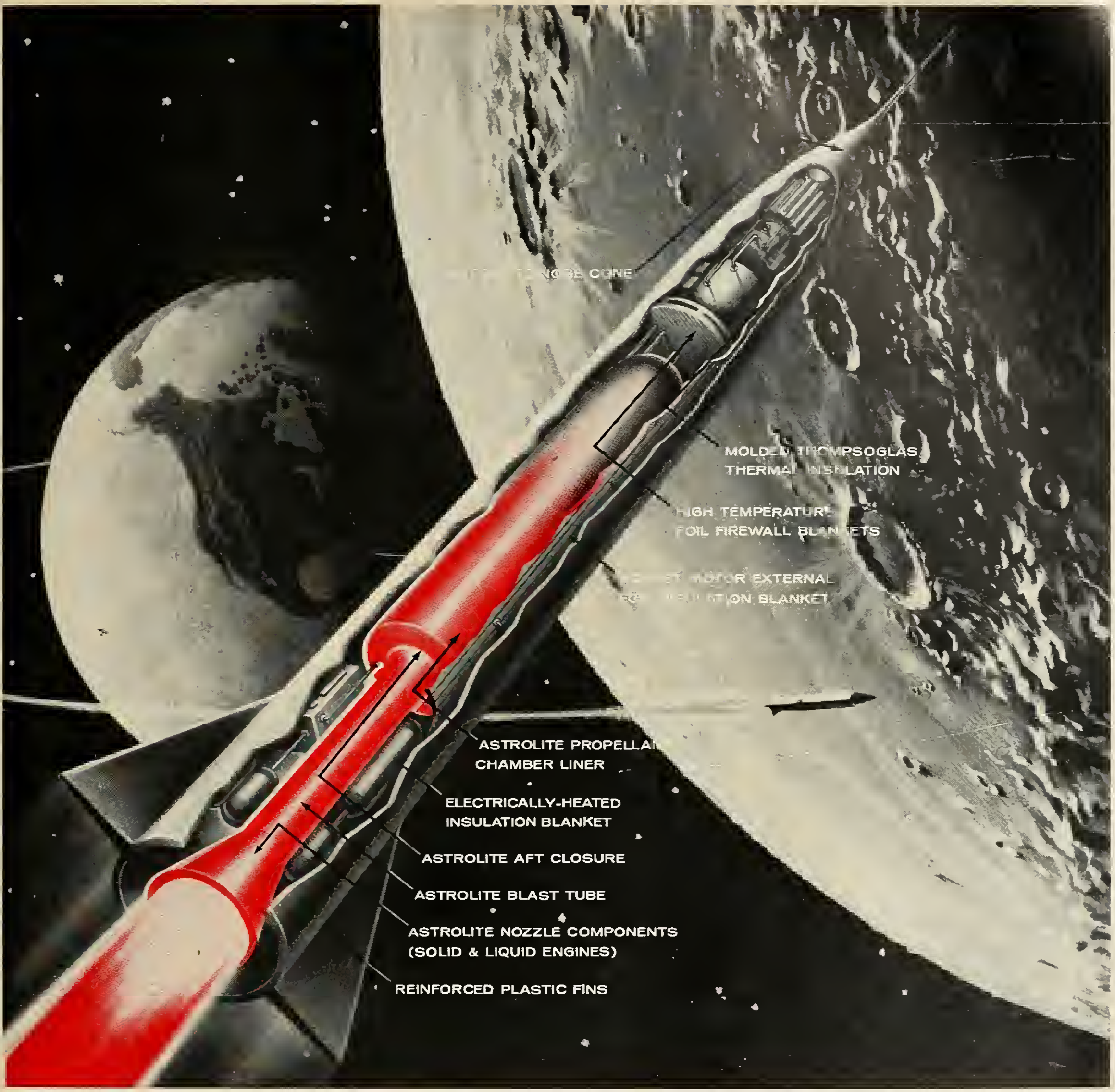
by W. C. Woodward

PITTSBURGH—The room temperature strength-to-weight ratio of high-strength aluminum alloys equals or exceeds those of most competing materials. We have produced 12" diameter, 45" long aluminum cases with a wall thickness of 0.210". They failed at an internal pressure of 3161 psi—or a bursting stress of 94,000 psi, and a strength-to-weight ratio of 935,000 inches. Steel and titanium equivalents of burst and design yield stress in psi are as follows:

Aluminum	Steel	Titanium
94,500	264,000	154,000
77,000	216,000	125,000

Three cases that have been proof tested to design yield will soon be loaded and fired statically. Another is undergoing stress-corrosion tests. No failures have been encountered at stresses below the guaranteed minimum mechanical property level of alloy 7178-T6. New experimental alloys may record strengths 10-to-15% higher.

Aluminum finds many missile applications. Can-type products—one end partially or entirely closed and the other flanged or plain—are used in missile frame shells and tankage, solid rocket fuel containers, missile launchers and special fittings. Tube-type parts—both ends open, with one end having an external or internal flange—find their way into missile frames, launcher tubes,



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With the giant 50,000-ton and 35,000-ton presses, huge pressure heads can be drawn from one-piece plate circles. It is also possible to draw a shell with a 60-inch diameter and a 0.50-in. wall thickness.

We have developed special techniques for premium strength castings of alloys A356 and C355. Having very high inherent elongation, these can be heat-treated to higher levels of tensile and yield strength than normally possible. Strength-to-weight ratio for premium strength castings has been increased 50%—more in some cases—over values given in Federal Specification 00-A601 for alloys 356 and 355.

W. C. Woodward is Manager, Aircraft and Missile Sales, for the Aluminum Co. of America.

In addition we have developed four aluminum powder metallurgy (APM) alloys with excellent mechanical properties in the 500°F to 1000°F range. These alloys are M257, M430, M470, and M486. They depend on dispersion hardening for their strength. They do not require heat treatment but are used in the as-fabricated condition. APM alloys are not time sensitive—but have the same properties after 1000 hours at 700°F as after one-half hour. They retain their original room temperature properties after repeated elevated temperature exposures.

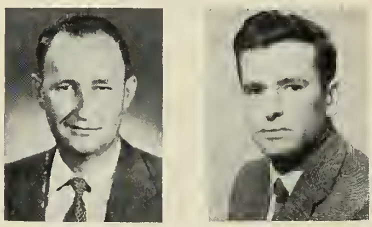
Mathieson Welds Al-Cu Alloy

by Dr. Joseph H. McLain and Dr. Michael J. Pryor

New Haven, Conn.—The high strength and low weight of aluminum results in its wide use in missile structures. Research continues on means of welding high-strength aluminum alloys such as 2014-T6 which retains a good portion of its strength at elevated temperatures and the development of even stronger alloys at higher temperatures.

Of current high-strength alloys, the heat treatable Al-Cu alloy, 2014-T6 enjoys primary favor for missile skins and structural components. Non-heat treatable alloys such as 5083 have been widely used for storing and handling liquid propellants and liquified gases.

Large amounts of copper in aluminum decreases weldability. In 2014-T6 weld cracking often occurs during consumable electrode inert gas welding. Efforts to remedy this include variations of filler alloy composition and application of more effective weld area cooling. As a result, today Al-Cu alloys can be successfully welded if process control is sufficiently careful.



Dr. Joseph H. McLain is in the Energy Division and Dr. Michael J. Pryor in the Metallurgical Research Laboratories of Olin Mathieson Chemical Corp.

Work is now under way to make heat treatable alloys as easily weldable as non-heat treatable alloys.

Efforts to improve aluminum alloy strengths at elevated temperatures involve work with heat-treatable Al-Cu-Ni and Al-Cu-Li-Cd alloys, which show some improvements in performance in certain temperature ranges. The welding techniques for 2014-T6 are applicable to these alloys.

Much more promising are superalloys—mixtures of prealloyed aluminum powders containing large amounts of such elements as chromium, nickel and vanadium. These show excellent properties at temperatures as high as 600°F, and represent a marked step forward. Development of joining techniques for these raises problems not encountered in conventional aluminum technology. Solutions of these problems will, however, further extend the temperature range of aluminum products in the missile and rocket field.

Entire System of Aluminum?

by H. G. McLaughlin

Oakland, Calif.—Aluminum, the "workhorse metal of the Air Age," is also playing a vital role in our new age of the missile.

Conceivably, an entire missile system could be assembled from aluminum parts which are, or have been used successfully in missile developments. Such a composite would include aluminum frame, skin, wings, wing spars, nose-cone structure, tailfins, brackets, wiring systems, fuel tanks, piping, fasteners, motor heads, rocket motor tubes, solid-propellant core molds, electronic components in the guidance system and numerous ground support units.

The proven qualities of aluminum—high strength-to-weight ratio, workability, low maintenance requirements, economy, adaptability, availability—will continue to stand it in good stead with the decision-making groups in the missile industry.

But with the tremendous rate of change in the missile industry, will this versatile metal continue its role? We firmly believe that it will. New aluminum alloys will be added to those already used, and more engineers and production men will learn about and use recently developed weldable, high-strength, non-heat-treatable alloys such as 5083 and 5086 (principal alloying constituents are 4% to 4½% magnesium and manganese as a lesser addition).

H. G. McLaughlin is Manager, Defense Industry Sales, for Kaiser Aluminum & Chemical Sales, Inc.

In addition to many other missile structural applications, aluminum is becoming an important material in the cryogenic field. Its alloy properties improve at ultra-low-temperature levels and this, with the ability to take a sound porosity-free weld, has made these new alloys particularly important as liquid gas storage and transportation containers.

High-temperature alloys have already been developed especially for missiles and high-speed aircraft. Such alloys now available include 2020, 2219, 2618 and most recently 2119 which, as an example, typically maintains a 23,000-psi yield after a half-hour exposure at 500°F.

Aluminum Alloys Easily Welded

by Melvin C. Duke

SHEFFIELD, ALA.—In 1952, sheet aluminum alloys used in the *Redstone* were mostly of the 0.90 and .125" thickness with a tensile yield strength of 38,000 psi. Today the same missiles use a newer aluminum alloy of comparable .063 and .080" thickness and 51,000 psi.

Early *Redstones* had weld joint tensiles of 24,000 psi. Today, with improved welding rods and techniques we surpass 38,000 psi.

The more than 12,000 inches of welding on the *Redstone* and its sister, the *Jupiter C*, are X-rayed—sometimes repeatedly. We use over 1600 sheets of X-ray film on each missile shell.

To perform better welding at lower cost, we have developed new equipment and techniques. Our new aluminum back-up welding bar dissipates heat more rapidly than stainless steel.

We also designed gantry welders to handle the large aluminum *Redstone* shells. Eight shells, six feet in diameter, varying from 24 to 60 inches long, have to be welded together to make the *Redstone* fuel tank. Maximum T.I.R. on this 34-foot section is 0.031 inches. Girth welding is done on an automatic Sigma SWM-3 machine at speeds up to 55 inches per minute. Power settings are usually 160-225 amps, 20-22 volts.

Several power interlocks are provided to prevent machines with heavy electrical current drains from starting during the critical weld cycle. There has never been a single case of a *Redstone* missile failing because of poor welding.

Shop technicians teamed with the scientists and designers in the switch made in the *Jupiter C* rockets from steel to aluminum in the rudder control assemblies.

The problem was weight, and Red-

Melvin C. Duke is the manager of the Missiles Plant of the Reynolds Metals Company.

stone Arsenal specified aluminum as the answer for this welded torsion bar and sprocket wheel assembly. A strong and highly machinable aluminum alloy was chosen. For an extra measure of safety, heat treatment and artificial aging of the component parts were specified. As a further assurance of strength we decided to heat treat and age after welding. The success of the *Jupiter C* and *Juno* rockets with this assembly made history.

Copper Passes Rugged Tests

by T. E. Veltfort

NEW YORK—Highly interesting to metals men was the recent revelation that the nose cones for both the *Atlas* and *Thor* ballistic missiles are of forged copper.

The **Lockheed** *X-17* research rocket also has a copper nose plated with extremely smooth nickel. This rocket has been used extensively in missile research and to launch nuclear bombs which were burst to form the artificial radiation belt in Project *Argus*.

Copper's heat conductivity enables it to distribute heat rapidly and evenly during the brief—but crucial—period of re-entry.

Dr. J. D. Stewart of **General Electric's** Missiles and Space Vehicles Department has pointed out (M/R June 8, 1959) that the copper heat sink re-entry vehicle has been successfully flight tested over a wide range of re-entry conditions. The data capsule has survived water impact and has been recovered intact from a large number of flights.

T. E. Veltfort is managing director of the Copper & Brass Research Assn.

The copper heat sink provided the necessary thermal protection for internal systems. Dr. Stewart further noted that no surface melting occurred and the aerodynamic performance of the re-entry vehicle has been good. The development, he said in conclusion, has been justified by flight tests.

Besides the important nose cone application, a recent survey of major missile contractors by **Copper and Brass Research Assn.** revealed that the copper metals are vital to missile design and performance, chiefly in electrical and electronic components and apparatus.

For example, in **Western Electric's** *Nike-Hercules,* copper's superior electrical conductivity makes it imperative for wiring, as well as for electrical splices, sleeves, plugs, jumpers and bus bars. The switch in the *Nike-Hercules* warhead section has copper gears and allied parts because of corrosion resistance and machinability.

Nike's thrust limiter has a beryllium-copper snap ring, and the missile's solenoid four-way valve embodies a phosphor bronze spring assembly.

Lockheed Aircraft Corp. pointed

out that, along with electrical-electronic applications, *Polaris'* use of copper includes connector pins and, because of excellent heat conductivity, chill bars for welding.

George F. Douglas, Vice President, Engineering, at **Northrop Division of Northrop Aircraft,** said his company uses copper metals for electrical conductors, as well as for non-magnetic, non-sparking, bearings and spring applications. Typical titles in a materials manual at Norair include Copper, Naval Brass, Commercial Bronze, and Aluminum Bronze bar; Copper sheet and plate, Beryllium Copper Strip, Phosphor Bronze sheet and plate, and Copper and Phosphor Bronze wire.

Titanium Increases Payload

by E. F. Erbin

New York—Weight savings inherent in titanium construction is perhaps best illustrated in the successful firing of *Pioneer IV*.

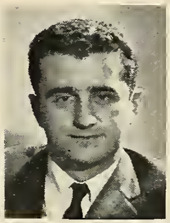
Titanium reduced fourth-stage weight enough that two pounds of instrumentation—in effect a 20% increase—could be added to the payload.

The titanium alloy grade selected for this casing was Ti-6A1-4V. This grade is currently titanium's leading contribution to the missiles manufacturing industry, although applications have been reported for unalloyed material, as well as Ti-5A1-2.5 Sn (in the Project *Mercury* capsule).

This Ti-6A1-4V grade can be heat-treated to tensile strengths in excess of 160,000 psi, retains its properties to –320°F, provides fusion-welded joints with useful ductility, and offers corrosion resistance not normally associated with structural metals.

Ti-6A1-4V is available in all mill shapes. It particularly lends itself to forging, since work temperatures are considerably below its beta transus. Beta titanium, however, will virtually eclipse all other titanium grades in solid-propellant missiles when the smoke of controversy lifts from notch sensitivity testing. Beta titanium has provided a burst strength-to-weight ratio consistently over 1 million, with recent results reaching 1.4 million. This demonstrates the alloy's weld and base metal strength under triaxial loading conditions and its notch insensitivity.

While additional details must necessarily originate from such firms as **Aerojet-General, Curtiss-Wright, Martin, Pratt & Whitney** or **Thompson Products,** the titanium industry can verify these characteristics of the beta alloy: (1.) In the annealed condition, it is quite ductile and readily formable. Since it is highly alloyed, air cooling from solution annealing temperatures retains the soft dispersion hardenable beta phase. Large increases in strength can be obtained by simple aging at temperatures between 800°F and 900°F. Quenching is not required. (2.) Various welding and heat treating procedures are available for obtaining combinations of high base metal strength and weld ductility. (3.) Titanium's basic resistance to corrosion is unchanged by the alloying additions.



Mr. E. F. Erbin is Assistant Manager of Technical Services with the Titanium Metals Corporation of America.

Price is conventionally cited as a limiting factor in selection and use of titanium. But all too often the factors which modify the initial price tag are overlooked. For example, fabrication costs for titanium and steel are often equivalent. Since these costs normally outrun input metal costs, the price difference between completed assemblies of both metals is not as severe as originally pictured. Further, the lighter density of titanium is an important element in pricing, since one pound of titanium will do the same task as almost two pounds of steel.

Malleable Has Good $$ Ratio

by Malleable Iron Founders Society

Cleveland—Malleable iron's suitability for selected applications in space vehicles is supported by the results of a three-year testing program just completed at Purdue University. These demonstrated malleable iron's reliable performance at 800°, 1000°, and 1200°F in stressed applications.

Malleable iron is a cast ferrous alloy rendered tough and ductile in a controlled heat treatment. Malleable thus attains many "steel-like" characteristics without the costly refining operations necessary in steelmaking. These characteristics include high tensile strength, ductility, excellent machining properties, impact strength and wear resistance—combining to give the material a favorable "strength-to-dollar" ratio.

The material differs from cast iron in that it is capable of absorbing shock and, under extreme loads, will bend or deform as much as 20% before it fractures. Measure of this attribute is its elongation range—minimum standards of 18% and 10% for the two standard grades of malleable; between 4% and 10% for the harder pearlitic grades.

At the culmination of the high-temperature study, no evidence was found of changes in structure or performance of the material during test periods which lasted from one to 2300 hours. The significant result was the fact that the stress-rupture curves for malleable irons do not reach a point at which they break sharply downward.

An application which takes advantage of malleable iron's rugged strength and ductility is a bead ring used in a carrier for the U.S. Navy's *Growler* and *Grayback* missiles. The ring, assembled of six close-tolerance malleable castings, is part of the air spring mechanism.

Ductility is essential in this application to insure coining to close tolerances—a time/dollar-saving step compared with machining.

Beryllium Lightens Gyros

by O. F. Quartullo

Sarasota, Fla.—Although most applications involving the use of pure beryllium components are classified, a high degree of success has been obtained in inertial guidance system parts and gyroscopes fabricated from this sophisticated metal.

Improved function has been so pointed and remarkable that many programs which were in the research and development stage as recently as a year ago are now in production and utilizing the special qualities inherent in beryllium to insure the high degree of accuracy and stability required for optimum performance in guidance equipment. Briefly, these qualities are: light

missile suppliers speak: Metals

weight, high melting point, high strength-to-weight ratio, high heat absorbency and thermal properties, and, most important in the categories outlined above, extreme stability.

An ultra-precise gyro part machined to 50 millionths of an inch tolerances will retain its dimensional stability under widespread temperature conditions and function more efficiently than any other known material.

Some other applications for precision machined beryllium parts are: X-ray cameras, high-speed aircraft cameras, nuclear power reactors, underwater instruments (where beryllium's corrosion resistance is a factor), gas turbine engine parts, rocket engine components, memory wheels, and memory discs.

The state of beryllium machining is such that configurations which have sectional cut-outs that would tend to distort and destroy tolerance requirements in other metals are being successfully produced of beryllium.

Future applications and fabricating technology, in a general sense, are broad in scope. The vast combined engineering knowledge of American industry will conceive and bring to practical levels new applications for machined beryllium parts which can be favorably analyzed on a "cost to worth" basis. Machining and fabricating technology will advance with this increased requirement, and better and less costly components will result.

O. F. Quartullo is the president of the American Beryllium Co.

Metal Working

100% Efficient Welds Needed

by Ludwig Roth

SAN DIEGO, CALIF.—Strength-to-weight requirements for solid rocket cases make it mandatory to produce weld joints that have 100% strength efficiency across the weld and 100% reliability.

The part geometry must be free of abrupt discontinuities at the junction of the weld and parent material, and the chemistry of the weld must be carefully controlled so that its response to heat treatment is comparable to that of the parent material.

We use three methods for producing weldments that fulfill these requirements. They are cold weld planishing, hot weld forging, and weld remelt with a mechanically controlled oscillating electrode.

Cold weld planishing has been used on sheet metal parts for several years. It is accomplished by passing the weld under steel pressure rolls one or more times to reduce the weld reinforcement height. It is normally used on material from .020" to .125" to improve the weld geometry and increase weld strength by work hardening.

The hot weld forging method was developed for material thicknesses greater than .125". In hot weld forging the edge of the sheet to be welded is "hot upset" adjacent to the weld seam. The weld is then made in the conventional manner. The upset area is heated to forging temperature and forged either by a pneumatic hammer or planishing rolls until the thickness of the upset area is similar to that of the parent material.

This process produces a homogeneous assembly wherein the weld is difficult to detect by X-ray or micro examination.

• **100% efficient**—In the mechanical oscillation remelt method, the weld

Ludwig Roth is chief engineer in the Research and Development Engineering Department, Solar Aircraft Co.

is made in the conventional manner with an automatic welding machine. The weld reinforcement on both sides of the weld is ground to a uniform height of 15 mils, then each side is remelted with a mechanical oscillating motion. The finished weld is 10 mils in height with a smooth contour. Such welds have 100% joint efficiency.

Cold weld planishing is the cheapest method of improving weldments. But many vehicles are made from material thicknesses above the range for this process. The mechanical oscillation process is least costly for thicker materials.

Alloy mechanical and metallurgical evaluations include current and proposed materials for rocket motor use, such as Ladish D6, X-200, 4340 and modifications, MS-1, 300M. The aim is to select the optimum material for the application and determine fabrication requirements. Research and development is directed toward evaluating all-beta high-strength titanium alloys, metal ribbon-wrapped structures and non-ferrous metals combined with heat-treatable steel. Non-ferrous metals appear applicable for components such as igniter and nozzle bosses.

Joining dissimilar metals poses difficult problems. Braze joining or diffusion bonding appear to be applicable for future rockets.

Braze joining offers excellent potential for reducing weight and improving reliability of all heat-treatable steel cases. We have shown the effectiveness of a process using braze alloys developed for joining igniter bosses on two current development cases.

• **Reinforcing shear loads**—Brazed sandwich structures consisting of honeycomb core braze-joined to facings is an excellent structural material. Optimum strength-to-weight ratio, high inherent rigidity and high-temperature capabilities indicate possibilities for efficient minimum-weight structures. Current developments include evaluation of honeycomb core for shear-load reinforcement at the case to closure joints.

High refractory metals and ceramics assembled to unique designs offer potential solutions for advanced nozzle structures. Thin-walled tungsten supported by tantalum marcel is currently being developed for rocket blast panels and nozzle linings. Problems with tungsten include forming and joining; special brazing and welding techniques have been developed.

Refractory metal open-faced sandwich structures provide an excellent medium for supporting high-temperature ceramics and reinforced plastics. Zirconium oxide-filled tungsten honeycomb resists temperatures over 4500°F for most current combustion periods. Borides, silicides and oxides promise to meet requirements of higher temperatures and longer periods of operation.

Forging Cuts Component Cost

by William C. Kunkler

WORCESTER, MASS.—The function of forging by plastic deformation is to contribute improved engineering properties and desired shape to the metal producer's cast ingot, sintered ingot or mill product.

Forged integral components permit reduction in the number of mechanical and welded joints and elimination of welds in critical areas resulting in reduced stress concentrations, increased reliability and weight savings.

Material utilization is often misinterpreted as a reliable cost index for a comparison between different manufacturing methods such as casting, forging and sheet metal fabrication. Actually the component cost at the point of assembly is the only accurate basis for comparison. This analysis introduces, in addition to added operations, the cost of inspection and test, quality control, re-work and rejection. The use of forging reduces and in some cases eliminates these expenses.

Payload components for re-entry and space vehicles have the most critical need for weight saving. Re-entry shields and structural parts of forged beryllium offer this weight saving. Forged beryllium provides increased advantages in soundness, tensile strength, ductility, machinability, material utilization and productibility. Hollow shapes of 160 lb. have been successfully forged and subsequently machined. Press-forged upset sheet is being recognized as the best starting point for beryllium sheet. Sheet blanks 40" and more in diameter are a present capability. Guidance components in beryllium are also being developed.

Inclosures for *Polaris, Minuteman* and *Pershing* solid-propellant motor casing, under high internal pressure and with many bosses and attachment points, must have a high strength-weight ratio and reliability. They must also be as free as possible of notches and stress concentrations and take moderate heat for a short time.

William C. Kunkler is senior application engineer in the Research and Development Department, Wyman-Gordon Co.

Two materials are dominating this application. Low-alloy, high-strength steels such as 300 M, X200, H-11, D6, types and AMS 6428 offer a material with metallurgical and production experience, high strength at relatively low cost, with a great flexibility in heat treatment. Steel closures up to 65" in diameter are being forged with integral skirts provided in some cases for spinning out into the cylindrical section. The second material is the all-beta titanium alloy B120VCA, which develops its outstanding strength by an aging heat treatment after cold working. Extensive work is being expended in producing closures currently up to 41" diameter. A 180,000 psi yield strength, 200,000 psi ultimate and 5% elongation appear feasible. At this level, B120VCA equals steel at 290,000 yield strength.

Forging development programs are under way and being proposed for sintered tungsten and tantalum alloys to meet higher temperatures. Many believe that only a forged component will have sufficient resistance to erosion and thermal shock plus reliability.

Deep Drawing Obviates Welds

by Larry Shiller

LOS ANGELES—It has become increasingly evident that the designers of solid-propellant rocket motor cases want to produce one-piece cases within the near future and thereby attain improved reliability and performance characteristics. The immediate objective is to eliminate as much welding as practicable, especially longitudinal seams.

We have had extensive experience over many years in deep-drawing millions of one-piece jatos, rocket motors, cartridge cases, other ordnance items and cylinders for high pressure gas and hydraulic applications. Rocket motor cases in which the pressure vessel sections have been produced by deep-drawing as a single piece include the 15 KS 1000 *Jato, Sparrow, Rat, Falcon, Terrier,* and *Hawk*. The AISI 4130 steel "as drawn" case for the

Hawk motor is 14″ by 96′ long.

Experience with these parts suggested the feasibility of employing the deep-draw technique to manufacture one-piece rocket motor cases from the higher strength steels, thereby eliminating the need for longitudinal seams. Materials including AISI 4340, Airsteel X200, Potomac A, Crucible 56, Tricent, UHS 260, Vascojet 1000, Crucible 218, MBMC #1, and Ladish D6 and D9 were evaluated. After preliminary forming experiments, the first four steels were selected for fabrication into pressure vessels that would indicate problems and results in larger size, full-scale motor cases for such programs as *Polaris* and *Minuteman*.

Deep-draw tooling was available for the fabrication of chambers 10″ in diameter by 12″ long with a 2 to 1 elliptical head and a .045″ mean wall thickness. Two chambers were joined with a central girth weld to produce a pressure vessel 10″ in diameter by 24″ long.

The four steels selected showed satisfactory forming characteristics. About a dozen chambers from each of these materials were fabricated and heat-treated to various strength levels in excess of 190,000 psi yield strength, .2% offset. The test results have been excellent at the 200,000 to 210,000 psi yield strength level. At this level, with few exceptions, burst strengths calculated on the thin wall pressure vessel formula have exceeded 240,000 psi.

Larry Shiller is chief research and development engineer, Norris Division, Norris Thermador - Corporation.

Some of these vessels, particularly those made from Crucible 56 and Potomac A, have withstood pressure cycling at a calculated hoop stress of 222,000 psi for at least 10 cycles without any evidence of failure. It appears probable that pressure chambers for various missiles can be designed to the 210,000 psi yield strength level.

We are in a position to produce one-piece rocket pressure chambers with existing equipment that have typical dimensions of 37.5″ x 65″ or 54″ x 35″. Longer cases can be readily produced without longitudinal seams by joining two or more cylindrical sections with a girth weld, or welds. In many cases it is practicable to further reduce weldments by forming head and aft closure attachments integral with the cylindrical sections.

By designing simplified and comparatively low-cost press equipment and tools we can deep-draw cases up to about 66″ x 144″ in one piece.

Shear Forming Spells Saving

by Wayne Stone

STRATFORD, CONN.—The desirability of manufacturing large missile components in one piece has made shear forming almost mandatory, stimulating intensive advancement in the state-of-the-art. Machine capacities have increased to 60″ diameter with 120″ diameter in demand. Starting wall thicknesses of up to 1″ have been shear formed.

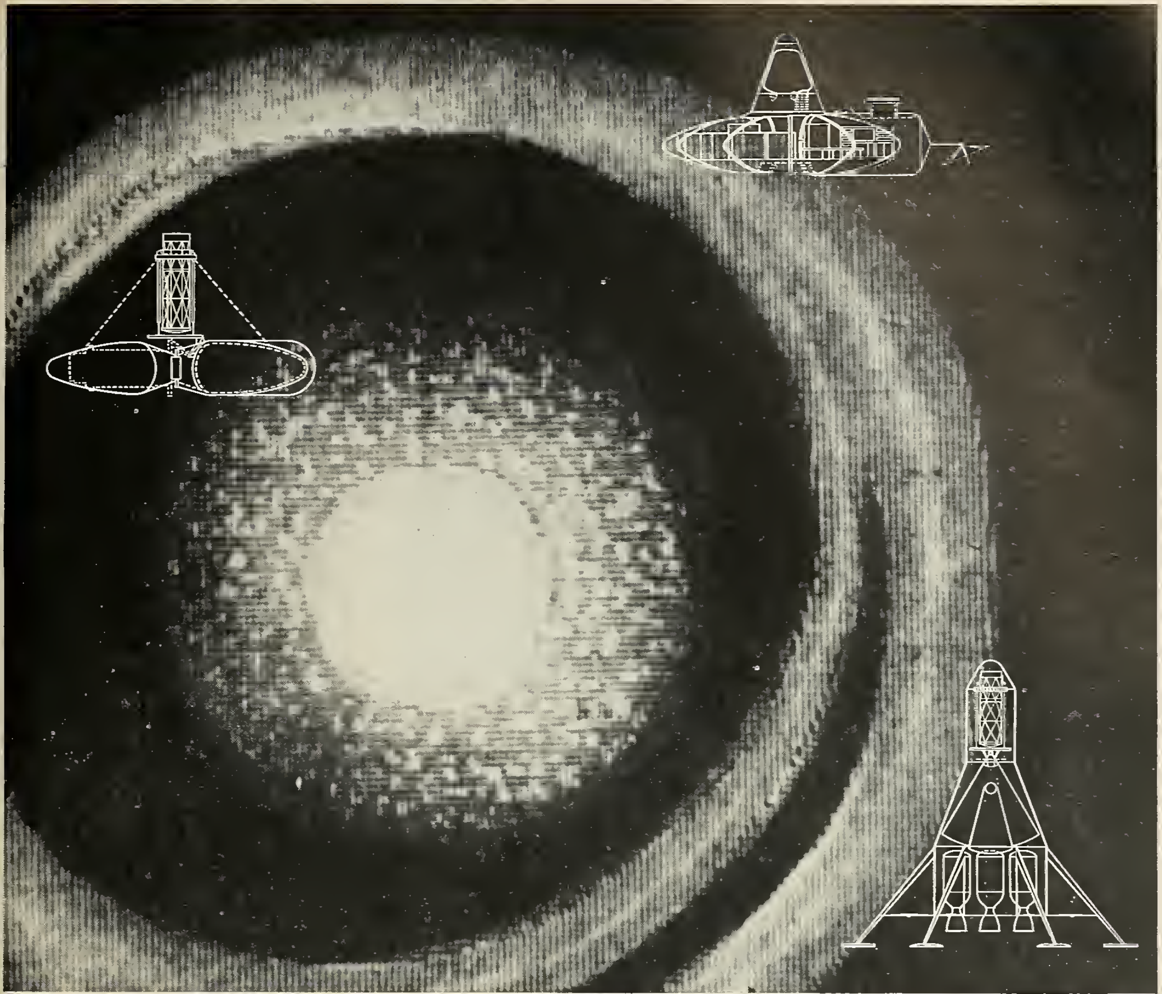
The method has been applied to a wide variety of materials including low-carbon steel, all types of aluminum, type 300 stainless steels, Inconel, Timken 17-22A (S), Vascojet 1000, Thermold J, Tricent, titanium, A 286 and N-155. Despite high forming pressures, no appreciable reduction in physical properties results. Micro-structure analysis shows no evidence of fracture developing in the crystalline structure.

Shear forming lends itself to many shapes including conical, cylindrical, ogive, parabolic, hyperbolic, venturi and spherical—all with either thin, heavy or tapered wall thicknesses.

Predictability of shear forming applications and limitations is being dependably established. Lead time is reduced and the aero-space industry using this method can produce superior parts at less cost with increased material utilization.

Parts are shear formed to accurate

Wayne Stone is supervisor, manufacturing engineering, for the Lycoming Division, Avco Corp.



New styles for the man-about-space

Every time a space traveler leaves home (earth), he has to wrap himself in the complete environment necessary to his physiological and psychological well-being. Styling sealed space capsules to suit man's every requirement has been a major project at Douglas for more than ten years. Forty basic human factors areas were explored in these studies. Now Douglas engineers have evolved plans for practical space ships, space stations and moon stations in which men can live and work with security thousands of miles from their home planet. We are seeking qualified engineers and scientists who can aid us in furthering these and other out-of-this-world but very down-to-earth projects. Some of our immediate needs are listed on the facing page.

Dr. Eugene Konecci, Head, Life Sciences Section, reviews a new concept in space cabin design with Arthur E. Raymond, Senior Engineering Vice President of **DOUGLAS**

MISSILE AND SPACE SYSTEMS ■ MILITARY AIRCRAFT ■ DC-8 JETLINERS ■ CARGO TRANSPORTS ■ AIRCOMB ■ GROUND SUPPORT EQUIPMENT

ID requirements with surfaces burnished to a smooth finish and only critical OD dimensions requiring machining. As an example, the repetitive production of diameter and wall thickness to within .002" on a 50" diameter spherical contour of AMS 4340, is indicative of present fabrication control. Finish is better than 32 RMS.

Pounds of forging weight and many man hours are being saved. Components heretofore considered impractical or impossible to manufacture as a single piece are being so fabricated.

Missiles demand close-toleranced, comparatively thin-walled, large diameter cylinders for rocket motor casings. Shear forming is a fabrication technique capable of producing such parts without the disadvantages of other methods. It presents a tremendous potential in cost reduction and saving of highly critical materials.

Spinning Fills Many Needs

by John H. Owens

MILWAUKEE—Metal spinning made its initial appearance in the United States sometime in the 17th century insofar as records reveal. Paul Revere dabbled in the art. So did other copper and silversmiths who confined the craft to the production of jewelry holloware, silver and gold chalices, and other precious vessels.

Today, metal spinning is a prime source for diverse missile components, ranging from skin sections produced for the *Honest John* to massive bulkheads for the *Jupiter*. Other important jobs produced in many sizes and in a wide range of alloys are: missile skin stiffener rings and "Z" sections; inert warheads; special oil containers; tank heads for missile fuel containers; control housings for gimbal mechanisms and gyroscopes; gondola sections for high-altitude balloons; cone spinnings for missile fuel tanks; and tank heads used in shipping containers for rocket motors.

As in other industries, automation plus hydraulic power are doing much to broaden the scope of the metal spinning industry. We pioneered the transformation from manual to mechanical to hydraulic power.

Hydraulic lathes, still under wraps in our plant because of their advanced design, include powerful robot spinning machines. These machines are now rapidly producing increasingly heavier gauges and ever-larger diameters for missile and other industries.

The internal structures spun for many missile jobs have involved extremely heavy gauges in difficult to shape alloys. The massive carrier case for the nose cone of the *Atlas* was spun automatically with tremendous forces by hydraulic power on the special "MET-L-FLO" lathes, originally designed and developed by us.

Metal spinning is nominal in cost compared to other methods of forming. It is available in such a wide range of metals, weights, and shapes that it plays an important part in experimental and development work.

Metal spinning can and often does: improve product design and appearance; reduce production time and labor; offer dollar savings in cost-per-unit; increase product efficiency; decrease weight; simplify fabrication; offer savings in tooling, both in time and cost through elimination of expensive dies, jigs, and fixtures; lower costs of tool modification.

John H. Owens is on the public relations staff of Spincraft Inc.

A few years ago the spinning of simple shapes in 1/16" copper was considered remarkable. Now aluminum in gauges of ¾" and more is successfully spun.

At our plants, tiny 2" cups stand side by side with huge 130" stainless steel covers and deep cylinders. These components are spun from all kinds of metals; copper, aluminum, brass, sheet steel, and stainless steel.

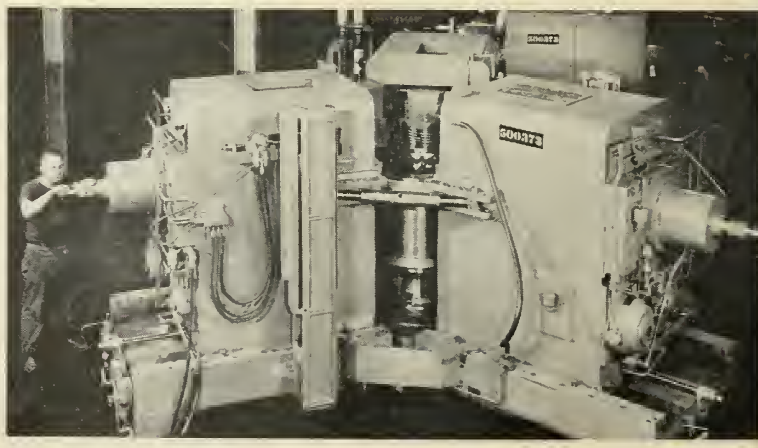
Roll Forming Art Advances

by Richard H. Gade

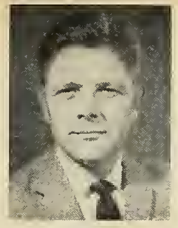
BRISTOL, PA.—Production rocket motor cases ranging from 14" diameter to 54" diameter and up to 78" long, with finished wall thickness ranges from .065" to .181" have been produced by roll forming within tolerances of ±.004". Roll forming permits the use of heavier-walled short cylindrical blanks, either machined ring forgings or wrapped and longitudinally welded cylinders of sheet material.

The blank is reduced in wall thickness 50% to 65%, sized to the forming mandrel, and increased in length to 2 to 2¾ times. Low alloy, medium carbon steels are roll formed in the spheroidize anneal condition. Consistent results are obtained when the spheroidization is a minimum of 80% to 85%, as determined by metallurgical examination. A slight decarburization appears to be beneficial, and in-

Floturn Equipment



SEAMLESS CYLINDERS are produced with this Floturn machine installed at the Pratt & Whitney plant in East Hartford, Conn.



Richard H. Gade is chief production engineer of Kaiser Fleetwings Inc.

sures that no local carburization exists.

The roll-formed welded blank exhibit a beneficial wroughting and homogenization of the weld area. But roll forming will not heal improper welding. Prior to forming, welds undergo 100% radiographic examination and magnetic particle inspection.

A further advantage of roll-formed welded shells is weight control. Mill tolerance variations in sheet material are ±10% in the gauges presently specified in motor case shells. Roll forming tolerances reduce this variation to 4%, and roll forming further eliminates a design allowance for "weld strength reduction," usually 85-90%.

Body shells have been produced from SAE 4130, SAE 4340, AMS 6434, modified AMS 6434, USS X-200 and Ladish D6AC steels. Vacuum-melted steels have a more consistent level of cleanliness and uniformity. However, air-melted steels have been successfully used.

Shear forming is also employed in producing missile chamber components. Symmetrical bodies of revolution of conical-ogival sections are being produced from 17-7 stainless steel. These parts, 35″ in diameter, replace a fabricated weldment made from two deep drawn details and a developed conical weldment. The one-piece shear-formed components are used as pressure vessel heads for a liquid rocket motor system. Elliptical shear-formed motor case heads of 54″ diameter have been made from the modified AMS 6434 and USS X-200 steels in limited quantities.

An area of interest is the roll forming of beta titanium weldments. The relatively new beta titanium alloy offers a high strength-to-weight ratio compared with presently available steels. However, the embrittlement of welds in this metal during simple or duplex aging is detrimental in motor case use. Welding after aging lowers the potential strength of the weld area to about 125 k.s.i. (equal to 200 k.s.i. in steel on an equivalent weight basis). Tests indicate that welds in beta titanium roll formed to a 40% reduction have aging characteristics similar to the base metal. Consequently, a welded, roll formed, and aged sequence of processing a beta titanium motor case shell may offer a significant advance in strength-to-weight ratio.

Missile Machining Demands Accuracy Control

by A. B. Albrecht

SIDNEY, OHIO—Most missile hardware requires both internal and external machining with the added problem of chucking on thin-wall sections. High-temperature requirements in this field have increased the use of the "superalloys" and materials such as zirconium and beryllium. The cost per lb. of these alloys is high, and initial forging or casting quite often represents a sizable investment. Thus control of accuracy and reduction in scrap losses are important factors.

To maintain the repetitive accuracy desired in contour-turning nose cones, nozzles, accumulators, closure domes, etc., most contract shops are utilizing "Air-Gage Tracer" lathes. Accurate template reproduction assures built-in inspection on complex contours which would otherwise require costly gaging. Final finish on most parts is below 62-microinch, and standard tolerances are ±.001″.

The missile frame, bulkhead, enclosure, and motor case are often of such large diameter that special machines are required to handle these parts efficiently. The design of the Series 170 Monarch Missile Lathe was based upon the need for greater accuracy in a large swing lathe for machining these parts. This 85″ swing lathe is template-controlled, and provides a wide range of spindle speeds: including a low range for thread milling on the missile frame.

The small prototype shops have long shared the responsibility for machining components to meet engineering test schedules in the missile field. Lead time in most cases is short, and design changes are frequent. The thin-wall sections and cold-working tendencies of the high-temperature alloys dictate single point tracer tools.

A. B. Albrecht is a technical consultant to the Monarch Machine Tool Co.

The basic machine of the industry has been the standard engine lathe with "Air-Gage Tracer" controls. Low setup time and flexibility are major factors for low-cost production of missile hardware. Numerical controlled machines are entering the field and are being considered for the general machining of nose cones, radomes, bodies and adapters. The complex contours call for a "path" type control which adds to the initial investment. Paradoxically, numerical control has been slow to enter into the missile field, and tracer controlled lathes still predominate.

The missile industry is becoming more competitive as newcomers enter it, and the larger aircraft companies convert their facilities in an effort to capture missile contracts. Development work in rocket, nuclear, and ram type engines calls for the machining of new alloys, and most of the first parts are turned from bar-stock. To keep abreast of these developments, machinability programs are being established for the purpose of obtaining practical cutting data on these new materials.

Unit Cuts Fragile Materials

by Industrial Division
S. S. White Dental Mfg. Co.

NEW YORK—Gas-propelled to supersonic speeds through a small, precise nozzle, finely graded abrasive particles produce a cool, shockless cutting action. There is no contact between the tool and the work. What little heat produced is immediately removed by the propellant gas. A high order of accuracy is possible because the stream is precisely controlled.

It has successfully performed delicate operations on germanium, silicon, mica, glass, ceramics, alloy steels: etching lines, cleaning metallic smears from ceramics, matting and abrading, and deburring precision metals parts.

The Airbrasive Cutting Unit never touches the work. There is no chatter, no vibration, and no pressure. This makes it possible to cut fragile materials with complete safety and freedom from breakage. Both hand pieces and nozzle tip holders that can be rigged in fixtures are available. A wide range of cuts can be made. The same tool can cut a line as fine as .008″ or frost a large area.

Several nozzles with various shapes and sizes of orifice are available. An .006″ .060″ rectangular orifice will produce a minimum cut of .008″. Even narrower cuts can be made with nozzles available on special order.

Excellent abrading results are obtained from the process. It is valuable in the removal of surface deposits: metallic smears on ceramics, oxides on metals, etc., especially from parts too delicate to stand manual scraping or power grinding.

Skull Casting Holds Promise

by A. E. LaMarche

PITTSBURGH—Skull casting exhibits all of the advantages of vacuum-arc melting, producing a clearer, less gaseous metal with attendant improved properties.

The skull casting process is particularly adaptable to metals such as titanium, zirconium, molybdenum, and tungsten—which react rapidly with atmospheric gases—as well as refractory (non-metallic) mold materials. Machined graphite is capable of yielding castings with a good surface and little contamination, although surface contamination is still in the order of 0.050″.

The skull melting and casting method also prevents contamination from refractory crucibles and can obtain ultrahigh temperatures needed for melting and refining by outgassing of the materials being melted.

A. E. LaMarche is a project engineer, Refractory Metals Section, Westinghouse Electric Corporation.

A water-cooled copper cylinder or chalice is commonly used in skull furnaces as the crucible or "melting pot" and can contain the melt if either a consumable or nonconsumable mode of melting is used. Since there is no crucible contamination in melting, the reactive and refractory metals can be cast and retention of the basic properties of the elements or alloys can be maintained in the solid state.

This newest of casting methods has been used recently to form a rocket nozzle casting weighing 62 pounds for **Aerojet-General Corp.** from the 50% molybdenum-50% tungsten alloy.

Heliarc Welding Increasing

by G. W. Oyler

Newark, N.J.—One of the leading metalworking advances of recent years has been the development of inert-gas shielded arc welding.

New metals and alloys, unheard of only a few years ago, have become the backbone of our national defense program. Military requirements hastened the use of these metals, but without the welding processes to fabricate them, much of U.S. military might would still be on the drawing boards.

Heliarc welding uses a virtually non-consumable tungsten electrode, and welds by fusion of the base metal. A filler wire may be fed into the weld puddle if additional metal is desired. Sigma welding uses a continuously driven wire electrode and welds by fusion of the base metal, with filler metal being added automatically as the consumable electrode melts off in the arc. Heliarc welding is primarily used on thin sheets under 1/8" thick, while Sigma welding is suited for thicknesses greater than 0.050." A space capsule fabricated with Heliarc or Sigma welding is essentially a single piece of metal, and will behave as such in outer space.

Heliarc argon-shielded welding was originally developed to improve welding of magnesium in the aircraft industry. It has since proven suitable for so many metals that it is now used in welding development work. To determine the weldability of such new metals as niobium, tantalum, uranium, vanadium and molybdenum, we carry out initial tests using Heliarc welding, with argon, helium, or mixtures of both for shielding. Some of the more reactive materials, such as zirconium alloys and hafnium, must be tested inside an inert-atmosphere chamber.

Titanium is extremely reactive at welding temperatures and sensitive to embrittlement by small amounts of some impurities. To adequately shield the puddle and surrounding weld area, an argon trailing shield is used in addition to the regular shielding cup.

G. W. Oyler heads the Laboratory Division, Electric Welding Department, Newark Development Laboratory of the Linde Co. Division of Union Carbide Corp.

• **Rigid standards**—Argon-shielded arc spot welding has solved many problems in missile fabrication. The confined spaces and low weight limits of guided missiles require fabricating with considerable spot welding. Depending upon material thickness, spot weld shear strengths must be between 200 and 5000 lb. per weld. Often these welds can be made from only one side of the joint. Both Heliarc and Sigma spot welding meet these rigid shear strengths.

A recent major breakthrough in tungsten-arc welding circuitry is the pilot arc. The electrode is kept hot and ready to fire at all times, and the pilot arc provides an ionized gas path as the torch approaches the workpiece, for instantly reliable starting. The arc replaces continuously troublesome high-frequency power.

The high-speed welding of extremely thin sheets of metal is now possible with short-arc welding. A new development of Sigma welding, the short arc process short circuits from 100 to 200 times per second, pinpoints the arc heat and produces a small "cold" puddle for welding of thin materials in the 0.020" to 0.100" thickness range without the addition of excessive filler metal.

Fusion Weld Must for Joints

by J. H. Berryman

New York—The design and fabrication problems inherent in space ship construction present many unique and peculiar problems. Only by fusion welding is it possible to make structural joints that possess the physical, corrosion-resistant, thermal-conducting properties necessary to successful space ship construction.

Outlined below are the major missile joint requirements and welded joint properties that can be evaluated to show the suitability of the welding process in missile fabrication.

• **Physical joint properties**—With few exceptions, welded joint efficiency in almost all structural metals and alloys is 100%. This means that a welded butt joint of this efficiency behaves under external load, corrosive conditions, and thermo-dynamic friction as though it were parent material.

• **Thermal joint properties**—A unique requirement of space vehicle fabrication is that the heat transfer across any joint is a vitally important factor. A butt-welded joint using a 100% cross section will have heat transfer across the joint equivalent to the parent material and is therefore preferable to any lap-type joint.

• **Corrosion joint properties**—A welded butt joint having no faying surface as a corrosion focal point or area, and which can be made using only fused parent metal or necessary fill metal selected from many desirable non-corrosive metals, is superior to other joint geometry and joining processes.

J. H. Berryman is general sales manager in the Special Products Department, Air Reduction Sales Co.

• **Availability of equipment**—Welding processes and equipment to weld various type joints, either manually or automatically, in a very wide variety of metals, is readily available to meet specified joint requirements. It should be pointed out here that machine or automatically welded joints are preferable in this area to manual welds.

• **Limitation of processes**—The fusion welding process has proven itself exceedingly adaptable to new requirements and new alloys. Temperature ranges up to 30,000°F are now available in commercial equipment for fusing and joining metals and ceramics.

Development in the welding art is widespread and continuing. This produces major improvements and opens up new joining techniques in both metallic and non-metallic materials.

How Honeycomb Panel Works

by Harold J. Black

NASHVILLE, TENN.—Honeycomb sandwich might be considered as a modern extension of the I beam section principle. For, to a much greater extent than in the I beam, honeycomb sandwich concentrates heavier bending materials at maximum distance from the neutral axis with an extremely lightweight cellular honeycomb core in between to stabilize the face sheets and carry out the shear stresses.

This structural arrangement is particularly efficient for design conditions involving panel bending, edge compression, rigidity, close adherence to contour under varying loads, and vibration environments.

For air vehicle speeds in the subsonic to Mach 2.0 range, operating temperatures are low enough to utilize bonded aluminum honeycomb quite effectively. As speed increases, structural designers are faced with two problems: (1) structural integrity at higher operating temperatures, and (2) ever greater emphasis on minimizing structural weight to reduce fuel requirements and increase payloads.

For sustained operation at temperatures of 450° to 650°F, and for short time operation up to perhaps 900°F, precipitation-hardening stainless steel alloys are in current use for brazed stainless steel honeycomb structures. Two of the most widely used alloys at present are the semi-austenitic alloys designed as 17-7 PH (17% Cr. -7% Ni) and PH 15-7 Mo (15% Cr.-7% Ni—2% Mo). These materials can be formed, brazed, and resistance—or fusion-welded fairly readily. Other alloys are also available for temperatures up to 1100°F, in the thin gages characteristic of lightweight structure.

Harold J. Black is director of Engineering at Avco Corp.'s Nashville Division.

Heat-treat Plus Cold Rolling

by Michael Watter

PHILADELPHIA—We instigated the development and application of high-strength alloys in which exceptional mechanical properties are obtained through cold rolling subsequent to heat treatment.

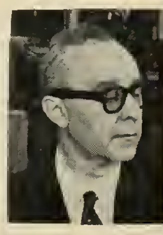
To exploit these materials requires special design concepts using spot and fusion welding. Structures of this type do not require final heat treatment, possess outstanding strength-to-weight ratio, and are dimensionally stable. At the present time structures whose thermal operating requirements fall into the range of room temperature to 1400°F can be fabricated using cold-reduced material.

The cold-reduced materials desirable for application from room temperature to 850°F are precipitation-hardening stainless steels, particularly cold-reduced AM 355. From 850°F to 1400°F, L605 answers requirements best. AM 355 is presently available in strength level of 300,000 psi, while a new experimental modification of this alloy, designated AM 357, has a strength level of about 360,000 psi at room temperature. L605 cold-rolled after heat treatment has the highest mechanical properties from about 900°F to 1400°F. From 1400°F to 1600°F René 41 shows up best. Beyond 1600°F, we prefer niobium because it can be formed and welded.

In addition, PH 15-7 Mo, A286 and Incaloy X were found suitable.

The two types of structural concepts of particular interest here are sequentially assembled rocket motor cases and structures employing welding steel sandwich or welded stringer-skin elements.

Michael Watter is on the research staff of the Budd Co.



In the sequentially assembled rocket case design, the assembly is composed of headers and cylindrical sections. The latter, due to the present limitations of the available width of 300,000 psi coils, do not exceed 36 inches. The individual subassemblies after being completely fabricated are fusion-welded together. Thus, while headers and cylindrical section material is at its maximum strength level, the joints remain ductile since the final assembly is not heat treated. The sequence of assembly is such that each individual subassembly and its attachment are sequentially checked, verified for pressure tightness and aligned, thus insuring dimensional accuracy and structural soundness.

The important feature of this type of design and method of fabrication is in its unsurpassed flexibility and economy. The size of the rocket or missile case does not depend on heat-treating facilities or elaborate metal forming machinery. The case can be made as large as desired and assembled where necessary without sacrificing its strength and efficiency.

The second structural concept of importance in missiles and space vehicles is the welded sandwich. The concept of welded sandwich was motivated by three major considerations: (1) to create a structural skin element which inherently made practical the eventual assembly of the whole structure; (2) to remove the temperature limitations that stem from the joining method; and (3) to keep the fabrication open to continuous control and inspection.

The two types of welded sandwich principally employed by us have double or single corrugated core with the apex of the corrugations having a very narrow flat or a radiused crown.

Structures of this type are not limited to steel or to resistance welding as the only method of assembly. We are developing a practical automatic welding machine using an inert gas tungsten electrode method. In addition to the materials mentioned, development work is being conducted with beta titanium, molybdenum and beryllium.

Defense Stockpile Hits Peak

by Heather MacKinnon

WASHINGTON—The United States is now at a peak of preparedness in its defense stockpile of strategic and critical materials, according to an Office of Civil and Defense Mobilization spokesman.

Of 73 materials listed as vital to the nation's defense, the OCDM program for FY 1960 calls for purchase of only three materials. Basic objectives in all other materials, assuring three years self-sufficiency in each in the event of a national emergency, have been fulfilled, under present and completed contracts.

The materials which have been authorized for open market purchase by the General Services Administration, are jewel bearings, used in instruments such as those in the guidance systems of rockets and missiles; small diamond dies, for forming fine wires used in rockets and missiles, and crysotile asbestos for insulation purposes.

Small quantities of materials already in the stockpile will be upgraded—converted to a more readily usable form—for emergency use. Companies holding contracts entered upon in FY '59 and still current are: **American Metal-Climax:** for the upgrading of electrolytic copper to oxygen-free copper and molybdenite to molybdic oxide; **The Wah Chang Corp.:** tungsten to tungsten carbide powder, and molybdenite to ferro-molybdenum; and the **Vanadium Corp.,** which is upgrading vanadium-oxide to ferro-vanadium. The total amount of these contracts will cost GSA approximately $4.5 million.

Two new contracts are in the process of negotiation. Additional amounts of tungsten carbide powder, upgraded from tungsten, is sought. It is useful for many high temperature applications. The other will be for more molybdic oxide from molybdenum, one use of which is in containers or reaction vessels requiring chemical inertness.

Within recent years, the number of strategic and critical materials listed by ODCM has been constantly increasing because of the many new processes and developments in industry. The programs named as making the most stringent demands upon the stockpile program are predominently in the missile/space industry. Studies are continually underway by ODCM to keep abreast of these new demands.

The volume of some materials in the stockpile, however, is not as large as in previous years because of increased efficiency of weapon and defense systems. For instance, the huge quantities of steel and aluminum needed to build the bomber and fighter planes of WWII are not necessary in the building of a missile defense system. Instead, the emphasis is continually on the search for new, higher grade metals.

Industry on the Move

Interstate Electronics Corp. and the A&E firm of **Benedict, Beckler and Associates** have teamed up to bid on missile range facilities and instrumentation projects . . . The A&E and electronic design groups of **Aerojet-General Corp.** are being combined into a new Aetron Division at Azusa, Calif. Aerojet also has opened a new $150,000 laboratory at Frederick, Md. . . . January is the starting date for construction of a $1.5-million administration building at the Newport Beach, Calif., facility of **Ford's Aeronutronic Division** . . . On steam—the **Linde Co.**'s 25,000-liter per month liquid hydrogen plant at Tonawanda, N.Y. . . . **Aeroquip Corp.** has completed a 30,000-square-foot plant expansion at Burbank, Calif. . . . **Dynamics Corp. of America** is doubling its quartz crystal production capacity at Carlisle, Pa. . . . **Reliability Engineering Associates** is now in a larger headquarters at Skokie, Ill. . . . Earth moving is under way for a headquarters of **Lockheed Electronics and Avionics Division Lead** at Newport Beach, Calif.

Forty-inch Forging Made Of Nickel-based Astrolloy

NORTH GRAFTON, MASS.—The **Wyman-Gordon Co.** says it has succeeded in producing a 40" diameter, closed-die forging of the new nickel-based astrolloy.

Astrolloy is a high-temperature alloy for which a 160,000 psi ultimate tensile strength is claimed at 1400°F. In addition to nickel, it contains 15% cobalt, 15% chromium, 5% molybdenum, 4.3% aluminum, 3.5% titanium, 0.7% manganese and smaller amounts of copper, sulfur, iron, silicon and boron. The alloy was developed by **General Electric Co.**

Unique Radio Link Joins North American Divisions

LOS ANGELES—A new microwave radio link will give **North American Aviation** a combined commercial computing facility larger than any now existing at any one location. The link will tie together six large-scale **IBM** computers at Los Angeles headquarters with the Rocketdyne Division 39 miles away, as well as the Missile and Autonetics Divisions at Downey.

This is the first time data has been transmitted between computers without the use of a direct-wire link.

The system, which can handle 180,000 words per minute, makes the computer facilities instantly available to engineers in the detached divisions. Previously, tape data had to be hand-carried between NAA's outlying plants.

Explosions Form Missile Metal Parts

Assessing claims made that the technique that violates all rules of forming; tougher metals give better results; solids behave like fluids or plastics

by John S. Rinehart

GOLDEN, COLO.—The shaping of metals—compaction, forming, drawing and swedging—is a technology that contributes heavily to the fabrication of missiles and rockets. Any advance in this technology implies advance in missile and rocket technology.

Recently, the introduction of metal forming using explosive charges has given rise to fabulous claims and it has been difficult for management and engineers alike to assess the true worth of this development.

What are the true facts? Does explosive forming violate all the rules for forming: The tougher the metal, the better the results? Under such loads do even the toughest metals behave strangely, acting more like fluids or plastics than solids?

In any such process, one is dealing with explosives, metals, and the nature of the coupling between the two. The source of energy is an explosive. There are two main types: High explosives, characterized by very high rates of reaction and high pressure; and deflagrating explosives or propellants, which burn more slowly and develop much lower pressures. The energy released on reaction is usually about 1,000 calories per gram whether the explosive detonates or burns.

In the case of high explosives, the pressure may be as high as 4,000,000 psi—at the surface of the explosive. A short distance away, pressure is much less but its duration much longer.

Propellants, when burned in the open, produce pressures no higher than a burning kitchen match. When confined, propellants can build up quite high pressures, which can be easily controlled, as in a gun, being usually limited to 40,000 to 50,000 psi.

• **Microsecond measure**—The sudden release of the energy of a high explosion takes place in a microsecond or so, the pressure building up in the same time; the explosion gases rapidly expand, dissipating energy, and the pressure drops suddenly, coming to zero in a few microseconds. The pressure generated by burning propellants takes several milliseconds to develop but, being confined, will be sustained for quite long times. Decrease in pressure comes about through cooling of the gaseous explosion products. Explosives forming groups into two situations:

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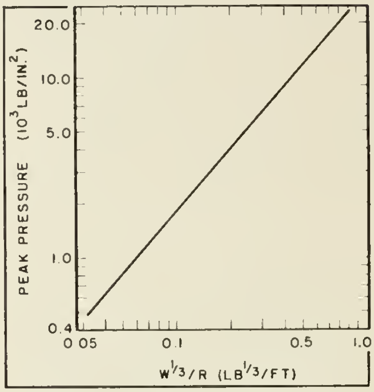


PRESSURE produced in "water" by spherical TNT charges in explosive forming plotted against charge weight $^{1/3}$ distance.

One in which the explosive is detonated in intimate contact with the metal, such as in the hardening of steels, compaction of metal powders, splitting of ingots, and cutting operations. The other in which objects such as cups, rocket nozzles, missile noses and aircraft parts are sized or formed by drawing—using propellants or explosives detonated in air or in water at some distance from the worked piece.

When the explosive is placed in intimate contact with a metal and detonated, the stresses just inside the metal will instantaneously become exceedingly high. A transient stress disturbance is set up and transmitted through the metal, producting fracture, plastic flow, and other deformations, the exact nature of which will be strongly dependent upon the configuration of the metal-explosive system.

Even under these extreme pressure conditions, the metal is seldom converted to a fluid, exhibiting in general the properties of a quasi-elastic brittle material.

• **Pounding pictures**—The stratagem in metal forming is to turn to advantage specific patterns of failures. Thus, ingots may be split by simultaneously detonating explosive charges on opposite sides of the ingot; or internal scale on heating pipes may be removed by detonating an explosive charge on the exterior surface of the tube—dislodging the scale in the same way a picture is knocked down by pounding on the reverse side of the wall.

Generally, in explosive forming the explosive is not placed in intimate contact with the metal but is separated from the work-piece by water or some other fluid.

If the intervening medium is air, the peak pressure will be greatly reduced even though the distance between explosive and metal is quite small. A liquid such as water provides a much better coupling medium between explosive and metal than does air. Water, or any other liquid, has the effect of rounding off the pressure pulse. It reduces the peak pressure, while prolonging the time over which the pressure acts.

Several parameters must be considered in analyzing the action of the pressure pulse upon the work-piece. It is not entirely clear whether it is peak pressure, total impulse, or kinetic energy that is the most important physical parameter needed to describe the interaction between coupling medium and work-piece. Both peak pressure and total impulse are dependent upon the weight of the charge and its distance from the work-piece, both pressure and impulse changing only as the cube root of the charge weight. Peak pressure and impulse are more sensitive to distance than charge weight, varying inversely with its first power.

• **Pressure variation**—At equal distances away from an 8 lb. charge and a 2 lb. charge, the peak pressure produced by the 8 lb. charge will be only twice that produced by the 2 lb. charge, indicating that in explosive forming operations the size of the charge will not be particularly critical. In the accompanying diagram, peak pressure produced in water by spherical TNT charges is plotted against (charge weight) $^{1/3}$ (distance). Curves for other explosives will not be substantially different.

In conventional metal forming, the metal of the part that is to be formed must, at some time during the forming operation, be in contact with the forming die. The distribution of stress established by the die is exceedingly complex—almost impossible to describe—with many opportunities for the development of regions of high stress concentration which, in turn, can lead to fracturing in localized areas.

A dynamic stress field of the kind set up when an explosive is detonated in a liquid usually distributes itself more uniformly over the whole piece to be formed, penetrating into every crack, crevice, and corner so that the metal is pushed about uniformly. In effect, it is almost as if one were using a well lubricated die of ever changing shape, the shape continuously and instantaneously conforming to the shape of the metal part as it is being formed.

A typical explosive forming operation such as the sizing of a metal nose cone, 5′-to-6′ in diameter, 1″ thick piece might be carried out as follows: The partially formed nose cone, dimensionally within several thousandths of final tolerance, is placed in a large female die. The cone is then filled with water and one or more small explosive charges, perhaps an ounce each, are suspended in the water at appropriate locations, the charges then being detonated electrically from afar. The charges explode, pushing the water ahead of them against the metal, the metal drawing itself out so as to fill the die completely.

• **Slow motion**—In other cases, water is placed in a polyethylene bag, with female dies sometimes being used, but in other instances the metal being allowed to form itself freely, taking whatever shape the pressure of the pulse dictates. The movement of the metal is not particularly rapid, being at most 100 to 200 ft/sec, a velocity below the critical impact velocity of most metals.

When propellants are used, the system must be gas tight, for the pressure must be allowed to build up relatively slowly. A typical operation could be the converting of a thin walled round tube into one of square cross section. The tube would be placed in a heavy walled container of square cross section suitably equipped with some means, such as a primed shot gun shell, for igniting a small amount of propellant powder. On ignition, pressure builds up, pushing the round tube outward so as to come up snugly against the square interior of the die.

In spite of much propaganda to the contrary, metals as a rule have less ductility when deformed rapidly than when deformed slowly, just as tar will stretch to great lengths when pulled slowly but will break in a brittle manner when struck a sharp blow. A few metals, notably the high manganese and high nickel steels and certain aluminum alloys, show as much ductility at high rates of strain as at low. Copper and certain other nickel steel alloys manifest increased ductility when strained rapidly.

There is a paucity of data on the

effect of rate of straining on the ductility of metals. But, the physical properties of metals at low temperatures have been extensively investigated, and many analogies can be drawn—both behavior patterns being dependent upon activation energies in much the same way. In none of these applications is the metal subjected to such pressures that it is converted to a fluid.

Metal forming using explosive charges is in its infancy. Its potential is now being evaluated with great intensity of effort in government, industrial and academic scientific communities. It is still too early to make a realistic appraisal of the engineering potentialities of explosive forming.

Method Can Increase Deforming Ability

by the du Pont Explosives Department

WILMINGTON, DEL.—The use of extremely high pressures generated by the detonation of high explosives appears to be uniquely suited for forming many metal parts not now easily made by more conventional means.

In some cases, particularly with some of the newer alloys, it has been found that the high forming rates produced by such intense pressures permit a significant increase in the extent to which materials may be deformed. Of great practical importance also has been the discovery that practically no "springback" is associated with the explosive deformation of metal sheets. There have been indications also that properties are enhanced additionally by the explosive sizing operation.

Explosive forming is still in its infancy. Present indications do not suggest it will supplant high-speed, repetitive-press forming, but it does appear attractive in areas where a limited number of parts are desired and tool amortization represents a large share of production costs. It is potentially capable of making as a unit objects which are now formed in several parts and later assembled.

In free-forming, material is allowed to form unrestrained into free space. Shapes were produced for the **Haynes-Stellite Co.**, Kokomo, Ind., using some of their high-temperature alloys. In this instance, the flat blank was retained on a draw ring with no die cavity beneath. When the explosive charge was detonated in a fluid medium above the blank the metal flowed into a dished configuration. Variations in shape from generally hemispherical to almost conical were found to be attainable, by varying not only the size, shape or location of the explosive charge but also certain physical aspects of the tooling. Similar shapes were formed by this technique from aluminum and stainless steel.

Considerable work has been done in forming a variety of shapes and sizes of dished heads. The largest head produced successfully to date was a railroad tank car end 8′ in diameter and 3/16″ thick for the **Graver Tank & Manufacturing Co.,** East Chicago, Ind.

Great dimensional accuracy in shapes formed from conventional materials and particularly the newer high-temperature, high-strength metals and alloys also is of paramount interest. Explosive forming, for instance, has been used to shape a scaled-down rocket motor venturi, a corrugated cylinder, and a flange for a duct-work joint.

Successes also have been recorded in producing corrugated shapes from flat blanks. Deep and wide grooves have been created explosively with high dimensional accuracy in 0.030″ 302 stainless steel. Deep and sharp spiral grooves also were formed satisfactorily for a fuel filter disc.

Process Might Be Used in Space Work

by Vasil Philipchuk

WEST HANOVER, MASS.—The art of fabricating certain materials for application to missile, rocket, and space vehicle parts through explosive forming is being accelerated. It is conceivable that the explosive process will be used in space, should fabrication techniques be required once the outer planets are reached—weight will constitute the greatest advantage when explosives are used as part of a process in space.

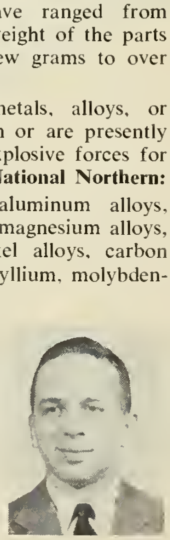
Currently we use explosive fabricating techniques for forming, forging, welding, locking and bonding, embossing, and compaction. Variables entering the process for particular parts are explosive type, explosive geometry, medium (for force transmittal) die material, die design, and set-up technique.

The state-of-the-art remains fairly new in the overall fabrication picture. Individual parts that are being produced and shipped are more advanced in the art, but rarely do two different parts get the same fabricating technique. Thicknesses of metals used in parts fabrication have ranged from .006 to 4.0 inches; weight of the parts has varied from a few grams to over two tons.

The following metals, alloys, or semimetals have been or are presently being tested under explosive forces for end applications at **National Northern:**

Copper alloys, aluminum alloys, stainless steel alloys, magnesium alloys, titanium alloys, nickel alloys, carbon steels, tool steels, beryllium, molybdenum, tungsten, tantalum, niobium, uranium, boron and zircalloy—2.

Vasil Philipchuk is Manager, Special Projects Division, of the National Northern Division, American Potash & Chemical Corp.



Explosive fabrication has a number of advantages: it reduces the number of operations; it requires no large capital equipment; it produces better tolerances in parts and imparts better physical properties to the finished part; it is the only known method for obtaining parts of certain designs, and facilities for its use can be set up with comparative speed and convenience.

Most parts will continue to be made more cheaply by conventional methods; explosive forming cannot compete with stamping machines or rotary process on an assembly line. Explosives always have and always will require the utmost respect in manufacturing, handling and detonation.

The Space Age has brought a demand for new metals and new designs. The new parts involved present problems to the conventional fabricator, and it is here that explosive forming can sometimes assist.

Medaris Would Cut 'Marginal' Projects

by William J. Coughlin

Los Angeles—Many current space projects should be dropped so the nation can concentrate its funding and technical effort on the few most important ones, Maj. Gen. John B. Medaris, retiring commander of the Army Ordnance Missile Command, told a press conference here.

Medaris declined to name any candidates to be scratched but did cite two projects which he believed should receive fullest support:

- *Saturn*. This is the first vehicle which will give the U.S. the possibility of doing a space job without straining technical capability to the maximum.
- *Nike-Zeus*. The nation must have confidence in this defensive project and move accordingly, despite the cost. "I have every reason to believe it will be successful," he said.

"For the first time in history," the general said, "there are more things which can be done in military and scientific endeavor than any nation in its right mind can possibly do."

The Army missile expert said the U.S. has two alternatives to do many things partially or a few things well. "Throughout my career I have favored doing fewer things and doing them better," he commented.

Medaris said the U.S. space program currently is pushing every vehicle to its limits, leaving no margin for reliability. *Saturn* will be the first in which work can be programmed on the basis of reliability and not over-sophistication.

"I definitely feel we should push *Saturn*," he said. "*Nova* as a follow-on also is important, but first we should push *Saturn*." He noted that the first full-scale static test of all eight engines in the clustered *Saturn* booster, capable of putting 25 tons into earth orbit, will be made late next spring. The *Nova* cluster, he said, will have a capability of up to 10-million pounds thrust.

• **Pound-foolish?**—Although refusing to suggest publicly which projects should be dropped, Medaris said: "The things I object to are the things that are a marginal improvement. It costs almost as much to engineer a small step forward. And engineering costs are the major cost."

Questioned on the award of the *Dyna-Soar* contract, in which the Air Force will retain the role of weapon system manager, Medaris said: "My own feelings are that a package should be kept together in the hands of someone who does the major portion of the work. A government agency should be used only if it has the resources to do the major part of the work. This was the case of ABMA."

• **Takes two to race**—Primary decision of whether the U.S. is or is not in a space race with the Russians has yet to be made, the general said.

"The people themselves have to make up their mind—are we in a race or are we not, and are we prepared to make the sacrifice?" he said. "So far, I've seen no evidence of a solid resolution to compete in a race."

Concerning the controversial decision to put U.S. space programs in the hands of the National Aeronautics and Space Administration, Medaris said he believed the effort must be brought under a single management in a mutually supporting, non-competitive effort. But he added: "I am loathe to agree this (NASA) is the final best agency for the purpose."

Officials Play Down Space Race at ARS

By James Baar

WASHINGTON—The 14th annual meeting of the American Rocket Society here Nov. 16-20 operated most of the time in a low key.

Government officials generally played down the lopsided East-West space "race," despite the feeling of many delegates that the need for revamping the U.S. space program is urgent. And a great number of the technical papers presented appeared to be little more than variations on popular themes.

Dr. William H. Pickering, director of NASA's Jet Propulsion Laboratory, charged that U.S. space efforts are too feeble to overtake Russia in space.

But Dr. Wernher von Braun, technical director of the Army Ballistic Missile Agency, was reduced by government pressure to talking about children and rocketry. And Brig. Gen. Homer Boushey, Air Force Advanced Technology Chief, no more than hinted broadly that contrary to the opinion of some top government officials the military has an important role to play in space.

More pointed comments by scientists and officials attending the meeting were made privately in hotel rooms and lounges.

• **Calm Russians**—A high-ranking Soviet delegation headed by Dr. Leonid I. Sedov, chairman of the Soviet Academy of Science's Interplanetary Travel Commission, sat through it all, politely answering some questions and politely ducking others.

Besides Sedov, the five-man delegation—first Russian group to present papers at an ARS meeting—included Prof. A. A. Blagonravov, a member of the Soviet Academy's Praesidium, and Prof. Valerian I. Krassovsky, chief of the Academy's Institute of Atmospheric Physics.

All declined to disclose any details of future Soviet space plans. But they appeared quietly satisfied.

Some of the more noteworthy papers presented during the four-day meeting:

• Dr. John Gustavson of **Grand Central Rocket** proposed the development of a 2.4-million-pound-thrust solid booster. He said six of them could be clustered to provide a gigantic solid booster yielding 14.4 million pounds of thrust. He named the smaller the *Cronus;* the bigger one the *Novus.*

• Dr. John C. Moise of **Aerojet-General** reported the development of a liquid hydrogen pump which would make possible construction of a 500,000-pound-thrust liquid hydrogen-LOX engine. He said the pump was tested this month in a 100,000-pound-thrust engine.

• Sedov reported on details of the orbits of the Soviet "Cosmic Rockets" and discussed the selection of sites, trajectories and times for earth-to-moon rocket launchings.

• Blagonravov discussed the isolation of instrument packages from rocket vehicles, temperature regulation in satellites and the orientation of satellites in space. Krassovsky discussed sodium vapor experiments, radiation measurements, cosmic rays, spectrometric determination of atmospheric ions and ionization and magnetic manometers.

• Four scientists from **Space Labs, Inc.**, reported that they successfully imbedded a two-ounce radio transmitter in the body of a space dog named Orbit. The transmitter was connected to the dog's heart so that it could transmit electro-cardiograms to monitoring stations from space.

• Irvin H. Schroder and John G. Chubbuck of the **Applied Physics Laboratory** said an orbiting astronomical telescope could be designed and placed in orbit within the next few years. The telescope would have a primary mirror 36 inches in diameter and a focal length of 8 to 10 feet.

• Rep. Peter W. Rodino Jr. (D-N.J.) warned that the world must find a means now to ensure international cooperation in space. He said "it will mean our final disaster if we permit space to become a new battlefield." He joined other delegates in calling for international agreements on space law.

• **Atomic progress**—AEC Chairman John A. McCone told ARS delegates at the annual Awards Night Dinner that first experiments in Project *Rover* already confirm the theories concerning the very high specific impulse attainable with nuclear energy."

"It is my judgment that this development will complement the chemical rocket engines and that the two in combination will provide the means for lifting large and heavy payloads in orbit," he said.

ARS elected Dr. Howard S. Siefert, **STL** special assistant for professional development, as president succeeding Air Force Col. John P. Stapp. Dr. Harold W. Ritchey, vice president of **Thiokol** was elected vice president.

ARS elected five directors for the three-year terms.

Exhibits included the first public showing of a **Martin** *Titan.* It was set up in front of the Sheraton-Park Hotel.

According to a possibly apocryphal story that made the rounds of convention sessions, Sedov asked when shown the *Titan:* "What is the scale?"

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As a special service M/R staff members have prepared a number of abstracts of papers presented at the ARS meeting. Some follow, more will be published next week.

ARPA Shifts Space Projects

WASHINGTON—ARPA has officially transferred three major space projects—*Samos, Midas* and *Discoverer*—to the Air Force and a fourth—the huge *Saturn* program —to NASA.

The *Saturn* transfer is on an interim basis pending congressional approval. Meantime, many strings to the program are being retained in Pentagon hands.

The transfer of *Samos, Midas* and *Saturn* was expected. The *Discoverer* transfer was a surprise.

The four programs make up more than half of ARPA's FY 1960 budget: *Samos,* the reconnaissance satellite, had about $120 million; *Discoverer,* the satellite experimental program, about $100 million; *Midas,* the early-warning satellite, about $35 million; *Saturn,* the 1.5-million-pound-thrust clustered booster and space vehicle, about $70 million.

Samos, Midas and *Discoverer* funds are being transferred to the Air Force. ARPA will continue to administer *Saturn* under technical direction of NASA and a *Saturn* Committee including representatives of NASA, ARPA, Air Force and Army Ballistic Missiles Agency.

Solid Rocket Technology

On the Use of Solid Propellants for Multimillion-pound Boosters, John Gustavson, Advanced Concepts Office, Grand Central Rocket Co., Redlands, Calif.

Solid and liquid space vehicle launchers are compared on the basis of the well-known velocity increment equation. Two solid-propellant launchers are presented of 2.4 and 14.4 million-pound initial thrust capable of launching 26,000 and 150,000 pounds of payload respectively into a 300-n.mi. satellite orbit. The merits of the suggested space boosters are discussed, including the new Nitrasol solid propellant, the lightweight plastic nozzle, control problems, continuous mixing and booster cost. It is pointed out that although solid propellant chemicals are more expensive than liquid ones, the handling and logistics problems will make solids available at a lower cost in the loaded vehicle. Also, since the solid system consists of fewer components than the liquid, the development time and cost is substantially less, and greater reliability is attained (ARS 1012-59)

Design Considerations for Spiralloy Glass-reinforced Filament-wound Structures as Rocket Inert Parts, A. H. Kitzmiller, Jr., C. C. DeHaven and R. E. Young, Hercules Powder Co., Cumberland, Md., and Rocky Hill, N.J.

SPIRALLOY structures of oriented continuous glass filaments and resins are presently being used in successful series of Allegany Ballistics Laboratory solid propellant rockets. These reinforced plastics offer a most attractive strength/weight ratio and a practical and economic rocket structure.

This report describes some of the basic factors which affect the design and fabrication of SPIRALLOY pressure vessels; e. g., the type and amount of resin; the winding angle, pattern and tension; and the contour and winding angle best suited to integrally wound end closures. The physical properties are given and the effects of material, design and fabrication upon these characteristics are discussed. (ARS 983-59)

Communications Equipment

Abrupt Telemetry Signal Strength Fades in Powered Flight on *WS107A* Re-entry Vehicles, Edward Niemann, Jr., Missile and Space Vehicle Dept., General Electric Co., Philadelphia.

Surveys telemetry data obtained during Atlas re-entry tests and shows cause of signal fades to be combination of shock wave and corona effects. (ARS 978-59)

Decommutation of 100% Duty Cycle Telemetered Signals, M. G. Pawley and E. D. Heberling, U.S. Naval Ordnance Laboratory, Corona, Calif.

Describes new commutator designed for 100% duty cycle commutated signals. Unit also provides improved performance with standard PAM and PDM commutated signals. Emphasizes details of synchronization technique. (ARS 979-59)

An Analog and Digital Airborne Data Acquisition System, James M. Walter, Jr., and Donald H. Ellis, Radiation, Inc., Melbourne, Fla.

Describes flexible transistorized analog-digital data acquisition system built for GE test facility at Edwards AFB. Includes details of low-level gate circuit, programming, accumulating, and coding techniques. (ARS 980-59)

The Effect of Different Types of Video Filters on PDM/FM Radio Telemetry, Myron Nichols and Arthur Bublitz, University of Michigan, Ann Arbor.

Extends previous analyses of filter comparison and corrects method of optimization described by Nichols and Ranch in their book "Radio Telemetry." (ARS 981-59)

Ion Propulsion

Experimental Studies with Small Scale Ion Motors, R. C. Speiser, Carl R. Dulgeroff and A. T. Forrester, Rocketdyne, North American Aviation, Inc., Canoga Park, Calif.

Presents results of cesium surface ionization ion sources in ion motor configurations. (ARS 926-59)

Physics of the Ion Thurst System, Raymond Fox, University of California Lawrence Radiation Laboratory, Livermore, Calif.

Describes study of source, acceleration, and neutralization of ions for space propulsion applications. Summarizes most important problems and solutions. (ARS 927-59)

Ion Propulsion Systems: Experimental Studies, Sam Maiditch, R. M. Worlock, D. Zuccaro, D. Barker, M. P. Ernstene, L. R. Gallagher and J. Mullins, Electro-Optical Systems, Inc., Pasadena, Calif.

Gives comprehensive survey of problems and solutions in development of ion propulsion. Covers ion sources, accelerators, neutralization. (ARS 928-59)

Thurst Multiplications by Successive Acceleration in Electrostatic Ion Propulsion Systems, David B. Langmuir, Thompson Ramo Wooldridge, Inc., Los Angeles, Calif., and B. R. Cooper, University of California, Berkeley.

Presents theoretical considerations of properties of idealized electrostatic propulsion systems in which ions are transmitted without loss through equipotential accelerating planes.

Guidance

An Orbiting Astronomical Telescope Design Study, Irvin H. Schroader, John G. Chubbuck, Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Md.

The authors describe basic elements of a satellite observatory: structure, optics and control, command, and telemeter system plus associated ground station. They note problems to be solved before observatory can be placed in orbit. (ARS 912-59)

Midcourse Guidance Rekuirements for Mars and Venus Probes, Friend H. Kierstead, Jr., Goodyear Aircraft Corp., Akron, Ohio.

This paper discusses midcourse accuracy requirements for typical Mars and Venus flights, presents numerical results obtained for proposed flights with various guidance techniques, and compares capabilities of the different systems. (ARS 914-59)

The Rotating Pendulum Accelerometer, Samuel Schalkowsky and Henry F. Blazek, Ford Instruments Co., Long Island City, N.Y.

The authors describe basic features of a new class of precision accelerometers particularly adapted to measurement of slowly varying low-level accelerations. They compare this with conventional techniques. (ARS 915-59)

Physics of the Atmosphere and Space

Photographic Studies of Horizon Patterns from High Altitudes, D. Hoffleit and T. R. Bechtol, Ballistic Research Laboratories, Aberdeen Proving Ground, Md.

The authors describe equipment developed for the study of the horizon from high altitudes. Horizon cameras, either balloon- or rocket-carried, are described. Photos obtained are analyzed and a summary of results indicates the usefulness of photometric horizons and the even greater value for studies of atmospheric structure. (ARS 917-59)

Ionospheric Structure Above Fort Churchill, Canada, from Faraday Rotation Measurements, Raymond E. Prenett, Ballistic Research Laboratories, Aberdeen Proving Ground, Md.

During the International Geophysical Year, a number of sounding rockets were fired into the ionosphere above Fort Churchill. By determining the Faraday rotation of the 76.06-mc DOVAP tracking signal transmitted from the rockets, the integrated electron content was computed. Evaluated data from two flights are presented. (ARS 918-59)

Convection Currents in the Earth's Mantle, A. L. Licht, National Aeronautics and Space Administration, Washington, D.C.

Characteristics of a hypothetical convection current in the earth's mantle have been determined by using recent measurements of the third zonal harmonic component of the earth's gravitational potential. The calculations are discussed and results are analyzed and evaluated by the author. (ARS 941-59)

Plasma Propulsion

The Plasma Jet as an Electric Propulsion System for Space Application, Gerhard Heller, Army Ballistic Missile Agency, Redstone Arsenal, Ala.

Describes a plasma jet-propelled moon supply mission. Propulsion system has a thrust of 70 pounds and an I_{sp} of 1000 sec. (ARS 1004-59)

NASA Research on Plasma Accelerators for Space Propulsion, W. Moeckel and W. Rayle, Lewis Research Center, National Aeronautics and Space Administration, Cleveland.

Describes current NASA research and future plans. Concludes that plasma accelerators are still too poorly understood to determine their place in space propulsion. (ARS 1005-59)

Magnetohydrodynamic Flow Experiments of a Steady State Nature, V. H. Blackman, MHD Research, Inc., Newport Beach, Calif.

Describes the facility set up in an effort to combine the steady-state flow characteristics of a wind tunnel with the high gas temperature capability of a shock tube. (ARS 1007-59)

Experimental Results with a Collinear Electrode Plasma Accelerator and a Comparison with Ion Accelerators, S. W. Kash, and W. L. Starr, Lockheed Aircraft Corp., Sunnyvale, Calif.

Presents results obtained from a collinear electrode plasma accelerator. Specific impulse greater than 2000 sec. obtained and up to 6000 are indicated. Efficiency of operation is greater than 30%; 50% should be possible. (ARS 1008-59)

On Magnetohydrodynamic Propulsion, Arthur Kantrowitz and G. Sargent Janes, Avco-Everett Research Laboratory, Everett, Mass.

Discusses properties of plasma accelerators using electrodes considered as circuit elements. Presents theorem relating minimum instantaneous power, efficiency, and specific impulse. (ARS 1009-59)

Plasma Propulsion, Gordon L. Cann and Adriano C. Ducati, Giannini Plasmadyne Corp., Pasadena, Calif.

Discusses possible application of arc jet propulsion. Concludes that the arc jet is competitive with chemical and ion propulsion systems only if propellant can be carried as a liquid or solid. (ARS 1010-59)

Miniaturization Advances

Molecular Electronics, Gene Strull, Semiconductor Div., Westinghouse Electric Co., Baltimore.

The author defines molecular electronics as "the complete merger of function and material." By simile he carries the definition further to more completely describe this concept of functional solid-state circuitry. The author provides a detailed description of two applications of molectronics; a light telemetry system and a pulse generator. Each consists only of a power supply load, and a single semiconductor wafer having a volume of 0.001 in 3. (ARS 1001-59)

Data Recovery—The Heart of the Flight Instrumentation Problem, P. A. Lathrop, and P. B. Aller, Missile and Space Vehicle Dept., General Electric Co., Philadelphia.

The need for more accurate, sophisticated and reliable flight instrumentation steadily increases, according to the authors. The problem is greatly magnified in unmanned space vehicles, missiles or satellites. Major considerations in the successful instrumentation design of two types of data recovery capsules are described in detail: free-fall and drag-retardation types. (ARS No. 1003-59)

Microminiaturization of Space Computer, Edward Keonjian, Missile Guidance Dept., American Bosch Army Corp., Garden City, N.Y.

The application of microminiaturization techniques to computer design can result in a vastly reduced (10:1) total volume and a significant increase in system reliability, states the author. Technique reduces total number of parts and corresponding number of soldered joints which previously were serious sources of trouble. Use of these techniques in Arma's Adder computer is described in detail. (ARS No. 998-59)

The Macro-Module Program, Stanley Schneider, Research Center, Burroughs Corp., Paoli, Penna.

The author describes the concept of tbe Macro-module construction for digital data processors for achieving compact, high-density modules. Method reduces vast number of required system intraconnections. Basic philosophy involves consideration of 2-dimensional circuits and a 3-dimensional system. Subsystem fabrication is described in detail. (ARS No. 999-59)

Far Space Communications

Some Recent Developments in Communications Equipments for Missile and Space Programs, Daniel Hochman, Lockheed Missiles and Space Div., Sunnyvale, Calif.

Describes recent developments at Lockheed Missile and Space Division. Covers PAM-FM telemetry links and solar-powered telemeter beacon. (ARS 961-59)

Re-entry H. F. Transmission Experiment, Jack B. Duryea, Edward F. Paski, and William L. Aseniero, Missile and Space Vehicle Dept., General Electric Co., Philadelphia.

Reviews current experimental program on feasibility of transmitting data through plasma sheath during hypersonic re-entry. Frequencies used during inconclusive tests were 3-30 mc. (ARS 962-59)

Support Equipment

Support Equipment Designers Look at the Moon, M. J. Neder, T. E. Walsh, Aerojet-General Corp., Azusa, Calif.

Environmental factors—high vacuum, solar and cosmic radiation, meteors, extreme temperature ranges and the possibility the moon is covered with a deep layer of dust —pose a whole new set of problems in developing support equipment for a manned lunar landing and return. The authors also discuss thermoelectric generation of power to support a moon operation. (ARS 994-59)

Ion Engine Test Laboratory Planning, R. O. Dietz, Arnold Engineering Development Center, Tullahoma, Tenn.

Ion and chemical rockets are compared for transferring a satellite from 150-mile altitude orbit to a 24-hour orbit; autbor also describes laboratory requirements for full-scale development testing of ion engine design for satellite propulsion. (ARS 995-59)

Altitude Facility Rocket Testing, I. C. Lightner, ARO Inc., Tullahoma, Tenn.

Presentation of performance capabilities of engine test facility at Arnold Engineering Development Center and examples (including "chuffing") of phenomena observed during altitude tests. (ARS 996-59)

Missile and GSE Transportation Environment, M. T. Kirkenmeier, Chrysler Missile Division, Detroit.

Discussion of shock and vibration factors encountered in the transport of missiles by rail, highway and overland. (ARS 993-59)

Are We Ready?—Developing Operational Weapon System Launch Control and Checkout Equipment, Leonard Chevlin, The Martin Co., Denver.

Operational and reliability requirements of *Titan* ground-based system are set forth by the author. (ARS 997-59)

Available Power Systems for Space Vehicles, Harris J. Howard, and Robert W. McJones, Vickers, Inc., Torrance, Calif.

Weight and performance data are presented for available and projected power systems, with results of some recent development programs included. Systems are compared against power requirements for non-recoverable solid rocket boosters, recoverable re-entry vehicles, and long-duration space vehicles. (ARS 1032-59)

The Advanced Stirling Engine for Space Power, H. W. Welsh, E. A. Poste and R. B. Wright, Allison Div., General Motors Corp., Indianapolis, Ind.

Presents results of studies on thermomechanical power systems. Analysis shows that high efficiency (over 30%) and operational characteristics of the advanced Stirling engine meet requirements for space power and result in significantly low system weight. (ARS 1033-59)

Thermoelectric Cooling, Irving Sochard, Diamond Ordnance Fuze Laboratory, Washington, D.C.

Described theory and application of Peltier refrigeration. (ARS 1034-59)

Propellant Type Open Cycle Secondary Power Systems for Manned Space Vehicles, Antonio Orsini, Walter Kidde & Co., Inc., Belleville, N.J.

Discusses use of both mono- and bipropellant systems for space power generation. Author deals with open-loop systems only and notes that comparable closed-loop data does not exist at present. (ARS 1035-59)

Safety and Reliability

Propulsion Aspects of the Piloted Space Flight Safety Program, James H. Madden, Aerojet-General Corporation, Azusa, Calif.

Present propulsion system reliability and safety prediction and achievement methods are examined and predictions made as to anticipated future growth of reliability and safety. Interrelationship between reliability and safety is considered and compatibility between requirements for these objectives is discussed. The use of multi-engine clusters and redundancy theory are introduced as the primary methods by which adequate space vehicle reliability and safety may be attained. Special equipment requirements for piloted vehicle applications are considered. Discussion of modifications to present safety requirements includes the need therefore as delineated by state-of-the-art status as well as trends in propulsion system development. The capability of present liquid rocket engines to provide for immediate manned space flight operations is treated.

Evaluating Crew Safety for Rocket-Powered Manned Space Vehicles, William L. Hadley, Bell Aircraft Corporation, Buffalo, N.Y.

The author discusses the steps to be followed in the prediction of crew safety and shows examples of the methods of prediction which have been successfully applied to determine the adequacy of safety provisions in manned space vehicles.

Performance and Reliability of Attitude Control Rocket Systems, O. S. Williams, Thiokol Chemical Corporation, Denville, N.J.

The author investigates the performance and reliability of three basic types of attitude control systems, stored gas, monopropellant and bipropellant, and their response characteristics. Considerations are given to system optimization, to improved performance and the effects of these improvements on overall reliability. A correlation between performance and reliability will be shown, and the need for further development in both areas will be discussed.

Effects of Manned Payloads on Booster Engine Requirements in Regard to Safety and Reliability, J. P. Hynds, C. J. Kaplan, Rocketdyne, Canoga Park, Calif.

Various aspects of engine design and development where alternatives exist are presented and the type of failure danger associated with each is compared: Clustered engines vs. single large engines; Simplified controls vs overriding and redundant controls; Mode of failure testing. The paper inspects liquid rocket engines as they appear in the current state-of-the-art, regarding safety and reliability for manned payloads.

Propellants & Combustion

The Stability of Laminar Flames, Russell E. Peterson, Howard W. Emmons, Harvard University, Cambridge, Mass.

The Markstein theory of stability of laminar flames is shown to be supported by experimental results on oscillated laminar propane-air flames. Disturbances in appropriate wave length ranges grow and distort while for other ranges disturbances are damped. These facts imply important restrictions on the nature of a turbulent flame and its interaction with the surrounding flow field.

An Experimental Method of Measuring Intensity of Turbulence in a Rocket Chamber, Martin Hersch, Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio.

Experimental values of intensity of turbulence in a two-dimensional hydrogen-LOX rocket engine were determined from the spread of a gas jet diffusing in the combustion chamber. The diffusion was determined photographically, using sodium d-line radiation as a flow tracer. A simplified model of turbulent diffusion was used to estimate the intensity of turbulence from the gas jet spreading. The results indicated that the intensity of turbulence is relatively high near the injector but diminishes downstream. The variation of lateral fluctuating velocity with downstream distance was in agreement with theoretical predictions for decaying turbulence in a cold flow accelerating stream. Changes of several operating parameters had little, if any, effect upon the intensity of turbulence.

Metal Combustion Processes, Irvin Glassman, Princeton University, Princeton, N.J.

The author presents some preliminary conclusions on burning characteristics. These conclusions are based on fundamental physical considerations and not on experimental results. An analytical approach to calculate the burning rate of metals is also suggested. This approach differs from the diffusion-droplet approach in that it includes radiation feedback and loss terms. Such terms can be important at the high temperatures of the diffusion film surrounding a metal.

The verification of many of the postulates given can be carried out ideally at some later date on the high-pressure, double-rocket motor flow reactor developed under the subject contract.

The Effect of Flame Configuration on Combustor Performance, C. C. Miesse, Armour Research Foundation, Chicago.

The author concludes that the efficiency of a combustor may be improved by providing increased flame-holding areas and/or additional length of combustor. The differences in the various types of flame-holder configurations become negligible as the combustor length approaches twice the length of the flame envelope. Theoretical results, based on the chemical law of mass action, are verified qualitatively by experimental data.

Problems of Space Travel

Survival Equipment for Emergency Space Vehicle Abandonment, Harold L. Bloom, Missile and Space Vehicle Department, General Electric Co., Philadelphia.

An analogy is drawn between "abandon ship" at sea and in space. The analogy is continued through a discussion of the emergency equipment available to the sailor and parallel equipment which should be available to the spaceman. The discussion points out the increase in "survivability" with increase in components and complexity of emergency equipment. The space "life-raft" and the space "life-boat" are singled out for specific treatment. Preliminary estimates of weights and components are determined. Comparisons are offered for the cases of the items remaining in space and items re-entering and landing on earth. Abandoning an earth satellite is treated as a special case.

The Radiation Problem in Low-Thrust Space Travel, Andrew D. Babinsky, Michael G. Del Duca, Angus F. Bond, Thompson Ramo Wooldridge, Inc., Cleveland.

The discovery of the Van Allen radiation belts, although the nature and energies of the radiation are not precisely known yet, has clearly established the need for: 1) the development of various low-radiation flight schemes which would permit penetration of the zones of high intensity radiation by manned vehicles and 2) the determination of vehicle requirements for proposed flight schemes. Preliminary investigations in addition to presenting magnitudes of radiation expected indicate that the total radiation received can be controlled by proper selection of launch and orbit parameters. Also, it is indicated that a large palyoad advantage can be gained by minimizing radiation due to the reduction in shielding requirements.

How Useful Are Low-thrust Space Vehicles, Ernst Stuhlinger, Army Ballistic Missile Agency, Huntsville, Ala.

The author sketched briefly the evolution of electric propulsion and describes in detail several missions involving the various concepts. The paper concludes with the prediction that electric systems will come into life in their own right and not as all-out competitors with other systems. Their development should be encouraged as part of the natural evolution of man's technology.

The Advantages of High-thrust Space Vehicles, W. Hunter, J. M. Tschirgi, Douglas Aircraft Co., Santa Monica, Calif.

The authors demonstrate that there is very little difference between microthrust and high-thrust vehicles as far as performance is concerned. But when the relative difficulty of developing reliable hardware is considered, high-thrust vehicles have a definite advantage.

Gas Wave Phenomena

Theory of the Structure of Gaseous Detonations, C. F. Curtiss, J. O. Hirschfelder, University of Wisconsin, Madison.

The authors discuss the structure of gaseous detonation waves. The effects of the transport phenomena, thermal conductivity, viscosity and diffusion are included. The transport phenomena lead to a coupling between the shock and reaction portions of the detonation. Normally this coupling is small and the solutions resemble closely those discussed by Von Neumann. However, if the reaction rate is sufficiently fast at the detonation temperature, the coupling is strong and the solutions are of the Cook type. Experimentally, strong coupling may be achieved by preheating.

Theoretical Analysis and Experimental Measurements of Detonation Induction Distances at Atmospheric and Elevated Initial Pressures, Loren E. Bollinger, Michael C. Fong, Rudolph Edse, Ohio State University, Columbus, Ohio.

The transition phenomenon from deflagration to detonation has been investigated. An empirical relationship involving the combustion temperature, the burning velocity, the sonic velocity in the unburned gas, and the Reynolds number based on the burning velocity has been established to predict detonation induction distances of certain combustible gas mixtures. For mixtures containing hydrocarbons the correlation is not satisfactory. An explanation for this is offered.

Methods of Predicting Composition Limits for Detonation of Hydrogen-Oxygen-Diluent Mixtures, Richard W. Patch, United Aircraft Corporation, East Hartford, Conn.

Two different methods of predicting Chapman-Jouguet detonation limits in hydrogen-oxygen-diluent mixtures are presented for a model of the detonation wave comprising a shock wave followed by an ignition-delay region and a combustion region. In the first method a constant ignition-temperature criterion for the gas behind the shock wave is employed to correlate the experimental data, while in the second method explosion limits determined from chain branching considerations are employed. Various degrees of rotational and vibrational relaxation behind the shock in the ignition-delay region are assumed for both methods to obtain three sets of temperature and pressure conditions behind the shock wave. Both methods are employed to predict detonation limits for various mixtures for which experimentally determined values are in the literature.

It is shown that the constant-temperature criterion computed for a gas having complete rotational relaxation but no vibrational relaxation provides the best correlation with experimental values obtained from the literature.

Dr. Mostafa B. Talaat, an Egyptian-born engineer whose work has been honored on several occasions by the American Institute of Electrical Engineers, has joined the Nuclear Division of The Martin Co. to direct all research and development efforts in the field of energy conversion.


TALAAT

Dr. Talaat holds two patents on thermoelectric generators and one on the cooling of electric machinery, and has published a dozen papers and technical discussions in the authoritative Transactions of the American Institute of Electrical Engineers.

Harry L. Henley has joined Meletron Corp., as Evaluation Engineer in charge of the engineering laboratory. He was previously instrumentation engineer, Research, at Rocketdyne's Propulsion Laboratory.

George J. Vila has been named Washington manager-NASA for Convair Division of General Dynamics Corp., and will be responsible for coordinating all of the division's efforts relating to NASA projects. He will report to **R. B. Swanson**, assistant to the vice president and Washington office manager.

Thomas G. Pownall, formerly in the Convair office at Dayton, Ohio, will succeed Vila as Astronautics' Washington representative.

Willard A. Hughes has been elected general manager of the Microwave Division, Kearfott Co., Inc., a subsidiary of General Precision Equipment Corp.


HUGHES

Hughes has served this division for a number of years as chief engineer and most recently as assistant general manager. In his new capacity, he has appointed **Mr. D. F. Metcalf** chief engineer; **N. P. Weinhouse** as manager of the Engineering Technical office, and **W. R. Biderman** as Quality Control Manager for the Microwave Division.

William H. Newell has been elected Assistant to the President of Ford Instrument Co., division of Sperry Rand Corp. Newell, who retired after 30 years with the company, has been recalled to assist the president in the future technical planning for the company and coordinate its research and development activities. He holds 56 patents and is a recognized authority on inertial systems and computing and control devices.

John C. Christian, former staff consultant, Market Development, for Hughes Aircraft Co., has joined Aeronutronic, a division of Ford Motor Co., as manager of Marketing for Space Technology Operations. He will be responsible for formulating a marketing program for the division's space age products and determining customer requirements in the field of space technology.


CHRISTIAN

Prior to joining Hughes, Christian was manager, Plans and Programs, Crosley Defense Product Div., Avco Corp., and before that was chief of the armament staff unit at Boeing Airplane Co.

Dr. Peter B. Myers has accepted a position as Staff Scientist with the Semiconductor Division of Motorola, Inc. He will be engaged in advanced research and development of semiconductor integrated circuits, and will serve as a division-wide consultant on mechanical problems.


MYERS

Dr. Myers was formerly associated with Bell Telephone Laboratories doing research work on instrumentation for high-frequency characterization of transistors.

Southwest Research Institute has announced three major staff changes: **Maj. Gen. Harry Reichelderfer**, USA, (Ret.), who joined the institute in 1956, has been named administrative vice president. **Dr. James Sharp** and **Henry Korp** have been appointed technical vice presidents.

James G. Dogherty, formerly assistant head, has been promoted to head of the Research and Study department at Vitro Laboratories, and **Morris Lebovits** has been appointed chief of astroaero sciences at Solar Aircraft Co.

Winfield Shiras, formerly with Westinghouse Electric Corp., has been named vice president and general manager of Telex, Inc., and **Franklin C. Spinney**, formerly a field engineer in the Washington office, has been elected manager of research sales for the Allison Division of General Motors Corp.

contracts

NAVY

$1,865,239—Control Instrument Co., Inc., Brooklyn, N.Y., for design, construction and supply of four missile F. C. switchboards.
$110,000—Boeing Airplane Co., Wichita, Kan., for research on low frequency vibration effects on human performance.
$59,686—North American Aviation, Inc., Canoga Park, Calif., for research in hybrid combustion.
$52,624—Texas Instruments, Inc., Dallas, for research on graded gap semiconductors.
$44,000—King Cowles & Associates, Inc., dba Robert W. King Construction Co., N. Hollywood, Calif., for construction of A.E.C. missile assembly building, Naval Missile Facility, Point Arguello, Lompoc, Calif.
$41,422—University of Chicago, for research on magneto convective instabilities.
$41,040—Carnegie Institute of Technology, Pittsburgh, for research on free energies of surfaces.
$40,775—Rensselaer Polytechnic Institute, Troy, N.Y., for design and construction of a series of bladeless propulsion systems of the duct type.

MISCELLANEOUS

$600,000—Reeves Instrument Corp., subsidiary of Dynamics Corporation of America, for the design, engineering and building of new type electric fuzes for an advanced weapon.
$106,000—Yardney Electric Corp., N.Y.C., for the manufacture of extremely powerful silver-zinc batteries for missile application. Subcontract from Boeing Airplane Co.

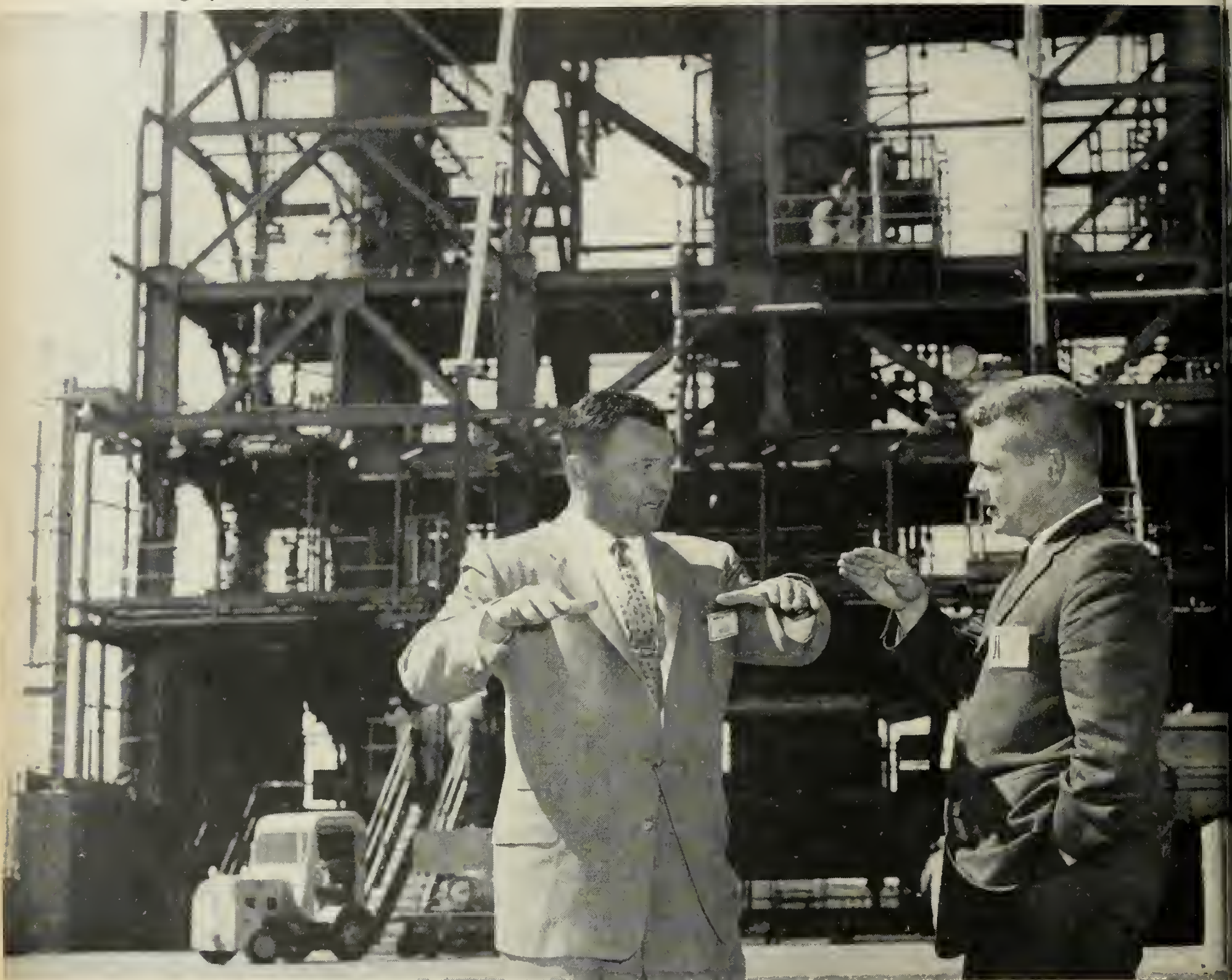
AIR FORCE

Boeing Airplane Co. has sublet three research and development contracts totalling $2,300,000 for work on the *Minuteman* ICBM. These contracts went to General Motors Corp., Cessna Aircraft Co., and Bendix-Pacific division of Bendix Aviation Corp. Amount of individual contracts not disclosed.
Sylvania Electric Products, Inc., has been awarded a contract calling for delivery of an experimental ultra-high-frequency receiver that will provide 10,000 hours continuous operation. Amount not disclosed.
The Electronics Division of Chance Vought Aircraft, Inc., has received a sub-contract from the Autonetics Division of North American Aviation, Inc., to design and develop the actuator system for the *Minuteman* ICBM. Amount not disclosed.
$10,000,000—Ryan Aeronautical Co., for further production of *Q-2C Firebee* jet-propelled target missiles.
$265,950—Gilfillan Brothers, Inc., Los Angeles, Calif., for oscilloscope, sychronizer set.
$150,000—Stanford University, for continuation of research on "Studies of elastic and inelastic scattering of HE electrons; production and interactions of various mesons; field theory; problems in quantum electro-dynamics."
$62,067—University of California, for research on "X-ray studies of unusual organic molecules."
$27,182—University of California, for continuation of research on "Studies of sampled data control systems."

ARMY

Elkton Division of Thiokol Chemical Corp., received a contract from Republic Aviation for design, development and production of solid booster motors for *Swallow* surveillance drone. Amount not disclosed.
$5,974,644—The Martin Co., Orlando, Fla., for engineering services, preparation of repair parts lists, documentation and test hardware and *Lacrosse* missiles and related equipment. (Four contracts).
$2,300,054—Radioplane Div., Northrop Corp., Van Nuys, Calif., for surveillance drones.
$997,859—Paul Smith Construction Co., Orlando, Fla., for reconstruction of Pad 12, Cape Canaveral Missile Test Annex, Patrick AFB.
$600,000—International Telephone & Telegraph Corp.'s Federal Division, Clifton, N.J., for additional ground support equipment for the *Lacrosse* missile. Subcontract from The Martin Co.
$556,154—Western Co., Inc., N.Y., for *Nike* spare parts and components. (Four contracts).
$306,000—Hayes Aircraft Corp., Birmingham, Ala., for engineering and design services, ground support equipment for *Saturn*.
$261,700—North American Aviation, Canoga Park, Calif., for rocket engines.
$178,486—E. I. Noxon Construction Co., Los Angeles, for additional nose cone facility items at Vandenberg AFB.
$105,148—Western Electric Co., N.Y., for *Nike* spare parts and components. (Two contracts).
$76,408—Radioplane Co., Van Nuys, Calif., for supplies and services re missile targets. (Two contracts).
$76,630—Hayes Aircraft Corp., Birmingham, Ala., for design, engineering, fabrication and maintenance services.
$70,646—Westinghouse Electric Corp., Micarta Div., Hampton, S.C., for research and development of test cones for nose sections.
$56,364—Douglas Aircraft Co., Inc., Santa Monica, Calif., for repair parts for *Nike* systems.
$49,424—Hayes Aircraft Corp., Birmingham, Ala., for engineering and design services and specialized services for manufacture of special tooling and fixtures of missile components.
$39,876—Auburn Research Fonndation of Alabama Polytechnic Institute, Auburn, Ala., for applied research entitled "Heat transfer studies and tests."
$25,000—Metal Hydrides Inc., Beverly, Mass., for 19,348 units of calcium hydride generating charges.

LEADER IN ROCKET PROPULSION — Dan M. Tenenbaum (left), Manager, Test Division, Sacramento Plants, discusses static ground testing with Richard van Osten of the Editorial Staff of MISSILES AND ROCKETS Magazine. Aerojet-General has over 180 test stands for liquid and solid propellant rockets with facilities to conduct tests involving up to a million and a half pounds-thrust. The stand shown above is used to test the mighty Titan engines.

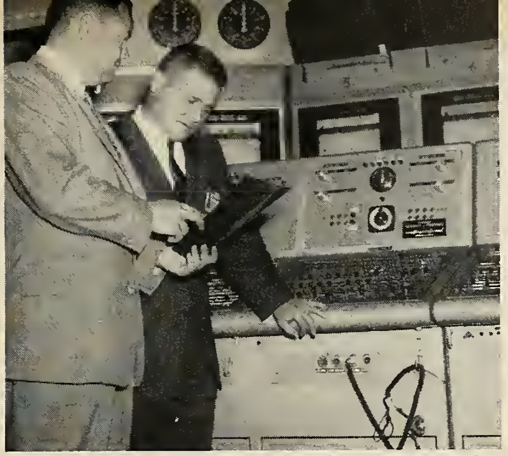


WHO READS MISSILES AND ROCKETS?

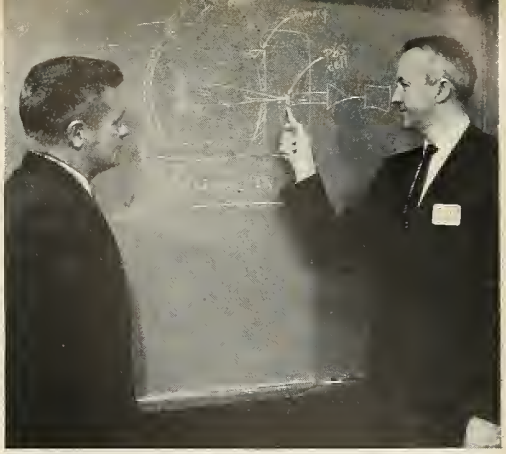
Well, for example . . . TOP ENGINEERS AT AEROJET-GENERAL

Aerojet-General Corporation, a Subsidiary of the General Tire and Rubber Company, is one of the outstanding leaders in the research, design, development, and production of both solid and liquid propellant rocket engines. An 18,000 acre site outside of Sacramento, California, is devoted entirely to major missile rocket engine development and production facilities. Aerojet-General has developed and produced propulsion systems that reac like a veritable Who's Who among Missiles. Fo example: Titan, Polaris, Minuteman, Able, Bomarc Vanguard, Regulus II, Aerobee-Hi, Tartar, Hawk Sparrow III, and Genie.

The Avionics Division produces special infrarec devices and equipment for a variety of militar

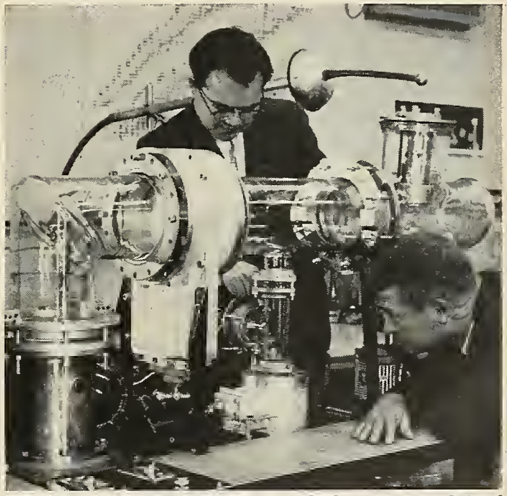


"The production of solid or liquid propellant rocket engines is just one part in today's complex race for space. This missile age of ours requires vast scientific and engineering technology. In addition to this, we must keep abreast of the latest developments within our industry. MISSILES AND ROCKETS Magazine keeps us posted in this market that expands daily." — Dan M. Tenenbaum (left), Manager, Test Division, Sacramento Plants.



"Month-old news to the missile engineer is like the consumer reading last week's weather report. Technical news developments concerning the industry are a day-to-day occurrence. The weekly issues of MISSILES AND ROCKETS Magazine keep us right up to date. Without question, MISSILES AND ROCKETS is a *must* for our money."—Dr. Raymond H. McFee (right), Director of Research, Aerojet-General's Avionics Division.

"Aviation is one thing — the missile/space industry is quite another. Our business is getting missiles into space. Today's missile industry evolved from the old concept of the aircraft-missile business but each is now a separate and distinct industry. We read MISSILES AND ROCKETS for that very reason. It deals 100% with Astronautics."—Marvin L. Stary, Director, Aerojet-General's Systems Division.



"This is a young industry and there are a lot of young people growing up with it. It is absolutely necessary that these young engineers be filled in on every bit of new data as it develops. MISSILES AND ROCKETS provides a complete, clear picture weekly of what's happening in the field of World Astronautics." — Dr. George Moe, (left) Aerojet-General's Space Technology Division.

ɔplications. In addition, the division is currently ɛsigning optical simulators and training devices. erojet-General diversification is found in the Anti- ubmarine Warfare Division which is developing new type torpedo for the Navy and in the Ord- ance Division which is producing warheads for ɪe Army. Aerojet-General Nucleonics, located at an Ramon, California, is now designing reactor sys- ms to provide power for space vehicles. Another ɲportant facet of the Nucleonics plant is the study nuclear-propulsion systems for space exploration.

—when and where—

DECEMBER

AFOSR/Physics Division, Physical Sciences Directorate and NAS/NRC, Conference on Problems Related to Interplanetary Matter, Northwestern University, Evanston, Ill. (Dates still not firm.)

Rocket and Missile Symposium, USAF Arnold Engineering Development Center and ARO, Inc., Arnold Air Force Station, Tullahoma, Tenn., Dec. 1-2.

Eastern Joint Computer Conference, Statler Hilton Hotel, Boston, Dec. 1-3.

National Conference on Application of Electrical Insulation, Sheraton-Park and Shoreham Hotels, Washington, D.C., Dec. 6-8.

American Institute of Chemical Engineers, 52nd Annual Meeting, Sberaton-Palace Hotel, San Francisco, Dec. 6-9.

American Management Association, Briefing Session on the Defense Market, Ambassador Hotel, Los Angeles, Dec. 7-9.

First Aerospace Finishing Symposium, sponsored by Southwest Society of Aircraft Materials and Process Engineers, and Dallas-Ft. Worth Branch of American Electroplater's Society, Hotel Texas, Fort Worth, Dec. 8-9.

Institute of Environmental Sciences, New York Metropolitan Chapter, Tecbnical Symposium and Product Exhibition, Henry Hudson Hotel, New York City, Dec. 10-11.

1960

Sixth National Symposium on Reliability and Quality Control in Electronics, Statler-Hilton Hotel, Washington, D.C., Jan. 11-13.

American Astronautical Society, Sixth Annual Meeting, New York City, Jan. 14-20.

Institute of Radio Engineers, 1960 Winter Convention on Military Electronics, Biltmore Hotel, Los Angeles, Feb. 3-5.

Engineering Materials and Design Exhibition and Conference, Earls Court, London, Feb. 22-26.

Univac Users Association, Semi-annual Meeting, Greenbrier Hotel, White Sulphur Springs, W.Va., Feb. 25-26.

American Rocket Society, Structural Design of Space Vehicles Conference, Biltmore Hotel, Santa Barbara, Calif., April 6-8.

American Welding Society, 41st Annual Meeting and Welding Exposition, Los Angeles, April 25-29.

National Association of Relay Manufacturers, Eighth Annual Conference on Electromagnetic Relays, Oklaboma State University, Stillwater, May 3-5.

ADVERTISER'S INDEX

CLASSIFIED

Needed: A Central Materials File

Stories in this special materials edition of M/R bring out one fact very clearly:

A great deal of research, both basic and applied, is going on in this country in every phase and facet of the materials field; hundreds of millions are being spent by private industry, universities and independent laboratories, the services and other government agencies every year.

But there is not enough communication of results. The distribution of information on the discoveries made in all of this research lags many months behind the discoveries themselves. This is true, apparently, on an industry-to-industry basis, on a government-to-industry basis and even on a government agency-to-government agency basis.

Part of this is due to the protection of proprietary rights within industry. A company which discovers a new method of improving the tensile strength or the heat resistance of a material is naturally reluctant to disclose this valuable secret until it has reaped the benefits of the achievement.

More often, however, the facts are available; they have been published in unclassified form. An example, as pointed out elsewhere in this issue, is that eight months after unclassified publication of technical papers on notch sensitivity of high-tensile steels, project engineers writing the specifications for solid-fuel rocket motor cases for nationally critical programs had never heard of notch sensitivity.

It seems apparent that in the field of structures and materials—and more so in this field than in any other because it covers almost every conceivable area of engineering—three things are needed:

First is open-mindedness on the part of the engineers and the companies and agencies which employ them—open-mindedness in the sense of being willing to compare their particular requirements with all known available materials and their capabilities.

Second, a willingness of industry and government to encourage the fastest possible dissemination of their findings in the research and experimental fields.

Third, the establishment of a central repository where information on all findings can be obtained quickly.

It is quite possible that with the accomplishment of the third requirement, the first two would follow easily and naturally. At the moment we have nothing even approaching such a facility, although some of the professional societies and some government agencies have either made a stab at it or are planning to.

We suggest that this is not a task for any one agency or group (unless it should be established as a separate agency unto itself) but that it should be a joint undertaking of some of the great American professional organizations.

The American Rocket Society, which met in Washington last week, certainly has a vital interest. So do the American Institute of Chemical Engineers, the American Chemical Society, the Society of Automotive Engineers, the American Coke and Coal Chemicals Institute—and dozens of others. They could collect the vast amount of data on materials, the combinations of materials and the treatment of materials. With the aid of the giant computers and data storing equipment available today, millions of facts gleaned from millions of experiments could be available to anyone needing them. It would be a project and an achievement worthy of such a joint effort.

CLARKE NEWLON

MOON GARDEN

You can't grow anything on moon soil . . . but Republic is . . . raising turnips, carrots, beets and snap beans in lunar greenhouse experimental garden. ➤➤➤ Republic is working on lunar garden studies as part of a researc program to determine the feasibility of establishing a base on the moon. ➤➤➤ Hyman Stein, manager of space projects and studies for Republic's Applied Research and Development Division . . . and his "green thumb staff" (Bill Taufman seen here), maintain a constant, studious vigil over these tests. ➤➤➤ A basic aim is to determine at how low a pressure vegetables can be grown to maturity. The lower the pressure, the less weight of the greenhouse structure. And weight is critical in delivering a payload to the moon. ➤➤➤ These experiments will determine whether significant increases in crop production can be obtained by lengthening the working day as past tests indicate. Our Moon Garden studies are but one of many bold concepts under development as part of Republic's multi-million dollar exploration into the realm of advanced aircraft, missiles, space travel and space.

REPUBLIC AVIATION

FARMINGDALE, LONG ISLAND, N. Y.

Designers and Builders of the Incomparable **THUNDER-CRAFT**

Experiments being corrie out in Republic's preliminory loborotory will be housed in our new 14 million dollor research ond development center, scheduled for operotion eorly in 1960.