

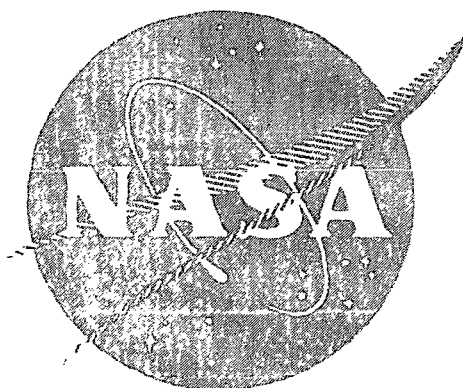
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# Applications of Aerospace Technology in Industry

*A TECHNOLOGY TRANSFER PROFILE*

**CASE FILE  
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**CRYOGENICS**



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The technology reviewed in this presentation and the applications noted represent the best knowledge available at the time of preparation. Neither the United States Government nor any person acting on behalf of the United States Government assumes any liability resulting from use of the information contained in this document, or warrants that such use will be free from privately owned rights.

APPLICATIONS OF AEROSPACE TECHNOLOGY  
IN INDUSTRY

A TECHNOLOGY TRANSFER PROFILE

CRYOGENICS

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## PROFILE HIGHLIGHTS

In the process of meeting its own needs for large quantities of efficient rocket fuels and life support systems, the American space program has affected the development of almost every dimension of the cryogenics field. Among its many contributions, NASA called into being large liquefier and storage facilities and fostered the development of new equipment and measurement techniques. The space agency's most significant contribution to this rapidly growing field, however, has been to systematically enlarge the foundations of cryogenics technology through the study of the low-temperature behavior of materials. NASA-generated technology has found its way into a wide variety of nonaerospace applications. For example, improved types of insulation now make possible more efficient transport of liquefied natural gas, and new knowledge of the physical properties of cryogenic materials has improved the performance of industrial processing facilities through cost savings and greater production.

The broad range of contributions support an emerging field in which improbable phenomena are harnessed to improve our lives. Fast freezing of food using liquid nitrogen helps preserve flavor, color and vitamin content. Cryogenic surgery has been used to treat Parkinson's disease, remove tumors and cataracts, and for bloodless tonsillectomies. Superconductivity, which is characterized by the abrupt disappearance of electrical resistivity, signals a new generation of motors, computer memory cores, power transformers, magnets and transmission lines.

## INTRODUCTION

The field of cryogenics has been selected as the subject of this technology transfer profile. While the field itself is of interest because of its increasingly important role in the American economy, cryogenics is especially interesting when viewed from the perspective of technology transfer. Its recent rapid growth has been due to demands of both industry and aerospace. This environment provides an unusual opportunity to identify some of the forces active during a period of broad technological change and at the same time further the understanding of the technology transfer process. That process is specifically defined here as the ways in which technology, generated in NASA programs, contributes to technological change.

In addition to presenting a brief overview of the cryogenics field and describing certain representative examples of the transfer of NASA-generated technology to the private sector, this presentation explores a singular relationship between NASA and another federal agency, the National Bureau of Standards. The relationship has operated both to generate and disseminate information fundamental to the broad growth of the cryogenics field.

This profile of the cryogenics field considers the industry that produces the cryogens; the completely heterogeneous user group comprised of industries and disciplines; and the scientific and technical developments that support the growth of the field. Section I presents the overview of the field, and Section II describes how NASA's pursuit of its mission has led to and relied upon the generation of basic cryogenic properties data. Section III presents new insight into the ways that NASA-generated technology is communicated, and specific examples of the results of this communication effort are presented in Section IV. Section V considers new information concerning the process of technology transfer developed during the preparation of this presentation.

## SECTION I. AN OVERVIEW OF THE CRYOGENICS FIELD

In a little more than a decade, cryogenics has evolved from a "science of the supercold" into a billion dollar business in the United States. During the 1950's the word cryogenics was synonymous with a wonderland of improbable phenomena: at temperatures near absolute zero, electrical currents can flow in certain metals without resistance; liquid helium will climb up and out of an open container; rubber will shatter like glass; and heat pulses will travel through metallic rods like shock waves.

These curiosities gave way to the concentrated development of cryogenic systems for commercial and aerospace applications. The six cryogenic fluids particularly important to these applications are: oxygen, nitrogen, helium, hydrogen, argon, and liquefied natural gas. The first five of these cryogenics had a combined shipment value of \$166 million in 1960; in 1970, the value had risen to \$597 million (Cryogenics and Industrial Gases, January/February 1971). The annual growth rate of fluid production is approximately 15 percent, while production value, including LNG, is projected to be one billion dollars by 1973, and \$2.5 billion by 1985 (Flynn and Smith, 1970). This projection of the value of cryogenics is exclusive of hardware and plant investment.

Industrial gas production is clearly the dominant economic element in a description of the cryogenics field. The production of these gases is the domain of the large companies both because of the capital intensive nature of the business and the improvements in production efficiency associated with very large plants compared to small- or medium-sized liquefaction facilities. The bulk of the business done by the industrial gas companies consists of building and operating air separation plants which produce oxygen, nitrogen and argon. A growing fraction of this product is sold "over the fence" to steel and chemical companies, but all of the major companies have extensive distribution networks for delivering their products to smaller users.

A decade ago, the industrial gas companies tended to produce a sizable share of their production, storage, and transport equipment. Cost center accounting has significantly reduced the activities of these companies in the equipment business and almost complete withdrawal is projected during the 1970's. Linde, Air Products, and Air Liquide have shops for producing cold boxes for air separation and cryogenic

process plants, and Air Reduction has a partially-owned subsidiary which engineers such products in the United States. The dominant companies in the industrial gas field are: Linde, Air Reduction, Air Products, NCG, Liquid Carbonic, Air Liquide, and Burdette Oxygen (McIntosh, 1971).

### Cryogenic Materials Properties

Because of the uncommon behavior of materials at very low temperatures, cryogenics has come to be treated as a special field with its own identity and characteristic dimensions. At the same time, cryogenic engineering has evolved as a specific discipline, requiring a unique collection of technological skills. This individualistic treatment tends, however, to distort the fundamental nature of cryogenic engineering. That nature is simply an extension of engineering practices into the extremely low temperature region. What characterizes the cryogenic engineer, then, is his knowledge of the behavior of cryogens and the materials used to control them in a context of new engineering problems.

The importance of cryogenic materials properties was dramatically demonstrated by a violent explosion in 1944 of a liquefied natural gas storage facility in Cleveland, Ohio. A large area in Cleveland was devastated by the resulting fire, and many lives were lost. The catastrophic failure occurred because a flaw in the normally ductile steel shell suddenly propagated when the steel became brittle at cryogenic temperatures. Conventional engineering practice was proven to be grossly inadequate. As a result, the accident set back the introduction of commercial liquefied natural gas by some 20 years.

A study of many events far less dramatic than the Cleveland explosion would show that the evolution and growth of the cryogenics industry can literally be traced to the availability of cryogenic properties data. Of the many engineering resources required for sustained growth, physical properties data are the most fundamental. Lack of such data inhibits the development of new equipment, and coarse data introduces a degree of uncertainty that can make otherwise optimum designs impractical because of economic and performance factors.

This fact is clearly evidenced in the LNG industry today. At the Second International Conference on Liquefied Natural Gas held in Paris, October 19-23, 1970, three papers were presented on the

properties of liquefied natural gas and methane (Olien and Sarkes, 1971). These papers summarized new data requirements as follows: (a) experimental thermodynamic data on pure methane is needed badly, and (b) the present statistical theory is such that one cannot accurately calculate properties for multicomponent mixtures based on either single component data or on data for other mixtures. It is possible to compensate for this lack of accurate data through overdesign; this, of course, is expensive.

The investigation of materials properties has moved ahead strongly in recent years, primarily because of the influence of the space program. As a result, the cryogenics industry has been able to enter a period of considerable growth. It was the development of volume production tools, techniques, data, and personnel for liquid hydrogen technology in the late 1950's which provided the resource base for a similar effort in the early 1960's to achieve liquid helium production. Without this base the now rapidly growing liquefied natural gas industry of the 1970's (projected fluid value of one billion dollars by 1976) would be years longer in developing (Lofstrom, 1968).

### Cryogenic Applications

The following discussion of application areas presents striking testimony to the advent of an era of considerable growth in the cryogenics industry. Although the specific applications are far more interesting than a discussion of the behavior of materials at cryogenic temperatures, it is well to keep in mind that without such data, many present and future applications of cryogens would certainly be delayed, if undertaken at all.

Food preservation. Preserving food by refrigeration dates to 1842, but until liquid nitrogen became commonly available recently, cryogenic freezing was regarded more a bane than a boon. The food industry's principal problem has been to utilize the advantages of cryogenic freezing yet preserve color, taste, and consistency, since the rate and temperature of the freeze-thaw process must be closely controlled to prevent ice crystal formation and thus cellular destruction. Immersion of foods in liquid nitrogen minimizes this breakdown; and precoating fruits with various sugar solutions has also helped to preserve flavor, color and vitamin content (Timmerhaus, 1965).

Liquid nitrogen freeze-drying has become routine, permitting indefinite exposure of food to room temperatures, and a return to

original flavor and consistency when rehydrated. Nitrogen is the most commonly used inert atmosphere gas, protecting food from rodents, bacteria and fire. Already a \$4 billion activity, the frozen food industry is expected by 1975 to use over 40,000 refrigerated delivery trucks, 10,000 trailers, and over 4,000 refrigerated railroad cars, all with liquid nitrogen systems. Quick freeze processing has come to rely on liquefied nitrogen -- an industrial gas second only in economic significance to oxygen -- with sales in 1958 of \$6.5 million and in 1970 of \$150 million.

Steel production. Basic oxygen processes used in steel production (including the revolutionary open-hearth oxygen lances) consume over 140 billion standard cubic feet of liquefied oxygen annually with shipments valued at \$260 million in 1970 (Cryogenics and Industrial Gases, January/February 1971). This consumption amounts to more than half of the national production. As a result, the trend has been to locate oxygen liquefaction facilities near the steel production centers in order to minimize distribution costs through local production operations.

Aerospace. Cryogenic systems have been widely used in aircraft and missile applications. Storage of breathing oxygen in the liquid state for high altitude military aircraft was one of the earliest of such uses. Other aircraft applications for cryogenics include cabin pressurization and cooling, along with the generation of auxiliary power. Liquid hydrogen is also being considered as a fuel for future hypersonic aircraft. In addition to providing high combustion energy, it is capable of absorbing large quantities of heat, thus making it an ideal coolant for aerodynamically heated surfaces.

Space propulsion depends on propellants that are normally gaseous in nature, but are carried in the condensed form, as liquids. The utility of cryogenic propellants was recognized by R. H. Goddard in 1923 when he offered hydrogen and oxygen as the optimum propellants for use in rockets. The launch of the NASA Centaur 40 years later represented the first successful application of a liquid hydrogen-liquid oxygen propelled rocket stage (Flynn and Birmingham, 1968). In addition to propulsion, cryogenics have also found use in systems for power generation and life support along with space environment simulation.

In the process of meeting its own needs for large quantities of efficient rocket fuels (i. e. , primarily liquid hydrogen and oxygen), the aerospace program has called into being (Flynn and Birmingham, 1968):

- Large liquefier facilities (liquid oxygen, hydrogen, fluorine);
- Engineering skills (roughly tenfold growth of the pool of trained specialists);
- Development of components on a new scale (tanks, valves, pumps . . . );
- Measurement techniques (for example, flowmeters rated for large rates of flow of cryogenic fluids); and
- Design data (a large body of accurate and reliable data on properties of materials and fluids at low temperatures having permanent archival value).

The impact of U. S. space program requirements on the growth of the cryogenics field has been major. In 1965, NASA's annual expenditure for cryogenic fluids alone exceeded \$50 million (Walker and Herman, 1965). NASA has used nearly one-third of the national production of high purity liquid hydrogen and, in 1968, one-half of the helium production (Lofstrom, 1968).

Health. Applications of cryogenics to the life sciences are not sizable in economic terms, but they are becoming increasingly important in such areas as cryosurgery, cryobiology and cryopreservation. To the surgeon and serologist the "21 day tyranny" indicates the time limit during which stored blood can be used for transfusion before aging renders it unsuitable. In New York City alone 30,000 pints of blood a year formerly had to be discarded. Frozen by a liquid nitrogen process, it is possible to keep blood stored for years, thus greatly ameliorating the problem of supplying particularly rare blood types on demand (Flynn and Birmingham, 1968).

It is also possible now to freeze-store bone marrow cells; human and cattle sperm (most cows in the United States are bred by artificial insemination from sperm selected from superior blood line bulls); tissue; organs; and biological specimens for research.

Cryosurgery is becoming commonplace, finding acceptance in the elimination of Parkinson's disease (by a cryogenically cooled needle inserted into the brain); shrinking tumors; bloodless tonsillectomies; cataract removal; skin cancer; malignant growth removal; in gynecology (tumors of vagina and uterus, increasing fertility, sterilization); and in prostate surgery, among other applications. Although cryosurgery procedures are still largely in the development stage, there seems cause for cautious optimism, while many new applications are explored.

Cryopreservation is a subject of rapidly growing interest, not only because of the increasing demand for a supply of (non-frozen) organs for transplant operations, but for storage banks and procedures for freeze-storing such biological material as blood, sperm, bone marrow, skin and bone grafts, heart valves and bowel segments. It has been necessary to develop several types of cryoprotectants for storing these materials, since the rate and temperature of the freezing-thawing operation critically determine their ultimate viability. Glycerol is a commonly used protective solution, glucose another. Although freeze-thaw technology is at least partially successful, much remains to be understood of its effects on osmotic fragility, on cation electrolytes such as sodium and potassium, and on the crucial energy enzyme adenosine triphosphate (ATP), and particularly on whole organs, which so far have not been stored by freezing for any substantial time period (Smith, 1969).

Other applications. Superconducting motors, high capacity computer memory cores, superconducting power transformers and transmission lines, and superconducting magnets have been developed in the last dozen years. For example, a 50-ton iron core magnet is required to produce the same magnetic field developed by a superconducting magnet weighing only a few pounds; and a 125,000 kilovolt ampere superconducting transformer requires refrigeration of only about 150 kilowatts, although combined copper and iron power losses in a similar conventional transformer would amount to 625 kilowatts (Timmerhaus, 1965).

The application of superconductivity to electric power engineering promises to increase capacity, reduce cost and improve reliability. Before this potential can be realized, however, there are developmental hurdles to be overcome such as more efficient low temperature liquefaction systems and pumps; less brittle superconductors; more commonly available materials than niobium for long distance power

transmission; and materials with higher transition temperatures in the liquid hydrogen (20.4°K) or even possibly liquid nitrogen (77.3°K) range, to reduce refrigeration costs (Cohen, 1968). Recent development work includes:

- A \$10 million, 150-meter-long linear electron accelerator now under construction at Stanford University, supported by the Office of Naval Research, will be the first large electronic system to be operated (with superfluid helium) at temperatures near absolute zero. This 'linac' is essentially a very large, highly instrumented microwave cavity, down which a beam of electrons is accelerated by RF power from Klystrons along the superconducting niobium accelerator cavity walls, thus reducing background (particle contaminant) interactions by a factor of 1,000 times that in a pulsed high-energy linac. The beam will be 10 times more powerful and 100 times more stable, and power losses will be reduced by a million to one over a more conventional room temperature linac (Industrial Research, January 1969).
- The General Electric Corporation and the Linde Division of Union Carbide Corporation, in cooperation with the Edison Electric Institute of New York and the Tennessee Valley Authority, Washington, D. C., are investigating various ways to use cryogenics and superconductivity in power transmission. Linde has begun an \$8 million, 12-year development program to put a superconducting cable into operation by 1981, increasing efficiency 25-30 times that of conventional conductors (Industrial Research, August 1969). General Electric's three-year program is directed at developing a full-scale high voltage cryogenic cable operating in either liquid hydrogen (20.4°K) or liquid nitrogen (77.3°K), rather than the very much more difficult to maintain liquid helium (4.2°K) temperature ranges. Tentatively, dielectric ac losses in a hydrogen-range cable insulation system are projected at 10 percent of the losses in an oil-paper insulation system; transmission of large blocks of high voltage power at cryogenic temperatures seems feasible; and at very high capacities (3,000 mVA and above) such transmission appears economically superior to traditional methods (Industrial Research, April 1969).

## Conclusion

This glimpse at the research dimensions and industrial applications of cryogenics provides a suitable stage for an examination of NASA contributions to the field, which is done in Section II and its attachment.

## SECTION II. SIGNIFICANT NASA CONTRIBUTIONS TO THE CRYOGENICS FIELD

The technological necessity for cryogenic spacecraft systems is evident in the hundreds of millions of dollars NASA has expended to develop and operate these systems. Cryogenics and cryogenic systems provided the most reliable and economical solutions to many of the space agency's technical problems related to launching and controlling manned spacecraft. Solving those technical problems often required the development of new or refined data concerning the behavior of different cryogenics and materials used to manage them.

Identifying significant NASA contributions to this field will be approached here by examining the links between the generation of technical data and the requirement for new cryogenic systems. The initial discussion centers on the fundamental reasons for serious NASA interest in cryogenics technology. Attention then is shifted to three specific cryogenic problems that required the discovery of basic technical data, data that has been and will continue to be of use to non-aerospace engineers working on new cryogenic applications.

### NASA Cryogenic Needs

In the broadest sense, the performance of any space mission is weight-limited. Only so much weight can reasonably be permitted before the costs and technical problems associated with launching and orbiting a spacecraft make space flight impossible. Accordingly, NASA engineers employed cryogenics in many spacecraft and booster applications; liquefied gases provided the most practical means to achieve significant weight and volume reductions in the storage tanks required aboard these vehicles. NASA interest in cryogenics would have been tangential were it not for this fact. Thus, a fundamental mission requirement to keep weight at a minimum stimulated an extremely broad engineering effort aimed at the development of propulsion, fuel cell, and life support systems utilizing liquefied gases together with the testing, procedures, and facilities which support such an effort.

The gases of primary significance to manned space flight are hydrogen, oxygen and helium: oxygen is basic in the life support systems of manned spacecraft; both oxygen and hydrogen are utilized in the production of cabin power; and all three gases are crucial to

both launch and powered flight propulsion systems. These three materials, all in a gaseous state at room temperature, become liquids at cryogenic temperatures. Oxygen liquefies at  $-297^{\circ}\text{F}$ , hydrogen at  $-423^{\circ}\text{F}$ , and helium at  $-452^{\circ}\text{F}$ . NASA's challenge was to develop propulsion, power, and environmental control systems that required fluid storage and use at extremely low temperatures.

The basic necessity for storing cryogenic fluids instead of high pressure gases can be illustrated in the following comparison. A storage system weighing 140 pounds can contain 40 pounds of hydrogen in the liquefied state at a pressure of 300 pounds per square inch; the same 140-pound system could hold only 10 pounds of hydrogen in a gaseous state under a pressure of 1,000 pounds per square inch. In this system, four times more hydrogen can be stored in a liquefied state (Davis, 1970).

While the lighter weight advantage of cryogenic storage systems over other types of systems is illustrated in the foregoing example, there are distinct economies as well. For example, the metabolic oxygen requirement for one man for a 24-hour period is approximately two pounds of oxygen. In tanks of the same size, almost 13 times more oxygen can be stored in liquefied form rather than in a gaseous state (Davis, 1970).

In order to capitalize on the weight and volume advantages of cryogenic fluids, NASA caused totally new cryogenic production, transfer, and storage technology to emerge. This, coupled with such new applications as the production of electrical power and drinking water from liquefied oxygen and hydrogen in manned spacecraft, provides an indication of the scale of NASA contributions to the cryogenics field.

In developing such cryogenic systems, aerospace engineers were continually confronted with the inadequacy and lack of basic technical data needed for design purposes. They found it necessary, therefore, to generate or refine data concerning the behavioral and engineering characteristics of cryogens and the materials used to manage these liquefied gases. Once such technical data became available, engineers were much better equipped to tackle the challenges associated with cryogenic hardware development.

The overall significance of NASA contributions to cryogenics technology is associated most directly with pioneering work in the

discovery and refinement of information concerning materials properties. In the process of creating flight systems, the space agency produced engineering data which not only serve as the keystone for cryogenic applications in space, but also have become essential links between NASA's mission-oriented efforts and engineering developments in other sectors of the American economy. Stated more simply, designing a component for biomedical applications relies as heavily on technical data as designing a component for propulsion applications because the common denominator is the behavior of the cryogen and the materials in contact with it.

### Flight Hardware and the Development of Engineering Data

Three examples of significant technical accomplishments will be reviewed in this section: fiber filament-wound pressure vessels; cryogenic insulation systems; and cryoforming of metals. These examples help focus attention on the role of materials properties in achieving engineering design objectives. Other NASA contributions to the development of cryogenic properties data are reviewed in Attachment II. The Attachment describes a unique relationship which has evolved between NASA and the National Bureau of Standards (NBS). By working with NBS, NASA has been able to expand a national resource: the data base on the thermodynamic, heat transfer, and physical properties of cryogenic fluids which now serves as the foundation for both new research and new applications.

Fiber filament-wound pressure vessels. As previously discussed, space missions rely upon cryogenic gas storage systems to supply oxygen, nitrogen, hydrogen, and helium to environmental control and electrical power systems. Until recently, there was no design alternative for the severe weight penalty paid when using double-walled, vacuum-jacketed tanks to achieve high pressure for cryogenic storage. The pressure-vessel, which is the innermost shell, is generally spherical in shape and contains the cryogenic fluid at operating pressure. The thickness of the pressure vessel shell is determined by a stress analysis based on known materials properties. Selecting the shell material requires knowledge of materials properties at both cryogenic and room temperatures, including, for example, fracture toughness, strength-to-weight ratio, fluid compatibility, corrosion resistance, formability, joinability, fatigue properties, chemical properties, configuration, permeation, creep properties, embrittlement, joint efficiency, galvanic corrosion, as well as availability and cost. Inconel, titanium,

stainless steel, and aluminum are the materials most commonly used for constructing pressure vessels operating in cryogenic and normal temperature environments (Davis, 1970).

NASA's ever-present concern for reducing the weight of on-board spacecraft systems has led to the development of an extraordinarily lightweight system for storing cryogenes under high pressure. The development involves the use of filament-wound fiber glass structures in cryogenic pressure vessels. This innovative application of fiber glass structures grew out of research conducted since 1965, first by the Douglas Aircraft Company, and subsequently by Aerojet-General Corporation.

Early in this research effort, engineers found that a filament-wound fiber glass structure would leak cryogenes even though it maintained its structural integrity. A thin, smooth-bonded metallic liner was employed to prevent leakage. This configuration presented two major technical problems, both of which specifically required a determination of cryogenic materials properties for resolution. The first was the classical cryogenic design problem that emerges when two highly dissimilar materials are combined. The metal liner exhibited a significantly lower elastic strain ( $1/4 - 1/2$  percent) than the working strain capability of the fiber glass composite ( $2 - 2-1/2$  percent). The liner, therefore, must be capable of plastically deforming up to  $2-1/4$  percent over several cooling cycles without failure. The second major technical problem was one of material embrittlement at cryogenic temperatures. At ambient temperatures the fiber glass matrix exhibited some degree of flexibility, but when chilled to cryogenic temperatures, thermal stresses alone caused cracking and crazing. Additionally, the adhesive which bonded the liner to the wall also became brittle at low temperatures. The solution of these problems demanded a complete understanding of the primary materials properties involved. Properties data for liner materials, filament-wound fiber glass, and several adhesives had to be determined over temperatures ranging from  $+75^{\circ}\text{F}$  to  $-423^{\circ}\text{F}$ .

To illustrate how a knowledge of materials properties enabled engineers to solve the leakage problem, their experience in applying adhesive to these ultra-lightweight storage systems can be cited. The adhesive in the composite glass-fiber structure must perform one basic function: it must prevent the metal liner from buckling during depressurization. To achieve this, it must strain without losing adhesion to either surface and without failing itself.

Douglas engineers identified thirteen basic adhesives for possible application. After narrowing the number of potentially useful adhesives down to four candidates, they proceeded to determine such basic behavioral properties as strength and wetting ability, rigidity, toughness, and contraction over temperatures ranging from +75°F to -423°F (NASA TSP 69-10074, 1969).

In meeting its own needs for acquiring such technical data, NASA contractors produced the most fundamental technical data available on the behavioral characteristics of adhesives at cryogenic temperatures. Similar investigations were undertaken to acquire data on the properties of glass fibers and the metallic liners. These data were uniquely combined through design and testing to achieve a high strength, lightweight storage vessel configuration. The effectiveness of this approach is indicated in the comparative performance factors, based on strength and weight parameters, shown in Figure 2-1.

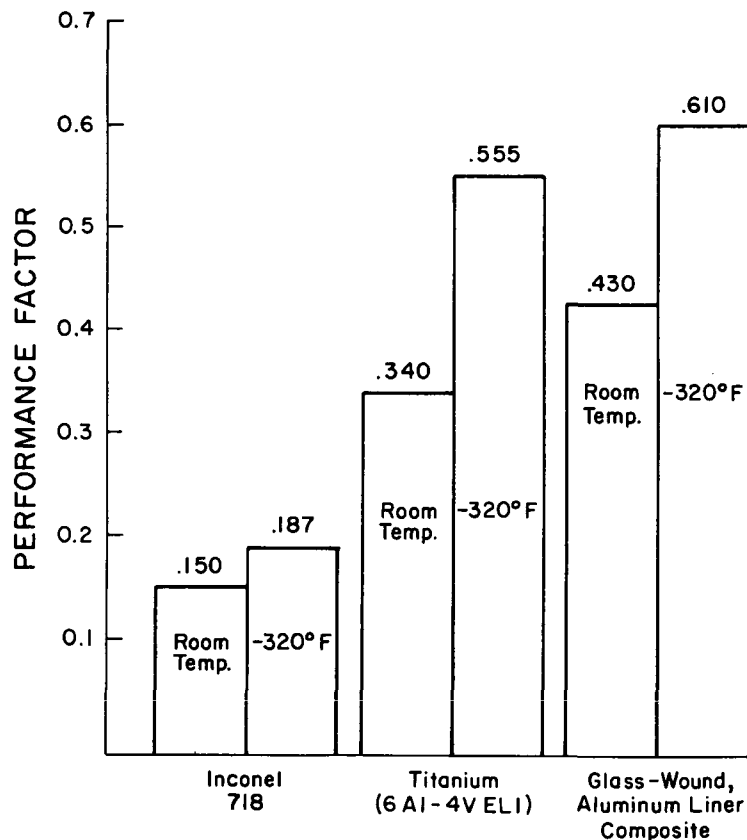


Figure 2-1. Performance Factors for Glass-Wound, Inconel and Titanium Spheres. [Source: Faddoul, 1971.]

Substantial weight savings are thus realized by the use of composite structures in the fabrication of pressure vessels. Improvements ranging from 10 percent to almost 200 percent were demonstrated. In addition to the increased specific strength, the composite vessels are also less hazardous (no shrapnel in the event of a failure) and have lower heat loss (by a factor of 10) than all-metal tanks. It should be noted that these improvements apply not only at cryogenic temperatures but at normal temperatures as well. In fact the room temperature comparison of performance factors is even more dramatic than that shown for cryogenic temperatures.

In addition to the important advance in pressure vessel design, this example highlights the creation of data which now allows designers to select adhesives for many cryogenic applications.

Cryogenic insulation systems. The need for highly efficient insulation systems for producing, transferring, and storing cryogens is directly related to the fact that cryogens have extremely low boiling temperatures and low heats of vaporization. In the production of the cryogens, insulation improves the efficiency of the liquefaction process and, accordingly, reduces the power required to produce fluids. Insulation also minimizes "boil-off" problems in both transfer and storage systems. Thus, thermal insulation systems are essential to every major dimension of the cryogenics field.

Over the past decade, NASA has been a primary force in the advancement of cryogenic insulation technology. Much of the increasing employment of refrigeration, liquefaction, transportation, and storage of the very low temperature fluids is directly traceable to NASA work in developing highly effective thermal insulations. In fact, several striking advances in the efficiency of thermal insulations can be directly attributed to the concentrated development efforts in support of the space program (Glaser, 1967).

These extensive development efforts again relied heavily on the generation and utilization of basic materials properties data at cryogenic temperatures. Since a single homogeneous insulating material cannot optimally satisfy both design criteria and economic considerations, combinations of materials have gained wide acceptance. Combining different materials to achieve a desired performance, however, has required a broad research effort aimed at the determination of physical properties of candidate materials in order to assure the design compatibility of these materials.

Heat can enter a cryogenic system in one or more of the following ways:

- Conduction through solid materials (e. g. , structural members, insulation) -- on a molecular level, the energy of thermal motion is passed along from one molecule to the next;
- The convection of heat from one place to another by the forced or free motion of materials; and
- The absorption of radiative energy and its conversion into heat.

Each mode of heat transfer has a somewhat unique set of physical properties that must be considered in the development of composite insulations. Accurate determination of the coefficient of thermal conductivity for candidate insulation materials is vital. The convection process is quite complex, depending as it does upon fluid density, viscosity, specific heat, and thermal conductivity as well as surface geometry. For heat produced by radiation, the rate at which energy is transferred is dependent upon the temperature and the emissivity of surfaces.

Aerospace uses of cryogenic insulation encompass literally every type of insulating scheme, including multilayer insulations, foams, powders, fibers and composite configurations. A brief look at the design problems of multilayer insulation provides insight into the role of materials properties data. As the name implies, multilayer insulation consists of many layers of alternate radiation-reflecting shields separated by low conductivity spacers. The design engineer selecting materials for multilayer insulation attempts to deal with each of the three possible heat transfer modes. Each layer contains a thin, low emissivity radiation shield which enables the layer to reflect a large percentage of the radiation energy it receives from warmer surfaces. Spacers separate the radiation shields from each other to reduce the heat transferred by conduction, and gas in the space between shields is removed to minimize both conduction and convection. Literally hundreds of materials and configurations can be considered for multilayer construction. Spacers, for example, have been fabricated from glass fibers, foams, crinkled polyester film, glass paper, silk screen, nylon screen and composite materials. Silver, copper, gold, and aluminum have all been used as coatings for radiation shields.

The payoff of these efforts is illustrated in Figure 2-2. This figure reflects three significant technological achievements over the 1966-1970 period (Hyde, 1971):

- 1,000 percent thermal performance gain;
- 400 percent thermal weight improvement; and
- Improved analysis and evaluation capabilities.

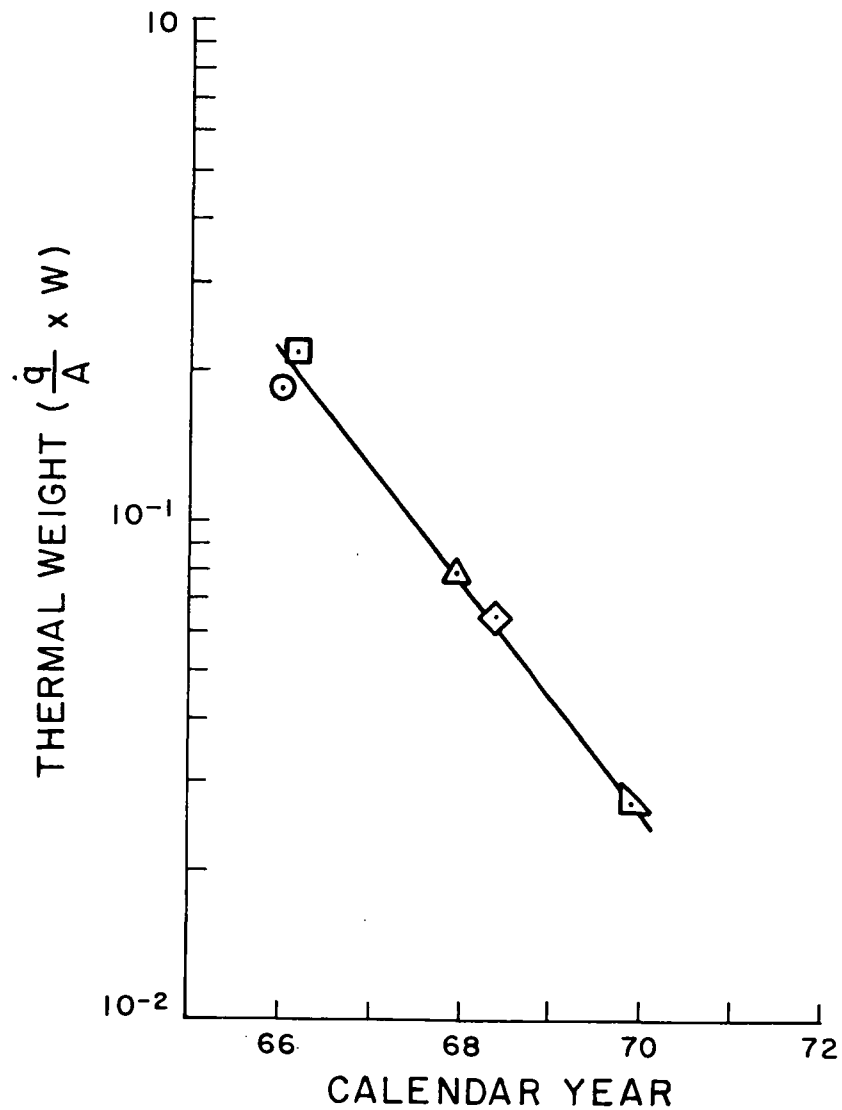


Figure 2-2. Multilayer Insulation Thermal Performance History (1966-1970). [Source: Hyde, 1971.]

These tremendous advances in insulation technology relied heavily on a continuous effort aimed at understanding materials performance at cryogenic temperatures. As new technological advances are realized and more efficient configurations are developed, data concerning the physical properties of related materials will continued to be of fundamental importance.

Cryoforming of metals. NASA's interest in cryogenic pressure vessels aided in the development of a novel process for significantly improving the strength properties of conventional alloys. The benefits of mechanically working stainless steels at temperatures as low as  $-320^{\circ}\text{F}$  were first reported in 1950 (Krivobok and Talbot, 1950). The results of this now classic research were striking. Cryoworking of the austenitic class of stainless steels was found to produce significant increases in the strength of the material. Furthermore, it was demonstrated that for a given tensile strength, processing at lower temperatures produces better ductility. In the case of type 301 stainless steel, for example, rolling to 40 percent reduction in thickness at  $-320^{\circ}\text{F}$  increased tensile strength from 100,000 pounds per square inch (psi) to 300,000 psi, whereas rolling at room temperature only increased the strength to 200,000 psi. Ductility was more than three times better for the cryoworked type 301 stainless steel specimens.

There was no problem in recognizing the significance of this work at that time. Little use for cryoformed parts could be found, however, during the 1950's. Problems of forming, machining, and joining these superstrong alloys were mainly responsible for retarding the diffusion of this innovation. Increased hardness of parts made machining exceedingly difficult. Joining operations (e.g., welding) cancelled the strength advantages because annealed material in the weld zone acted as a weaklink in a chain; it mattered little that the bulk of a part had superstrong characteristics.

A significant breakthrough was realized late in the 1950's when Arde, Incorporated of Paramus, New Jersey developed an ingenious method for cryoforming high pressure storage tanks. In the Ardeform process, a tank wall undergoes plastic stretching to its final size while at liquid nitrogen temperature. During the process, stainless steel alloy experiences a metallurgical transformation which produces a significant increase in physical strength while retaining excellent fracture toughness. Aging at  $800^{\circ}\text{F}$  for 20 hours provides an additional increase of 30,000-50,000 psi (Cozewith, 1971). The beauty of the process is

not only that a method for utilizing the advantages of cryoworking was achieved, but that the resulting pressure vessels also have their greatest strength in the areas of highest stress. Cryogenic stretch forming imposes a severe loading on all structural parts of the pressure vessel and provides a "proof test" at pressures greater than the vessel will be exposed to in service.

While several NASA field centers (e. g. , Lewis Research Center, Marshall Space Flight Center, Manned Spacecraft Center) and contractors (e. g. , McDonnell-Douglas, Aerojet-General, North American Rockwell) have aided the development of Ardeform, NASA's contribution to cryoforming technology has continued in the application of the concept to other metals.

Martin Marietta Corporation, under contract to NASA's Lewis Research Center, investigated the feasibility of improving material properties of several alloys using cryoform techniques. Fifteen metallic alloys were tested to determine whether straining (uniaxial tension) at cryogenic temperatures developed higher strengths than did straining at room temperature. Two alloys were significantly strengthened by cryostraining: PH 14-8 Mo, a precipitation hardening stainless steel; and MP 35 N, a nickel-cobalt alloy (see Figure 2-3). Seven alloys -- 6061, 5456, Inconel 718, Nickel 440, beryllium copper, A-286, and 21-6-9 -- could be strained more effectively at cryogenic rather than at room temperatures. For the other alloys, 2219, L-605, LA141A, TRIP steel, Ti 6Al-4V ELI, and Ti 5Al-2.5Sn ELI, straining at cryogenic temperatures was not beneficial (Masteller, 1970).

It has been demonstrated that mechanical working of selected metals at cryogenic temperatures significantly improves strength properties. Cryoforming of conventional austenitic stainless steels, such as the one shown in Figure 2-3, produces a material which is competitive on a strength-to-weight basis with the well-known superalloys. This technique has already gained acceptance in the fabrication of high pressure storage vessels. The discovery of new ways to handle the inherent machining and joining difficulties will produce other applications where strength and weight are vital design criteria. The day may well come when alloys are cryoformed during production at rolling mills. Such processing would do more than just satisfy demands for cryoformed metals. Considerable economies could be realized because the rolling equipment would last much longer, and the required deformation in the stock could be produced in a single pass rather than by multiple passes as now required.

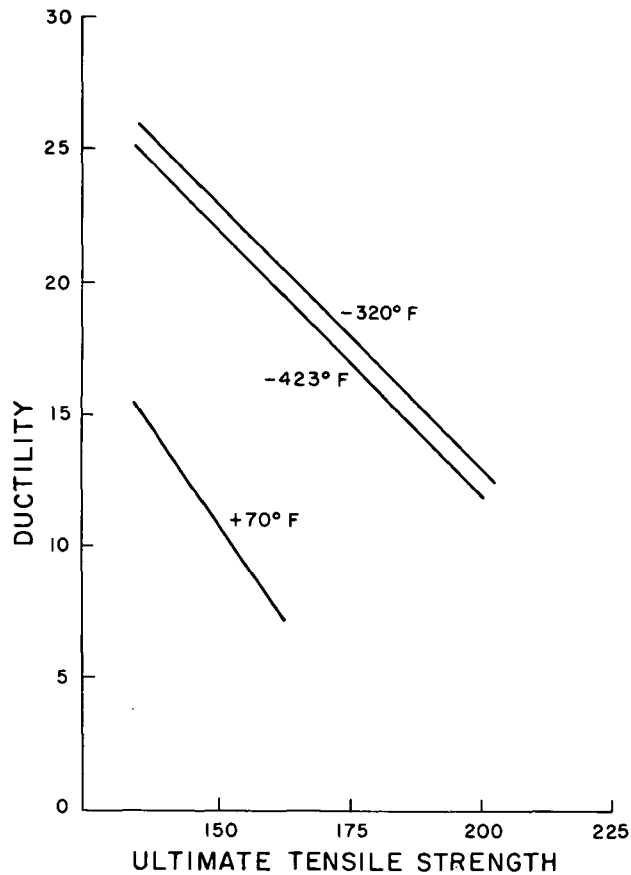


Figure 2-3. The Ductility of Cryoformed PH 14-8 Mo Stainless Steel Compared to the Ductility Produced by Conventional Coldworking of the Same Alloy.

### Conclusion

The approach taken in the development of this section was to examine solutions to three cryogenic problems that illustrate NASA contributions to the foundation of the cryogenics field through research into basic materials properties. The choice of materials properties as the focus for examination is the result of a unique situation: NASA technical accomplishments in cryogenics are highly specific to its mission; the developments rarely match needs found in nonaerospace applications. Yet, the basis of these technological developments was directly dependent on the systematic discovery of materials performance data. It is through knowledge of these same data that nonaerospace cryogenic applications also will evolve.

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### SECTION III. COMMUNICATIONS OF NASA CONTRIBUTIONS

How people outside of NASA come to know and interpret cryogenic technology developed initially for use in the space program is fundamental to understanding technology transfer. Transfer, as distinct from innovation, always involves the formation of communication links between technical innovators and consumers of the innovations.

This section focuses attention on three important communication channels NASA has used to familiarize nonaerospace cryogenic technologists with the results of its work in this field: the activities of NASA contractor firms, the operation of the National Bureau of Standards' Cryogenic Data Center, and the publication of several hundred different documents. Other transfer media, such as the movement of people from NASA to other organizations or the participation of NASA contractor personnel in cryogenic conferences, could be cited to illustrate ways communication has occurred. The operation of these three media, however, are sufficiently well understood to underscore the main idea of this section: by participating in these communication activities, thousands of persons outside of NASA concerned with cryogenic problems have been able to identify potentially relevant technical solutions to many of their problems.

#### NASA Contractor Activities

One of the more important procedures for fostering transfer involves the commercial utilization of technology by NASA contractors, which they have developed during the course of their work for the space agency. In the case of cryogenics technology, two examples will be cited to demonstrate the operation of this specific transfer mechanism. It is helpful to note that the technologies involved in the following transfer cases were generated by contractors to satisfy, at a minimum, NASA mission requirements.

The Space and Information Systems Division of North American Aviation has held several NASA contracts in the cryogenics field over the last ten years. During the course of its contract work, North American engineers in this division evaluated and tested numerous cryogenic materials, originated a variety of composite materials, designed structures for minimizing heat transfer, developed advanced insulation systems, and refined unique fabrication and loading techniques. Since satisfying its NASA mission requirements, advanced programs

director Bud Franklin said North American has been able to attract a number of nonaerospace insulating contracts. In 1970, for example, North American's contracted nonaerospace work totaled more than \$500,000. The applications include the insulation of liquefied natural gas facilities, large oceanic methane tankers and a tuna boat. (See "Polyurethane Foam" Transfer Example Summary in Attachment IV.)

The Garrett Corporation's AiResearch Manufacturing Division has developed an inexpensive, trouble-free aircraft galley refrigeration system that uses basic technology company engineers developed under contracts to the Air Force and NASA. The Air Force work led to the development of a cooling and ventilating system for suited personnel handling toxic materials at missile sites. Under a subsequent contract with NASA's Manned Spacecraft Center, Garrett applied the technology in suits worn by Gemini astronauts during extravehicular activity. Since that time, Garrett adapted the technology for use in refrigeration systems now used on such commercial passenger aircraft as Boeing 707's, 727's, and 737's.

In both of the illustrations cited, contractor firms have been able to transfer technologies developed or applied initially for NASA purposes to other applications extending beyond the original contract. NASA interactions with contractors served to clarify problem areas requiring new cryogenics technology; communications involving NASA, the contractors, and third parties subsequently provided opportunities to extend the applications beyond the NASA mission for which the work was undertaken originally. The transfer example file summary reports in Attachment IV present more elaborate descriptions of the technical work performed and the transfer activities associated with these cases.

#### Cryogenic Data Center Documentation Activities

The Federal government's activities in cryogenic engineering are focused, to a great extent, around operations of the Cryogenics Division of the National Bureau of Standards (NBS) at the Boulder, Colorado Laboratories. As noted in Attachment II, NASA has provided a great deal of the support required to conduct the basic materials properties research of this NBS division. The results of such research have enabled this cryogenic laboratory to become the primary agency of the United States government for providing comprehensive and current information in the very low temperature field.

To facilitate the collection, storage, and dissemination of cryogenic information, the division operates a Cryogenic Data Center. That center, funded largely by NBS, maintains the most exhaustive collection of technical literature on the cryogenic properties of materials in the world. The center's outputs include charts and tables prepared from experimental or "compiled" data, and the publication of "best values" of thermodynamic and transport property data (Flynn and Birmingham, 1969). In addition, nearly 800 paid subscribers receive a center-prepared weekly current awareness service as well as special searches both of new literature and of research and engineering activities. According to center director Victor Johnson (1971), the documentation base of the Cryogenic Data Center includes over 70,000 titles -- nearly 15 percent of which are documents published by NASA. Approximately 150 special searches of the documentation base were performed in 1970.

To illustrate the important role the data center can play in disseminating cryogenic information generated under NASA funding, the experience of cryogenic engineers at the Chicago Bridge and Iron Company (CB&I) can be cited. In March 1970, data center personnel completed a special literature search for the Chicago Bridge and Iron Company entitled, "Information Relating to Long-Distance Transfer of Cryogenic Fluids Including Heat and Mass Transfer, Cooldown, Uninsulated and Insulated Transfer Lines." CB&I made extensive use of four NASA publications identified in that search in preparing a successful \$5,000,000 contract proposal to design and install a liquefied natural gas system. The contract since has been expanded to \$7,000,000 based on excellent preliminary results.

Another illustration of the way the Cryogenic Data Center facilitates the dissemination of NASA contributions to the very low temperature field involves a Stanford University physicist, Dr. Michael Macashan. Macashan asked the data center to identify documents related to the "Dielectric Properties of Solids in the Range 1 MHz to 100 GHz at Cryogenic Temperatures." One of the documents identified was a NASA publication (Tech Brief 67-10366) that describes the dielectric properties of cryogenic capacitor materials. Macashan is using information in the supporting documentation to guide his research on the dielectric losses of energy in superconducting cavities.

These two examples illustrate the importance of the NBS Cryogenic Data Center in disseminating information concerning NASA

contributions to the cryogenics field. While the examples are in no way exhaustive of all the ways industrial engineers benefit from such literature searches, they indicate what happens as the data center carries out its ordinary activities.

### NASA-Funded Formal Publications

Feeding into the operation of many other communications channels -- including the Cryogenic Data Center -- is the space agency's extensive formal publications program. Both in-house and contractor personnel use a variety of different types of NASA publications to report the results of their research and development work in the cryogenic field. Table 3-1 shows the number of titles related to very low temperature technology in each NASA-funded publication category from 1958 to 1970.

TABLE 3-1. NASA PUBLICATIONS PRESENTING SPACE PROGRAM CONTRIBUTIONS TO THE CRYOGENIC FIELD: 1958-1970

YEAR OF PUBLICATION	TYPE OF PUBLICATION					TOTALS
	Contractor Reports	Tech Brief	Technical Memorandum	Technical Note	Other	
1970	31	26	15	10	25	107
1969	73	30	15	25	18	161
1968	92	22	19	26	19	178
1967	75	43	25	13	44	200
1966	115	46	14	27	25	227
1965	80	13	18	13	27	151
1964	40	2	12	2	9	65
1963	13	10	0	1	1	25
1958-1962	<u>12</u>	<u>0</u>	<u>5</u>	<u>0</u>	<u>7</u>	<u>24</u>
TOTALS	531	192	123	117	175	1,138

Some indication of the scope of cryogenic technology presented in these publications can be gained by examining the titles of the 192 Tech Briefs issued during the past eight years. Attachment III presents those titles. The relevance of these Tech Briefs to work outside the space program is attested to, in part, by the interest people have shown in them. During the last three years, for example, there have been 2,021 specific requests to NASA for the Technical Support Packages (TSP's) associated with the 192 Tech Briefs. The particular interest of nonaerospace engineers in obtaining NASA-developed physical properties data is shown in Figure 3-1. Several specific

ways those engineers have been able to use cryogenic-related TSP's are examined in Section IV.

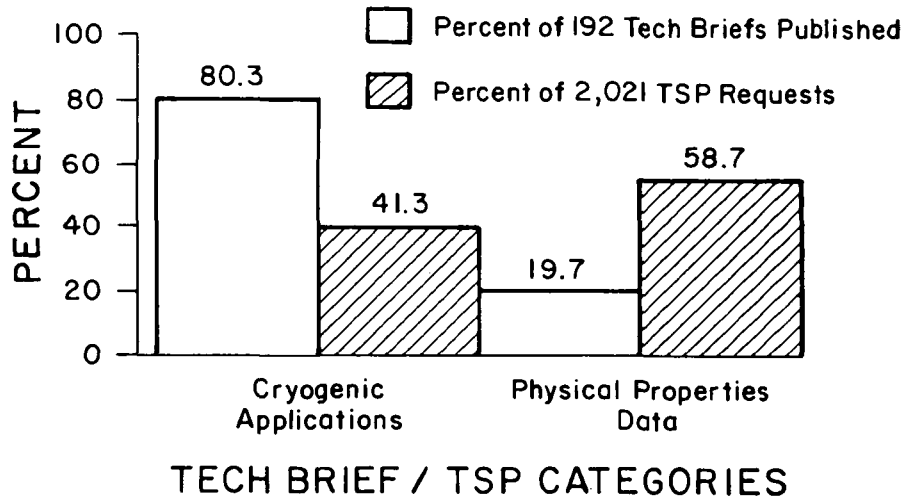


Figure 3-1. Comparison of TSP Requests Associated With the Two Principal Categories of Tech Briefs Reporting NASA Contributions to the Cryogenic Field.

### Conclusion

The three communication mechanisms described in this section have linked the space agency and its contractors with hundreds of potential users of NASA-generated cryogenic technology. The real value of establishing such links can be understood when viewed in the context of what happens once the information has been communicated. Section IV presents a profile of the ways non-NASA cryogenic scientists and engineers have been able to apply these different NASA contributions to the very low temperature field.

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## SECTION IV. NONAEROSPACE APPLICATIONS OF NASA CONTRIBUTIONS

Fundamental to an understanding of this report is the idea that "technology transfer" is not complete until someone in a nonaerospace environment applies, in his own work, technology developed originally in a government-sponsored aerospace research or development project. Inherent in such application activities are complex problems of definition. Exactly what does it mean to apply aerospace technology in non-aerospace applications? Where and when do transfer activities begin and end? In the special case of cryogenic technology developed for space program purposes, how can the relative success or failure of transfer programs be determined?

These basic questions help define the purposes of this section. Specifically, the section examines the ways selected cryogenic technologies generated by or for NASA have been transferring to other sectors of the American economy and presents tentative answers to the questions raised above.

### Approach

Transfer processes involving cryogenic technology have been triggered and facilitated by such different communication mechanisms as NASA's publication of technical documents, literature searches by the National Bureau of Standards' Cryogenic Data Center, and the diversification activities of NASA contractor organizations. It would be possible, of course, to examine the wide variety of transfer processes associated with the operation of all these mechanisms; transfer cases illustrating this variety are presented in Attachment IV. For the purposes of this section, only transfer activities associated with uses made of NASA Tech Briefs and Technical Support Packages (TSP's) have been selected for close examination.

The principal reason for focusing on TSP uses is that a substantial amount of transfer information related to these documents has already been developed. It is useful to emphasize the idea that transfer activities associated with nonaerospace uses of TSP's represent only a small portion of the aggregate number of transfer activities involving NASA-developed technologies; nonetheless, the total number and wide variety of transfers flowing from cryogenic TSP uses has been impressive and can be used to gain some qualitative understanding for the

ways research and development activities in meeting space program objectives have positively affected work in the very low temperature field.

### TSP Users Survey

During the past three years, persons outside of the space program have made 2,021 requests for TSP's associated with the 192 Tech Briefs reporting NASA-supported contributions to the cryogenics field. Mail questionnaires were sent by the Denver Research Institute to approximately 800 of the TSP requesters six months after they had ordered the documents. This time delay was considered sufficiently long to permit TSP users to reach tentative conclusions concerning applications of the cryogenic technologies presented. More than one-half (56.2 percent) of those contacted returned questionnaires. To amplify the specific nature of transfer activities, telephone interviews were conducted with those questionnaire respondents who indicated making substantial progress in using the technologies to solve specific problems.

### Transfer Activities Revealed In Survey Results

The technology transfer process begins when someone or some organization in the private sector of the American economy first becomes aware of some contribution to a technical field resulting from government-supported research and development -- in this case, space program contributions to the cryogenics field. Assuming the technology is judged to be relevant to his interests, the next steps involve a series of tasks to prepare (a) the technology itself, along with (b) the private sector organization, and (c) the market in which that organization operates for eventual adoption of the technology.

Survey respondents were asked to indicate how far they had progressed in adapting the NASA-developed cryogenic technology for their purposes. Responses were divided into four categories or stages, as shown in the transfer profile presented in Figure 4-1.\*

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\* Regardless of the technical classification (i. e., physical properties data, cryogenic applications) of questionnaire responses, individual transfer profiles are approximately the same as the combined profile in Figure 4-1.

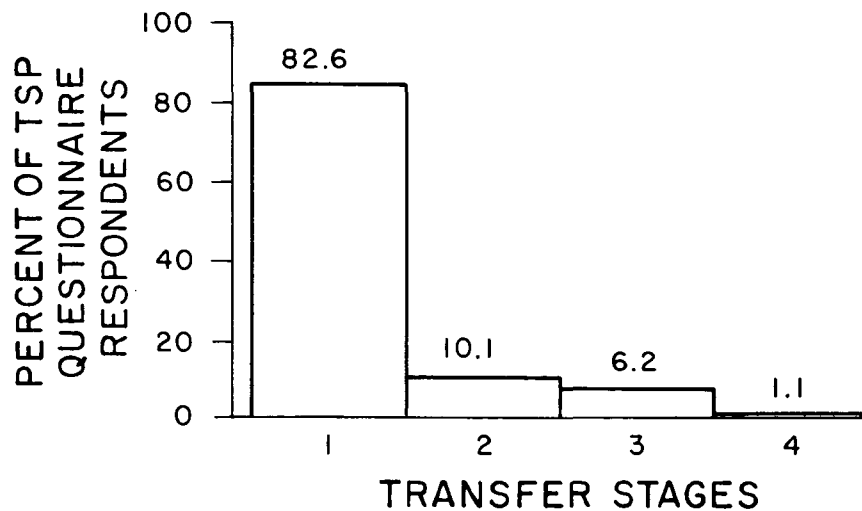


Figure 4-1. Transfer Profile of 454 Persons Using TSP's Related to the Cryogenics Field.

Transfer activities were characterized as being in stage one when TSP users indicated they recognized potential technical opportunity and/or were seeking additional information to determine the relevance of a particular NASA contribution to their professional activities. The transfer experience of Frumerman Associates, Incorporated in Pittsburgh, Pennsylvania can be cited to illustrate stage one transfer activities. The president of this consulting engineering firm said he has reviewed a NASA document describing cryogenic fluid flow instabilities in heat exchangers and plans to use information presented in the document as the need arises during the course of his work. (See "Cryogenic Fluid Flow Instabilities In Heat Exchangers" Transfer Example Summary in Attachment IV.)

Another example of stage one transfer activities demonstrates that benefits sometimes are established in this stage and require no further adaptation activity. It involves the Bishop Manufacturing Corporation of Cedar Grove, New Jersey, a firm producing rubber electrical insulating products. Bishop's vice president for research and development originally acquired a TSP describing dielectric properties of materials for cryogenic capacitors as part of a general attempt to determine whether the company should develop such capacitors. To date, the principal value of the TSP has been to provide the

firm with state-of-the-art knowledge in the area of cryogenic capacitors. (See "Dielectric Properties of Promising Materials For Cryogenic Capacitors" Transfer Example Summary in Attachment IV.)

The transfer process enters stage two when the recipient begins to test the technology to determine its "fit" with organizational resources and facilities. When the technology is in the form of hardware or techniques, second stage transfer activities include laboratory experiments. In cases where the technology involves data and information, a design engineer using a TSP for reference purposes would be typical of a second stage transfer. For example, engineers at the Robbins and Myers' machining company in Springfield, Ohio regularly use the NASA handbook presenting aluminum alloy 7075 properties data to provide basic materials properties information during the early stages of product development projects. (See "Materials Data Handbook, Aluminum Alloy 7075" Transfer Example Summary in Attachment IV.)

An organization progresses into the third transfer stage under one of two conditions: either when it begins market testing prototypes of hardware, or at the time it incorporates techniques or equipment into its in-house operational activities. In other words, stage three transfer activities involve the first full-scale applications of an adapted technology. Rovanco, Incorporated of Joliet, Illinois, for example, is market testing prototypes of a new preinsulated pipe. The company entered stage three after adapting a NASA-developed idea for insulating cryogenic vessels with fiber glass and polyurethane foam to preinsulate pipe sections. (See "Fiber Glass/Polyurethane Foam Insulation On Cryogenic Vessels" Transfer Example Summary in Attachment IV.)

The final stage of the transfer process involves the adoption and diffusion of a technology into the private sector. What this means is that an organization in the private sector has adapted a NASA-developed technology for application, and is promoting the widespread adoption of the adapted technology. One case where this has happened involves the Cryogenic Service Corporation (CSC) in Glendale, California. After acquiring a TSP describing a new method for controlling the level of a cryogenic liquid, the president of CSC decided to apply to NASA for a nonexclusive, royalty-free license to use the space agency's invention. CSC received the license in December 1970. The company subsequently made two minor modifications of the device and began marketing it to research laboratories; more than one dozen have been sold at \$300 each.

(See "Control For Level Of A Cryogenic Liquid" Transfer Example Summary in Attachment IV.)

The results of the TSP users survey reflected one of two situations: either the interest in a particular technical contribution was continuing, or it had been terminated in one of the four transfer stages. Approximately eight percent of the 454 respondents indicated they had terminated their interest in particular TSP's during first stage transfer activities. The transfer experience of the Webster Machine Products Company in Webster, Massachusetts illustrates this point. The firm's general manager said he had seriously considered the possibility of manufacturing a hand-tightened, high-pressure seal developed originally for space program purposes. After reviewing the related TSP in detail, however, he decided that the seals would be too far afield from his company's product line. (See "Hand-Tightened, High-Pressure Seal" Transfer Example Summary in Attachment IV.) From this case and others presented in Attachment IV, it is clear that certain nontechnical factors may lead to termination of transfer activities. In any event, this example illustrates that a stage one transfer can have value: the firm learned quickly from the TSP that the seal was unsuitable from a marketing standpoint.

Another dimension of the action status of transfer cases concerns the type of activity that is likely to occur when TSP users are interested in the acquired technology; it should be noted that well over 90 percent of the questionnaire respondents and interviewees indicated a continuing interest in the technologies reported in these documents. Briefly, their interest in a NASA-developed cryogenic innovation may progress through all four transfer stages, or it may continue indefinitely in one or another of those stages. One example of interest continuing indefinitely in a stage involves Electro-Tec, a division of KDI Corporation in Blacksburg, Virginia. Electro-Tec produces electronic components in which aluminum alloy 6061 is used extensively. Company engineers regularly use the NASA handbook describing behavioral characteristics of this alloy as a reference tool during the course of their work. (See "Materials Data Handbook, Aluminum Alloy 6061" Transfer Example Summary in Attachment IV.)

### Conclusion

The technology transfer experiences of seven different companies have been cited to illustrate the various ways in which

persons in the private sector of the American economy have attempted to solve some of their work-related cryogenic problems by using technology developed originally for space program purposes. More elaborate descriptions of these and 29 other cases are presented in Attachment IV.

The examples cited were arrayed according to the typical activities associated with four different transfer stages: awareness, evaluation, preliminary adoption, and general diffusion. In four out of every five cases, TSP users reported they are still in the awareness stage six months after acquiring the documents; and regardless of transfer stage, nine out of ten indicated they are still interested in using the information in their work.

The transfer activities identified in this survey have been described to emphasize three points: first, cryogenic technology developed originally for space program application often must be modified or adapted before it can be put to use in the private sector. Such modification may be substantial in the case of "embodied" technology (e. g., cryogenics equipment); on the other hand, the adaptation may require little or no modification, such as in the case of physical properties data. Second, the transfer process frequently takes time. It begins with an initial awareness of the space program contribution by someone in the private sector and either proceeds through, continues indefinitely in, or terminates in one or another of the various transfer stages. Third, any attempt to evaluate the relative success of transfer efforts in the cryogenics field must consider, among other things, both the progress being made in attempts to adapt the technologies and the extent to which the technologies are diffusing in the private sector.

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## SECTION V. A FOCUS ON ISSUES

The fundamental difference between technical information and the hardware embodying such information came into clear focus in the preparation of this transfer profile. This distinction bears directly on the question of how cryogenics technology generated in the space program transfers to nonaerospace sectors of the U.S. economy. Because of the very special propulsion, life support, and electrical power generation requirements of the space program, the specific cryogenic systems developed to meet those needs have found little application in nonaerospace situations. While this observation does not necessarily extend to "ground" or support systems, it is clear that the technical information concerning the behaviors of cryogenics and materials in contact with cryogenics has been found to be very useful in emerging nonaerospace cryogenic applications. What the evidence cited in this profile suggests, therefore, is that basic technical information sometimes can be more useful to nonaerospace engineers than the specific innovations whose very existence depended upon the generation and application of such information.

Another important factor affecting transfers of NASA contributions to the cryogenics field was discovered in this investigation. It involves the unique ways one government agency can assist another in generating and disseminating new technical information. As shown in both Section II and its Attachment, NASA and the National Bureau of Standards have worked closely to create technical information concerning the behaviors of several liquefied gases and materials used in conjunction with them. Following the generation of such information, NBS Data Center personnel have employed a variety of familiar communication techniques to disseminate that information to cryogenics specialists throughout the world. This example of interagency cooperation illustrates the pervasiveness of transfer activity, activity not usually so distinguishable in other technical fields.

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**ATTACHMENT I**

**A Brief Chronology of the Cryogenics Field**

## ATTACHMENT I

### A BRIEF CHRONOLOGY OF THE CRYOGENICS FIELD

- 1702 Concept of an absolute zero temperature formulated by Amontons.
- 1738 Theoretical treatise by Bernoulli established a kinetic theory to explain the concept of absolute zero formulated by Amontons.
- 1820 Specific heat relationships developed by Dulong and Petit.
- 1822 Discovery of the salient feature of the gas-liquid equilibrium, the so-called critical point, by de la Tour.
- 1823 Chlorine liquefied by Faraday.
- 1877 First liquefaction of oxygen followed one week later by the liquefaction of nitrogen by Cailletet.
- 1879 First successful refrigeration of ships for shipment of meat from Australia to England.
- 1883 Air first liquefied on a small laboratory scale by Wroblewski and Olszewski.
- 1890's Patents for the use of turbines in gas separation processes taken out by Thrupp and Johnson.
- 1892 Development of the double-walled vacuum cryostat for containing liquefied gases by Dewar.
- 1898 Hydrogen first liquefied by Dewar.
- 1902 Separation of oxygen from air on a commercial scale was performed successfully by Claude.
- 1905 Linde liquefaction plants were erected in Germany and France. The "Societe l'Air Liquide" was formed to exploit the Claude process for making pure liquid oxygen.
- 1906 Nernst postulated the third law of thermodynamics (i. e., total and free energies become equal as absolute zero is approached).
- 1907 Linde Air Products Company started operation in the United States.

- 1907 Einstein used quantum theory to explain low temperature specific heats.
- 1908 Helium first liquefied by Onnes.
- 1911 Superconductivity in mercury discovered by Onnes.
- 1923 Goddard proposed  $LH_2$  and LOX as optimum rocket propellant.
- 1926 New method of refrigeration, proposed independently by Giauque and Debye, involving the adiabatic demagnetization of a suitable paramagnetic salt.
- 1930's First liquefaction turbines successfully operated by the Linde Company in Germany.
- 1933 Discovery of the disappearance of magnetic induction of a metal in the superconductive state by Meissner and Ochsenfeld.
- 1933 Adiabatic demagnetization method of refrigeration first carried out by Giauque and MacDougall at Berkeley using gadolinium sulphate octohydrate as the paramagnetic salt.
- 1934 Development of a helium liquefier that did not require liquid hydrogen for its operation, by Kapitza.
- 1943 Liquefied natural gas (LNG) first utilized as a peak shaving technique by power companies to meet peak power demands associated with power production.
- 1944 Cleveland disaster resulting from an enormous LNG explosion due to failure of the storage container.
- 1946 Invention of a helium liquefier with piston expansion engines by Collins.
- 1947 First large-scale industrial use of liquid oxygen in steel manufacturing which quadrupled the steel output of the same furnace, pilot plant in Austria.
- 1952 First industrial size liquid hydrogen plant and research laboratory put into operation by the National Bureau of Standards in Boulder, Colorado.
- 1953-54 Operational weaponry applications of LOX and  $LH_2$ .

- 1956 A temperature of two hundred thousandths of a degree Kelvin ( $2 \times 10^{-5}$ ) achieved by Kurti, Robinson, Simon, and Spohr, using a magnetizing method to orient copper nuclei in metallic copper, similar to the method involving the adiabatic demagnetization of paramagnetic salts.
- 1957 Theoretical explanation of the behavior of superconducting alloys by Abrikosov.
- 1959 A series of seven shipments of liquefied natural gas were transported by the transport tanker Methane Pioneer on a successful experimental basis from Lake Charles, Louisiana to Canvey Island, England.
- 1963 First superconductive coil producing 100,000 oersted developed by Bell Telephone Laboratories, General Electric and Westinghouse.
- 1963 NASA's first successful launch of a liquid hydrogen-oxygen propelled rocket stage at Cape Kennedy using the Centaur space vehicle.
- 1967 NASA announced successful operation of world's largest and strongest superconducting magnet, designed for thermo-nuclear propulsion research.
- 1965-71 Liquefied natural gas plants constructed by power companies in seventeen cities in the United States and Canada for application to peak load shaving activities.
- 1965-71 National Bureau of Standards, under major NASA funding, developed basic properties data on cryogenic materials.

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**ATTACHMENT II**

**Nasa Contributions to the Development of  
Cryogenic Materials Properties**

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## ATTACHMENT II

### NASA CONTRIBUTIONS TO THE DEVELOPMENT OF CRYOGENIC MATERIALS PROPERTIES

NASA programs and sponsored research cut across the major dimensions of the cryogenics field in substantial ways. These dimensions, previously described in Section I, include the production, storage, transport, and use of cryogenic fluids and systems. Literally hundreds of NASA-sponsored research and development programs, conducted by field center or contractor personnel, have been identified which contribute directly to the sustained growth of the field.

One way of gaining a perspective on the nature of NASA contributions to the field is to identify general categories of research and development effort that are common to the major field dimensions. For present purposes, the categories chosen include:

- Equipment (e. g. , low temperature electrical connectors, improved cryogenic refrigeration systems);
- Insulation (e. g. , low cost insulation system for cryostats, frost as an insulator);
- Techniques (e. g. , liquid oxygen compatible crack detection method, stress relieving cryogenic piping);
- Apparatus (e. g. , cryogenic optical gyro pickoff, composite gaskets for liquid oxygen service);
- Instrumentation and measurement (e. g. , liquid level meter with no moving parts, liquid hydrogen densitometer); and
- Materials properties (e. g. , behavior of Inconel 718 at cryogenic temperatures, thermodynamic properties of liquid parahydrogen).

From a technical viewpoint, significant NASA contributions can be found in all of the categories, and this fact is demonstrated in the program description found in Section II. One category, however, provides a particularly useful insight into the nature of NASA contributions to the cryogenic field; and it will be the focus for the discussion

in this attachment. The category is that of materials properties, and the significant research reviewed considers basic properties data developed through the joint efforts of NASA and the National Bureau of Standards (NBS). The choice of materials properties as the theme for further elaboration in this attachment is a consequence of the fact that cryogenic applications are uniquely dependent on the behavior of the materials in any system. While the determination of these properties is the result of scientific investigation, the data generated are integral to and inherent in all nonaerospace applications.

The necessity for developing information about the properties of cryogenics and materials to be used at cryogenic temperatures is reflected in the decision of NBS to first establish a cryogenic laboratory in 1950 and later, in 1958, to create the Cryogenic Data Center -- both of which are located in Boulder, Colorado. The laboratory and the data center now form the Cryogenic Division of NBS.

The Cryogenics Division has emerged as the primary agency of the United States government responsible for providing comprehensive and current information in the field of very low temperatures (Timmerhaus, 1971). The laboratory furnishes advisory, coordinating, and consulting services on low temperature problems to other government agencies as well as to industrial firms, in addition to the conduct of basic and applied research. These services include provision of specific technical information to organizations outside the Bureau in support of their activities involving cryogenic systems: i. e., programs in materials research, measurement methodology and cryogenic engineering.

The Cryogenic Data Center was established to organize the world's literature pertinent to the field of cryogenics, and thereby broaden the base of reliable information and data. The data center is not only responsible for maintaining a comprehensive awareness of worldwide cryogenic literature and activities of interest to the division staff, but also to the cryogenic community and the public. Included in this responsibility is the critical evaluation of materials properties data and furnishing such information to requesters (Johnson, 1971).

NASA played a pioneering role in its support of the Cryogenics Laboratory during the initial development of hydrogen liquefaction processes and the compilation and determination of physical property data for cryogenic temperatures; and later, NASA was active in its

support of programs to determine cryogenic properties of oxygen, argon, helium, and other cryogenics (see Figures II-1 and II-2). NASA-funded projects presently active at the Cryogenics Laboratory consist of 18 out of the total 69 current projects. A recent report to NASA (Johnson and Diller, 1970) published by the Cryogenics Division of NBS, provides a summary of the work performed on NASA contracts during the last five years. Much of the data presented in the following discussion, illustrating the important NASA contributions to the field, have been taken from this NBS report.

The choice of the joint NASA-NBS work as one focus of this presentation is particularly appropriate: it demonstrates the continued and significant thrust that NASA has made into one area of critical concern to the growth of the field. Further, it demonstrates a cooperative aspect of NASA's approach to a total program of research, an approach which capitalizes on the quality of the existing NBS research and extends its impact.

#### NASA-Sponsored NBS Thermophysical Research

The thermophysical properties of oxygen have been evaluated extensively at NBS, based on precise and close spaced thermodynamic properties measurements. These measurements, augmented by a thorough search of the world literature, were made from the triple point\* to 350 atmospheres and 300°K for both the liquid and gaseous phases. The NBS data represent nearly 80 percent of the world's experimental data for this topic. They were published in NBS Report 9710 on June 20, 1968.

The primary purpose of this program was to provide NASA engineers with accurate, wide-range fluid property data so that processes involving the storage, transport, and pumping of compressed gaseous and liquid oxygen could be designed reliably, safely and economically. Many informal contacts with NASA aerospace engineers suggest that this general purpose has been accomplished. A specific example of the value of these data to NASA's programs concerns the recent failure of the oxygen storage tank on the Apollo 13 lunar mission.

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\* The condition in which liquid, solid, and gas all exist in equilibrium.

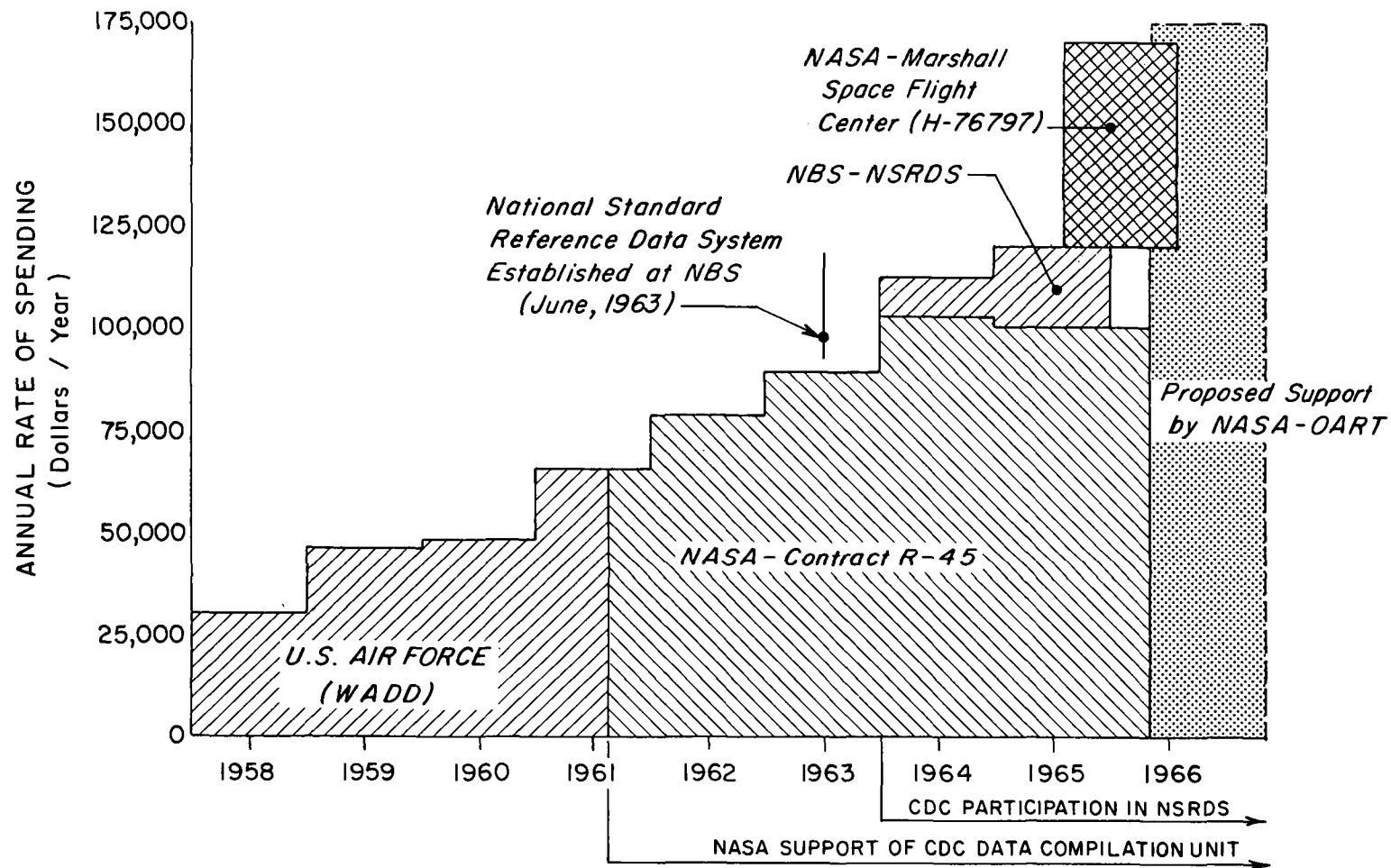


Figure II-1. Project Support for the Thermophysical Data Compilation Program for Materials at Cryogenic Temperatures, at the NBS Cryogenic Data Center. [Source: Johnson and Diller, 1970.]

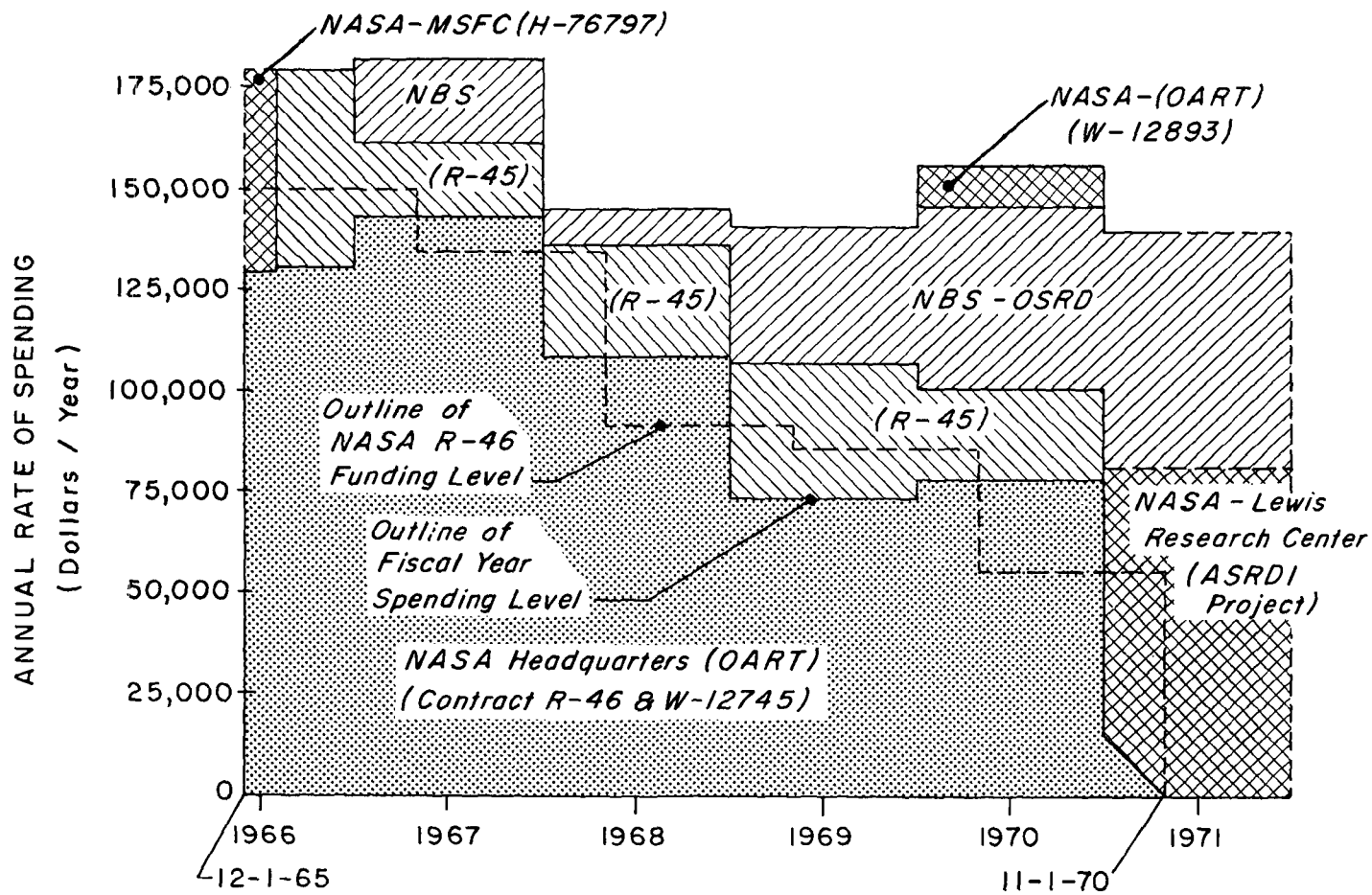


Figure II-2. Project Support for the Thermophysical Data Compilation Program for Materials at Cryogenic Temperatures, Since December 1, 1965, at the NBS Cryogenic Data Center. [Source: Johnson and Diller, 1970.]

The NBS Cryogenics Division was able to make an important contribution to the analysis of this failure due to the availability of knowledge on the thermophysical properties of oxygen. This knowledge established the general features of the tank failure and assisted in deducing the series of unfortunate events preceding the failure. It has subsequently provided the basis for a safe and reliable redesign of the system (Johnson and Diller, 1970).

NASA has recently formed a new group (at LERC) called the Aerospace Safety Research and Data Institute (ASRDI) for anticipating and dealing with the potentially hazardous aspects of aerospace missions. One requirement of the group is to provide for safety in the use of cryogenic fluids. The NBS Cryogenics Division has been selected to assist ASRDI in the review of published reports on oxygen and to provide safety-oriented abstracts of the reports. The nucleus of the physical property data on oxygen, assembled for this purpose, will be derived from the projects previously completed for NASA's Office of Advanced Research and Technology.

A compilation of the thermodynamic properties of argon was undertaken by NBS which again involved a comprehensive search of the world literature. A single, continuous equation of state was formulated to provide values of pressure, density, and temperature from the triple point at 1,000 atmospheres pressure and to 300°K. Tables of derived properties (enthalpy, entropy, and internal energy) were developed as well as charts for specific heats at constant pressure and constant volume. The data were published as Monograph 27 in the NBS National Standard Reference Data Series. This effort has produced important benefits for both engineers and physicists: for engineers because it contains a large body of consistent data, including the thermofunctions for wide ranges of temperature and pressure useful in the design of processes and equipment; and for physicists because it established a state-of-the-art review for such a vast amount of data that heretofore had not been well correlated. Due to its monatomic structural makeup, argon can serve as a model for the study of thermophysical properties of gases, providing consistent, critically evaluated data are available. The data obtained through the argon research at NBS will permit a more direct classical investigation and experimental verification of the theoretical model predictions. It is interesting to note that soon after the publication of the argon monograph, the atmospheric Gases Panel of the IUPAC\* Thermodynamic Tables Project

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\* International Union of Pure and Applied Chemistry.

met in Russia and selected the NBS document as the primary basis for an international table on the thermodynamic properties of argon.

The importance of the thermodynamic properties of helium to the aerospace program, as well as the scientific community, subsequently led to the evaluation and compilation of data on this fluid. The "best values" for the region from 2° to 1,500°K for pressures from 0.1 to 1,000 atmospheres for P-p-T, enthalpy, entropy, internal energy,  $C_p$ ,  $C_v$ , and speed of sound are presented in NBS Report 9762. Final publication will be made in the NBS-NSRD Series. This task has not only made available the best thermodynamic property data for helium-4, but also has revealed the regions of greatest uncertainty of the data and the need for better experimental measurements.

The progress made on the transport properties of fluids and the results that have been published are considered a real advance in the state-of-the-art for analyzing, correlating, and compiling data for viscosity, thermal conductivity, and thermal diffusion of the simple gases (helium, hydrogen, neon, nitrogen, oxygen, argon, krypton, and xenon) in both dilute and dense gas states. This work is of fundamental value to the disciplines of heat transfer and fluid flow and also provides guidelines to experimentalists measuring transport properties. The work uniquely establishes levels of precision necessary for the data to be useful to evaluators, as well as other criteria for optimum measurement procedures and requirements.

An extensive amount of work was done by NBS, under NASA contract, which produced a number of publications and thermodynamic charts on hydrogen properties. Additional work involved the development of curve fitting techniques for evaluation of thermodynamic data, the completion of a study of temperature scales to allow conversion of data from various laboratories to the thermodynamic scale, and the preparation of special temperature-entropy charts for liquid parahydrogen. These charts were prepared to meet both space program requirements and research demands for precise graphical presentation of thermodynamic data for parahydrogen in the compressed liquid region near saturation.

Technical and scientific interest in deuterium stems from the recent use of deuterium in bubble chambers and its continuing importance in certain experimental physics studies. Also, as the principal isotope of hydrogen, the evaluation of deuterium data, with

the functions and methods used for hydrogen, provides confirmation of the hydrogen properties work that had been done earlier under NASA contract. These two reasons alone show the necessity and value of creating fundamental properties data. All the available data on the thermodynamic properties of deuterium were correlated and compiled into numerical tables of property values, thermodynamic charts, and the development of a suitable equation of state. This work resulted in a Master of Science thesis and an NBS report that are accepted internationally as the best thermodynamic properties data for deuterium (Timmerhaus, 1971).

NBS developed, again through NASA support, an annotated bibliography for the properties of methane, which provided one of the most comprehensive classifications and listing of references ever produced. The final bibliography, containing 660 references, was issued as an NBS Technical Note in May 1968. It has been widely distributed, undoubtedly because of the rising interest in liquid methane and liquefied natural gas for use as a domestic fuel and aircraft fuel.

A comprehensive, annotated bibliography on all of the thermophysical properties of air below room temperature to the lowest temperatures for which data were reported was prepared. The collection of documents began over eight years prior to the formal initiation of this task in conjunction with the data compilation presented in the compendium. Since the time of the compendium's publication, the Compilation Unit of the Cryogenic Data Center has actively acquired all articles dealing with the thermophysical properties of air at cryogenic temperatures. A total of 608 articles was selected for the formal bibliography. It was published in October 1969 as an NBS Technical Note and has been quite widely distributed by the U.S. Government Printing Office, the Clearinghouse, and the Cryogenic Data Center.

In contrast to the work on cryogenic fluids, the properties of materials operating at cryogenic temperatures are of complementary importance. Again under NASA contract, NBS prepared a compendium on the properties of materials at low temperatures. Included was a section on the electrical resistivity of 53 metallic elements. A standard format was adopted for presenting the electrical resistivity data and associated documentation for each metal. It consisted of a bibliography of the source literature from which data were selected, then listing all other references found. Concise comments were then compiled from the review and evaluation of the data. All of the selected data were

listed in tabular form, resulting in a graphical presentation of electrical resistivity ratios. The aim was to provide researchers and engineers with a complete picture of data already available so that work could be planned to fill in "gaps" on existing data, or to check or "reinforce" existing measurements. Likewise, for the engineer, the aim was to present a method of predicting the electrical behavior of a metallic specimen of known purity.

The thermal conductivity of metals, alloys, and nonmetallic solids was initiated in response to a widespread need for low temperature data on the thermal conductivity of metals and alloys at low temperatures. The objective was to compile, review, and critically evaluate an overwhelming amount of experimental data of materials below 300°K, plot the most meaningful data on graphs, and tabulate all of the sources of information. To achieve maximum value for all scientists and engineers, much effort was put into a theoretical discussion of thermal conductivity below room temperature. The final document, currently in press, contained nearly 600 references and 130 individual graphs.

### Conclusion

The foregoing has been a review of major tasks, conducted by the National Bureau of Standards, related to the evaluation and compilation of thermophysical property data for industrially important materials at low temperatures. All of the tasks derived their major financial support from NASA contracts for the five-year period from December 1, 1965 to November 1, 1970. As has been shown, a number of the documents produced in connection with the NBS-NASA work have since become basic reference sources both within and outside of the aerospace sector.

Before concluding this attachment, two important points must be made -- one related to the scope of the potential impact of NASA-sponsored cryogenic work and another concerned with the communication of research results. The materials properties research funded by NASA in the NBS Cryogenics Division was basic in the most powerful sense of that word. Mission requirements were not at the root of the research tasks; certainly space program applications of resulting data have been and will continue to be found. From this point of view of transferring the newly-generated technology, however, the fundamental nature of the materials properties data make it crucial to

cryogenics work being conducted in dozens of other fields, such as cryosurgery in medicine, artificial insemination in animal husbandry, and the production and utilization of liquefied natural gases. To facilitate the eventual utilization of this technology, NASA has done something else quite significant and unusual: contractors performing the fundamental research have a clear agreement with the space agency that their research work is not completed until they have published the research results in the professional literature of the cryogenics field. By providing these researchers with appropriate encouragement and support in this regard, NASA has in effect assured the broad and lasting impact of the contributions to the field.

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**ATTACHMENT III**

**Tech Brief Exhibit**

ATTACHMENT III  
TECH BRIEF EXHIBIT

Technical Category	Tech Brief Number	Tech Brief Title
Physical Properties Data	65-10092	Lightweight Aluminum Casting Alloy Is Useful At Cryogenic Temperatures
	66-10121	Compound Improves Thermal Interface Between Thermocouple and Sensed Surface
	66-10185	Improved Adhesive for Cryogenic Applications Cures at Room Temperature
	66-10613	New Weldable High Strength Aluminum Alloy Developed for Cryogenic Service
	66-10657	Simple Technique Determines AC Properties of Hard Superconductive Materials
	67-10049	Cryogenic Fatigue Data Developed for Inconel 718
	67-10113	Nonwoven Glass Fiber Mat Reinforces Polyurethane Adhesive
	67-10301	Materials Data Handbook, Aluminum Alloy 7075
	67-10346	Thermodynamic Properties of Saturated Liquid Parahydrogen Charted for Important Temperature Range
	67-10349	Excellent Spring Properties Developed in Two Nickel Alloys for Use at Cryogenic Temperatures
	67-10365	Magnesium-Lithium Alloys Developed for Low Temperature Use
	67-10366	Study Made of Dielectric Properties of Promising Materials for Cryogenic Capacitors
	67-10413	Study of Hydrogen Slush-Hydrogen Gel Utilization
	67-10462	Fluid Behavioral Patterns Found in Subscale Geysering Study
	67-10610	Handbook of Cryogenic Data in Graphic Form

## TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Physical Properties Data (Continued)	68-10274	Viscosity and Density of Methanol/ Water Mixtures at Low Temperatures
	68-10323	Hydrogen Safety Manual
	68-10360	Fiberglass-Reinforced Structural Materials for Aerospace Application
	68-10523	Evaluation of a Fluorocarbon Plastic Used in Cryogenic Valve Seals
	69-10055	Thermal Expansion Properties of Aero- space Materials
	69-10065	Materials Data Handbook, Aluminum Alloy 6061
	69-10068	Tensile and Fatigue Properties of Inconel 718 at Cryogenic Temperatures
	69-10071	Fatigue Failure in Metal Bellows Due to Flow-Induced Vibrations
	69-10074	Adhesive for Cryogenic Temperature Applications
	69-10086	Techniques for Controlling Warpage and Residual Stresses in Welded Structures
	69-10179	Manual of Typical Low Temperature Mechanical Properties of Several Materials
	69-10471	A Biaxial Weld Strength Prediction Method
	69-10707	Technique for Predicting the Thermal Expansion Coefficients of Cryogenic Metallic Alloys
	70-10199	Fatigue Properties of Sheet, Bar, and Cast Metallic Materials for Cryogenic Applications
	70-10259	Metal Cooldown, Flow Instability, and Heat Transfer in Two-Phase Hydrogen Flow
70-10285	Investigation of the Reactivity of Organic Materials in Liquid Oxygen	
70-10310	High Precision Cryogenic Thermal Conductivity Standards	

## TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Physical Properties Data (Continued)	70-10333	Uniform Data System Standardizes Technical Computations and the Purchasing of Commercially Important Gases
	70-10347	Liquid Cryogenic Lubricant
	70-10573	Filled Polymers for Bearings and Seals Used in Liquid Hydrogen
	70-10576	Low-Temperature Radiation-Resistant Material for Ball-Bearing Retainers
	70-10621	Stainless Steel 301 and Inconel 718 Hydrogen Embrittlement
	70-10673	Low Temperature Uses of Helium
Cryogenic Applications	63-10235	Cryogenic Filter Method Produces Super-Pure Helium and Helium Isotopes
	63-10237	Supercold Technique Duplicates Magnetic Field in Second Superconductor
	63-10250	Level of Super-Cold Liquids Automatically Maintained by Levelometer
	63-10251	Helical Tube Separates Nitrogen Gas From Liquid Nitrogen
	63-10340	Cryopumping of Hydrogen in Vacuum Chambers Is Aided by Catalytic Oxidation of Hydrogen
	63-10365	Low-Cost Insulation System for Cryostats Eliminates Need for a Vacuum
	63-10367	Connector for Vacuum-Jacketed Lines Cuts Tubing System Cost
	63-10368	Composite, Vacuum-Jacketed Tubing Replaces Bellows in Cryogenic Systems
	63-10378	Liquid-Level Meter Has No Moving Parts
	63-10613	Cryogenic Waveguide Window Is Sealed With Plastic Foam

## TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Cryogenic Applications (Continued)	64-10278	Sensitive Low-Pressure Relief Valve Has Positive Sealing Against Leakage
	64-10327	Connector Seals Fluid Lines at Cryogenic Temperatures and High Vacuums
	65-10068	Automatic Thermal Switch Accelerates Cooling-Down of Cryogenic System
	65-10107	Crack Detection Method Is Safe in Presence of Liquid Oxygen
	65-10115	Inert Gas Spraying Device Aids in Repair of Hazardous Systems
	65-10129	Apparatus Permits Flexure Testing of Specimens at Cryogenic Temperatures
	65-10160	Low-Cost Seal Compensates for Surface Irregularities
	65-10202	Quick-Disconnect Coupling Provides Safe Transfer of Hazardous Fluids
	65-10227	Diaphragm Eliminates Leakage in Cryogenic Fluid Duct Coupling
	65-10240	Insulation Accelerates Rate of Cooling with Cryogenic Fluid
	65-10296	Coaxial Capacitor Used to Determine Fluid Density
	65-10297	Superconductor Shields Test Chamber From Ambient Magnetic Fields
	65-10368	Vacuum Chamber Provides Improved Insulation and Support for Cryostat
	65-10402	Lightweight Door Seals Cryogenic Container Against Diaphragm Type Loading
	66-10008	Automatic Fluid Separator Supplies Own Driving Power
	66-10020	O-Ring Tube Fittings Form Leakproof Seal in Hydraulic Systems
	66-10024	Aluminized Fiber Glass Insulation Conforms to Curved Surfaces
66-10039	Control System Maintains Selected Liquid Level	

## TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Cryogenic Applications (Continued)	66-10045	Complementary System Vaporizes Sub-Cooled Liquid, Improves Transformer Efficiency
	66-10052	Combustion Chamber Inlet Manifold Separates Vapor from Liquid
	66-10079	High-Pressure, Low Temperature Electrical Connector Makes No-Leak Seal
	66-10083	Cryostat Modified to Aid Rotating Beam Fatigue Test
	66-10103	Mount Makes Liquid Nitrogen-Cooled Gamma Ray Detector Portable
	66-10122	Niobium Thin Films Are Superconductive in Strong Magnetic Fields at Low Temperatures
	66-10128	Optical Gyro Pickoff Operates at Cryogenic Temperatures
	66-10131	Surfactant for Dye-Penetrant Inspection Is Insensitive to Liquid Oxygen
	66-10136	Cryogenic Trap Valve Has no Moving Parts
	66-10138	Bismuth Alloy Potting Seals Aluminum Connector in Cryogenic Application
	66-10145	Portable Power Tool Machines Weld Joints in Field
	66-10157	Cryogenic Liquid Transfer System Reduces Residual Boiloff
	66-10183	Insulation for Cryogenic Tanks Has Reduced Thickness and Weight
	66-10192	Coating Permits Use of Strain Gage in Water and Liquid Hydrogen
	66-10209	Special Tool Seals Conductors with Combination of Plastic Sleeves
	66-10249	Fluid Damping Reduces Bellows Seal Fatigue Failures
	66-10278	O-Rings with Mylar Back-Up Provide High-Pressure Cryogenic Seal

## TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Cryogenic Applications (Continued)	66-10325	Bimetallic Devices Help Maintain Constant Sealing Forces Down to Cryogenic Temperatures
	66-10342	Gas Diffuser Facilitates Withdrawal of Cryogenic Liquids from Tanks
	66-10348	Inexpensive Insulation Is Effective for Cryogenic Transfer Lines
	66-10394	High Pressure Cryogenic Liquid Flow Sight Assembly Provides Streamlines Flow for Easy Observation
	66-10395	Composite Gaskets are Compatible with Liquid Oxygen, Resist Compression Set
	66-10408	Closed Loop Operation Eliminates Need for Auxiliary Gas in High Pressure Pumping Station
	66-10412	Leak Locator for Vacuum Jacketed Pipelines Eliminates Need for Removal of Outer Jacket
	66-10438	Densitometer System for Liquid Hydrogen Has High Accuracy, Fast Response
	66-10482	Automatic Cryogenic Liquid Level Controller Is Safe for Use Near Combustible Substances
	66-10514	In-Tank Shutoff Valve Is Provided with Maximum Blast Protection
	66-10517	Cold Trap Increases Sensitivity of Gas Chromatograph
	66-10565	Mixer Conditions Temperature of Liquefied Gas Streams
	66-10580	Resistor Monitors Transfer of Liquid Helium
	66-10615	Feed-Thru Flange Is Useful in Vacuum Applications to Cryogenic Temperatures
	66-10627	Quick Attach and Release Fluid Coupling Assembly Is Self-Aligning, Self-Sealing

## TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Cryogenic Applications (Continued)	66-10654	Cryogenic Fluid Sampling Device Permits Testing Under Hazardous Conditions
	66-10661	Study of Fast Response Thermocouple Measurement of Temperature in Cryogenic Gases
	66-10688	Preformed Stiffeners Used to Fabricate Structural Components for Pres- surized Tanks
	66-10697	Combination Double Door High-Vacuum Valve Provides Access to Vacuum Chamber
	66-10702	Teflon Sheet Permits Valve and Valve Actuator to Move as a Single Unit in a Cryogenic Pipeline
	66-10704	Metal Boot Permits Fabrication of Hermetically Sealed Splices in Metal Sheathed Instrumentation Cables
	67-10039	Simple Pump Maintains Liquid Helium Level in Cryostat
	67-10048	Technique for Stripping Teflon Insulated Wire
	67-10057	Mechanisms of Superconductivity Investigated by Nuclear Radiation
	67-10078	Purification Train Produces Ultrapure Hydrogen Gas
	67-10080	Instrument Continuously Measures Density of Flowing Fluids
	67-10100	Synthesis of Various Highly Halogenated Monomers and Polymers
	67-10115	Liquid Hydrogen Densitometer Utilizes Open-Ended Microwave Cavity
	67-10128	Improved Cryogenic Refrigeration System
	67-10264	Inexpensive Cryogenic Insulation Replaces Vacuum Jacketed Line
	67-10299	Liquid Oxygen Ducting Cleaned by Falling Film Method

## TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Cryogenic Applications (Continued)	67-10308	Jacketed Cryogenic Piping Is Stress Relieved
	67-10350	Soft Metal Plating Enables Hard Metal Seal to Operate Successfully in Low Temperature, High Pressure Environment
	67-10377	Stabilizing Stainless Steel Components for Cryogenic Service
	67-10384	Crack Growth Measured on Flat and Curved Surfaces at Cryogenic Temperatures
	67-10420	Concept for Cryogenic Liquid Reclamation System
	67-10424	Temperature-Sensed Cryogenic Bleed Maintains Liquid State in Transfer Line
	67-10474	Method for X-Ray Study Under Extreme Temperature and Pressure Conditions
	67-10506	Performance of Turbine-Type Flowmeters in Liquid Hydrogen
	67-10512	Flow Liner Extends Operating Life of High-Angulation Bellows
	67-10526	Dynamic Valve Seal is Reliable at Cryogenic Temperatures
	67-10532	Copper and Nickel Adherently Electroplated on Titanium Alloy
	67-10539	Lead Plated Aluminum Ring Provides Static High Pressure Seal for Large Diameter Pressure Vessel
	67-10594	Self-Aligning Rod Prevents Eccentric Loading of Tensile Specimens
	67-10600	Dynamic Captive Plastic Seal
	67-10613	Polystyrene Cryostat Facilitates Testing Tensile Specimens Under Liquid Nitrogen
	67-10617	Test System Accurately Determines Tensile Properties of Irradiated Metals at Cryogenic Temperatures

## TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Cryogenic Applications (Continued)	67-10618	Environmental Control System for Cryogenic Testing of Tensile Specimens
	67-10619	Feed-Thru Conduit Minimizes Heat Pickup
	67-10628	Tensile Testing Grips Are Easily Assembled under Liquid Nitrogen
	67-10642	Highly Stable Microwave Delay Line
	67-10644	Development of Dual Solid Cryogenics for High Reliability Refrigeration System
	67-10667	Solenoid Valve Design Minimizes Vibration and Sliding Wear Problem
	67-10673	Cryogenic Seal Concept for Static and Dynamic Conditions
	68-10031	Panelized High Performance Multilayer Insulation
	68-10048	Simple Test for Physical Stability of Cryogenic Tank Insulation
	68-10059	Thermal Short Improves Sensitivity of Cryogenically Cooled Maser
	68-10061	Electronic Circuit Provides Automatic Level Control for Liquid Nitrogen Traps
	68-10064	Flexible Ring Baffles for Damping Liquid Slosh
	68-10070	Development of Biaxial Test Fixture Includes Cryogenic Application
	68-10078	Device Damps Fluid Pressure Oscillations in Vent Valve
	68-10108	Study of Cryogenic Container Thermodynamics During Propellant Transfer
	68-10145	High-Pressure Gas Facilitates Calibration of Turbine Flowmeters for Liquid Hydrogen
68-10262	Silicon Strain Sensors Enable Pressure Measurement at Cryogenic Temperatures	

## TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Cryogenic Applications (Continued)	68-10341	Superconductive Thin Film Makes Convenient Liquid Helium Level Sensor
	68-10375	One-Dimensional Reacting Gas Non-equilibrium Performance Program
	68-10377	Axisymmetric Reacting Gas Non-equilibrium Performance Program
	68-10406	Fiberglass Prevents Cracking of Polyurethane Foam Insulation on Cryogenic Vessels
	68-10417	Hand-Tightened, High-Pressure Seal
	68-10506	Dual-Purpose Chamber-Cooling System
	68-10517	Heat Transfer Coefficients for Liquid Hydrogen Turbopumps
	68-10543	Temperature Controlled Strain Gaged Extensometer
	69-10049	Teflon-Packed Flexible Joint
	69-10100	Electromechanical Rotary Actuator Operates Over Wide Temperature Range
	69-10178	Design and Testing of Liquid Hydrogen-Cooled, Ultrahigh-Speed Ball Bearings
	69-10283	Automated Measurement of Thermal Conductivity
	69-10298	Four-Bar Linkage for Thermal Compensation In Test Mounts for Structures
	69-10321	A Method for Predicting Interfacial Freezing of a Liquid Flowing Over a Cold Surface
	69-10408	Self-Lubricating Gear
	69-10419	Thermal Calibration Target
	69-10446	Method for Predicting Pump Cavitation Performance
	69-10457	Abrasion and Fracture Testing in a High-Pressure Hydrogen Environment
	69-10504	Report on a Cryogenic Gyroscope

## TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Cryogenic Applications (Continued)	69-10541	Cryogenic Fluid Flow Instabilities in Heat Exchangers
	69-10543	Burst Diaphragm Leak Detector
	69-10556	Modified Cryogenic Storage Tank Subsystem
	69-10564	A New Method for Fabrication of Flexible Vacuum Purge Jackets
	69-10573	Control for Maintaining Constant Level of a Cryogenic Liquid
	69-10588	Two-Functional Seal for Hose Connection
	69-10599	Liquid Oxygen-Compatible Insulation System
	69-10601	Cryogenic Pressure Transducer
	69-10649	High-Pressure Seals for Rotary Shafts
	69-10780	Thermal Conductivity Probe
	70-10102	Optimizing Insulation Weight on Cryogenic Storage Tanks
	70-10122	Control of Equilibrium Pressure-Temperature Conditions in Cryogenic Storage
	70-10173	Improved Calibration of Accelerometers at Temperatures Down to -450 °F
	70-10182	Preparation of Fine-Particles at Cryogenic Temperatures
	70-10197	Cryogenic Thermocouple Calibration Tables
	70-10291	Development of Lightweight Cryogenic Tank Supports
	70-10306	Low Heat-Gain Cryogenic-Liquid Transfer System
	70-10415	Evaluation of Two Designs for Cryogenic Insulation
	70-10423	Strain Compatibility Tests for Sprayed Foam Cryogenic Insulation
	70-10491	Kinetic Inductance Measured in a Superconducting Wire
70-10591	The Water-Cryogen Heat Exchanger	

## TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Cryogenic Applications (Continued)	70-10592	The Low-Cost Cryostat
	70-10593	Frost as an Insulator
	70-10628	Accurate, Rapid, Temperature and Liquid-Level Sensor for Cryogenic Tanks
	70-10644	Nonflammable Organic Adhesives Effec- tive Over Wide Temperature Range
	70-10678	Development of Superconductive Magnets

**ATTACHMENT IV**

**Summaries of Technology Transfer Activities Involving  
NASA-Generated Cryogenics Technology**

SUMMARIES OF TECHNOLOGY TRANSFER ACTIVITIES INVOLVING  
NASA-GENERATED CRYOGENIC TECHNOLOGY

NASA CONTRIBUTIONS	TRANSFER STAGES							
	1		2		3		4	
	Cont. #	Term.	Cont.	Term.	Cont.	Term.	Cont.	Term.
<b>MATERIALS PROPERTIES</b>								
• A Biaxial Weld Strength Prediction Method					41946**			
• Adhesive for Cryogenic Applications			35382		30895			
• Dielectric Properties of Promising Materials for Cryogenic Capacitors	3941		9115		50864			
• Handbook of Cryogenic Data			9548		50223			
					8784			
					9554			
					9562			
					9587			
• Hydrogen Safety Manual					22064			
• Materials Data Handbook, Aluminum Alloy 6061			30073		29435			
• Materials Data Handbook, Aluminum Alloy 7075			30206					
• Thermal Expansion Properties Handbook			4511		7493			
					30398			
					32416			
<b>INSULATION</b>								
• Fiber Glass/Polyurethane Foam Insulation on Cryogenic Vessels					49055			
• Frost as an Insulator					50869			
• Polyurethane Foam Insulation							50221	
• Superinsulating Materials							37434	
• Thermal Insulation Systems					50224			
<b>PERFORMANCE OPTIMIZATION APPARATUS</b>								
• Connector Seals Fluid Lines at Cryogenic Temperatures and High Vacuum							49067	
• Hand-Tightened, High-Pressure Seal		49057			49059			
<b>PERFORMANCE OPTIMIZATION TECHNIQUES</b>								
• Cooldown of Cryogenic Transfer Systems							50868	
• Cryogenic Fluid Flow Instabilities in Heat Exchangers	34684			35176	39954			
<b>EQUIPMENT</b>								
• Aircraft Galley and Cargo Refrigeration System							430	
• Specialized Microwave Equipment							9002	
<b>INSTRUMENTATION AND MEASUREMENT</b>								
• Control for Level of a Cryogenic Liquid							49069	
• Superconductive Thin Film As a Liquid Level Sensor	49066							

\* The action status, continuing or terminated, of transfer cases at the time DRI-PATT contacted users. Cases are classed as terminated when (a) no further adaptation or adoption is contemplated, (b) a better technical alternative has been found, or (c) continued transfer activity is not economically feasible.

\*\* Numbers in columns refer to PATT case numbers.

A BIAXIAL WELD STRENGTH PREDICTION METHOD  
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Douglas Aircraft Company, under contract to Marshall Space Flight Center, has developed a method for design of structures which are subjected to multiaxial loading due to internal pressure. This method, described in Tech Brief 69-10471, is especially applicable to the design of liquid propellant tanks. It permits the prediction of a structure's biaxial strength by using a slightly modified uniaxial formula. For welded structures in which the uniaxial and biaxial properties are essentially the same for the weld and parent metal, an equation is given for calculating the biaxial strengths directly from the uniaxial strength. Because aluminum alloys usually have welds with different mechanical properties than those of the parent metal, a graphic method for modifying this equation also is given.

A design engineer with Eastman Kodak's chemical plant in Kingsport, Tennessee (41946), who used the prediction method, has been able to improve significantly plant safety conditions at relatively little cost to his company. Specifically, he redesigned pipes which had been rupturing by using information derived from the weld strength prediction method. Since he found the method satisfactory in solving that problem, he intends to use it again as the need arises.

Control Numbers

Tech Brief Number: 69-10471  
NASA Center: Marshall Space Flight Center  
PATT Case Number: 41946  
TEF Number: 359  
Date of Latest Information Used: March 1, 1971

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ADHESIVE FOR CRYOGENIC APPLICATIONS  
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Among possible materials for construction of cryogenic pressure vessels, filament-wound fiber glass composites have been acclaimed because of their high strength-to-weight ratios. Problems have occurred in efforts to use these materials, notably the tendency of the composites to become permeable after stress-induced straining. Such permeability reduces the capacity of a vessel to contain a cryogenic fluid during desired pressurization cycles. An obvious solution is the use of a nonpermeable, thin metal liner for the vessel; however, this solution would require the application of a special bonding agent to hold the liner in order to prevent buckling during depressurization. The adhesive must strain with the composite without losing adhesion to either surface or failing internally.

Under contract to NASA's Lewis Research Center, the McDonnell-Douglas Corporation developed an appropriate adhesive. As described in a March 1969 Tech Brief, the adhesive consists of adducts of urethane and epoxy resins that exhibit the best properties of both substances. The high strength and modulus of the epoxy is obtained without the brittleness of epoxy, and the strain capabilities and peel resistance of the urethanes are added without the common soft rubber appearance of the urethanes.

EpoxyLite Corporation in South El Monte, California (30895) has used information presented in the NASA Technical Support Package to make proprietary improvements in one of its products and to suggest new applications for one of its adhesive materials. Samples of the improved adhesive are being evaluated by selected customers, with full-scale production and marketing planned for 1972.

Aquanomics in Santa Fe Springs, California (35382) tested prototype samples of the NASA-developed adhesive in the desalination units it produces. Although initial test results were not satisfactory, Aquanomics is still interested in developing a modified version of the adhesive in order to improve its products and reduce production costs.

The Electronics Corporation of America in Cambridge, Massachusetts (50864) has been able to improve one of its products by using the urethane/epoxy adhesive. The product, an infrared detector

system with a cryogenic subsystem, now has a longer and more reliable operating lifetime. Other ECA products also may be improved in the future through applications of this adhesive material.

Control Numbers

Tech Brief Number: 69-10074  
NASA Center: Lewis Research Center  
PATT Case Numbers: 30895, 35382, 50864  
TEF Number: 307  
Date of Latest Information Used: March 21, 1971

## DIELECTRIC PROPERTIES OF PROMISING MATERIALS FOR CRYOGENIC CAPACITORS

### TECHNOLOGY TRANSFER EXAMPLE SUMMARY

The peripheral components required to construct a cryogenic capacitor system are well developed. The principal unknown, however, concerns the complexity of the development task to perfect the dielectric system itself. Experimental investigations were conducted at the General Electric Company, under contract to Marshall Space Flight Center, in an effort to determine dielectric properties of promising materials for cryogenic capacitors to be used in energy storage and pulse applications. Dielectric data were obtained on promising materials through screening tests, tests in liquid nitrogen, and techniques for winding or stacking small test capacitors.

GE researchers investigated three classes of materials in this study: inorganic bonded ferroelectric materials, anodic coatings on metal foils, and polar low temperature liquids. The investigation produced several possible approaches to developing cryogenic capacitors with improved mechanical characteristics. By using the dielectric parameters developed during their investigation, GE researchers provided estimates of the sizes, weights, and losses for cryogenic capacitor systems. In general, the data indicate that relatively compact capacitor systems are possible.

The vice president for research and development at Bishop Manufacturing Corporation in Cedar Grove, New Jersey (3941) requested additional information from NASA after reading a Tech Brief announcing the results of this investigation. He used the documentation to obtain current data on the development of cryogenic capacitors. Although the Bishop Company has no related projects at the present time, the development of these capacitors may lead to potential applications by the firm.

A researcher at Corning Glass Works in Corning, New York (9115) read an article describing the technology in Industrial Research magazine and requested additional information. Corning researchers had developed some new glass ceramics which were observed to have very high dielectric constants at cryogenic temperatures. After comparison with the dielectric data reported in the NASA document, Corning researchers realized the importance of these new ceramics for cryogenic capacitor applications. The company is currently investigating the commercial potential of the materials, using the TSP as a reference for cryogenic capacitors.

A Stanford University physicist (50223) obtained the NASA document as a result of the literature search conducted for him by the National Bureau of Standards' Cryogenic Data Center. He is using the document as a reference source during the course of his research on the dielectric losses of energy in superconducting cavities. This research is part of a superconducting project which is expected to produce basic results and practical applications. The physicist described the NASA document as being his primary source of data on dielectric properties at cryogenic temperatures.

#### Control Numbers

Tech Brief Number: 67-10366  
NASA Center: Marshall Space Flight Center  
PATT Case Numbers: 3941, 9115, 50223  
TEF Number: 363  
Date of Latest Information Used: March 19, 1971

## HANDBOOK OF CRYOGENIC DATA

### TECHNOLOGY TRANSFER EXAMPLE SUMMARY

As part of a project to design high-pressure vessels for storing gases, a Boeing Company engineer developed a cryogenic data handbook. The primary reason for creating the handbook was to present in a single volume and a useful format cryogenic data previously available only in widely scattered sources. One of the main tasks in preparing the handbook involved the creation of simplified graph formats to make the data more useful to cryogenic engineers and scientists. The handbook includes such information as the boiling heat transfer rate from copper to liquid nitrogen; temperature-enthalpy functions for liquid nitrogen; saturated liquid/gas relations; linear contractions of teflon, stainless steel, and other materials of construction; and gaseous air density and compressibility factors versus pressure. It concentrates extensive data on common materials of construction and properties of fluids frequently encountered in designing cryogenic systems.

American Atomics Corporation in Tucson, Arizona (8784), which produces self-luminous light sources, used the data presented in the handbook to improve the performance and predictability of a cryogenic system employed in its manufacturing processes. The firm's supervisor of research and development stated that having the data compiled in a single document helped him save at least 30 hours of research time. American Atomics will continue to use the handbook as a reference tool.

A consulting engineer in St. Louis, Missouri (9548) is using cryogenic data presented in the NASA handbook to verify the adequacy of equipment being used in a new process to liquefy natural gas. If the overall process is adopted, field operation costs could be reduced by as much as \$50 million per field site. The engineer indicated that the design of the new process could not have been successfully completed without the NASA information.

The process design group at Hooker Chemical Corporation in Niagara Falls, New York (9554) is concerned with predicting the thermodynamics of chemical processes and manufacturing operations. The NASA handbook provided the group with enthalpy data for analyzing thermodynamic problems, which then led to the design of improved equipment and processing techniques. Two improved methods resulting from their use of handbook data involved chemical processing and pollution control. The firm's process design manager stated that the availability of the NASA information enabled the firm to save research time.

Consulting engineers at Mason & Hanger-Silas Mason Company, Incorporated in Lexington, Kentucky (9562) have used data from the handbook to design four liquefied natural gas storage facilities and to redesign a refrigeration system used to freeze runny ground for excavation. The refrigeration system is being used in a major sewage system project in New York City. Mason & Hanger consultants were asked to redesign the previous system which was subject to several very expensive problems. Data in the NASA handbook provided approximately 50 percent of the input to redesigning the system. The new system reportedly works very well. The firm also has used the handbook to determine design specifications and materials for low temperature equipment in plants which Mason & Hanger operate for the government. The handbook was described as being a very important and timesaving reference tool for the company's low temperature consulting jobs.

A U.S. Civil Engineering Laboratory in Port Hueneme, California (9587) used the handbook as a primary reference source in its investigation and evaluation of a commercial underwater power module. The module incorporated a liquid nitrogen system to provide nitrogen gas which ran pneumatic tools. The project engineer reported that without the handbook the evaluation of the modules' cryogenic system would have been incomplete. He indicated that the handbook is still used as a basic reference tool at the laboratory for evaluating cryogenic equipment.

#### Control Numbers

Tech Brief Number: 67-10610  
NASA Center: Kennedy Space Center  
PATT Case Numbers: 8784, 9548, 9554, 9562, 9587  
TEF Number: 248  
Date of Latest Information Used: March 26, 1971

HYDROGEN SAFETY MANUAL  
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Hydrogen, in both liquid and gaseous states, is an indispensable component of rocket fuel and spacecraft energy cells. The presence of hydrogen, however, constitutes one of the greatest single fire hazards in the space program. This hazard is caused by the fact that this odorless gas is ten times more flammable than gasoline; in addition, hydrogen fires are colorless. NASA engineers have developed extensive safety procedures for storing, handling and using hydrogen. The Advisory Panel on Experimental Fluids and Gases at Lewis Research Center has written the Hydrogen Safety Manual (NASA TM X-52454) which presents a unified statement of these procedures. The manual describes the characteristics and nature of hydrogen, design principles for hydrogen systems, protection of personnel and equipment, and operating and emergency procedures. It is an operating manual which sets forth acceptable standards and practices for minimum safety requirements at the Lewis Research Center. Because of its relevance to increasingly common nonaerospace scientific and industrial uses, NASA issued Tech Brief 68-10323 in August 1968 to announce publication of the manual.

Dow Chemical Company in Midland, Michigan (22064) reviewed the Tech Brief and ordered the manual. Dow engineers have used data from the manual in conducting a study of gas cloud explosions and are still using the manual as a reference for designing equipment and facilities for the company's chemical processing plants.

Control Numbers

Tech Brief Number: 68-10323  
NASA Center: Lewis Research Center  
PATT Case Number: 22064  
TEF Number: 258  
Date of Latest Information Used: June 6, 1971

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MATERIALS DATA HANDBOOK, ALUMINUM ALLOY 6061  
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

A comprehensive compilation of technical data on Aluminum Alloy 6061 has been presented in a handbook prepared by the Syracuse University Research Institute under contract to Marshall Space Flight Center. The handbook includes data on the properties of the alloy at cryogenic, ambient, and elevated temperatures, as well as other pertinent engineering information required for the design and fabrication of components and equipment utilizing the alloy. In particular, it contains information on procurement, production and manufacturing practices, static and dynamic properties, corrosion resistance and protection, surface treatments, and joining techniques. In March 1969 NASA published a Tech Brief announcing the availability of the handbook.

Two divisions of Honeywell, Incorporated have used the TSP for reference purposes. The Aerospace Division in St. Petersburg, Florida (29435) improved manufacturing processes in-house by using the data on Alloy 6061. Information contained in the handbook on the alloy's forming characteristics is used in the production of chassis and containers made from the alloy. Subsequent improvements have saved the division both time and money. An in-house materials consultant with the Industrial Division in Fort Washington, Pennsylvania (30073) also reports he has saved time in providing information on the alloy to production engineers and sales personnel in his division. Both divisions will continue to use the TSP as a reference tool.

Electro-Tec, a division of KDI Corporation in Blacksburg, Virginia (30206), has saved research time by using the handbook as a reference tool. The company produces electronic components in which Aluminum Alloy 6061 is used extensively. The handbook is one primary source of information which Electro-Tec design engineers use when working with this alloy.

Control Numbers

Tech Brief Number: 69-10065  
NASA Center: Marshall Space Flight Center  
PATT Case Numbers: 29435, 30073, 30206  
TEF Number: 358  
Date of Latest Information Used: March 9, 1971

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MATERIALS DATA HANDBOOK, ALUMINUM ALLOY 7075  
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

A comprehensive compilation of technical data on Aluminum Alloy 7075 was prepared by the Syracuse University Research Institute under contract to Marshall Space Flight Center. Published by NASA in 1967, the handbook includes data on properties of the alloy at cryogenic, ambient, and high temperatures, as well as other information required for the design and fabrication of components and equipment using this alloy.

Beckman Instruments, Incorporated in Palo Alto, California (7493) used the handbook as a reference text in a recent study of low cycle fatigue characteristics of Alloy 7075. The alloy was evaluated for use in high speed ultracentrifuges made by the company. Upon completion of the study, the firm adopted Alloy 7075 for several components of its ultracentrifuge. The NASA handbook was deemed valuable for its suggestion of the probable outcome of the study, assistance in designing the research, and for verification of test results.

Robbins and Myers, Incorporated, a machinery manufacturer in Springfield, Ohio (4511), regularly uses the NASA document describing Alloy 7075 as a general reference book during the early stages of new product development programs. According to a company spokesman, Robbins and Myers' engineers have been able to make small, but important, changes in a variety of mass production processing techniques.

Control Numbers

Tech Brief Number: 67-10301  
NASA Center: Marshall Space Flight Center  
PATT Case Numbers: 4511, 7493  
TEF Number: 243  
Date of Latest Information Used: March 26, 1971

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NYLON-FILLED EPOXYPOLYAMINE  
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Employees of Telecomputing Corporation, under contract to NASA's Western Operations Office, devised a method of formulating an adhesive that cures at room temperature and maintains effective bonding at cryogenic temperatures. The method entails adding one part of powdered nylon filler to two parts of an epoxypolyamine resin. As described in a 1966 Tech Brief, the nylon filler also markedly improves the adhesive strength and toughness of the epoxypolyamine resin.

LUSOL Company in El Monte, California (27958) is engaged in custom compounding of epoxy resins, silicones, and polyurethanes for high and low temperature uses. The company used the Tech Brief to guide preparation of a proposal and sample material for a potential client. When the client abandoned his project, the proposal was rejected. Although he foresees no additional applicability of the Tech Brief in his work, the general manager of the company estimated that the document saved 40 to 50 hours of research time during preparation of the sample and proposal.

Control Numbers

Tech Brief Number: 66-10185  
NASA Center: Western Operations Office  
PATT Case Number: 27958  
TEF Number: 295  
Date of Latest Information Used: August 13, 1970

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THERMAL EXPANSION PROPERTIES HANDBOOK  
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

A NASA Tech Brief published in March 1969 announced the availability of a new handbook concerning thermal expansion properties of materials used in aerospace systems. Compiled by E. F. Green of North American Rockwell Corporation under contract to Marshall Space Flight Center, the handbook consists of charts and tables for data on thermal expansion properties at cryogenic temperatures (to  $-423^{\circ}\text{F}$ ) and at high temperatures (to  $2,000^{\circ}\text{F}$ ). The data were derived from experimental measurements and supplemented by information from various literature sources.

Pyromet Industries in San Carlos, California (30398) has used data in the handbook to help improve the design of its production fixtures and quality control procedures. According to a company spokesman, the firm's custom production of specialized metal parts and brazing and heat treatment services has been improved during the first months of application. He estimates that Pyromet will save approximately 100 man-hours annually by using the handbook.

Engineers employed by Eastman Kodak in Kingsport, Tennessee (32416) have used the NASA information to save approximately 25 percent of the design cost and a considerable amount of construction cost for a new support facility recently built at the Tennessee plant. The facility, designed for producing hydrogen gas, is estimated to have cost between \$500,000 and \$1,000,000. Kodak's engineers are continuing to improve existing production equipment by using the NASA technology.

Control Numbers

Tech Brief Number: 69-10055  
NASA Center: Marshall Space Flight Center  
PATT Case Numbers: 30398, 32416  
TEF Number: 321  
Date of Latest Information Used: March 22, 1971

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FIBER GLASS/POLYURETHANE FOAM INSULATION ON  
CRYOGENIC VESSELS

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Polyurethane foam applied as insulation on metal cryogenic vessels tends to separate from the metal surfaces as the result of differential shrinkage when the vessel is cooled to cryogenic temperatures. Voids between the separated polyurethane insulation and the metal surfaces become filled with moisture and air and cause excessive cracking of the insulation. Under contract to Marshall Space Flight Center, McDonnell-Douglas Corporation engineers recently found a solution to this problem. The shrinkage is eliminated by interposing a layer of fiber glass insulation between the polyurethane foam and the outer surfaces of cryogenic lines and tanks. The fiber glass material retains its resilience at cryogenic temperatures and provides an expansion layer between the metal surfaces and the polyurethane foam. A Tech Brief describing the technology was issued in 1968.

Rovanco, Incorporated in Joliet, Illinois (49055) developed a new method of preinsulating metal pipe sections which uses the fiber glass and polyurethane foam technology developed for NASA. Rovanco subsequently applied for a patent on the method. Several prototypes are in the process of being field tested by potential customers. The company president reports that initial reactions to the preinsulated pipe have been favorable. He indicated that a large potential market for the pipe exists in the liquefied natural gas industry.

Control Numbers

Tech Brief Number: 68-10406  
NASA Center: Marshall Space Flight Center  
PATT Case Number: 49055  
TEF Number: 350  
Date of Latest Information Used: February 18, 1971

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FROST AS AN INSULATOR  
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Frost is generally considered to be an undesirable, inert, homogeneous, crystalline structure that must be eliminated to enhance the heat transfer of cooling coils. When frost forms under other conditions, however, such as on the outside of cryogenic lines, its qualities can be used advantageously. It possesses an insulating capacity which compares favorably with some common low efficiency insulation materials such as shredded bark, insulating brick, asbestos and leather.

Basic insights on the insulating quality of frost and mechanisms for using frost in specific applications have been derived from recent tests and studies at the Los Alamos Scientific Laboratory under contract to the Space Nuclear Systems Office. Frost is an ice layer formed by condensed crystals of liquid air. If the liquid air is allowed to escape, the frost layer cracks, sloughs off, shifts position, and repairs itself with consequent changes in insulating value and thermal conductivity. However, by maintaining relative humidity above set values and blowing the moist air past cryogenic lines at certain velocities, frost can be formed to set thicknesses and densities which can be sustained. Once this occurs liquid air run-off is eliminated, and the frost layer becomes a uniform insulator. This technique could be applied in operations where it is difficult to wrap or attach standard insulating materials. Conditions can also exist where space constraints or lack of access impedes the placing of insulation. With an available supply of moist air, frost possesses the inherent advantage of easy insulation of cryogenic lines which otherwise might not be protected.

Chicago Bridge and Iron Company (CB&I) in Plainfield, Illinois (50869) learned of this development through the results of a literature search conducted for the company by the National Bureau of Standards' Cryogenic Data Center. After executing tests on frost to verify the Los Alamos results, CB&I engineers used the technology in designing a liquefied natural gas transfer system to be used by a customer. The customer has installed this system in a slightly modified form, using some insulation with the frost. CB&I reportedly

saved approximately \$10,000 in research costs by using the data. A CB&I engineer says the company will use the technology in future cryogenic system design work.

Control Numbers

Tech Brief Number: 70-10593  
NASA Center: Space Nuclear Systems Office  
PATT Case Number: 50869  
TEF Number: 365  
Date of Latest Information Used: March 30, 1971

## INSULATION TECHNOLOGY TRANSFER EXAMPLE SUMMARY

The use of high energy cryogenic fluids to boost large payloads into space and to furnish power during space missions has required the development of cryogenic insulating materials which will adequately protect highly volatile fluids during ground storage, launch, and mission operation. As principal contractor to NASA for the Apollo command and service modules and the S-II second stage of the Saturn V launch vehicle, the Space and Information Systems Division (S&ID) of North American Aviation, Incorporated in Seal Beach, California (50221) has devoted a large share of its engineering and manufacturing resources to the development and use of cryogenic technology. In addition to testing and evaluating numerous cryogenic materials, S&ID's cryogenic technology program has involved the origination of various composite materials, design of structures for minimum heat transfer, development of advanced insulation systems, and refinement of unique fabrication and bonding techniques.

S&ID obtained a contract from Marshall Space Flight Center for the S-II. To meet the insulating requirements for the S-II fuel tanks, S&ID engineers designed sandwich-type cryogenic insulation panels which could be adhesive-bonded to the outer wall of the fuel tank. Special adhesives and advanced bonding techniques were developed to ensure a bond which would withstand the temperature extremes and other stresses imposed upon the insulation. The insulation panel consists of a polyurethane foam-filled phenolic-glass honeycombed core, to which a laminated skin is bonded. The skin is composed of polyvinylfluoride film and nylon fabric impregnated with phenolic resin. The 33-foot diameter S-II is joined to the Saturn S-1C stage by an interstage skirt. An important requirement is cryogenic insulation for the bolting ring at the juncture of this skirt and the S-II's liquid hydrogen and liquid oxygen propellant tanks. To facilitate insulation of the bolting ring's complex surface, S&ID developed a closed-cell polyurethane foam which, unlike open-cell foams, requires no external seal membrane and is able to withstand thermal shock without cracking. An effective insulator in cryogenic environments to  $-423^{\circ}\text{F}$ , closed-cell foam can be used without surface treatment for warm-side temperatures to  $500^{\circ}\text{F}$ .

To foam-spray the complex surface of the S-II bolting ring, S&ID developed special techniques, including a holding fixture which permits the spray gun to be adjusted for movements on all three axes.

S&ID's cryogenic test facilities are used to demonstrate the reaction of cryogenic materials to actual mission profiles. In addition to being exposed to temperatures in the -423 °F to 500 °F range, materials proposed as cryogenic insulators are tested for thermal shock; helium permeability; tensile, compression, and shear strength; elongation; and coefficient of expansion.

S&ID has distributed an advertising brochure which states:

In accepting the contracts for the Apollo spacecraft and the Saturn S-II booster, the Space and Information Systems Division committed itself to producing equipment of the highest efficiency and reliability. The facilities and experienced personnel acquired to meet this challenge, as well as the manufacturing processes developed during five years of spacecraft manufacture, are now available to meet the unique development or production requirements of other organizations.

The company's advertising and sales campaign subsequently produced between \$500,000 and \$1,000,000 in contracted, nonaerospace insulating business in 1970. Current or completed insulation applications include large liquid methane tankers and a tuna boat. S&ID also has entered into a license agreement with a division of Wanner-Isofi, a world-wide, French-based insulation and tank company, to supply the insulation system designs, materials testing, polyurethane foam application equipment, and technical representatives for Wanner-Isofi's liquefied natural gas installations in North Africa, Asia and Europe.

#### Control Numbers

Tech Brief Number: None  
 NASA Center: Marshall Space Flight Center  
 PATT Case Number: 50221  
 TEF Number: 361  
 Date of Latest Information Used: March 16, 1971

## SUPERINSULATING MATERIALS

### TECHNOLOGY TRANSFER EXAMPLE SUMMARY

The National Research Corporation (NRC) developed an aluminized film, NRC-1, in the mid-1950's, and announced as early as 1957 that sales were being made to the military and to industry for insulation applications. In 1958, the firm expanded its work to include cryogenic insulation modifications of the material. By 1962 the firm had secured a patent on NRC-2, a crinkled, aluminized .0025-inch plastic film (MYLAR). The material possessed the highest insulating efficiency per pound of any known material.

In 1962, National Research Corporation (37434) began to execute a variety of NRC-2 application contracts with NASA, mainly with the Lewis Research Center. NRC-2 eventually was used as the outer skin of the Echo I satellite, in components storing cryogenic liquids, and in suits worn by astronauts. These were the first applications of NRC-2. The company also granted licenses to two manufacturers for use in cryogenic vessels, some of which were used to store and transport cryogenic fluids for the space program.

Norton Company bought control of NRC in early 1965, shortly after NRC had introduced the first consumer product from NRC-2: a .005-inch, uncrinkled film for use as a disposable rescue blanket. This product was not successful, and a reusable blanket was announced in late 1965. Although it was a stronger, grommeted lamination of polyethylene and NRC-2, the material did not "breathe," could not be stitched, and was not very durable. In 1968, NRC developed a method for coating fabrics with NRC-2 by using vacuum deposition. This technique provided the solution to the three previous problems.

NRC became the Metallized Products Division of Norton Company in 1969, and a sales campaign based on the new coating method was initiated. Early in 1969, the new Norton division contracted with McGregor-Doniger, Incorporated to apply the coating to McGregor's fabrics which were then used to produce sportswear. Norton's annual business for this coating service has leveled off at about \$2,000,000, with McGregor continuing to be the major customer. Norton also introduced several newer versions of the "space blanket," as the rescue blankets are now called, which incorporated the same coating process on several different fabrics. Since then approximately one million of the blankets have been produced annually. They have suggested retail prices ranging from \$2.00 to \$7.95.

In March 1971, the Norton division was sold to King-Seeley Thermos Company. Thermos has a national sales network for its line of camping equipment, and the consumer-oriented applications of NRC-2 are being integrated into this product line.

Control Numbers

Tech Brief Number: None  
NASA Center: Lewis Research Center  
PATT Case Number: 37434  
TEF Number: 160  
Date of Latest Information Used: June 8, 1971

THERMAL INSULATION SYSTEMS  
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

NASA contributions to the development of advanced thermal insulation technology have been directed primarily to applications in cryogenic systems. That technology, however, also has influenced the development of thermal insulations for use at higher temperatures. Different materials must be selected to withstand higher temperatures, but similar principles of heat transfer apply. The thermal insulations available today fall into two major categories: those which are gas filled, and those in which gases have been evacuated to achieve a required low pressure. Although multilayer insulations are considered by many to be the most striking of the important new developments, space program research in this area also has produced improvements in the effectiveness of foam, evacuated powder and fibrous insulations. Information on thermal insulations developed in the course of space research programs has been made available to scientists and engineers through contractor reports and technical articles in professional journals. Until recently, however, this information has not been applied outside of the space program, primarily because relevant concepts and applications have been difficult to extract.

To facilitate the transfer of this technology, Arthur D. Little, Incorporated conducted a survey of NASA work in the development of thermal insulation systems. The results of that survey subsequently were published in a NASA Special Publication, entitled Thermal Insulation Systems. The document includes an extensive discussion of the principles of thermal protection systems, the insulation components for such systems, and their integration, installation, and performance in typical applications.

Stanford University (50224) recently installed cryogenic storage vessels to support cryogenics research work in its physics laboratory. Stanford personnel were able to design the necessary insulation systems by using the NASA document. Scientists and engineers described the

handbook as their primary reference tool in designing insulation systems for cryogenic research equipment.

Control Numbers

Special Publication Number: SP-5027  
NASA Center: NASA Headquarters  
PATT Case Number: 50224  
TEF Number: 362  
Date of Latest Information Used: March 19, 1971

CAPTIVE PLASTIC SEAL  
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Cryogenic temperatures impose especially difficult conditions for the functional integrity of most plastics and elastomers used in seals. In order to obtain zero leakage of cryogenic materials, a seal must have total surface conformity; however, the very low temperatures cause plastics to become brittle, shrink, and lose resilience with the result that a seal using these materials does not perform well.

An engineer employed by North American Rockwell's Rocketdyne Division, under contract to Marshall Space Flight Center, invented a "captive plastic seal" that achieves total surface conformity. For cryogenic applications, teflon provides ideal sealing characteristics when its extrusion under pressure is contained by abrasion-resistant metal rings. The surfaces to be sealed are tightly compressed; the resulting pressure on the teflon exceeds its compressive yield point and causes it to act as a fluid flowing into adjacent surface irregularities to provide sealing. The reusable seal thus minimizes requirements for "superfinishing" sealing surfaces, and it can accommodate misalignment and surface separations. It operates under fluid pressures to 12,500 psi and temperature ranges from -450°F to +550°F.

The basic invention was described in a 1967 Tech Brief. In August of 1967, a waiver was granted to North American. The Seals Division of Shamban Corporation in Los Angeles, California (4574) then received a license from North American to produce and market the device. Initially, only one size was produced; but the firm now offers a full range of standard sizes. Captive plastic seals may be used for all flange-type plumbing, and as components in hydraulic systems, hazardous fluid systems and cryogenic systems.

Control Numbers

Tech Brief Number: 67-10600  
NASA Center: Marshall Space Flight Center  
PATT Case Number: 4574  
TEF Number: 207  
Date of Latest Information Used: July 27, 1970

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CONNECTOR SEALS FLUID LINES AT CRYOGENIC  
TEMPERATURES AND HIGH VACUUM  
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

In 1964, engineers at NASA's Goddard Space Flight Center invented a fluid line connector to meet rigid, low pressure, and low temperature sealing specifications. The invention incorporates a metal disk gasket which is compressed between a set of concentric serrations on each of the connector halves. Compression on the disk is applied by uniform tightening of the flange bolts. Uniform compression on both sealing surfaces is ensured by the spring action of the disk. Any difference in the coefficient of thermal expansion between the disk and flange, which is normally very slight, is offset by the spring action of the disk. The connector serves as a positive seal for fluids at temperatures ranging from near absolute zero to 300 °F; it also is suitable for use in vacuum systems at pressures down to  $10^{-8}$  mm of mercury. The connectors can be installed or removed quickly. Installation does not require soldering or welding within vacuum chambers and, hence, reduces the possibility of chamber contamination. A Tech Brief describing the invention was issued in December 1964.

Cryolab, Incorporated in Los Osos, California (49067) is currently producing the NASA-developed connector in several sizes. The decision to include the connector in Cryolab's product line of cryogenic and vacuum components was made shortly after the company received the Tech Brief. Cryolab subsequently received a license to manufacture the NASA invention in August 1965. Since that time, the company has had total sales of approximately \$20,000 for this product.

Control Numbers

Tech Brief Number: 64-10327  
NASA Center: Goddard Space Flight Center  
PATT Case Number: 49067  
TEF Number: 354  
Date of Latest Information Used: February 17, 1971

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HAND-TIGHTENED, HIGH-PRESSURE SEAL  
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

A need existed in the space program to provide flared tubing and hose connections for high-pressure (10,000 psi) cryogenic service that could be assembled without the use of tools. North American Rockwell Corporation engineers, under contract to Marshall Space Flight Center, modified existing high-pressure fittings to provide hand-tightened, leak-proof connections. Two types of fittings were modified to receive a special, double-truncated, cone-shaped Kel-F washer. The use of this type of hand-tightened seal on cryogenic lines to  $-320^{\circ}\text{F}$  is limited to seal diameters of 0.75-inch and less. There is no apparent limit to the size of this seal design when it is used at ambient temperatures. A Tech Brief describing the invention was issued in December 1968. Two magazines, New Products Newsletter and Machine Design, subsequently published articles describing the invention. In each example cited below, the individual involved requested a copy of the Tech Brief and license information for the invention as a result of the publicity given the technology in the magazines.

An engineer with the National Division of Ritter Engineering Company in Pittsburgh, Pennsylvania (49059) has developed prototypes of the NASA connector in a slightly modified form. Tests conducted at National have shown that the prototypes provide improved tubing connections in hydraulic systems produced by the company. Present economic factors are being evaluated prior to initiating full-scale commercialization of the seals.

The manager of Webster Machine Products, Incorporated in Webster, Massachusetts (49057) considered the modified metal fittings described in the Tech Brief for possible adoption as new products. He subsequently decided that the fittings were too far afield from the company's product line, and terminated all adaptation activities. He indicated that he plans no further use of the seal technology at this time.

Control Numbers

Tech Brief Number: 68-10417  
NASA Center: Marshall Space Flight Center  
PATT Case Numbers: 49057, 49059  
TEF Number: 357  
Date of Latest Information Used: February 18, 1971

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## COOLDOWN OF CRYOGENIC TRANSFER SYSTEMS TECHNOLOGY TRANSFER EXAMPLE SUMMARY

The fluid flow and heat transfer characteristics of cryogenic cooling systems during the start-up of NASA's nuclear rocket engines have been the subject of extensive research at Los Alamos Scientific Laboratory, under contracts with the Space Nuclear Systems Office and the Lewis Research Center. The published results constitute the principal body of available knowledge on the cooldown of cryogenic transfer lines. These publications provide experimental results and analytic models for predicting the transient flow, thermal stress, and heat transfer characteristics of warm pipelines when they are cooled to operating temperature by either a small, steady flow of liquid cryogen or a flow of chilled gas from the cryogen. If the cooldown flow-rate is too low, then the resulting two-phase, stratified flow produces undesirable effects. On the other hand, if the flow-rate is too high, then large thermal stresses are produced in flanges and valve bodies on the pipeline.

In March 1970, the National Bureau of Standards' Cryogenic Data Center conducted a literature search for the Chicago Bridge and Iron Company (CB&I) in Plainfield, Illinois (50868). CB&I subsequently made extensive use of the publications identified in that search during the preparation of a successful \$5,000,000 contract proposal to design and install a liquefied natural gas (LNG) transfer system. The contract has subsequently been expanded to \$7,000,000, based on excellent preliminary results. The new system will use 24-inch diameter transfer pipelines to carry LNG from huge ocean tankers into shore storage tanks. The company, under a contract with Distrigas Corporation, will make the initial installation of the LNG transfer system in Boston, Massachusetts. CB&I is also building the shore storage tanks for this installation, which is scheduled for operation in the fall of 1971.

CB&I's director of cryogenic research reported that the company had no previous experience with ship-to-shore transfer systems, and had never worked with LNG transfer pipes larger than 10 inches in diameter. He also indicated that, without the NASA documents, CB&I probably would not have received a contract of this type. He said the documents were very important to his engineers in writing the proposal, establishing their expertise, and designing the system which is now under construction. In terms of future benefits to the firm, the newly

developed system has become a very significant development for the company. Additional installations of similar ship-to-shore transfer systems will probably be made by CB&I and its licensees in England, Europe, and Japan as the rate of importing LNG increases in each country.

Control Numbers

Tech Brief Number: None  
NASA Centers: Lewis Research Center and Space Nuclear  
Systems Office  
PATT Case Number: 50868  
TEF Number: 364  
Date of Latest Information Used: March 30, 1971

## CRYOGENIC FLUID FLOW INSTABILITIES IN HEAT EXCHANGERS

### TECHNOLOGY TRANSFER EXAMPLE SUMMARY

An experimental investigation was conducted at the General Electric Company, under contract to Marshall Space Flight Center, to determine the nature of oscillations and instabilities that occur in the flow of two-phase cryogenic fluids at both subcritical and supercritical pressures in heat exchangers. The objective was to obtain a fundamental understanding of the phenomena, without regard to the design parameters of a particular heat exchanger configuration.

The major experimental work was conducted with liquid nitrogen at subcritical pressures in an apparatus designed to provide data on the nature and rate of fluid flow, heat transfer rates and pressure drops. The results of the tests with varying system parameters suggest certain design approaches with regard to heat exchanger geometry which should increase system stability.

The president of Frumerman Associates, Incorporated, a consulting engineering firm in Pittsburgh, Pennsylvania (34684), requested additional information on the technology after reading a Tech Brief which described it. He studied the NASA document and plans to use it in his consulting work as the need arises.

A researcher with the Shell Development Company, the research branch of Shell Oil Company, in Houston, Texas (35176), recently used the NASA document during a low temperature research project. Although that project was completed successfully, there are no immediate plans to utilize the results in Shell's production facilities. The TSP is credited with allowing the Shell researchers to save valuable time on the project.

Union Carbide's Linde Division in Tonawanda, New York (39954) has improved one of its products by using this technology developed for NASA. The product, a cryogenic vaporizer, was subject to pressure surging. While surging presented only minor difficulties in most applications, it was potentially quite dangerous in others. The problem

has since been eliminated by modifying the product. Linde engineers plan to conduct a more complete analysis of the problem by using the mathematical model described in the NASA document sometime in the near future.

Control Numbers

Tech Brief Number: 69-10541  
NASA Center: Marshall Space Flight Center  
PATT Case Numbers: 34684, 35176, 39954  
TEF Number: 356  
Date of Latest Information Used: March 11, 1971

## HEAT TRANSFER COEFFICIENTS FOR LIQUID HYDROGEN TURBOPUMPS

### TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Numerous complex modes of heat transfer occur during transient start-up operation of liquid hydrogen turbopumps. A Marshall Space Flight Center contract with North American Rockwell Corporation resulted in documentation of empirical equations that establish appropriate heat transfer coefficients for operation of these turbopumps. As written by W. R. Wagner and W. R. Bissel of North American, the equations are expressed as functions of temperature drops and heat transfer rates for a wide range of convective and boiling conditions at different locations in the pump.

Engineers at the Convair Division of General Dynamics Corporation in San Diego, California (26264) used the NASA publication presenting these equations to improve prediction of chill-down time for liquid hydrogen turbopumps on Centaur engines. Ground chill-down is accomplished with liquid helium, but subsequent in-flight starts require propellant dumping to achieve chill-down. The improved ability to predict chill-down time permits reduction of the amount of in-flight propellant dump required for chill-down, which allows an increased payload capability.

#### Control Numbers

Tech Brief Number: 68-10517  
NASA Center: Marshall Space Flight Center  
PATT Case Number: 26264  
TEF Number: 268  
Date of Latest Information Used: December 16, 1969

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## AIRCRAFT GALLEY AND CARGO REFRIGERATION SYSTEM TECHNOLOGY TRANSFER EXAMPLE SUMMARY

The AiResearch Manufacturing Division of the Garrett Corporation in Los Angeles, California (430) has on the market a refrigeration system for aircraft galleys and cargo containers. The basic technology was developed under contracts with the Air Force and NASA. The Air Force work resulted in a cooling and ventilating system for suited personnel handling toxic materials at missile sites. Later, under contract with the Manned Spacecraft Center, Garrett applied the technology in suits worn by Gemini astronauts during extra-vehicular activity. Finally, the technology was adapted by Garrett to an aircraft refrigeration system which was first marketed in mid-1968.

The technology is simple and reliable. Liquid nitrogen is vaporized in a heat exchanger and vented into the enclosure (food compartment or space suit) by a jet pump ejector. The vaporized nitrogen mixes with compartment air and the mixture is cooled as it flows across the heat exchanger. The cooled air recirculates through the compartment, providing continuous forced low-velocity circulation capable of maintaining temperatures within a two-degree range.

The aircraft systems are self-contained, use no batteries or external power, need no mechanical maintenance, and the nitrogen atmosphere retards food spoilage. Operating costs are low: liquid nitrogen for 24 hours of operation costs only 27¢.

The cargo refrigeration unit is containerized, providing capability for many uses from the field to the supermarket. Since the unit is entirely self-contained and requires no external power, it is remarkably adaptable for shipping all kinds of perishables. Evaluation by a major airline has been completed with excellent results. Vine-ripened Hawaiian pineapples were flown to California and immediately displayed in a supermarket. Despite a price increase of 5¢ per pound, pineapple sales rose 40 percent within a few weeks. Meat and papayas have also been shipped successfully.

Since 1968, 55 aircraft have been equipped with the galley refrigeration unit. The unit price was \$4,000 for each of the 25 units installed in Boeing 737's, and \$9,000 for each of the 30 systems placed in Boeing 707's

and 727's. The Royal Canadian Air Force has made a recent purchase: four units are now in operation on RCAF planes.

Control Numbers

Tech Brief Number: None  
NASA Center: Manned Spacecraft Center  
PATT Case Number: 430  
TEF Number: 228  
Date of Latest Information Used: June 9, 1971

SPECIALIZED MICROWAVE EQUIPMENT  
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Two new products have been developed by Maury Microwave Corporation in Cucamonga, California (9002) as the result of contractual work performed for NASA's Jet Propulsion Laboratory (JPL). Since 1962, the firm has held contracts with JPL to develop and manufacture various pieces of microwave equipment. The first contract was for a cryogenic termination, also known as a "cold noise source," which provides an integrated noise-temperature input for calibrating and measuring the performance of microwave equipment. Following completion of this particular NASA contract, the firm continued its own internal development of the instrument. According to a company spokesman, the resulting instrument is superior to other such devices because of its greater accuracy.

Maury Microwave's development of the cryogenic termination led to a second product, which in itself requires a test instrument for calibration. Based on inventions originating at JPL and protected by NASA-owned patents, the firm developed for commercial use an instrument known as the "Insertion Loss Test Set." This instrument provides precise measurement of losses caused by insertion of a microwave component into a circuit, and is used for calibrating the cryogenic termination. The instrument's development began in 1963 and was completed in August of 1964. Since 1964, 107 cryogenic terminations have been sold at an average price of \$3,600 each and 26 test sets for an average \$3,200 each. Total sales since 1964 have been approximately \$468,400.

The president of Maury foresees additional product developments arising from its NASA contract work. He indicated, for example, that an antenna monitor receiver developed for use in the space program is being adapted to a commercial product. In addition, the firm has the capability to make very precise measurements and calibrations of microwave equipment, a service previously available only from the National Bureau of Standards.

Control Numbers

Tech Brief Number:     None  
NASA Center:            Jet Propulsion Laboratory  
PATT Case Number:     9002  
TEF Number:            136  
Date of Latest Information Used: June 8, 1971

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CONTROL FOR LEVEL OF A CRYOGENIC LIQUID  
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

When a cryogenic liquid is used to cool a cold trap in a vacuum system, the liquid level of the operating vessel must be kept fairly constant to ensure effective operation of the trap. The supply of this liquid as it vaporizes and boils off to the atmosphere must be replenished constantly. An intricate glassware device was invented at the Jet Propulsion Laboratory, under contract to the NASA Pasadena Office, to maintain the liquid level automatically. The device, powered by the build-up of gas vapor pressure from boil-off, pumps in more liquid from a storage vessel to replace the amount which has vaporized. The device is actuated by changes in the volume of a second gas, such as methane, produced by temperature variations associated with boil-off in the operating vessel.

The president of Cryogenic Service Corporation in Glendale, California (49069) read a Tech Brief which described the level control device. He subsequently received a nonexclusive, royalty-free license to produce the NASA invention. In December 1970, the company hired an expert glass blower and began manufacturing the device. The new product is almost identical to the NASA invention. It is being advertised in Cryogenic Technology, and more than a dozen have been sold to research laboratories for \$300 each. The company president reported that the product has good market potential.

Control Numbers

Tech Brief Number: 69-10573  
NASA Center: NASA Pasadena Office  
PATT Case Number: 49069  
TEF Number: 351  
Date of Latest Information Used: February 18, 1971

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SUPERCONDUCTIVE THIN FILM AS A LIQUID  
HELIUM LEVEL SENSOR

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

A convenient sensor was invented at NASA's Langley Research Center for measuring the level of liquid helium in a Dewar flask. It consists of a superconductive film mounted on a dipstick. The sensor is made by depositing a thin film of niobium metal to a thickness of approximately 2,000 angstroms on a quartz substrate, which is then mounted on a graduated dipstick.

To use the sensor as a gage for measuring the level of liquid helium, the niobium film is connected in series with a 1.5-volt battery, an indicating lamp, and a normally open pushbutton switch. With the pushbutton closed, the top of the dipstick is held with thermally insulated gloves and the sensor is slowly and cautiously lowered into the Dewar until the indicator lamp glows. At this point, contact of the sensor with the liquid helium surface reduces the temperature of the sensor to that of the liquid helium and the resistance of the sensor suddenly falls to zero, permitting sufficient current from the battery to light the lamp. The reading on the dipstick then corresponds to the liquid level. The level or depth of the liquid helium may be measured to an accuracy of  $\pm 0.25$ -inch.

Andonian Associates, Incorporated in Waltham, Massachusetts (49066) is planning to develop a new product similar to the NASA-developed sensor. The company already produces a semicontinuous level sensor and other cryogenic equipment. The new product will satisfy the anticipated requirements of Andonian customers for continuous sensing capabilities.

Control Numbers

Tech Brief Number: 68-10341  
NASA Center: Langley Research Center  
PATT Case Number: 49066  
TEF Number: 355  
Date of Latest Information Used: February 16, 1971

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