

# AEROSPACE RELATED TECHNOLOGY FOR INDUSTRY

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A conference held at  
LANGLEY RESEARCH CENTER  
Hampton, Virginia  
May 22, 1969



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

# AEROSPACE RELATED TECHNOLOGY FOR INDUSTRY

*The proceedings of a  
Technology Utilization Conference  
held at Langley Research Center,  
Hampton, Virginia  
May 22, 1969*



*Technology Utilization Division*  
OFFICE OF TECHNOLOGY UTILIZATION  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
1969  
*Washington, D.C.*

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## PREFACE

This compilation consists of papers presented May 22, 1969, at the Langley Research Center at a Conference on Aerospace Related Technology for Industry cosponsored by the National Aeronautics and Space Administration, Small Business Administration, Virginia State Technical Services, and Old Dominion College. The presentations were subdivided according to subject matter as follows: (1) Technology Sources and Services, (2) Examples of Technology Transfer, (3) Special Tools, Equipment, and Shop Techniques, (4) Electronics, (5) Materials and Processes. Displays of the items accompanied each presentation; additional displays are presented as photographs at the end of the compilation.



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## 1. INTRODUCTORY REMARKS

By Melvin S. Day

Office of Technology Utilization, NASA Headquarters

The National Aeronautics and Space Administration is a research and development agency. As such, its final product is knowledge – knowledge for use in the aerospace program and, just as important, for use in nonaerospace activities. NASA has a vigorous experimental program to bring about the multiple uses of the new knowledge coming out of the aerospace program. By using this new knowledge in nonaerospace industries, you, the taxpayer, earn an additional dividend on the investment which you have made in your national aerospace program. The purpose of the Technology Utilization Program is to speed up the transfer of this technology across regions, across disciplines, across industries, across medicine, and across education.

As generators of new technology, NASA began in 1964 to sponsor regional conferences for the purpose of acquainting commerce and industry with the results of aerospace-related research and development that could have practical application in the marketplace.

In May 1967 the Small Business Administration cosponsored with NASA a conference on technology utilization at the Lewis Research Center. That conference was followed by a similar conference at the Jet Propulsion Laboratory, California Institute of Technology, in the fall of 1967. There have since been several jointly sponsored regional conferences on technology utilization, and at all these conferences, the Office of State Technical Services of the Department of Commerce has been represented on the program, as it is today by the State Technical Services group of the Commonwealth of Virginia.

These several conferences have had a common purpose and objective, namely, to acquaint industry representatives with the different kinds of new technology resulting from aerospace research and development programs and to explain how you in industry may gain access to that technology and put it to profitable use.

Between 3 and 4 billion dollars is spent by NASA each year right here on earth and not on the moon. About 90 percent of the work is performed by contractors; thus much of the space technology is in reality U.S. industrial technology used for space purposes but also very useful here on earth. In addition, the NASA laboratories, such as the Langley Research Center laboratory, produce a great deal of exciting and useful technology. Some of the new materials, techniques, and processes in use at Langley Research Center will be described with the hope that many of you will extract from these presentations technical information of value to you in your own businesses.

The Technology Utilization Program that I represent at NASA Headquarters in Washington is charged by the Congress with the responsibility for providing the widest

practicable and appropriate dissemination of space activities and the results thereof. This type of conference is but one of several means by which an attempt is made to bring the results of the space investment to the attention of the nonaerospace public in order to maximize the taxpayers' investment in government sponsored research and development.

A document which is available to you upon request is a booklet entitled "Useful Technology from Space Research." It describes the NASA Technology Utilization Program, a vigorous program, which John Samos will describe to you in more detail. The program has three principal elements – identification, publication, and dissemination. Identification, the first of these elements, is an area in which NASA has been a pacesetter. The NASA is the only Government agency which obligates a contractor to identify, document, and report all inventions, innovations, improvements, and the other technical advances made or conceived in performance of work under contract. The familiar Tech Brief is the product of that effort. More than 5,000,000 copies of Tech Briefs were distributed last year.

The publications program involves the preparation of a variety of informative publications useful to those with a need or a desire to be brought up to date in technical fields of their specific interest. A booklet, entitled "Transferable Technology" has been prepared which describes these publications and how you may obtain them.

Dissemination, the third principal element, involves the conduct of measured experiments designed to lead us to the most effective means for transferring new knowledge from the point of its origin to the point of its intended use. I need not tell you how complicated a phenomenon this is. There are several mechanisms used. The major thrust in this area centers around six university-based experimental regional centers. The regional dissemination center closest to Langley Research Center is the North Carolina Science Technology Research Center at the Research Triangle Park near Durham, North Carolina.

The NASA scientific and technical information data base consists of 700,000 documents and articles and about 6,000 new items are added every month. This data base is available for your use. In addition more than 3,000 separate innovations have been announced and from 800 to 1,000 more are produced each year. It has been said that mankind's total body of knowledge accumulated from the beginning of time has doubled in the last 10 years, and it is more likely that an answer already exists for most technical problems. The challenge is to locate the answer in an efficient fashion. So much for a very brief overview of NASA's Technology Utilization Program. I have tried to set in proper perspective the rationale which has motivated NASA – specifically the Langley Research Center – The Office of State Technical Services, and the Small Business Administration to have this conference.

It is hoped that you will be able to capitalize on some part of the new technical knowledge that scientists, engineers, and other professionals from Langley Research Center will impart to you. The technology you will hear described is your technology – you as taxpayers have already paid for it. It is a bonus dividend from your space program.



## 2. SERVICES PROVIDED BY THE SMALL BUSINESS ADMINISTRATION

By L. Parker Fairlamb

Small Business Administration

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The growth of scientific and engineering knowledge has profound and far-reaching effects in changing our environment, reshaping the world of business and industry, and altering our way of life, that is, eating, working, amusement, health, travel, and communication habits; in short, it affects the lives of every human being and of those to be born in the decades to come. The owners and managers of small manufacturing and industrial concerns and other men involved in small business are the logical users of this great pool of knowledge.

The rate of change in today's society means that all business must be on the alert for new situations which affect profits, either through opportunities or threats to markets. Examples discussed herein clearly indicate that there is a great volume of practical commercial or industrial potential to be derived from nuclear energy, space exploration, and defense technology. Already business, commerce, and industry are busy at the task of seeking, sorting, and applying the added benefits from those government research and development (R&D) programs. Many responsible scientists and engineers assert that the solutions to the terrible dilemmas of the times may be found in today's technology.

The role of the Small Business Administration (SBA) in government and commerce is unique in that it was created solely to assist small business. The Small Business Act which established the Small Business Administration states: "The essence of the American economic system of private enterprise is free competition. It is the policy of the Congress that assistance be given to small business concerns to enable them to undertake and to obtain the benefits of research and development in order to maintain and strengthen the competitive free enterprise system and national economy."

The SBA does not conduct scientific or engineering research and development. Its function is to assure that small business concerns are kept informed of the technology dissemination programs conducted by the agencies that are so engaged and to assist in making benefits thus derived available to small businesses. When it is noted that over 300 000 small manufacturers and R&D concerns operate in the United States, the magnitude of the problem seems staggering. The problem is not diminished by the recognition that the small business concerns are of various sizes, cover all fields of manufacture, and display varying levels of management competence, financial resources, and degrees of technical sophistication. Therefore, an inescapable corollary is that small manufacturers cannot long survive if they fail to maintain a competitive posture by keeping abreast of changing technology.

Despite many years of wide publicity on the wonders of science and despite considerable directed effort in technology transfer, relatively few firms, in a handful of industries, are actually consumers of technology. An editorial in "Research/Development Magazine" included the following statement: "Have you talked recently with the business news editor of your local newspaper, with the U.S. Chamber of Commerce, or even with your congressman about today's rate of failure among small private enterprises? If you had, you'd have been a rare space age individual on two counts: (1) for initiative in doing business research yourself, (2) for knowing that, in general, today's small businesses face a high probability of failure in a relatively short time, and depend for survival upon a leadership insight that is seldom present. Figuratively speaking, the great majority of modern companies are in the same relative position of the buggy whip makers and the blacksmith shops at the advent of the automobile economy."

The SBA assists small concerns collectively and individually to make the maximum effective application of technological advances to their own productive efforts through a program of stimulation, motivation, and application in collaboration with federal agencies, such as the National Aeronautics and Space Administration, the Atomic Energy Commission, and the Department of Commerce, and with state technical service activities. In addition, technical publications and other information are distributed to the small business community.

The total federal effort engaged in disseminating technology is vast and complex. There are approximately 75 or 80 federal agencies or activities engaged in R&D, and the rate of accumulation of technical studies and reports is on the order of 50 000 per year. Obviously, the problem of organizing, classifying, storing, and retrieving this voluminous information is enormous. The National Aeronautics and Space Administration, the Atomic Energy Commission, and the Department of Defense account for 85 percent of the federal R&D effort, which provides the greatest volume of hardware development. Although much of the hardware technology remains classified, there are great technological advances in electricity, electronics and components thereof, metallurgy, metal working, chemistry, instrumentation, and associated and interlocking fields.

In collaboration with other agencies and in using their technology dissemination resources, technology utilization officers of SBA act as transfer agents for small manufacturers by assisting them to identify their technical information needs. Thus, small companies with limited technical resources and limited access to information centers may obtain assistance in this area by contacting an SBA field office, of which there is at least one in every state.

The concept of technology transfer assumes that additional and substantial secondary uses can be found for technical knowledge originally developed for specific agency missions. Two examples of the practicality of this technical assistance are as follows:

(1) A Seattle concern engaged in rebuilding diesel engine cylinders received an SBA technical publication describing an NASA innovation for positioning a drill and controlling hole depth. The company using two of these adapters at each of three plants cut drilling time from 90 minutes to 20 minutes at a saving of about \$114 000 per year. This is an example of an improved production process.

(2) A New England electronics manufacturer through the services and leads furnished by an SBA technology officer and using federal technological information resources developed a photoresist fine-line printed circuit. The company expects to add 100 employees to its payroll. This is an example of a new product development.

Technology transfer is an effective alternative for original research in many instances. Technical publications referencing engineering and technical advances in numerous fields which have the potential to improve shop techniques, lead to the development of a new product or process, or enable users to stay abreast of the state of the art are published as a public service. The number of small manufacturers that have the in-house capability to identify technological needs and to provide the engineering and technical expertise to solve problems or the management skills to plan and to finance a technological forecasting program is small. However, SBA's programs in management training and counseling, finance and procurement, and subcontract assistance support and extend the technology utilization programs.

In addition to holding management training conferences and workshops at local levels throughout the nation, SBA has published over 400 management, technical, and marketing aids and research summaries on a variety of subjects, among which are how to start and manage various kinds of small retail and service businesses, how to analyze markets, technical pointers such as the principles of plant layout, and finding new products for manufacturers. These publications are available at or through the more than 60 SBA field offices located in principal cities throughout the country or from the U.S. Government Printing Office. They are widely used by trade associations, schools, and universities in training and management courses, both those which are independently sponsored and those encouraged or participated in by SBA.

An indispensable part of the SBA management assistance program is to provide wise and knowledgeable counseling. Supplementing the rather limited full-time staffs in our field offices is SBA's service corps of retired executives (SCORE). These dedicated and patriotic citizens are available to counsel and advise small business management in whatever type of problem with which it is confronted. Serving without pay, they keep active and in the mainstream of their specialities by helping to solve the problems of small companies. It is believed that through this expert counseling, small manufacturers will be shown the way to develop long-range plans involving the systematic application of

technical advances. Underway now throughout the country is a program for augmenting the SCORE chapters by recruiting more retired engineers and scientists.

One of the ever present problems confronting small businesses is the difficulty of obtaining credit on terms and conditions that are consistent with needs but at a cost that is geared to their financial capacity. The SBA provides opportunities for small companies to obtain loans, not reasonably available through normal commercial sources, up to \$350 000 for construction, expansion, or conversion of facilities, for purchasing buildings, equipment, or materials, and for working capital. Wherever possible SBA loans are made in participation with local banks and may be for as long as 10 years. The SBA has three main objectives in its business loan program; namely, to encourage economic growth through increased productivity, to assure a competitive environment by assisting in the establishment of productive small businesses, and to promote local economic development through assistance to depressed areas or otherwise aiding in strengthening a local economy. Note that SBA's business loan program includes the support of new business ventures and the introduction of innovations and new products inasmuch as it has long been an accepted belief by the business world that small business and the lone inventor are the most prolific sources of the new idea, the innovation, and the new product.

In today's rapidly changing world, the need to act in response to the pressures that the technology explosion is exerting is urgent. Thirty years from now the environment will be vastly different and changes will have come from the development and application of today's technology. It is predicted that in 1999, colonies of earthlings will be living in controlled environments in outer space and in the sea. Food will be manufactured and land will no longer be tilled nor used for grazing. Through nuclear energy, an abundance of power will have eliminated air and water pollution and will provide ample water for the tremendously increased population. Mankind will enjoy a life span extending so far beyond the present expectancy that a child born in the 1990's can confidently expect to greet, in good health, the 22nd century.

### 3. FIELD SERVICE OPERATIONS OF THE VIRGINIA STATE TECHNICAL SERVICES

By Joseph Tusinski

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Field Service Representative  
Old Dominion College

#### INTRODUCTION

The Federal State Technical Services Act was passed in 1965. Virginia began participating in the State Technical Services (STS) program in June 1967; however, it was not until August 1967 that two Field Service Representatives (FSR's) were assigned to cover the entire state. Today there is a force of seven full-time and four part-time FSR's in the Virginia State Technical Services (VSTS). In addition to these representatives a seafood specialist, a specialist in forest-product utilization, and an air-pollution and industrial-hygiene expert cover the entire state.

The purposes of the Virginia State Technical Services are to effect wider distribution and application of science and technology, to promote commerce and economic growth, to reduce time lag between discovery and application, and to assist Virginia industry, business, and commerce through educational programs and the services of FSR's.

#### DISCUSSION

The fields of interest of the FSR's are varied and comprehensive. Most of these representatives are engineers and/or specialists; however, all are practical men with diverse backgrounds and experience in industry. Thus they are able to converse with management and with engineering or other technical people in the language that is understood.

The FSR's are affiliated with various institutions of higher learning throughout the state. A liaison is thus established between the academic or research society and the entrepreneurs.

The VSTS program is administered by Virginia Polytechnic Institute (VPI) and organizationally is part of the VPI Extension Division. An attempt is made to have at least one FSR stationed at each of the participating institutions, which are located in Blacksburg, Fairfax, Richmond, Norfolk, Lexington, Gloucester Point, and Charlottesville.

The STS program is administered nationally by the Office of State Technical Services, U.S. Department of Commerce. The prime purpose of STS is to promote the

economic growth of the Nation, and VSTS, of course, concentrates its efforts in Virginia. The STS program is a joint venture supported by Federal and State funding, and there is no charge to clients for services.

Requests for a visit by an FSR in Virginia can be made by contacting VSTS Headquarters, located at Virginia Polytechnic Institute in Blacksburg, Virginia. The addresses and phone numbers of the administrating agencies for State Technical Services in all the states are listed in reference 1.

The VSTS program is considered to be in its infancy, but is growing rapidly. During the initial year, certain growing pains were encountered; however, experience has dictated that the method used today is by far the most effective means of operation. This method involves contacting people in industry at the administration, production, and working levels. Through a considerable amount of missionary work, the program is gaining acceptance, as evidenced by the increasing number of requests for assistance from various types of industry.

Typically, when an FSR calls upon a prospective client to explain the goals of the program, a certain air of suspicion prevails. That is, a plant president, manager, or engineer has an initial feeling that the representative is a government man who is either going to do something that will result in more paper work or possibly examine his tax structure. After this suspicion is erased, the representative can get down to the task of discussing problems that exist.

However, most businessmen are reluctant to reveal the fact that problems exist in their businesses. Others feel hesitant about letting an outsider come in and possibly take away some of their secrets. It should be emphasized that proprietary functions are not revealed to anyone by an FSR. They are kept in the strictest confidence; in fact, there is an unwritten code of not even discussing these facts among FSR's. If it is revealed to an FSR that a proprietary system or process exists, the FSR actually prefers not to discuss it with management.

By use of an industrial directory published by the State Chamber of Commerce, two or three companies located in the same general area are randomly selected for an initial visit by an FSR. When a follow-up call is made, an entire day or longer may be allocated for the purpose. Work on some problem areas involves weeks of searching for an answer. It should be pointed out that not all problems encountered are solved. On the other hand, some of the problems encountered are minor and can be resolved easily and quickly. For example, one manufacturer was considering changing a process from sand casting to die casting, and he wanted to know the names of firms that manufacture die-casting machines and whether there were any firms in his area that did job die-casting. The FSR obtained brochures from various die-casting firms in the area and delivered them to his client.

It was decided early in the program that each call to a company would be reported on a form devised to make information gained or the solution affected available to STS program supervisory and back-up personnel for reference on future calls made to the same company or to similar companies.

The FSR's have many ways of keeping abreast of current events that may affect business and industry. A constant review is maintained of business, commercial, and industrial publications. Perusal of documents, including NASA briefs, available in the college or university libraries is part of the overall effort to keep posted on new technology in order to be better prepared to identify problems encountered in the business world and to contribute to their solution. FSR's also attend pertinent technical conferences, seminars, and workshops held on Virginia college campuses and elsewhere; they participate in planning those for which a need has been expressed by industry and function as catalysts in bridging the gap between the industrialist and the academician by promoting a better understanding of the needs and of the resources available.

The STS program may be thought of as analogous to the Agricultural Extension Service. That is, just as the farm agent assists the farmer in boosting his economic growth, the FSR wants to enhance the economic prospects of the business community by lending technical assistance.

As mentioned previously, the method used by FSR's is to personally contact company officials and explain the STS program. The company official or generally someone whom he designates reviews technical problems encountered, and generally a tour of the plant ensues. In the event that a tour of the plant is not offered, the FSR tactfully suggests this desirable step, for the representative needs to know the capabilities of the plant and the details of its operation as well as any current problems.

In one case, a small manufacturer was producing some printed-circuit boards for an electronic device. He said that he really did not have any problems but that it was taking a long time to etch the copper of his printed-circuit boards. It was taking between 45 minutes and an hour to etch a board. The FSR happened to be in the field of electronics and knew that, for the equipment the manufacturer was using, he should have been producing at the rate of about 5 to 7 minutes. The representative informed him of how to test his etchant for proper concentration. He had been working with the idea that the stronger the acid, the better. However there is a specific concentration at which copper is removed at the fastest rate. Also, the operating temperature had been too low. Thus, the manufacturer's difficulty had been quickly resolved by the visiting representative. Of course, many problems require that the FSR consult experts in the pertinent fields before solutions can be offered. For example, a problem with the machine design of a bed spring that developed squeaks after a few months of use has been turned over to a consultant.

Besides solving existing problems, VSTS would like to promote new areas of business. In particular, it is interested in generating new uses for waste products. For example, 50 tons of hogs' hair are destroyed each week. Hogs' hair, in its previous uses, has been replaced by synthetics, and VSTS would like to generate a new industry. Another interesting waste product is peanut shells. There are 60 000 tons per year available for a new business venture, and tests have indicated that the shells can be successfully used as a binder in foundry sand.

#### CONCLUDING REMARKS

During the evolution of the VSTS program it became reasonably clear that to be effective, the FSR's would have to make personal contact with people at the plant level in order to develop a knowledge of industry and its needs. The FSR would then be in a more favorable position to accurately identify existing problems and to select appropriate new technology for transfer to industry. Thus, information retrieval and dissemination, referral services, and educational programs could be provided in response to specific requests and identified needs.

This program philosophy establishes the FSR as the focal point for all methods of technology transfer. He has personal communication with the faculties of the entire State system of higher education and with management of industry. The faculties are linked to a storehouse of formal information and to many sources of expertise throughout the nation; thus there is very little existing information which cannot be acquired.

#### REFERENCE

1. Anon.: State Technical Services Helping Business and Industry Through Science and Technology. U.S. Dept. Commerce, Mar. 1969.

## 4. NEW TECHNOLOGY DOCUMENTATION AND SERVICES AVAILABLE THROUGH THE NASA TECHNOLOGY UTILIZATION PROGRAM

By John Samos  
Langley Research Center

### SUMMARY

The NASA created the Technology Utilization Program to encourage and more rapidly effect technology transfer. This paper describes the documentation media, the sources established for disseminating the information, and the services available from the Technology Utilization Offices.

### INTRODUCTION

One definition of technology transfer is "the acquisition, development, and utilization of technological information in a context different from that in which it originated."

Technology transfer offers an opportunity for the United States to increase its rate of economic growth, improve the international competitive position of its industry, raise its standard of living, and enhance national prestige.

### DISCUSSION

#### Technology Utilization Offices

The NASA encourages the transfer of technology generated by its research and has established a Technology Utilization Officer at each of the following NASA installations to more rapidly effect the transfer:

NASA Headquarters, Washington, D.C. 20546  
Ames Research Center, Mountain View, Calif. 94035  
Electronics Research Center, Cambridge, Mass. 02139  
Flight Research Center, Edwards, Calif. 93523  
Goddard Space Flight Center, Greenbelt, Md. 20771  
Kennedy Space Center, Kennedy Space Center, Fla. 32899  
Langley Research Center, Hampton, Va. 23365  
Lewis Research Center, Cleveland, Ohio 44135  
Manned Spacecraft Center, Houston, Tex. 77058  
Marshall Space Flight Center, Huntsville, Ala. 35812

NASA Pasadena Office, 4800 Oak Grove Dr., Pasadena, Calif. 91103  
Wallops Station, Wallops Island, Va. 23337  
AEC-NASA Space Nuclear Propulsion Office, U.S. AEC Building,  
Germantown, Md. 20545

The Technology Utilization Office at any of these installations can be contacted for additional information about the Technology Utilization Program.

#### Announcement Media

New technology (developed within NASA or under NASA contracts) that has commercial potential is announced through the following media:

- Tech Briefs
- Cumulative Index to Tech Briefs
- Special Publications
- An index to Special Publications
- Documentary films

Tech Briefs and Cumulative Index to Tech Briefs.- The Tech Brief is the most popular announcement medium. It is a single-sheet bulletin concisely describing an innovation and explaining its basic principles in nontechnical language. More detailed information on a particular Tech Brief can be obtained from the address listed on the Tech Brief. Tech Briefs are issued in six categories and are available from the Clearinghouse for Federal Scientific and Technical Information at a cost of 15 cents each or by annual subscription. The annual subscription rates for the various categories are as follows:

Electrical (electronic) . . . . .	\$6.00
Physical Sciences (energy sources) . . . . .	\$2.50
Materials (chemistry) . . . . .	\$5.00
Life Sciences . . . . .	\$2.50
Mechanical . . . . .	\$6.00
Computer Programs . . . . .	\$6.00
All categories . . . . .	\$20.00

The address for obtaining Tech Briefs is:

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The Cumulative Index to Tech Briefs is the best guide for selecting desired Tech Briefs. It lists the Tech Briefs by technical subject as well as by the six categories. The Cumulative Index to Tech Briefs is also available from the Clearinghouse at a cost of \$3.00.

Special Publications and index.- The NASA publishes many Special Publications (SP's). The SP's that are published through the Technology Utilization Program have the greatest transfer potential; they include Technology Utilization Compilations, Technology Utilization Reports, Technology Utilization Surveys, and Conference Proceedings.

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Superintendent of Documents  
U.S. Government Printing Office  
Washington, D.C. 20402

A listing or index of Special Publications can be obtained from any of the Technology Utilization Offices.

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New knowledge is acquired piecemeal more often than in readily usable packages. To solve a problem in one context, information acquired for many other purposes often must be compiled, applied to the specific situation, and possibly expanded. Six Regional Dissemination Centers established by NASA help potential users obtain new technology in packages appropriate to their needs. No two of these centers are alike. Each, however, is based at a university or nonprofit research institute and is staffed with professional personnel skilled in the use of computer search-and-retrieval techniques for assembling information. These centers establish government-university-industry partnerships by serving fee-paying industrial clients, both large and small, in a variety of ways.

Current Awareness Searches.- Computer tapes bearing about 6000 new citations of scientific and technical reports are searched each month for items of likely value to each client. This search is made by machine matching an "interest profile" of the client's objectives, problems, needs, and desires against indexed descriptions of aerospace researchers' findings. Specialists then screen the citations obtained in this way for relevance and quickly forward the results to the client, who may then request and receive copies of any documents among those cited that he decides may be useful.

Retrospective Searches.- More thorough searches are made in response to a client's specific question. Computer tapes bearing citations of earlier documents as well as the most recent additions to the aerospace library are machine searched. The output is evaluated by the RDC experts and sent to the client. Copies of the documents located in this way are also sent when requested.

Standard Interest Profiles.- The Regional Dissemination Centers prepare and use Standard Interest Profiles when they have numerous clients with closely related interests. Like ready-made clothing, these profiles reduce the cost to customers who do not require "custom-tailored" information service.

Distribution of Publications.- The RDC's send Technology Utilization publications to their clients each week and supply additional detailed information and back-up data to particular clients on matters of especial interest to them.

Assistance to management.- In addition to providing basic information, the Regional Dissemination Centers increase the value of the information by relating it to their clients' specific problems. They help companies systematize collection methods and use of knowledge generated elsewhere. They call attention to developments and trends that may affect their clients' current operations and long-range plans. Their services are helpful in such areas as product innovation, process improvement, cost reduction, resource allocation, the setting of research and development priorities and avoidance of duplication, and the continuation of education for professional personnel. Each RDC is responsive to a different geographic area and economic environment. Hence the services and fees of the six RDC's vary. Their addresses are given below, and a prospective client can consult any RDC about its services and charges:

Aerospace Research Applications Center, Indiana University Foundation,  
Bloomington, Ind. 47405 (Phone: Area Code 812 - 337-7970)

Knowledge Availability Systems Center, University of Pittsburg,  
Pittsburgh, Pa. 15213 (Phone: Area Code 412 - 621-3500, Ext. 6352)

New England Research Application Center, University of Connecticut,  
Storrs, Conn. 06268 (Phone: Area Code 203 - 429-6616)

North Carolina Science and Technology Research Center, Post Office Box 12235,  
Research Triangle Park, N.C. 27709 (Phone: Area Code 919 - 834-7357 or  
549-8291)

Technology Application Center, University of New Mexico, Box 185,  
Albuquerque, N. Mex. 87106 (Phone: Area Code 505 - 277-3118)

Western Research Applications Center, University of Southern California,  
Los Angeles, Calif. 90007 (Phone: Area Code 213 - 746-6133)

#### Computer Software Management and Information Center (COSMIC)

COSMIC was established by the NASA to enable users of computers to benefit from the millions of dollars that NASA has invested in programs for computing machines. This center, at the University of Georgia, collects, evaluates, and distributes tapes, card decks,

program listings, and machine-run instructions. It sells this "software" to potential users at prices determined by the cost of reproducing and distributing it. Thus a computer program that originally cost up to \$100,000 to develop may be purchased by a company for less than \$300.

Further information about this service may be obtained from the Director, COSMIC, University of Georgia Computer Center, Athens, Ga. 30601. A directory of available programs can be obtained from COSMIC.

#### ASSISTANCE TO SMALL BUSINESS

There is one other service established at the NASA that should be mentioned. It is not a part of the Technology Utilization Program but is of interest to small businesses and industry. NASA has a Small Business Advisor at Headquarters and a Small Business Specialist at each of its installations. By contacting the Small Business Specialist at any of the NASA installations, a firm can be listed as a potential supplier of suitable items or services in connection with NASA programs. A booklet providing detailed information about the services available can be obtained from the Small Business Specialist at any of the NASA installations.

#### CONCLUDING REMARKS

The Technology Utilization Officer at any NASA installation will be pleased to provide assistance in obtaining new technology or to answer questions about the program and services. The Technology Utilization Office at the Langley Research Center can be contacted by telephone at Area Code 703 - 827-3281.

## 5. CHAIN VIBRATION DAMPERS

By Wilmer H. Reed III

Langley Research Center

### INTRODUCTION

To the title of this paper might be added a subtitle "From Launch Vehicles to Lamp Poles." This transfer of technology from launch vehicles to lamp poles is but one illustration of the theme of this compilation.

Before describing what a chain damper is or how it might function in a lamp pole or in other industrial applications, the aerospace problem that led to its development is briefly discussed. Although launch vehicles are designed to accelerate through the atmosphere at thousands of miles per hour, the most severe loads and stresses can occur before flight, that is, while the vehicle is still on its launch pad. These loads are the wind loads created by surface winds blowing against the vehicle. Under certain conditions such loads can lead to severe, possibly destructive, side-to-side swaying oscillations of the tall flexible structure. A spectacular manifestation of this so-called vortex shedding phenomenon is the well-known Tacoma Narrows Bridge disaster in 1940.

### WIND-TUNNEL MODEL STUDIES

To assure that NASA launch vehicles can withstand any wind conditions likely to be encountered during prelaunch operations, wind-tunnel tests are conducted as a matter of course on each new launch-vehicle design. Figure 1 shows some of the models used in wind-tunnel studies of the problem at the Langley Research Center. These models are scaled to simulate not only the shape but also the mass and flexibility properties of the full-size structure.

If a potential wind load problem is identified in the wind-tunnel studies, an attempt is then made to find an appropriate solution. A case in point is the Saturn V - Apollo vehicle. It was discovered in early wind-tunnel model tests that at a surface wind speed of about 55 knots, the full-size structure would probably undergo violent lateral bending oscillations. To prevent the occurrence of such oscillations at the Cape Kennedy launch site, energy-absorbing devices, in the form of hydraulic cylinders, were installed between the tip of the vehicle and the adjacent launch tower. This damper system remains attached to the vehicle until just prior to launch.

## WIND-INDUCED VIBRATIONS OF ANTENNAS

Because of the specialized research techniques developed at Langley in connection with ground wind loads on launch vehicles, the U.S. Navy asked NASA for assistance in solving a similar wind load problem encountered on a shore-base antenna system. This system consists of an array of vertical free-standing antenna masts, as shown in figure 2. During exposure to wind, including steady light breezes, bending vibrations of the masts were often observed and, in time, fatigue cracks began to appear in the conical fiber-glass insulators located between the mast and the lower cylindrical base structure.

A simple but effective solution was found to alleviate this vibration problem. A few links of ordinary steel chain were hung in a cluster inside the tip of the mast. When the mast vibrated, the chains would impact against each other and the inner walls of the antenna mast. These impacts provided a mechanism for absorbing vibration energy and thus served the same function on the antenna as did the hydraulic cylinders on the Saturn V - Apollo vehicle. To muffle impact noise, each chain was covered with a plastic sleeve and the entire cluster was wrapped in a rubber shroud as shown in figure 2.

After some experimentation with various chain sizes and weights, a damper consisting of a cluster of eight 15-inch-long chains and weighing 12 pounds was selected for evaluation in wind-tunnel tests of the antenna. The effect of this chain damper on wind-induced vibrations of the antenna, which weighed 260 pounds, is shown in figure 3. As can be seen in the figure, the vibration level of the antenna with the damper is approximately one-half that of the unmodified antenna. Also, the damper essentially eliminates the sharp peak in the response curve at wind velocities near 5 knots. In fact, the peak level of vibration response at 5 knots on the unmodified antenna is not reached on the antenna with damper until the wind speed exceeds 60 knots.

As a result of these findings, which are reported in reference 1, the Navy has specified that antennas at all future installations of this type are to be equipped with chain dampers.

## FURTHER RESEARCH ON CHAIN DAMPERS

The development of a damper for the Navy antenna was accomplished on a somewhat cut-and-try basis. It was believed, however, that because of the simplicity and effectiveness of this device, further research should be conducted to identify and evaluate some of the basic parameters that govern the performance of chain dampers. For this purpose, a simplified version of the antenna-damper configuration was chosen for study, namely, a single chain covered with a rubber sleeve and suspended inside a vertical-wall container. A clearance gap between the chain and the container was provided so that when the container oscillated in a horizontal direction, the chain could impact against the vertical

walls. Since these impacts provide the mechanism for absorbing vibration energy, the chain damper may be characterized as belonging to a class of so-called impact, or acceleration, dampers. (See, for example, ref. 2.)

As illustrated in the sketch of the chain damper in figure 4, some of the significant variables studied are the chain length  $l$ , chain mass  $m$ , gap distance  $d$ , and amplitude of sinusoidal vibration  $x$ . The relationship between these parameters and damping performance is investigated in reference 3 by use of mechanical impedance concepts. On the basis of this combined experimental and analytical study, it is believed that the performance of chain dampers can be predicted with reasonable accuracy.

Also illustrated in figure 4 is a hypothetical chain-damper design application. Assume that a lightly damped, vertically mounted cantilever beam is excited by some vibration source such as a piece of rotating machinery. At some point during startup or shutdown of the machine, the excitation frequency coincides with the natural frequency of the beam  $f_n$ . At this resonant condition, the beam vibration response reaches a peak level indicated in figure 4 by  $x_1$ . The problem now is to specify the characteristics of a chain damper which, when attached to the beam, would reduce this peak response from  $x_1$  to some other more acceptable level, say  $x_2$ .

Certain dynamic properties of the structure are assumed to be known. These properties are the effective mass  $M$ , natural frequency  $f_n$ , number of cycles of free vibration for the amplitude to reduce to one-half its initial value  $N_{1/2}$ , and the peak response of the unmodified structure  $x_1$ . With application of results presented in reference 3, it can be shown that the chain damper should approximately have the characteristics indicated by the following equations:

$$l > \frac{4}{f_n^2}$$

(where  $l$  is in ft and  $f_n$  is in cps)

$$\frac{x_2}{x_1} = \frac{1 + \frac{m}{M}}{1 + 9\left(\frac{m}{M}\right)N_{1/2}}$$

$$d = 5x_2$$

Although the development of these equations is not presented in this paper, a few general comments about them can be made. The equation relating to chain length reflects a requirement that the fundamental frequency of the chain should be one-third or less of the frequency to be damped. It should also be pointed out from the equation for the response reduction ratio  $x_2/x_1$  that, when the damping of the unmodified structure is

very small ( $N_{1/2} \gg 1$ ), the response of the structure with damper is reduced approximately in inverse proportion to the chain mass. In other words, the heavier the chain the more effective it becomes in suppressing vibration response. The equation for the gap distance indicates that for maximum effectiveness the gap distance should be about five times greater than the vibration amplitude with the damper attached. If the ratio  $d/x_2$  becomes much greater than this optimum value, however, the chain will cease to impact against the container walls and, thus, the effectiveness of the damper is lost.

### POTENTIAL CHAIN-DAMPER APPLICATIONS

A NASA Tech Brief on chain dampers (ref. 4) was issued in February 1968. Inquiries relating to this Tech Brief revealed a variety of potential chain-damper applications, some of which are illustrated in figure 5. Another inquiry, not shown in this figure, came from the Chief Engineer at Disneyland who was concerned over violent oscillations of an aluminum flag pole. Perhaps this paper will suggest some other industrial applications for chain dampers.

### REFERENCES

1. Reed, Wilmer H., III; and Duncan, Rodney L.: Dampers To Suppress Wind-Induced Oscillations of Tall Flexible Structures. Developments in Mechanics, Vol. 4, J. E. Cermak and J. R. Goodman, eds., Johnson Pub. Co., c.1968, pp. 881-897.
2. Lieber, Paul; and Jensen, D. P.: An Acceleration Damper: Development, Design, and Some Applications. Trans. ASME, vol. 67, no. 7, Oct. 1945, pp. 523-530.
3. Reed, Wilmer H., III: Hanging-Chain Impact Dampers: A Simple Method for Damping Tall Flexible Structures. Wind Effects on Buildings and Structures, Vol. II, Univ. Toronto Press, c.1968, pp. 283-321.
4. Reed, Wilmer H., III: Suspended Chains Damp Wind-Induced Oscillations of Tall Flexible Structures. NASA Tech Brief 68-10042, Feb. 1968.

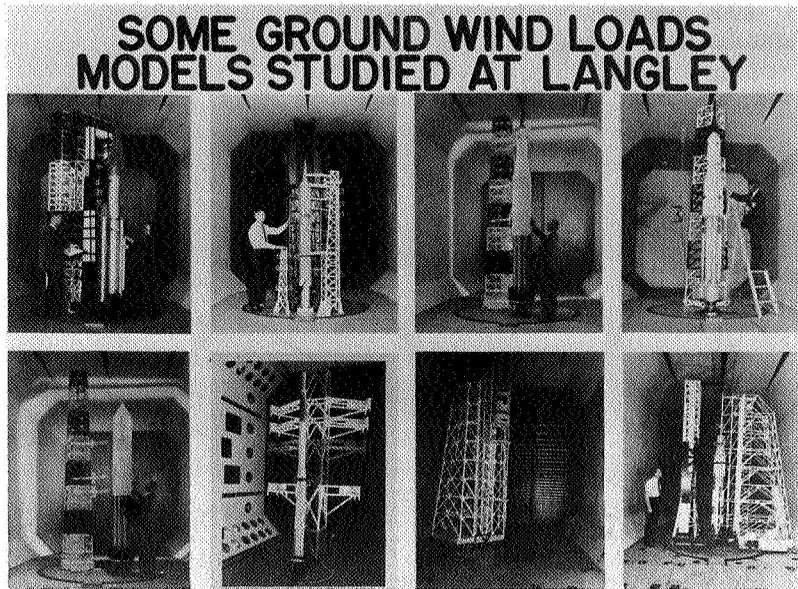


Figure 1

L-69-3326

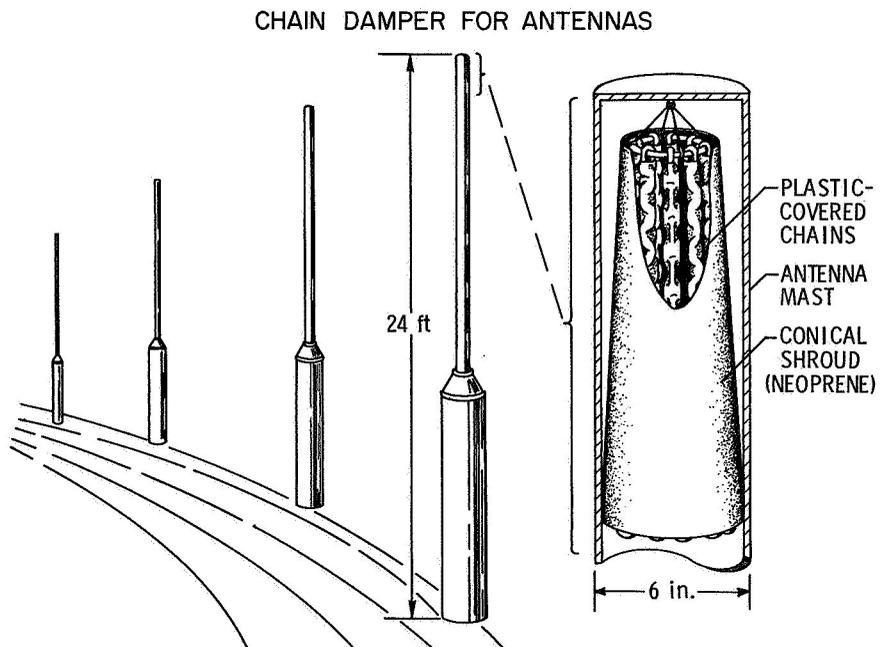


Figure 2

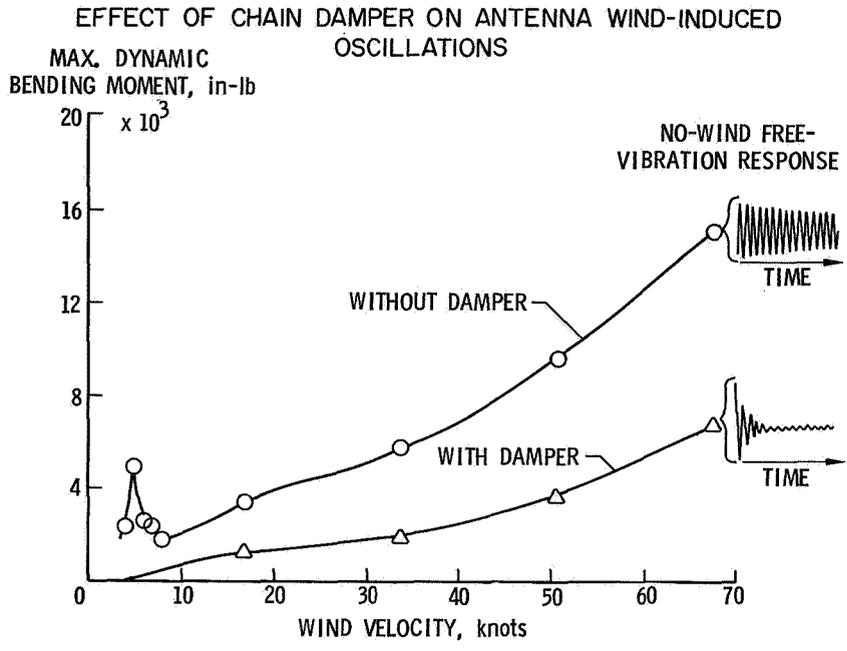


Figure 3

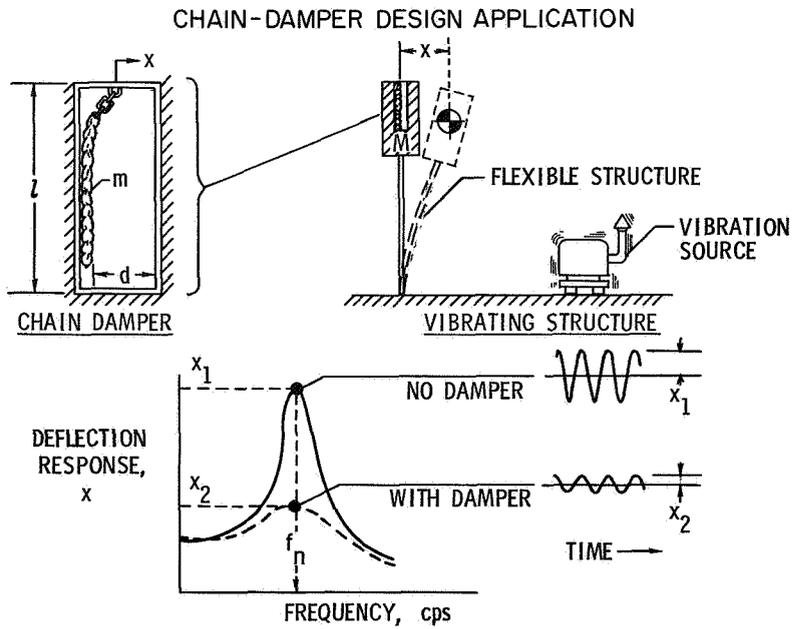


Figure 4

POTENTIAL CHAIN-DAMPER APPLICATIONS

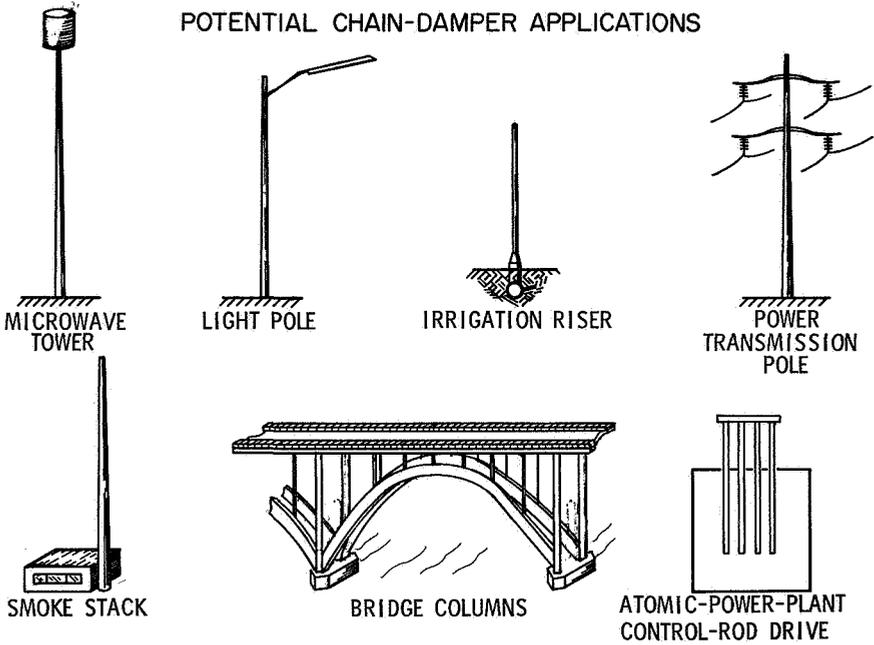


Figure 5



## 6. PNEUMATIC-TIRE HYDROPLANING

By Upshur T. Joyner

Langley Research Center

### INTRODUCTION

The need for better traction between aircraft tires and wet runways is emphasized each time a news story shows an aircraft in the dirt off the side or off the end of a runway. An example of an accident due to hydroplaning is shown in figure 1. Aircraft tire traction has been a subject of research by the National Aeronautics and Space Administration for a number of years, and during this research the phenomenon of pneumatic-tire hydroplaning was discovered. (See ref. 1.) This phenomenon was thoroughly researched for its application to aircraft, and a film entitled "Hazards of Tire Hydroplaning to Aircraft Operation" was produced to inform aircraft operating personnel of this peril. It soon became obvious that this research had a direct relation to almost everyone's daily life through the pneumatic tires on automobiles, trucks, and buses. At this point, the Technology Utilization Office became involved and through contacts with the Bureau of Public Roads promoted joint production of a film by NASA and BPR entitled "Automobile Tire Hydroplaning - What Happens!"

### DISCUSSION

The film on automobile-tire hydroplaning explains what hydroplaning is, when it occurs, what its consequences are, and what precautions can be taken to avoid it.

#### Tire Hydroplaning

When a car is driven on a wet highway, water may penetrate between the tire and the pavement. This penetration results in the formation of water pressure which raises part of the tire off the pavement. This pressure increases with increasing vehicle speed and supports more and more of the tire until at a critical speed, termed "the hydroplaning speed," the tire is supported only by the water and loses all contact with the pavement.

#### Occurrence of Tire Hydroplaning

Tire hydroplaning occurs when the speed of the vehicle, tire-inflation pressure, water depth on the road, condition of the pavement surface, and the condition of the tire tread are combined in such a way that the tire loses contact with the pavement. Hydroplaning depends primarily on speed and water depth on the pavement.

Hydroplaning speed.- If sufficient water is present for hydroplaning to occur, the speed at which a vehicle will hydroplane may be predicted with fair accuracy solely on the basis of tire inflation pressure. Since a tire is flexible and deforms under changing loads, the ratio of weight carried by the tire to the area of tire contact on the pavement remains about the same. This ratio of weight to area will always be very near the tire inflation pressure. A simplified equation has been developed to predict the hydroplaning speed of a pneumatic tire; namely,  $V = 10.2\sqrt{p}$ , where  $V$  = hydroplaning speed in miles per hour and  $p$  = tire inflation pressure in pounds per square inch. For example, a tire pressure of 16 psi gives a hydroplaning speed of 41 mph; 24 psi, 50 mph; and 32 psi, 58 mph. These speeds, which are well within legal speed limits, are speeds at which total hydroplaning occurs with total loss of traction for steering or braking. Partial loss of traction owing to partial support of the tire by the water may occur well below hydroplaning speeds and may result in critical loss of traction for a given maneuver at speeds well below those predicted.

Water depth on the pavement.- The preceding equation for hydroplaning speed presumes sufficient water on the pavement for hydroplaning to occur. The actual water depth needed in a particular situation depends upon the size and number of "escape channels" present. These channels allow the escape of the water from beneath the tire and delay the buildup of water pressure. These escape channels may be provided by the pavement surface through surface unevenness and grooves or by an effective tire-tread pattern. Research has shown that smooth or badly worn tires will hydroplane on a smooth surface in less than 0.04 inch of water. Tires with good tread will hydroplane at the predicted speed when the water depth is great enough so that the grooves in the tires become "choked" with water. Judgment of water depth on the pavement is difficult; therefore, patches of standing water or water deep enough to cover pavement unevenness should be assumed to indicate the possibility of hydroplaning.

### Consequences of Tire Hydroplaning

The most serious consequence of tire hydroplaning is the loss of traction, which is necessary for safe steering and braking. A partial loss of traction at low speeds or a total loss of traction at total hydroplaning speeds may occur. The loss in braking capability due to partial hydroplaning on a smooth surface is illustrated in figure 2. The losses here are due to partial hydroplaning, since the tires on the test automobile were inflated to 24 psi and total hydroplaning does not occur until a speed of 50 mph is reached. Good treads were reasonably effective in providing good tire traction in the test water depth of 0.1 inch.

Losses in traction not only result in increased braking distances but in decreased steering control. This decrease in steering capability may result in an inability to effectively control the hydroplaning vehicle. The effect of side winds on hydroplaning vehicles could also result in increased loss of steering control.

## Tire Hydroplaning Precautions

- (1) Slow down when the roads are wet. A wet road may be just as slippery as an icy road; all traction is lost at hydroplaning speeds.
- (2) Be alert for standing water or puddles, especially on curves.
- (3) Maintain good tread on tires, and keep the tires properly inflated.
- (4) Increase following distances so that more time and distance is allowed for stopping or controlling the vehicle.
- (5) Be alert for side winds which can affect vehicle control.
- (6) Adjust vehicle speed to road conditions, and remember that hydroplaning can occur well below posted speed limits.

Since the two films mentioned were produced, continued research aimed toward improved aircraft tire traction under wet conditions has led to the grooving of runways and highways to improve water drainage from the tire footprint area. (See figs. 3 and 4.) The latest information on grooving can be obtained from reference 2. To illustrate the effectiveness of highway grooving in reducing highway accidents, figure 5 shows accident statistics on certain California highway sections, both before and after grooving. The reduction in accidents on wet roads by grooving is dramatic. The grooves are very effective in reducing tire hydroplaning. A third film on tire hydroplaning has been produced which summarizes much of the grooving research and experience. The business opportunities brought about by the application of grooving to runways and highways have been the subject of many inquiries to the Technology Utilization Office.

## DESCRIPTION OF HYDROPLANING FILMS

Three motion-picture films pertaining to hydroplaning are available on loan. These films are described as follows:

### Hazards of Tire Hydroplaning to Aircraft Operation

Film serial L-775

The film (16 mm, 15 min, color, sound) is based on tire studies at the NASA Langley Research Center and draws attention to the potentially dangerous hazards of tire hydroplaning on wet runways.

### Automobile Tire Hydroplaning -- What Happens!

Film serial L-944

The film (16 mm, 12 min, color, sound) was prepared to point out and to alert the public to the dangerous hazards of tire hydroplaning on the highways.

## Hazards of Tire Hydroplaning – A Sequel

Film serial L-957

The film (16 mm, 14  $\frac{1}{2}$  min, color, sound) describes the loss of tire traction from dynamic hydroplaning and viscous and reverted rubber skidding. Tests using air jets and grooved pavements for the reduction of skidding are shown and the effectiveness of these techniques is described.

Requests for loan copies of these films should be addressed to

Technology Utilization Office  
NASA Langley Research Center  
Langley Station  
Hampton, Virginia 23365

### CONCLUDING REMARKS

Since hydroplaning occurs for automobiles as well as aircraft, the general public needs to be informed of the causes, effects, and preventions of this phenomenon. Motion-picture films pertaining to hydroplaning have been made for this purpose and are available from the Technology Utilization Office.

### REFERENCES

1. Harrin, Eziaslav N.: Low Tire Friction and Cornering Forces on a Wet Surface. NACA TN 4406, 1958.
2. Anon.: Pavement Grooving and Traction Studies. NASA SP-5073, 1969.



Figure 1

L-3253-1

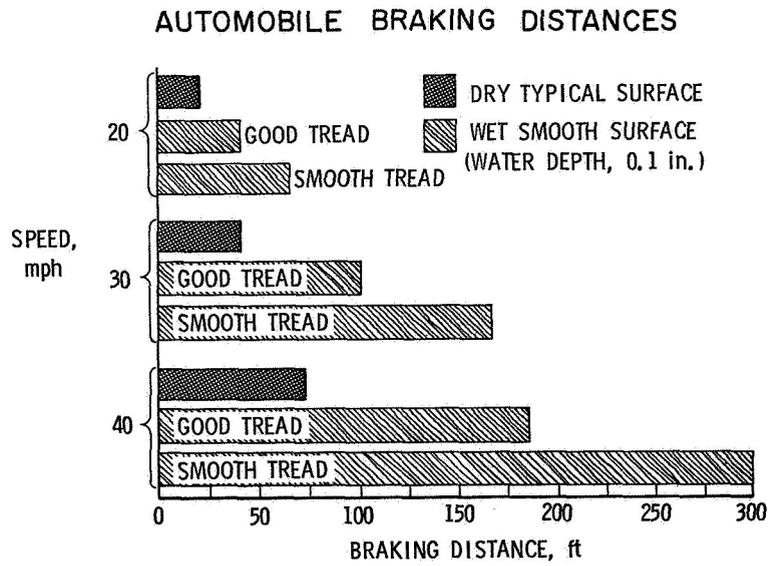
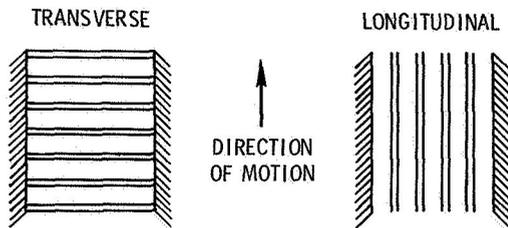


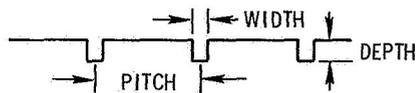
Figure 2

# PAVEMENT GROOVING

## TYPES



## GEOMETRY



## METHODS

- DIAMOND SAW
- FLAIL
- PRECAST

Figure 3



Figure 4

L-69-5208

ACCIDENT REDUCTION RATE RESULTING FROM  
PAVEMENT GROOVING IN CALIFORNIA

RAINY OR WET CONDITIONS

90.5% REDUCTION OF ALL ACCIDENTS

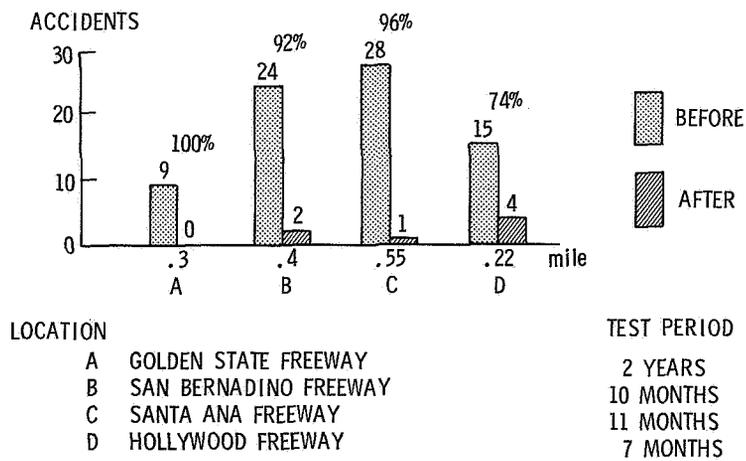


Figure 5



## 7. UNDERWATER LOCATION DEVICE

By John C. McFall, Jr., and Ray W. Lovelady  
Langley Research Center

### INTRODUCTION

The underwater location device is used to find submerged objects. This use is accomplished by prior attachment of a small sonar transmitter to either the inside or outside of the object to be located. The transmitter signal is activated by the jolt of the object hitting the water or by the wetting of a water switch as the object submerges. The signal is transmitted in all directions for about 2 miles and can be detected by listening for the loudest sound while a special sonar receiver is pointed in different directions. The receiver is similar to a radio compass in that it is highly directional. By following the bearings given by the receiver, a skin diver can go directly to the object.

### DISCUSSION

#### Development and Use of Underwater Location Device

When the need arose for an underwater location device, the Flight Instrumentation Division of the Langley Research Center devised the two types of transmitters shown in figure 1. A transmitter may be mounted to the outside of an object if the object is solid or if suitable internal mounting space is unavailable. If the surface of the object must be smooth and if suitable internal mounting space exists, a transmitter may be mounted to the inside of the object. In figure 1, the cylindrical transmitter on the left is generally mounted externally and the transmitter on the right is generally mounted internally. Both transmitters are complete with power supplies and have the characteristics shown in table I.

The frequency of 38 kHz for the signal was chosen because the best direction-finding characteristics at short ranges and for the lowest battery weight are obtained between 35 and 40 kHz. The other signal factors of output, signal type, pulse duration, and repetition rate were chosen for their efficiency of being detected for the longest time. The power sources were chosen for their low weight and their ability to operate over a wide temperature range. Since these transmitters are attached to many kinds of objects including rough-burning solid-fuel rockets, all components must withstand high acceleration, shock, and vibration and still operate with high reliability.

The sonar receivers used with the underwater location device are shown in figure 2. They were designed to be easily portable to the place where the object is submerged and to be easily handled by a skin diver in the water. During operations from a small boat, the

receiver head is attached to a rod that is held over the side and pointed toward the loudest signal. When very close to the location of the object, the head is attached to a hand-held receiver and is used in the water by a skin diver. The standard receiver on the left in figure 2 can be used to water depths of 200 feet whereas the later version on the right can be used to saturation-diving depths of 1000 feet.

In a typical search off Wallops Island for a scientific payload, the search pattern shown in figure 3 might be used. The small boat proceeds at high speed to the search area and, then, follows the search pattern. The receiver is dipped about every 2000 yards. During use of the hand-held receiver, the boat is usually stopped while a new bearing is obtained in order to reduce interference noise from the propeller.

#### Current and Future Underwater Location Devices

Extensions to new equipment from the original underwater location device have been made when required. Current and future devices for the increasing needs of underwater location are listed in table II. The 10-kHz transmitter was developed to extend the signal range to 10 miles. The 37-kHz transponder transmits only when signaled by a 55-kHz transmitter. The result is both a longer transmitting life and security of the submerged object. The 37-kHz long-life transmitter was developed for use when no recovery facilities are available within a short time. The shipboard receiver is mounted to the hull of the NASA Wallops Station USNS Range Recoverer which can search continuously at 10 knots. Additional work on more effective search techniques by means of ship-towed and helicopter-dipped receivers is planned for the future. Also, the guidance and control of deep submersible craft will be investigated.

#### CONCLUDING REMARKS

Since the initial development of the underwater location device, the Langley Research Center has furnished consulting service and equipment loans to numerous governmental and industrial groups. A listing of these groups is given in table III along with a general indication of the applications of the underwater location device. The future applications are considered to be numerous and await only the imagination and needs of industry.

TABLE I

## UNDERWATER-LOCATION-DEVICE CHARACTERISTICS

	<u>EXTERNAL</u>	<u>INTERNAL</u>
FREQUENCY	----- 38 kHz -----	-----
OUTPUT AT 1 meter	3000 dynes/cm <sup>2</sup>	1500 dynes/cm <sup>2</sup>
SIGNAL TYPE	----- Pulse -----	-----
PULSE DURATION	----- 10 to 15 milliseconds -----	-----
REPETITION RATE	----- 6 to 8 per second -----	-----
OPERATING LIFE	----- 15 to 30 days -----	-----
POWER SOURCE	----- Replaceable Mercury Battery -----	-----
SWITCHING	Water Activated	Force, Time, or Water Activated
WEIGHT	8 to 12 oz	8 oz
SIZE	1 1/4" diam.; 3 3/4" long	2 5/8" diam.; 1 7/8" long
OPERATING TEMPERATURE	----- -28 <sup>0</sup> F to 100 <sup>0</sup> F -----	-----
ACCELERATION	----- 200g for 2 seconds -----	-----
SHOCK	7000g for 0.2 milliseconds(3 axes)	3000g for 0.2 milliseconds
VIBRATION	----- 20 to 2000 cps Swept Sine and Random -----	-----

TABLE II

## EXTENSIONS FROM ORIGINAL UNDERWATER LOCATION DEVICE

<u>ORIGINAL</u>	<u>CURRENT</u>	<u>FUTURE</u>
	10-kHz TRANSMITTER	HELICOPTER-DIPPED RECEIVER
	37-kHz TRANSPONDER	
EXTERNAL AND INTERNAL 37-kHz TRANSMITTERS	TWO 37-kHz HAND-HELD RECEIVERS (STANDARD)	SHIPBOARD RECEIVER
	37-kHz LONG-LIFE TRANSMITTER	DEEP SUBMERSIBLE GUIDANCE AND CONTROL
	37-kHz SATURATION-DIVER HAND-HELD RECEIVER	SHIP-TOWED RECEIVER

TABLE III

APPLICATIONS OF THE UNDERWATER LOCATION DEVICE AND  
GOVERNMENTAL AND INDUSTRIAL GROUPS WHICH HAVE  
CONSULTED WITH AND RECEIVED EQUIPMENT LOANS  
FROM THE LANGLEY RESEARCH CENTER

Upper atmosphere and space research:	Manned-spacecraft research:
NASA Wallops Station	NASA Manned Space Craft Center
NASA Goddard Space Flight Center	NASA Marshall Space Flight Center
NASA Headquarters, Washington, D.C.	Downed aircraft and flight-data recorders:
NASA Lewis Research Center	Federal Aviation Administration,
Reentry-vehicle research:	Department of Transportation
General Electric Reentry Systems	National Aeronautics and Space
Department	Administration
AVCO Missile Systems Division	Naval Air Systems Command
Air Force Cambridge Research	Grumman Aircraft Engineering
Laboratory	Corporation
Undersea-warfare research:	British Aircraft Corporation
Navy Undersea Warfare Center,	Naval Ship Systems Command
Pasadena	Potential civil use:
Naval Ammunition Depot, Oahu	Wellhead marking
Naval Ordnance Laboratory, White Oak	Rescue beacon (submersibles and divers)
Naval Weapons Station, Yorktown	Hazardous-material ships (sulfur,
Office of Naval Research	chlorine, and other chemicals)
Naval Underwater Weapons Station,	Atomic-waste marking
Newport	
Ocean and lake research:	
Navy Oceanographic Office	
Department of Commerce, Environmental	
Science Services Administration	
HEW Public Health Service	
Reynolds Corporation, Submarine Services	
Old Dominion College, Institute of	
Oceanography	
Navy, SEA LAB	
Project Tektite	

UNDERWATER LOCATION TRANSMITTERS

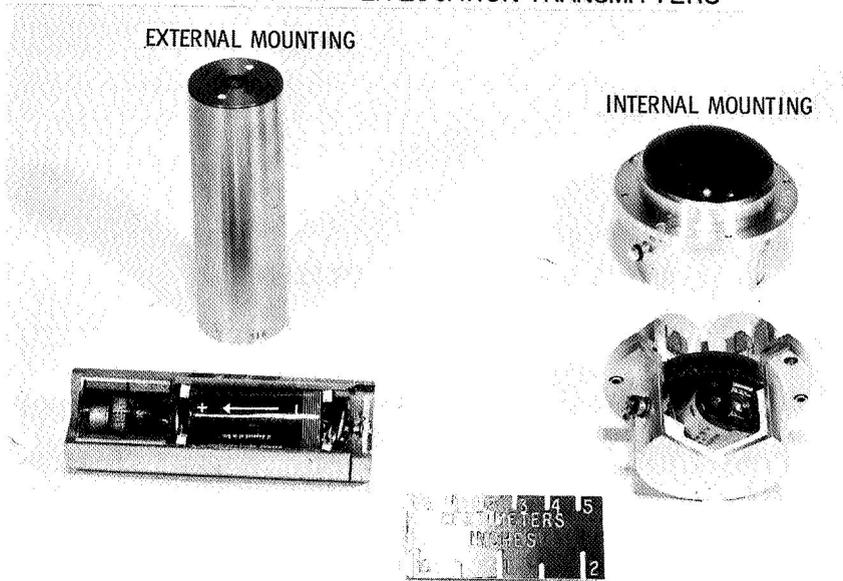


Figure 1

L-3258-1

PORTABLE SONAR RECEIVERS

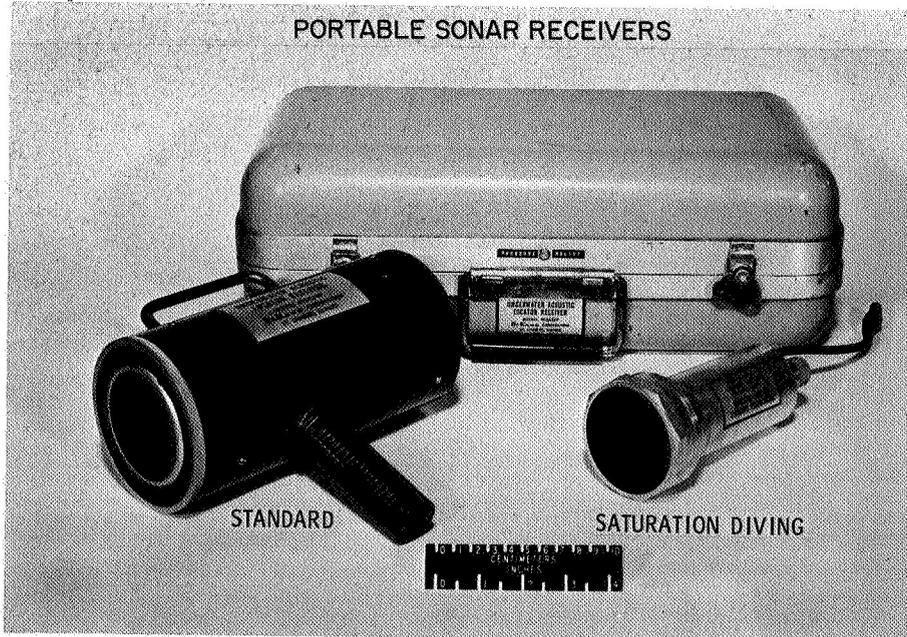


Figure 2

L-3258-2

TYPICAL SEARCH PATTERN

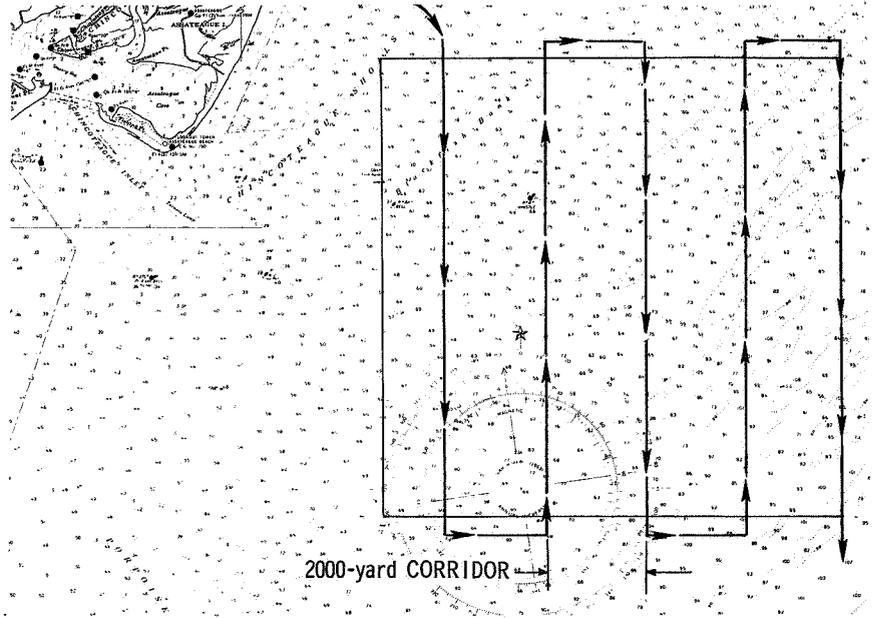


Figure 3

## 8. COMPRESSION MOLDING PROCESSES

By Thomas P. Kelly  
Langley Research Center

### INTRODUCTION

The conversion of molding compounds into cured shapes is accomplished by the application of heat and pressure on the material while confined in a rigid metal mold. During conversion the resinous material in the molding compound changes physically from a powdery or granular form to a semiliquid form and finally to a dense solid form. Chemically, it changes from a composition of low molecular weight to a highly cross-linked material of high molecular weight. Therefore, complex physical and chemical changes occur simultaneously as a result of the externally applied pressure and heat.

### DISCUSSION

When molding materials by the standard compression molding process, many undesirable effects are often created in the molded part by air entrapped within the molding compound during the closing of the mold, residual volatiles, and gases given off during cure of the resin. The air and gases are trapped and cause internal forces which tend to weaken the part. Some of these undesirable effects have been eliminated by using a vacuum technique to withdraw air and evolved gases from the mold and by controlling the method of closing the mold on stops to eliminate pressure fluctuation of the hydraulic system and to give precise control of the density required of the molded part.

Figure 1 shows two compression molds: A conventional steam-heated compression mold and the same mold with "O" ring seals, fittings, and grooves which allow the application of a continuous leak-proof vacuum during the molding cycle. This improved design allows the vacuum to be applied to the top and/or the bottom of the mold. The vacuum ports are connected to a machined groove located just inside the vertical wall of the mold; this allows the vacuum to be drawn around the full circumference of the mold.

In order to allow the gases to be withdrawn without removing the fine particles of the molding compound, a so-called volatile sink is used between the compound and the vacuum ports. The volatile sink consists of a glass fabric and a ceramic paper in contact with the molding compound. By slowly applying a vacuum, the air escapes through the volatile sink without disturbing the molding compound. A dwell under full vacuum insures a complete bleed off of air before the mold is closed. Vacuum is maintained during the complete molding cycle; thereby any gaseous by-products are removed. The

volatile sink allows their removal even though the compound is under pressure. This technique has been successfully used to mold ablation compounds of various densities and has been very effective in allowing parts to be molded that are reproducible, homogeneous, and free of residual stresses.

A high density conical ring was molded of fiber-glass cloth impregnated with a phenolic resin. (See fig. 2.) The ring had a major diameter of 20 inches and a minor diameter of 18 inches and it was 4 inches high and 1 inch thick. The molded part was to be used as a structural component on a flight project; therefore, the laminate had to be of high strength and void free to obtain the maximum mechanical properties. In order to produce a high quality laminate, a positive continuous pressure is necessary during cure to eliminate air, volatiles, and excess resin. Two other methods were considered and found to be unacceptable. Standard vacuum bag technique in an autoclave would produce insufficient pressure and compression molding with matched metal dies would cause the plies to slip and wrinkle, giving lower quality.

To mold the conical ring, a device was constructed which would transfer a continuous hydrostatic pressure to the laminate. (See fig. 3.) This device consists of a heavy duty inner tube encapsulated in a silicone rubber casting, a hydraulic pump to supply pressure to the inner tube, an aluminum insert centered inside the rubber casting to provide a passageway and support for the hydraulic line, and the female mold component. The preimpregnated fiber-glass cloth was applied to the aluminum mold with standard hand lay-up methods. The layers of cloth are shaped to fit the mold inner surface and are applied with the butt joints staggered. After the correct number of layers has been applied to form the desired laminate thickness, two layers of teflon film are arranged on the inside surface of the lay-up to act as a release agent. The inner tube is centered between the lay-up and the aluminum insert and encapsulated with silicone rubber to form a void-free casting. After fabrication, this device may be used over and over again.

The mold is assembled in a hydraulic press (fig. 4), the press is closed on the mold, and hydraulic pressure is applied to the laminate through the silicone rubber casting. Heat necessary to cure the laminate is applied from heating coils and the heated press platens. The conical laminate was successfully molded. After a machining operation and nondestructive testing, the laminate was found to be of a high quality.

Molding related to a rocket motor nozzle is now discussed. This nozzle had to be light in weight, have high mechanical properties, and be able to withstand high temperatures for a short period of time. Previous nozzles were molded with an asbestos-phenolic molding compound, after which a graphite insert was bonded in position with an adhesive. Because of the difference in thermal expansion and the inability of the bonding adhesive to contain the graphite insert, the insert would separate from the nozzle and this would cause an unstable condition within the rocket motor. The previous graphite inserts

worked fine while the motor was firing; however, when the motor cut off, the graphite inserts would separate from the nozzle and pop into the motor. This is illustrated in figure 5.

A process was developed for molding a rocket motor nozzle containing a molded-in graphite insert. This process insures complete support of the insert and was accomplished with a steel compression mold of unique design.

On the left of figure 6 is shown a section of a molded nozzle. It has a diameter of 5.5 inches, a height of 6.5 inches, and total weight of 1 pound. The external threads allow the nozzle to be attached to the rocket motor without additional locking devices. The light area is the captured graphite insert. Molded in this position, the insert cannot move in any direction. On the right, the graphite insert is shown in position on the mold mandrel. After applying release agent to the mold mandrel, the graphite insert is bonded into position with an epoxy filler to insure that the insert is fully supported during the molding cycle. Upon completion of this step, the mold is assembled in the press and the mold cavity is loaded with preweighed molding compound.

Figure 7 shows the position of the motor nozzle with the graphite insert during the molding process. The mold surfaces which come in contact with the molding compound are chromium plated; the mold design is such that these surfaces will be heated from room temperature to 300<sup>o</sup> F within 60 seconds. The heat is provided by admitting steam into the mold assembly through three separate inlets. At the same time ducting provides the rapid and thorough distribution of steam. On the left of the figure the mold is shown closed sufficiently to permit the mold cavity to be placed under vacuum. "O" ring seals are at both the top and bottom and a machined groove connected to a vacuum port is in the base. Vacuum is held on the mold cavity for 30 minutes, then heat and pressure are applied to the mold. On the right, the mold is shown fully closed. For this asbestos-phenolic molding compound the cure is 325<sup>o</sup> F at 2500 pounds per inch<sup>2</sup> for 1 hour.

Several of these nozzles have been test fired. The test results have demonstrated that the nozzle holds up well in the test environment.

#### CONCLUDING REMARKS

Techniques used at the Langley Research Center for compression molding have been discussed. These techniques have been successfully used in solving some problems encountered in molding.

# COMPRESSION MOLDING

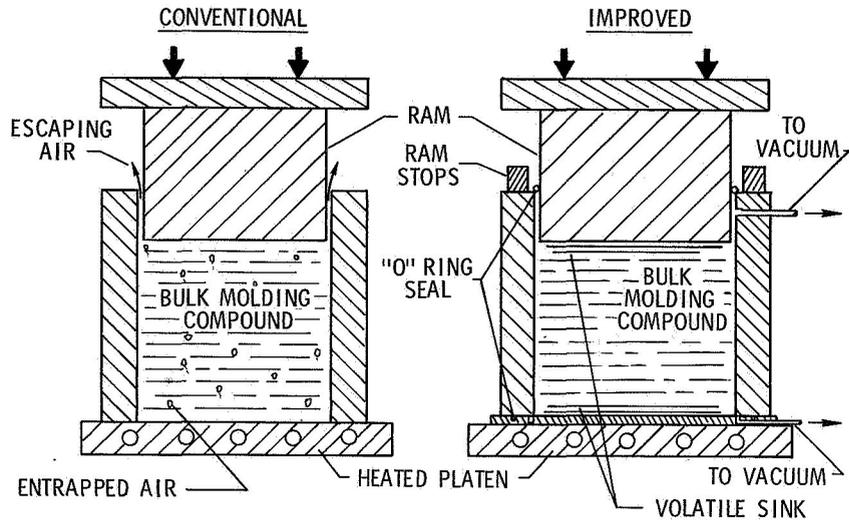


Figure 1

# CURED FIBER-GLASS LAMINATE

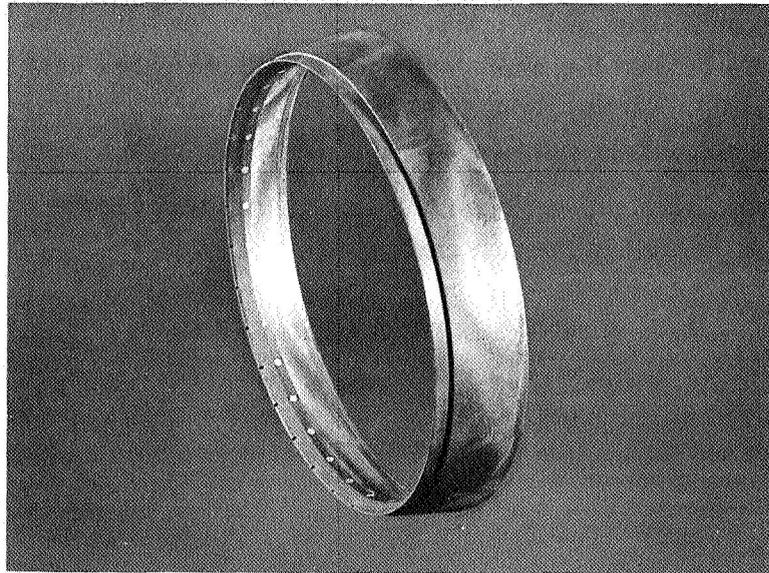


Figure 2

L-3247-2

### COMPONENTS FOR HYDROSTATIC MOLDING

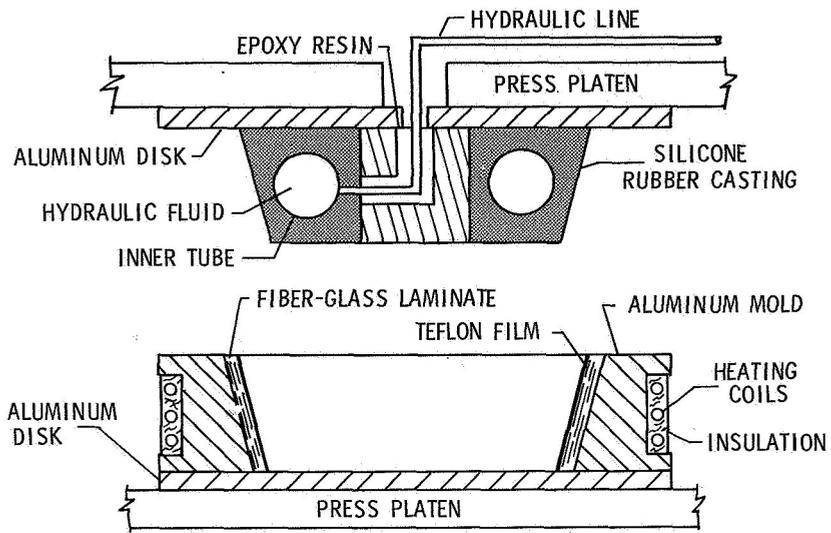


Figure 3

### APPLICATION OF PRESSURE AND HEAT

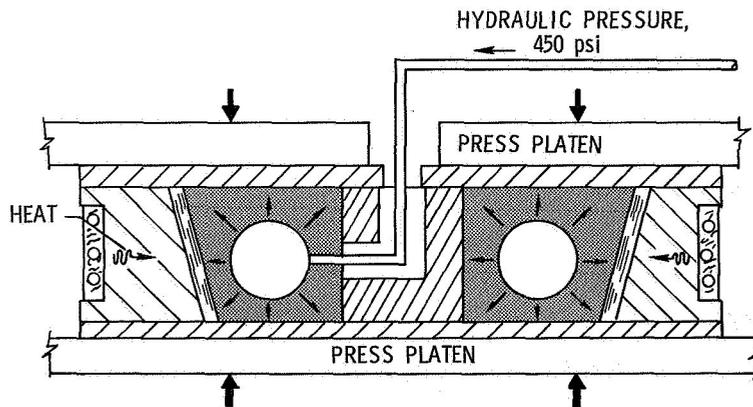


Figure 4

MALFUNCTION DUE TO LOOSENED NOZZLE INSERT

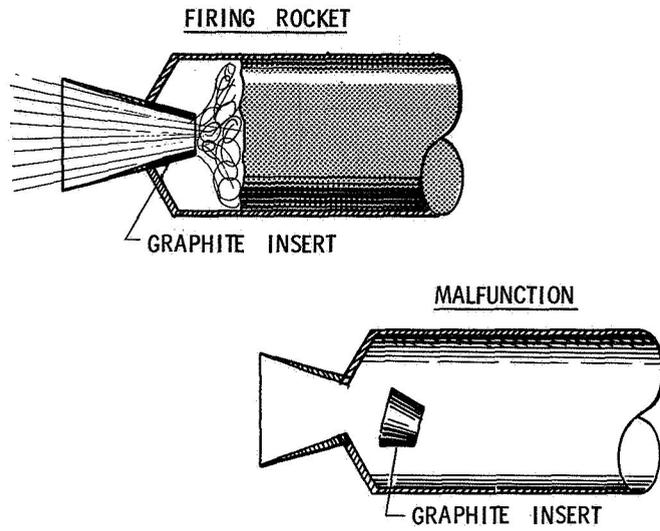


Figure 5

POSITIONING GRAPHITE INSERT FOR MOLDING

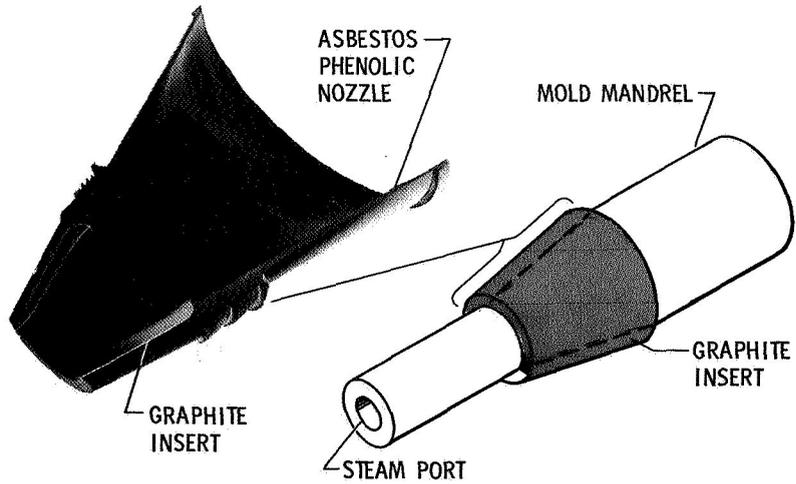


Figure 6

POSITION OF MOTOR NOZZLE WITH GRAPHITE INSERT  
DURING MOLDING

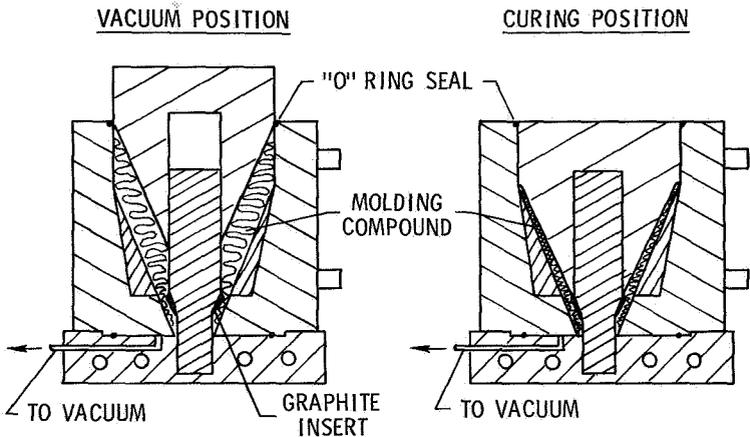


Figure 7



## 9. BUTT-WELDING FINE-GAGE WIRE

By Walter P. Kabana  
Langley Research Center

### INTRODUCTION

Aerospace research is now requiring very precise measurements of high temperatures to be made in a short readout time. At the Langley Research Center accurate temperature measurements at precise points on research models are required. These measurements are made with thermocouples. Thermocouples are two dissimilar metals welded together that create a small electric current when their weld junction is heated. The electric current produced is related to a temperature and can be measured.

As aerospace research advances, the thermocouples required have to be welded from smaller and smaller wires. How can wires 0.005 inch or smaller in diameter be butt-welded? There is no machine available that is capable of making such welds. This paper presents the solution to that problem derived at the Langley Research Center.

### DISCUSSION

In figure 1, a thermocouple made by a former method from 0.005-inch-diameter chromel-alumel wire can be seen. The ends were lapped approximately 1 diameter and were welded between two opposed electrodes. A poor junction is obtained despite tedious dressing and straightening of this type of weld under a microscope. In the photographs the appearance of more than one wire is an illusion caused by uneven light reflection from the wire. All the wires that are shown are single strand.

Figure 2 shows a 0.003-inch-diameter thermocouple wire that has been butt-welded by the new technique. A human hair is included in the photograph for size comparison. Butt-welds of this size are made frequently at Langley. The thermocouple shown is made of tungsten rhenium wire that becomes hard and brittle at the weld; this property rules out any dressing or straightening of the junctions. Note that the weld junction is no larger than the nominal size of the wire and also the wire on each side of the junction is relatively straight. Because the wires experience the same temperature as the junction for a set distance, the heat conduction errors are reduced.

One of the aims of materials studies at the Langley Research Center is to develop lighter heat-shield materials. Such lightweight heat shields would permit larger payloads on a spacecraft. Ablation material is used to make heat shields to protect the astronauts and their spacecraft from the very high temperatures of reentry heat. These temperatures approach 5000° F. Figure 3 shows a multipoint temperature sensor used for

ablation material studies. This sensor is an important application of the butt-welding technique. This sensor is made up of several thermocouples that are accurately positioned and supported from a base by fine alumina insulators. The material to be tested is molded around the thermocouples. The completed sensor is then inserted into a larger specimen of the same material for arc-jet heat tests. As the material ablates, temperature readings can be made at various points in the specimen.

Figure 4 shows a butt-welder for fine-gage wire that has been constructed partly from commercial items and partly from items made from stock materials. The welder consists of a capacitor-discharge power supply, a parallel-gap weld head with adjustable electrode gap and vertical force, bow-shaped electrodes, a two-section copper weld base, an inert-gas tube, and a binocular microscope to view and position the work. The items made from stock materials were the bow-shaped electrodes, the weld base, and the inert-gas tube.

With this welder, butt-welds on wire from 0.001 inch to 0.010 inch in diameter can be made. The wires to be used for welding should be cut square or if not square, the butts should match. The wires should be free of burrs and clean.

Figure 5 shows two wires to be welded in their relative positions on the weld base. The electrodes are in the down position with one electrode pressing on each wire. The electrode tips should be as close to the ends of the wire as possible but allowance must be made for the closing motion of the electrodes. Notice that the two sections of the weld base are insulated from each other by a 0.005-inch-thick insulator. It is on this insulated joint that the wires are butted. After the weld current is turned on, it passes down electrode "A" through wire 1 and then to wire 2 and back up to electrode "B." The interface of the butted wires offers the most resistance to the weld current, and thus maximum heating occurs at this point; as a result the wires are fused. The bow-shaped electrodes not only pass current through the wires, but by their unique action keep them butted with a closing motion as they weld and cool. If the electrodes did not produce a follow-through motion as the wires weld, an arc or blowout would take place. Inert argon gas flows at about 2 cubic feet per hour across the junction during welding to prevent oxidation of the weld. At no point during the weld cycle do the electrodes touch one another because if they should touch the weld, the current would be shorted.

Except for periodic dressing of the electrode and weld base, the system requires very little maintenance. The performance of the welder is better than had been anticipated. It is possible to make repeatedly strong clean weld junctures that are of the same nominal size as the wire and require no dressing.

Two special welds and a butt-weld made with the welder are shown in figure 6. On the left is a 0.005-inch-diameter wire welded to the edge of a 0.005-inch-thick by

0.125-inch-wide metal ribbon. On the right is a 0.005-inch-diameter wire welded perpendicular to another wire. Adjacent to the perpendicular weld is a butt-weld.

### CONCLUSIONS

This butt-welding device should have possible applications in industry where strong smooth welds of fine-gage wire are essential. This process could be readily adapted to production work.

FORMER METHOD OF WELDING FINE-GAGE WIRE

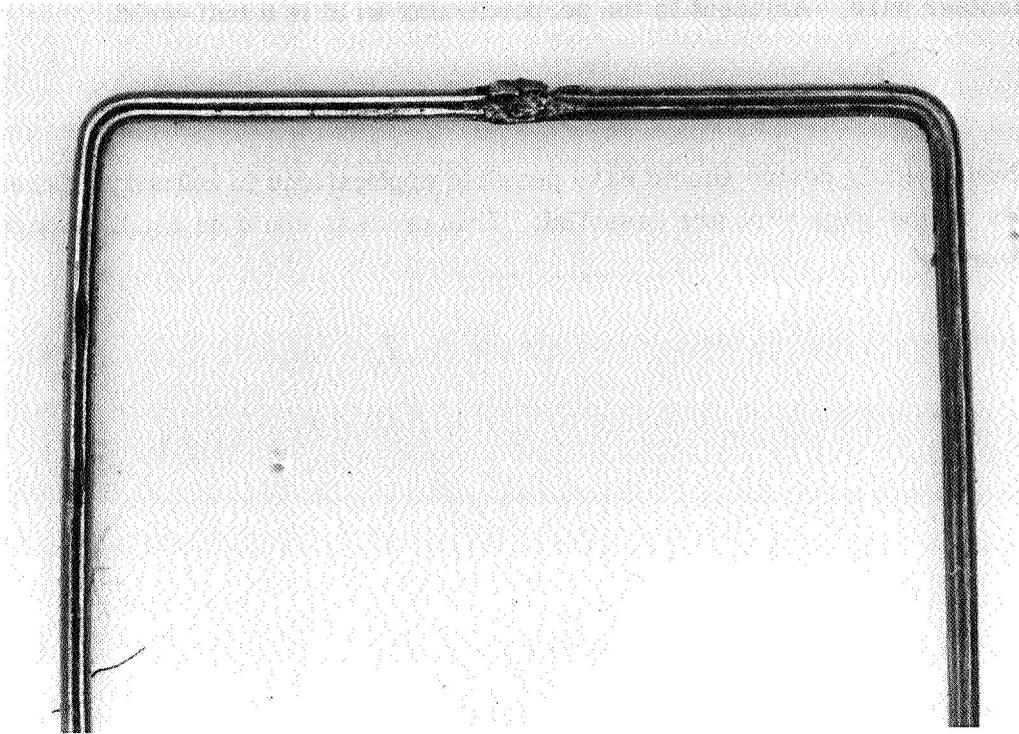


Figure 1

L-3251-2

TYPICAL FINE-GAGE WIRE BUTT WELDED

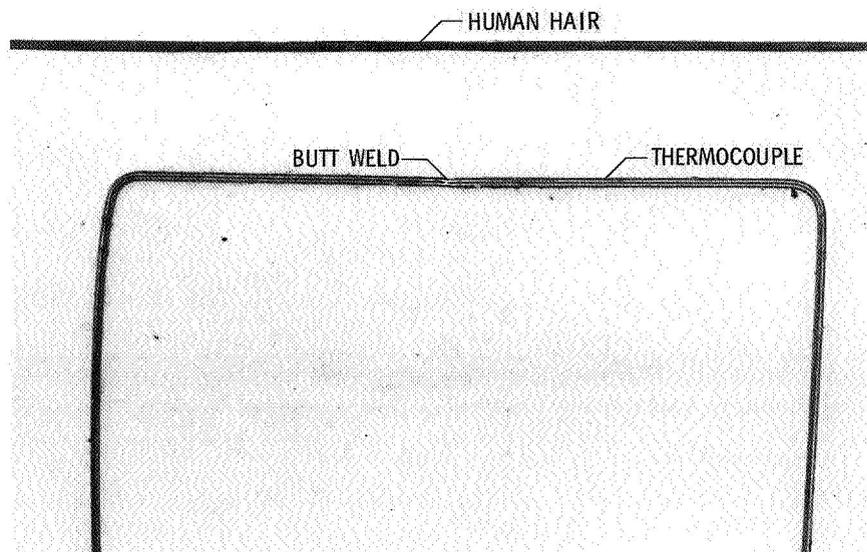


Figure 2

L-3251-1

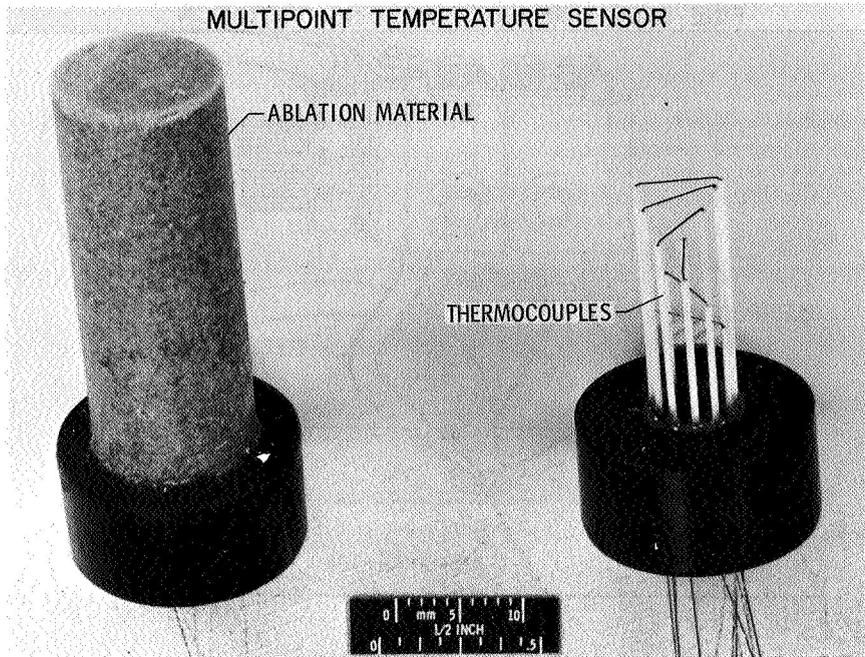


Figure 3

L-3251-6

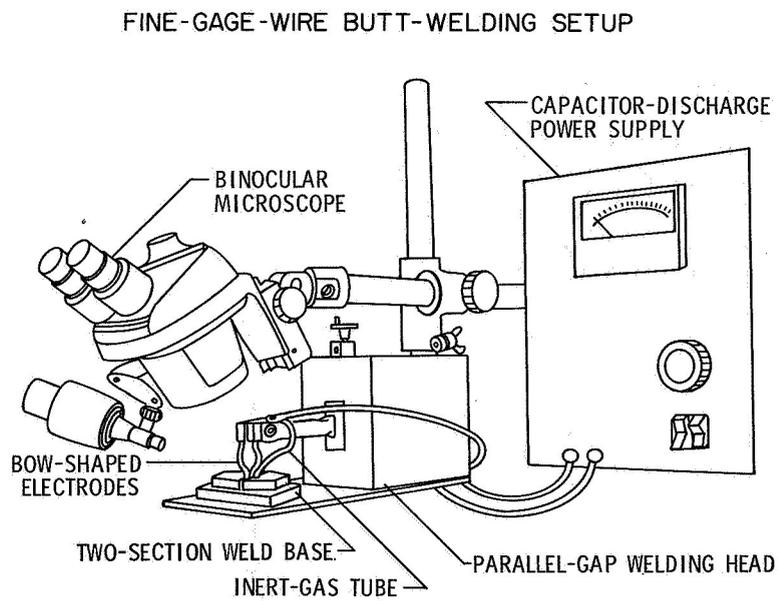


Figure 4

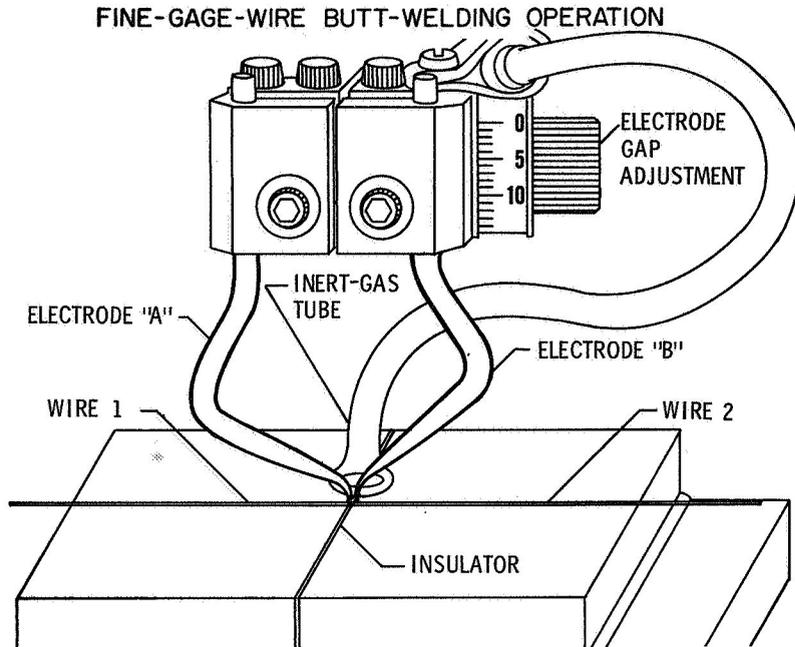


Figure 5

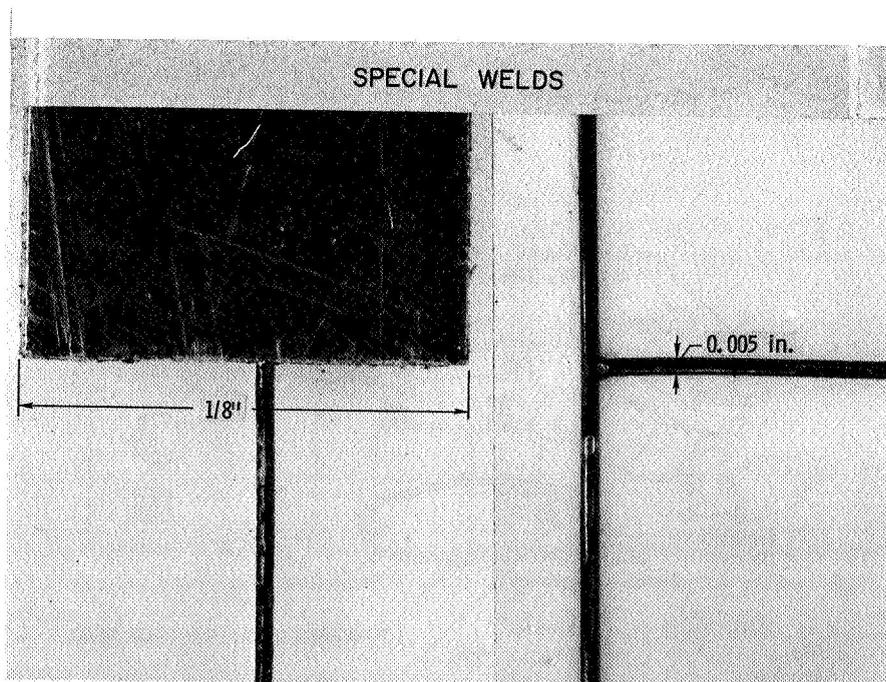


Figure 6

L-3251-5

## 10. DEAERATING CASTINGS AND CONTROLLING BOND LINE THICKNESS

By Albert B. Stacey, Jr.  
Langley Research Center

### INTRODUCTION

Among the problems which industry has had for many years are removing air from liquid plastic materials and controlling bond line thickness. At the Langley Research Center, much effort has been directed toward solution of these problems. As a result, methods have been developed which have proved to be very successful in these fields.

### DEAERATION OF LIQUID PLASTICS

Solution of the first problem involved the development of an improved method of molding and casting liquid plastic materials. In mixing a resin and an activator, the usual method is to stir the two materials together in a container. The mixture is then poured into a mold and allowed to cure. Stirring causes air bubbles to form throughout the mixture. Oftentimes the material begins to harden before the entrapped air can escape and, thus, a porous casting results.

The conventional way of deaerating or removing air from the mixture is illustrated in figure 1. Evacuating the air from the chamber causes the air bubbles to rise to the surface of the liquid material. Some plastics begin to harden before deaeration is completed because of the amount, or the viscosity, or the pot life of the mixture. A more rapid means of removing entrapped air was required to minimize voids.

Deaeration was more rapidly achieved by modifying the existing vacuum chamber. A funnel and flow-control valve were added to the top of the vacuum chamber and a vacuum port tube was added to the interior of the chamber (fig. 1). The tube is flattened on the end so that the material falls into the mold in a thin flat ribbon from which the air bubbles are rapidly removed. The vacuum causes a pressure differential which forces the material into the chamber. The rate at which the material enters the chamber must be determined by experience.

The molding procedure consists of positioning the mold under the vacuum port tube as illustrated in figure 2. The pressure is lowered to 22 to 28 in. Hg in the chamber. The plastic material is forced into the chamber and is deposited in the mold. After the mold is charged, the chamber pressure is raised to atmospheric pressure. The chamber is opened and the mold is positioned under the force plug which has been precoated with a parting agent. Pressure is reapplied to vacuumize the chamber and the mold is closed by lowering the ram. The mold is left in the chamber under pressure for the required

curing period. The chamber is pressurized with inert gas to prevent voids caused by volatiles liberated during curing. The mold and the force plug may be designed so that after casting and curing they may be removed and only the finished product will remain. In figure 2 a cone-shaped cavity is indicated in a block of material.

If required, heating the vacuum chamber during material deaeration and curing can be accomplished by glass woven electrical resistance heaters, steam jackets, or any other practical means. The ram may be designed for either manual or power operation. The vacuum chamber can be fabricated from a suitable pressure vessel or constructed to the desired dimensions.

### CONTROLLING BOND LINE THICKNESS

Solution of the second problem involved finding a method of controlling the bond line thickness between components and checking the bond line prior to actual bonding in order to determine the maximum and minimum bond line thickness between components. It was found that the bond line thickness could be controlled by spacer buttons as shown in figure 3. The spacers may be made from any rigid material that is compatible with the adhesive to be used and the components to be bonded. The spacer buttons may be in the shape of disks, squares, or rectangles and the size, shape, location, and quantity of spacers required are dictated by the size and configuration of the components to be bonded. If the spacers are used to maintain a minimum bond line, all the spacers are machined to the specified minimum thickness and are then bonded to one of the components. If the spacers are used to maintain a maximum bond line, overly thick spacers are bonded to one of the components with the same adhesive that is to be used in the bonding process and are then machined to the specified thickness.

The spacers as shown in figure 3 are machined so that all are within the specified bond line thickness which, in this case, is 0.015 to 0.030 inch. This precise alignment is accomplished by determining with suitable measuring devices the highest point on the surface to be bonded and then machining the spacers to the proper radius or angle. Spacers bonded in recessed or dimpled areas are machined to the same angle or radius as the other spacers. Although the foregoing procedure produces spacer buttons of varying height, the machined surface of the spacers serve to align the components by forming straight-line elements and true radial contact points.

The method of checking the bond line thickness between components prior to bonding used room temperature vulcanizing (RTV) silicone elastomer patches. (See fig. 4.) A coat of RTV silicone primer was applied to an approximately 3/8-inch-square surface adjacent to the spacers. The primer is applied only to the surface to which the spacers are bonded in order to facilitate application and adherence of the elastomer patches. The

primed areas are coated with enough RTV silicone elastomer to assure contact with both surfaces upon assembly. The components are assembled and the elastomer is permitted to cure. The components are then disassembled and the final bond line thickness is easily determined by noting the location of the patches and measuring their thicknesses. This method is very effective and accurate.

### ADHESIVE PUMPING

Figure 5 illustrates the solutions to the problems of deaerating the adhesive and bond line control being used in conjunction with each other and, also, the adhesive being pumped into the bond line under pressure. Some adhesives must be pumped into the bond area because of the viscosity of the adhesive or because of the bond line thickness. In adhesive pumping, the adhesive is deaerated into a vacuum chamber. The vacuum line and the adhesive line are removed and the piston is lowered to the surface of the adhesive. The two openings in the piston are plugged and the vacuum chamber then becomes a pressure chamber. The adhesive is then pumped into the 0.015- to 0.30-inch-thick bond area which is controlled by the spacer buttons while the whole assembly is under vacuum. This method has been used many times on various jobs with great success and assures controlled-thickness bonding without voids.

### CONCLUDING REMARK

The methods used for deaerating liquid plastic materials and controlling bond line thickness have been very effective and it is believed that they will help industry to overcome some of the problems involved in these processes.

# CONVENTIONAL AND IMPROVED DEAERATION METHODS

## CONVENTIONAL

## LRC IMPROVEMENT

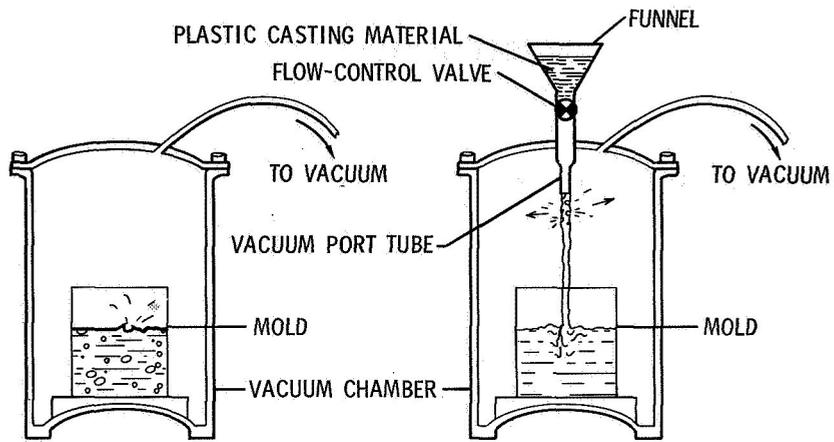


Figure 1

## CASTING AND MOLDING IN VACUUM CHAMBER

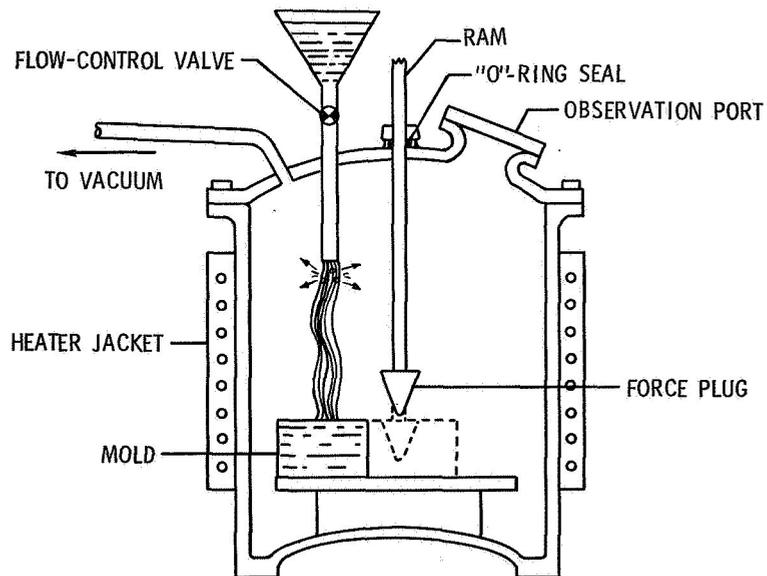


Figure 2

### CONTROLLING ADHESIVE THICKNESS WITH SPACER BUTTONS

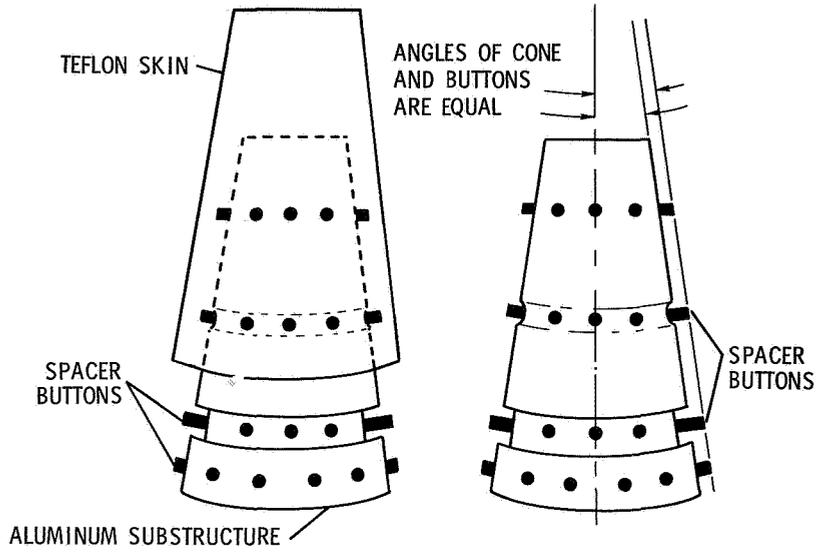


Figure 3

### MEASUREMENT OF ADHESIVE THICKNESS

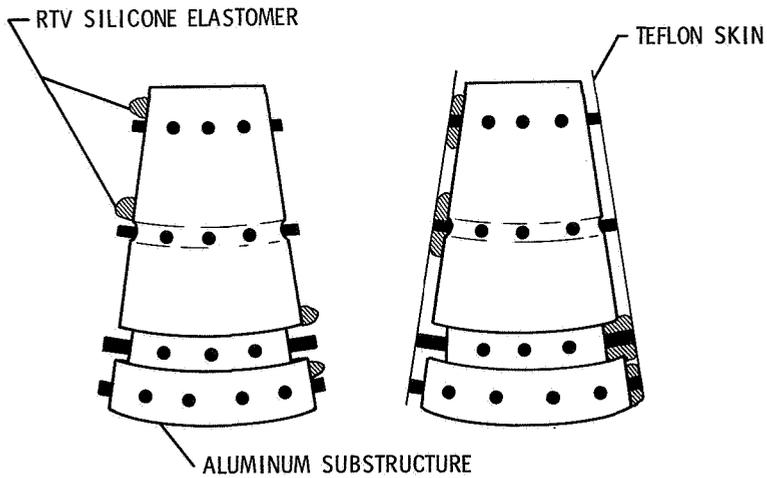


Figure 4

# CONTROLLED-THICKNESS BONDING WITHOUT VOIDS

DEAERATING  
ADHESIVE

PUMPING ADHESIVE  
INTO BONDING AREA

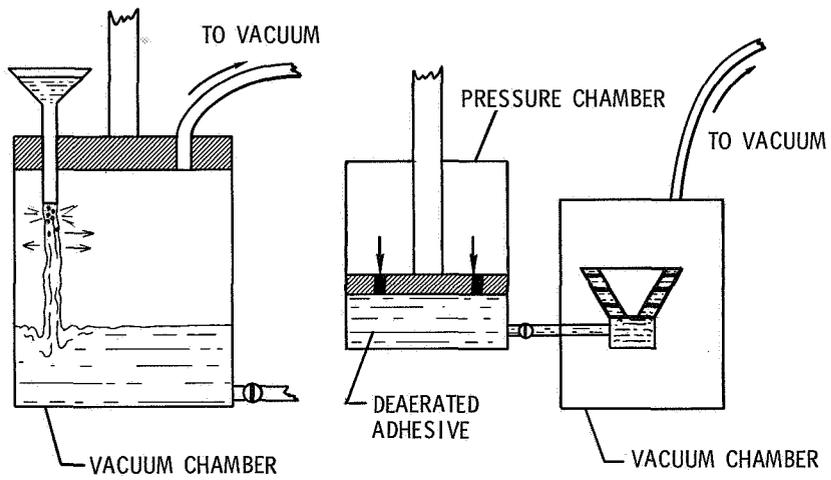


Figure 5

## 11. EXPLOSIVE-SWAGING TOOL FOR TUBING

By Dwight G. McSmith  
Langley Research Center

### INTRODUCTION

In airplanes and spacecraft there are many tubes serving many functions. Typically, the tubes carry air, oil, hydraulic fluids, fuel, reactive chemicals, and water. Their complex arrangement in the restricted volume of aircraft and spacecraft dictates the use of many couplings and fittings. In addition to adequate performance, the weight of these joints becomes quite significant in the overall design criteria. One method used previously involved a lightweight aluminum sleeve and tube combination that was plated and sweat-soldered. Reliability was inadequate.

A technique developed at the Langley Research Center for tubing assembly is unique in that the tubes are coupled by swaging with the use of explosive force (see ref. 1). Deformation of metal by explosive force is not new; some coins are made by an explosive lamination method.

The explosive-swaging tool takes advantage of the unique yield behavior of metals at an explosive rate. By contrast, mechanical swaging would "work harden" the materials and cause "springback" and consequently is inadequate to produce a tight joint.

### EQUIPMENT AND PROCEDURE

Figure 1 shows a phantom drawing of the explosive-swaging tool, with all the significant features indicated. The blank cartridge provides a convenient and inexpensive means of generating an explosive force on the order of 10 000 to 15 000 lb/in<sup>2</sup>. It is fired into the annular chamber within the tool body and provides the force necessary to crimp or swage the tube sleeve onto the tube being joined, thus creating a seal area. The vent can be used to control the amount of pressure and provide some pressure adjustment. The swing loading and firing mechanism is not unlike that in a standard hand pistol. In operation, this tool makes a loud bang that sounds much like a pistol shot.

In order to produce a typical explosively swaged joint, a modified tubing cut-off tool (fig. 2) is used to roll a "receiving groove" into the basic tube that is to be joined. This technique provides a sharp ledge or "tooth" and a trough into which the outer coupling sleeve is driven by the explosive force. This trough also acts to rigidize the tube and prevent collapse. The pregrooved tubing is assembled inside the coupling sleeve. The tool is then clamped over the desired seal area, a blank cartridge is inserted, and the tool is fired.

## RESULTS AND DISCUSSION

The photograph in figure 3 shows a cutaway of a typical joint produced by the explosive-swaging technique.

Figure 4 is an enlarged view of the seal area showing the receiving groove and the coupling sleeve which has been swaged into it by the explosive force. The resulting groove visible in the outer sleeve gives a good indication of the seal provided. The principal area of seal is in the ledge area of the receiving groove. In general, it is necessary to use a softer temper for the outer sleeve.

Several variations of the technique described herein are possible. For example, the annular cavity of the tool can be filled with a hydraulic medium such as grease to get equal pressure over a larger area if tubes greater than about 1 inch in diameter are to be joined. Normally a hand tool is designed for the largest size tubing to be swaged and adapter collets are added to accommodate tubings of smaller diameter.

Test results, to date, of tubing swaged by this method have been gratifying. Most of the work has been done with copper and with aluminum tubing (in particular, 6061-T6 alloy). Hydrostatic pressures up to 2000 lb/in<sup>2</sup> and vibrational loads up to 100 times the force of gravity have been sustained with regularity. Thermal shock properties are also excellent. Helium leak tests indicated satisfactory performance at 10<sup>-6</sup> torr.

## CONCLUDING REMARKS

The excellent economy and the convenience and speed of this method suggest several applications for potential commercial utilization. Possible commercial applications include uses in household, industrial, and special areas. For example, in house plumbing, copper tubing presently being used can be swaged instead of soldered for less than 5 cents in less than 1 minute per joint. In addition, aluminum and stainless steel are now potentially practical metals for use in plumbing systems. The tool can also be used in constructing air conditioning and electrical conduit systems. In industry the tool can be utilized in hydraulic and vacuum systems, reactive-chemical lines, and heat exchangers. Special uses include nuclear encapsulation, remote sealing, and construction of underwater joints. It should be noted that the tool can be used to assemble both similar and dissimilar metals for structural purposes. Applications seem limited only by the imagination.

## REFERENCE

1. McSmith, Dwight G.: Tube Swaging Device Uses Explosive Force. NASA Tech Brief 68-10235, July 1968.

### EXPLOSIVE-SWAGING TOOL

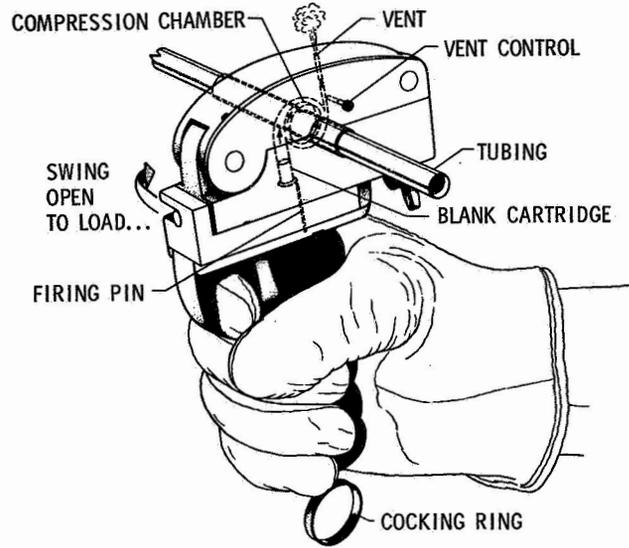


Figure 1

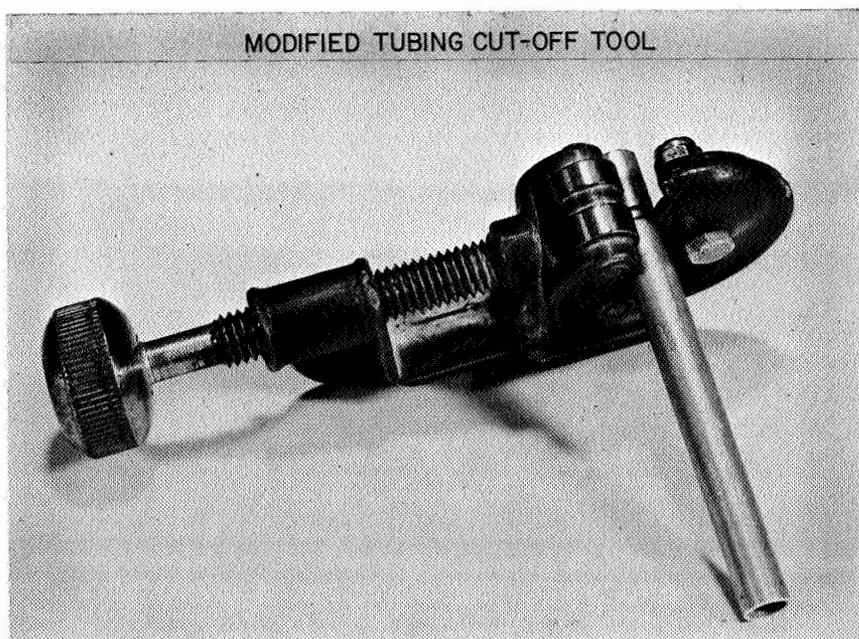


Figure 2

L-3244-2

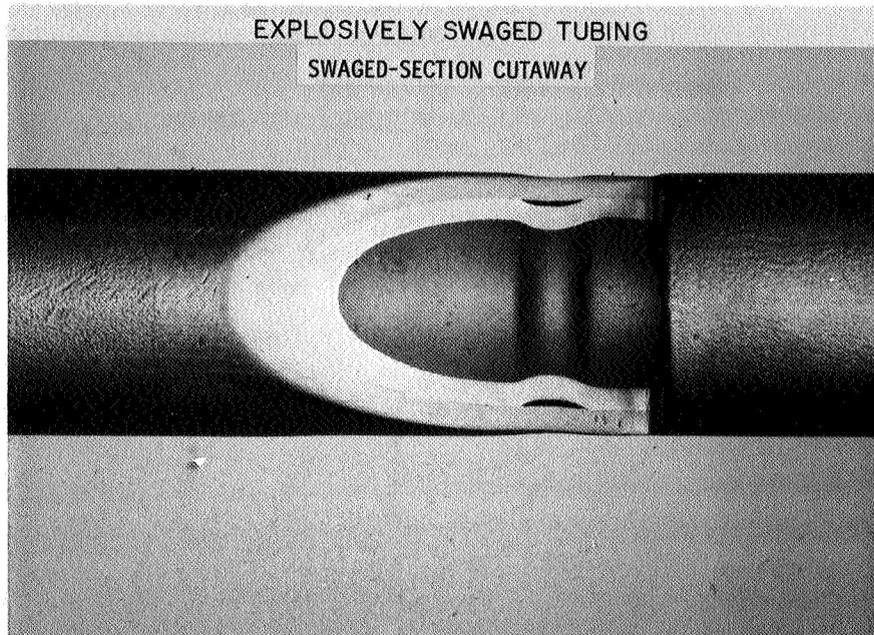


Figure 3

L-3244-3

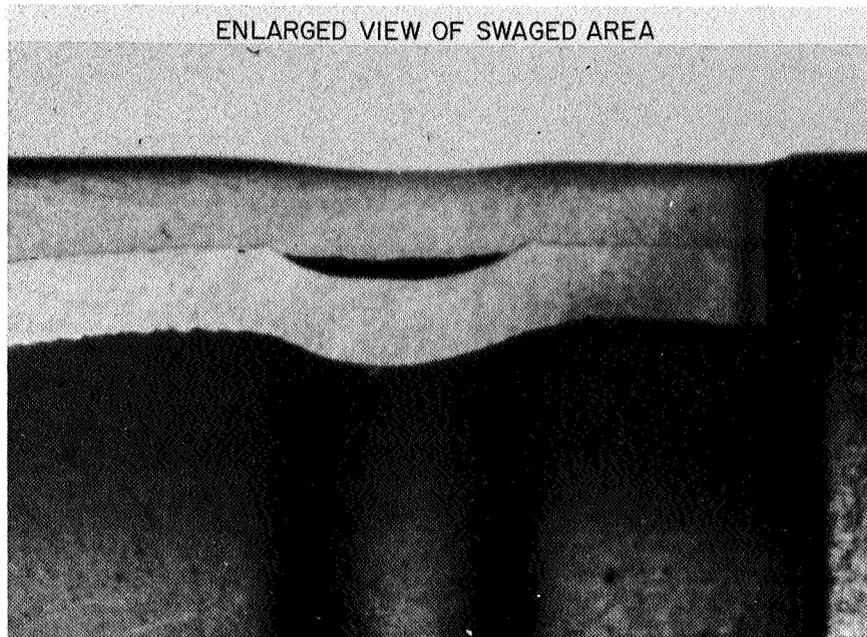


Figure 4

L-3244-4

## 12. TEFLON ETCHING AND BONDING TECHNIQUE

By Arthur J. Lambiotte

Langley Research Center

12

### INTRODUCTION

Teflon has high antifriction qualities and is one of the most difficult materials to bond to other surfaces. This paper presents the development of a method for constant and uniform etching of teflon components which will neither affect the physical shape of the teflon nor result in rejection of the teflon components due to nonetched surfaces.

### DISCUSSION

The former method of etching teflon components was to Freon clean and vapor rinse teflon in an ultrasonic tank. The teflon component was dipped into a sodium etching solution and etched to permit adhesive bonding of teflon to various substrates. This technique resulted in nonuniform etching in the surfaces. The physical characteristics of teflon prohibit reetching on nonetched areas. (See fig. 1.)

At the Langley Research Center, a simple surface preparation method that greatly improves the etching for the bonding of teflon to other materials has been developed. This technique produces 100 percent surface etching. (See fig. 1.)

Figure 2 shows a combination ultrasonic cleaner and vapor rinse tank. The teflon component is placed in the vapor rinse tank and Freon cleaned for 5 minutes, submerged and ultrasonically cleaned for 5 minutes, and then vapor rinsed for 5 minutes. The teflon component is then placed in a grit blasting booth, and the area to be etched is abrasively cleaned or grit blasted with aluminum oxide grit No. 120 at an air pressure of 40 psi. This step is the key to preparing the teflon surface to be etched. The teflon component is returned to the ultrasonic cleaner tank and the cleaning cycle is repeated. Then the component is ready to be etched.

Figure 3 shows the steps in the etching of the prepared teflon. (For safety in handling sodium etching solution, it is recommended that rubber gloves and goggles be used.) The teflon component is placed in the sodium etching solution and agitated constantly for 15 or more seconds. The teflon component is then removed from the etching solution, and the etchant is neutralized by dipping the teflon in water. The etched component is then removed from the water and cleaned with a solvent solution such as Freon, acetone, naphtha, or methyl ethyl ketone, and so forth. Areas not to be etched can be masked off.

Sodium etchant is an activated form of sodium in solution, which reacts with the fluorocarbon polymer, extracts fluorine atoms at the surface, and forms a carbonaceous film which is compatible with most adhesives. In general, sodium etching solution prepares fluorocarbon surfaces, such as teflon, for potting, bonding, and marking. It is extremely simple to use with standard adhesives or potting compounds. The etchant is suitable for use in the laboratory or on the production line and is among the safest materials made for this purpose. Commercial sodium etchant is manufactured as a super-saturated solution of a sodium aryl compound in highly polar solvents. No free metallic sodium is present. The solvents used are rated nontoxic in reasonable exposures.

#### CONCLUDING REMARKS

The benefits anticipated from this method are constant and uniform etching of teflon components without affecting physical shape and no rejection of teflon components due to nonetched surfaces. As a result, there is a saving of machine operation time, labor, and material. After etching, teflon can be bonded with almost any adhesive.

Etched teflon has many possible commercial applications such as pads on furniture and appliance legs for easy moving on linoleum or tile floors, runner strips on drawers in furniture, rollers of all types, tools, tank linings, and so forth.

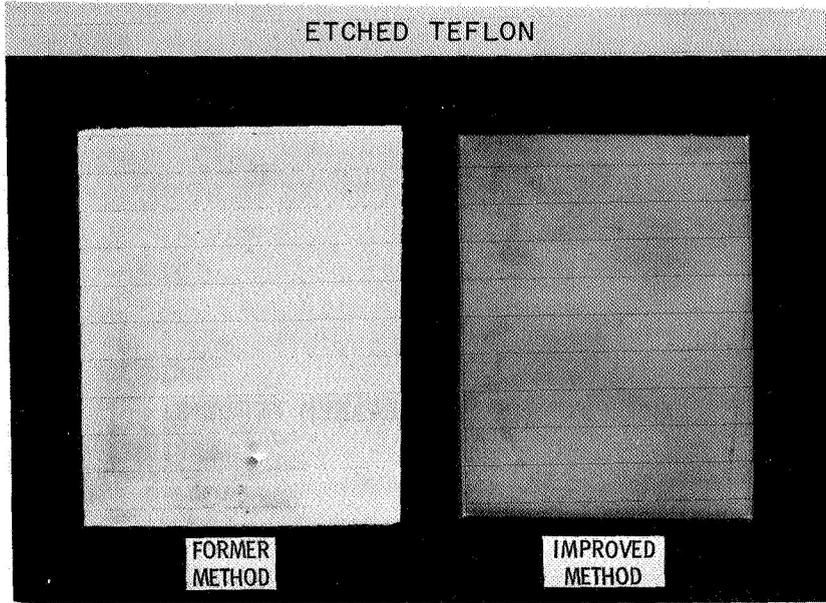


Figure 1

L-3242-3

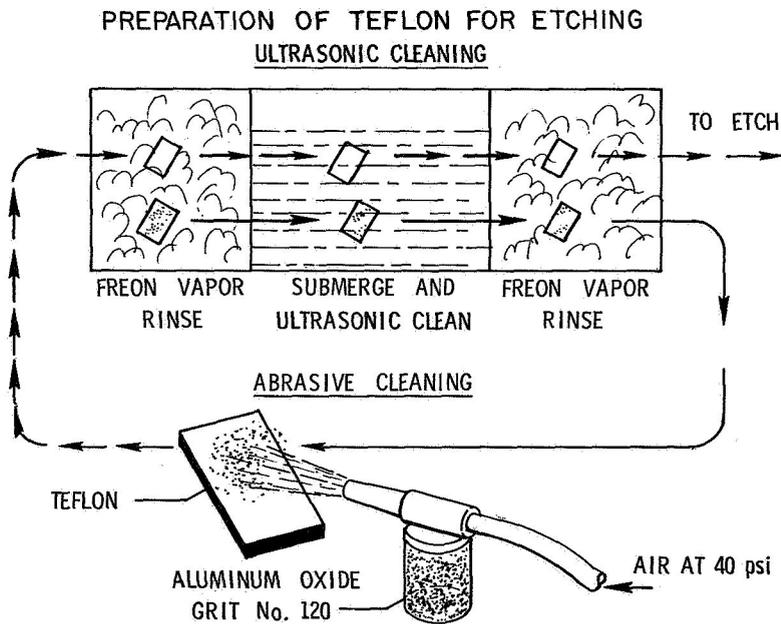


Figure 2

ETCHING OF PREPARED TEFLON

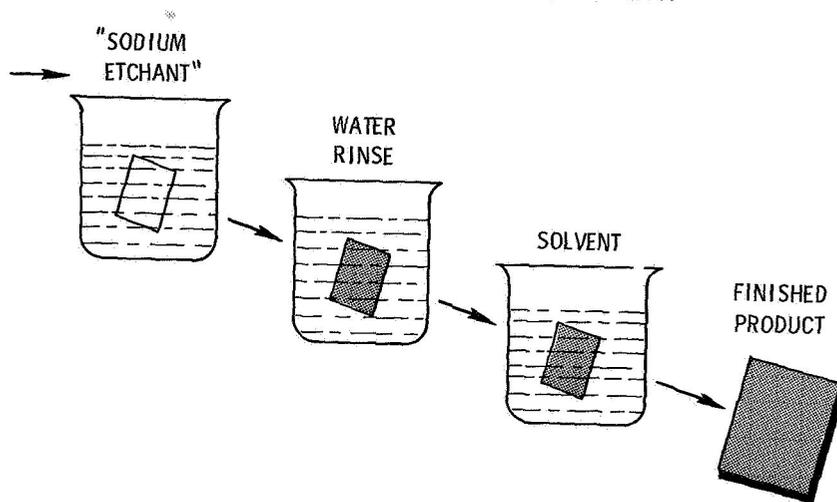


Figure 3

## 13. ULTRASONIC THICKNESS MONITORING TECHNIQUE

By Wayne A. Wright

Langley Research Center

### TECHNIQUE

The burning rate of solid propellants is related to internal motor pressure, time of burn, and motor thrust. For a number of years a method has been needed to measure the burning rate of solid fuel propellants under actual combustion conditions. A number of methods have been used but none that would give the continuous data needed under actual combustion conditions. A new technique based on ultrasound has therefore been developed to give continuous thickness measurements of burning solid fuel propellants.

The small test motor shown in figure 1 is the experimental rocket motor used in previous research to develop this ultrasonic method. The burning propellant yields temperatures in excess of 4000<sup>o</sup> F, chamber pressures range from 350 to 1000 lb/in<sup>2</sup>, and the total burning time is only 5 seconds. By using the ultrasonic technique under these combustion conditions as many as 640 measurements of the burning propellant have been taken in the 5-second allotted time, and the accuracy of the measurements has been within 0.001 inch.

### INSTRUMENTATION

The instrumentation for previous experiments was obtained from the Langley Research Center and is commercially available with the exception of the test motor which was designed especially for these experiments. The test motor is approximately 12 inches long and 6 inches in diameter.

Figure 2 shows a simplified block diagram that describes the basic ultrasonic equipment. An electronic signal originates at the synchronizer and splits. Part of the signal forms the base sweep line on the cathode ray tube and part goes to the pulse generator which generates a short voltage pulse at high-frequency rates. This pulse is converted into an ultrasonic burst by the ultrasonic transducer. The ultrasound travels through the acoustic spacer and the solid propellant as indicated by the arrows. The ultrasound is reflected back to the transducer which reconverts it into an electronic signal which is amplified and displayed on the cathode ray tube as a visual display.

Figure 3 shows the equipment used during previous experiments. The igniter in the motor pressure chamber is triggered by the programmer shortly after the oscillograph recorder and high-speed camera are turned on. The timing light is triggered by the

ignition circuit and gives a visual time record on the same film used to record the thickness history. The oscillograph records the program history. An accurate motor pressure record provided by the pressure transducer is also recorded. These records can be compared with the film-recorded ultrasonic thickness data.

A typical display of the ultrasonic signal is shown in figure 4. The constant velocity of ultrasound allows a comparison of the premeasured total length of the propellant to the length of the propellant at any time during the 5-second motor burn. Note that the signal representing the burning surface moves toward the front surface as the propellant burns away. The burning rate obtained by this low-cost test motor can be used to predetermine accurately burning rates for future solid propellant motors. The original test motor has provided enough information to warrant an advanced version of the system (incorporating internal flow control, pressure control, and thrust data) which will be used in a research program to determine the effect of strain on solid propellant burning. The system is programed through a computer and the test data are computer reduced during the testing. Ultrasound has been a useful measuring tool for a long time. Some other instrumentation has been coupled with the ultrasonic equipment to gather thickness data over a very short time period.

#### CONCLUDING REMARKS

Ultrasound can detect flaws in metal and measure the thickness of metal parts from one side and may also be applied to low-density materials such as propellants, ablative materials, and other similar organics. A more detailed explanation is given in reference 1.

#### REFERENCE

1. Hale, Hubbert Jackson: The Demonstration of an Ultrasonic Technique to Measure Solid Propellant Burning Rates Under Actual Combustion Conditions. M.S. Thesis, Virginia Polytech. Inst., 1967.

### TEST MOTOR ASSEMBLY

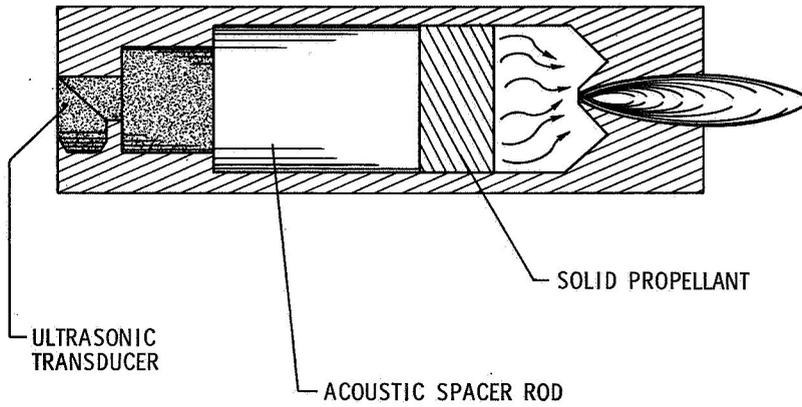


Figure 1

### ULTRASONIC TEST INSTRUMENT

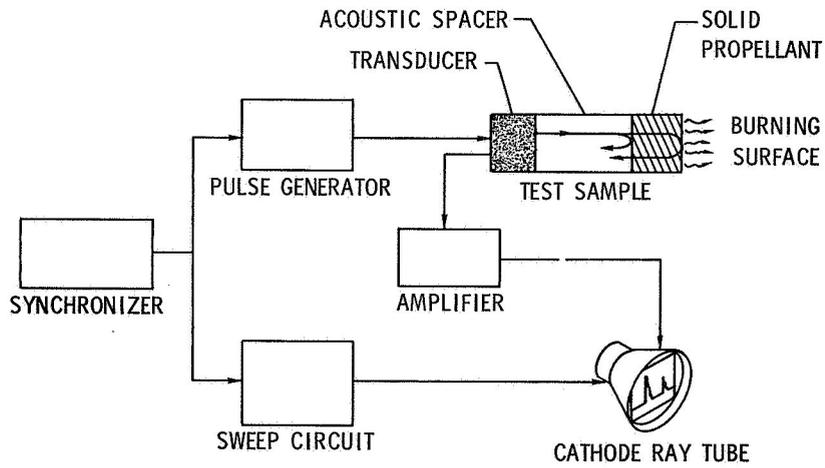


Figure 2

### ULTRASONIC BURNING-RATE APPARATUS

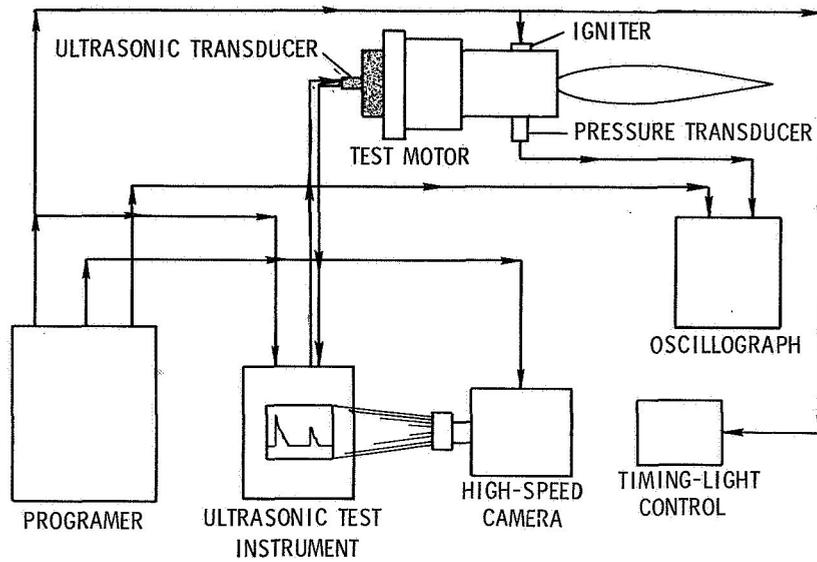


Figure 3

### TYPICAL OSCILLOSCOPE DISPLAY OF ULTRASONIC PULSE-ECHO DATA

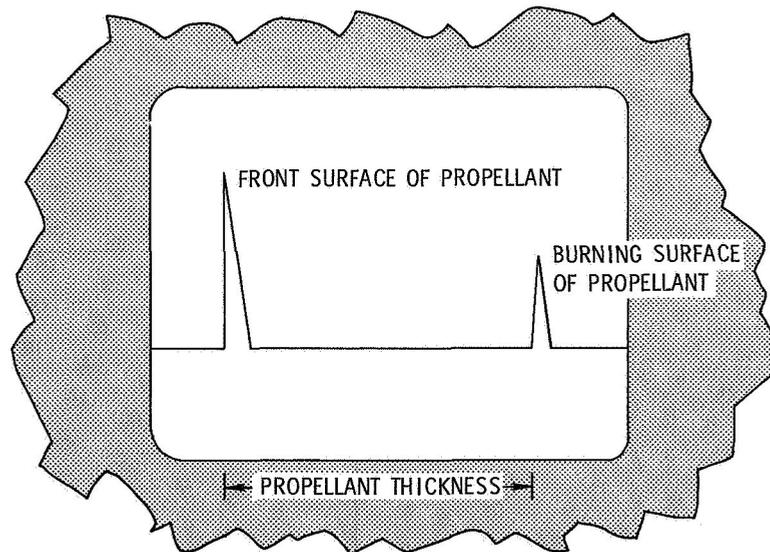


Figure 4

## 14. PHENYL SALICYLATE USED AS A HOLDING MEDIUM FOR MACHINING FRAGILE ITEMS

By David D. Alexander, Jr.  
Langley Research Center

### INTRODUCTION

At the Langley Research Center the problem of holding small fragile parts for certain machining operations has often occurred. Figure 1 shows a finished product machined from a small germanium crystal which was too small and fragile to be held by a mechanical clamp.

### DISCUSSION

This problem has been solved on many occasions with the use of phenyl salicylate, an easily obtainable chemical compound possessing some unusual qualities. This compound is a white granular substance which resembles moist salt and it melts at a convenient working temperature of 104° F. You can see the chemical rapidly melt as it reaches the proper temperature. (If the temperature drops below 104°, it becomes a solid.) When the compound is completely melted, it is ready for application. The liquid, which is now colorless and pours like water is flowed around the work piece and bonds the work piece to the back plate which can be easily clamped for the machining operation. As the phenyl salicylate drops below 104° F, it begins to crystallize to form a solid, and holds the work piece for the machining operation. (Crystallization normally takes about 5 minutes.) The use of a glass plate permits inspection of the underside to determine when the solidification is complete. (See fig. 2.)

The piece to be machined is now clamped onto the work chuck for ultrasonic machining of the desired geometric shape. After the machining operation, the compound is reheated to 104° F to release the work piece. The phenyl salicylate can be washed away with hot water or poured into the container for reuse; however, during the machining process, cold water has no effect upon it.

Another use for this holding technique is for precision machining of miniature ceramic tubing used for electronic insulators. (See fig. 3.) A number of lengths of ceramic material are inserted into a glass tube and the space filled with liquid phenyl salicylate. (It is not harmful if it is spilled on your hands.) After hardening, the tube is sawed to predetermined lengths with a diamond slitting saw. (See fig. 4.) Unlike wax, the compound is nongumming to a diamond grinding wheel. The slab containing

the insulators is placed in hot water and the individual ceramics are washed free. Samples of these ceramics are shown in figure 5. Any remaining traces of phenyl salicylate residue can be removed with Freon solvent or methyl ethyl ketone.

#### CONCLUDING REMARKS

The use of phenyl salicylate has proven to be a very effective method for holding miniature ceramics for precision machining. Although the holding power is limited, it has been very effective for ultrasonic machining and drilling of fragile parts. It has also been used for certain surface grinding operations where diamond abrasive wheels are used with a minimum of pressure.

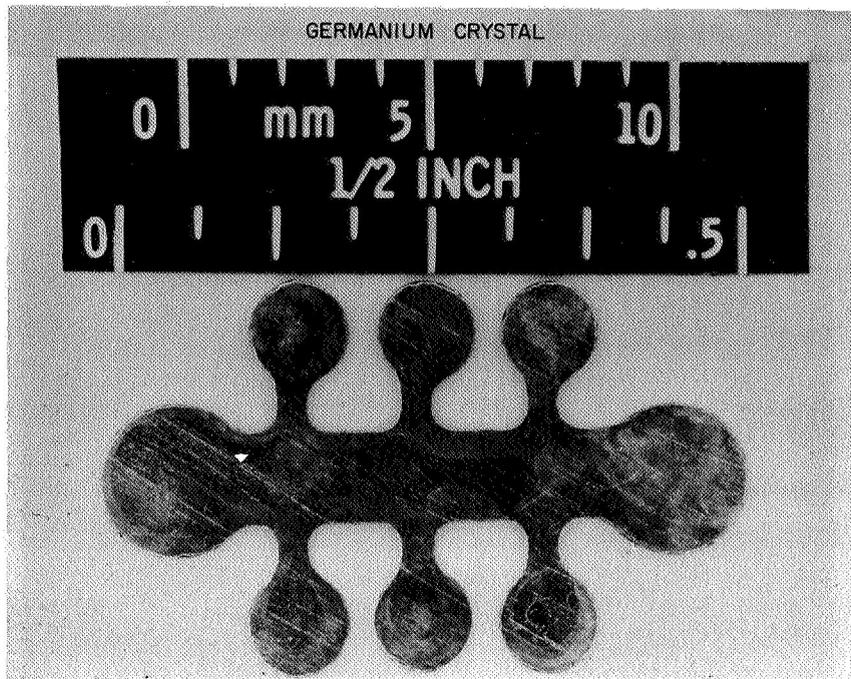


Figure 1

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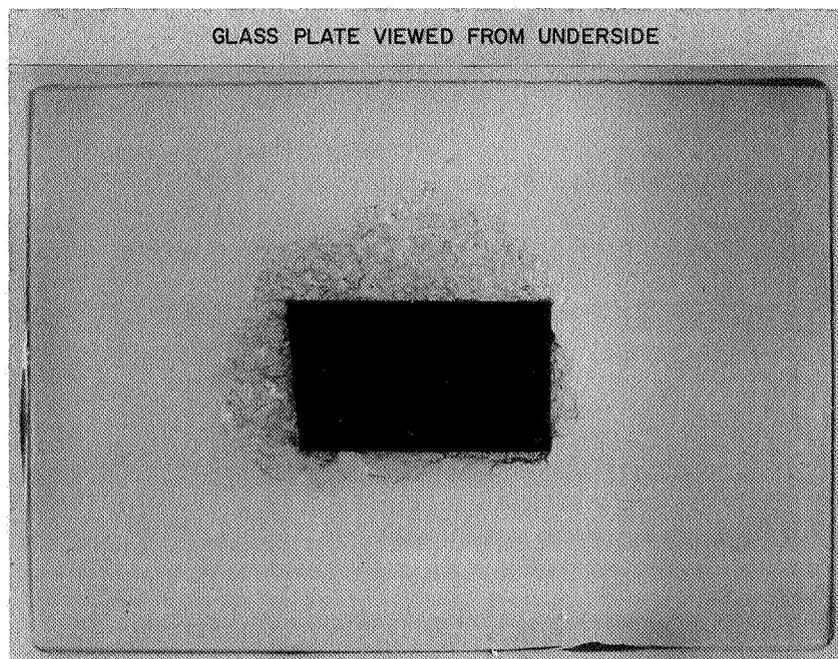


Figure 2

L-69-5210

CERAMICS AND GLASS TUBES

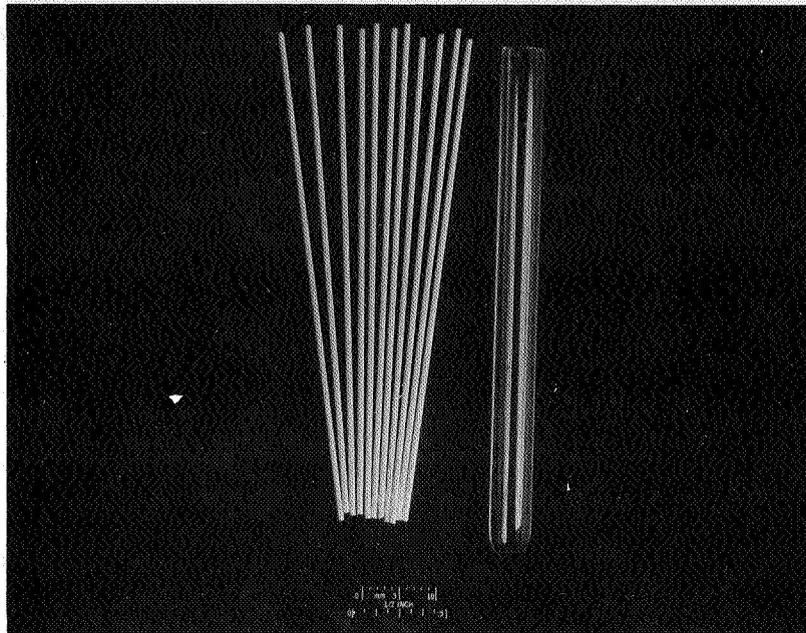


Figure 3

L-69-5211

TUBES CUT WITH SAW

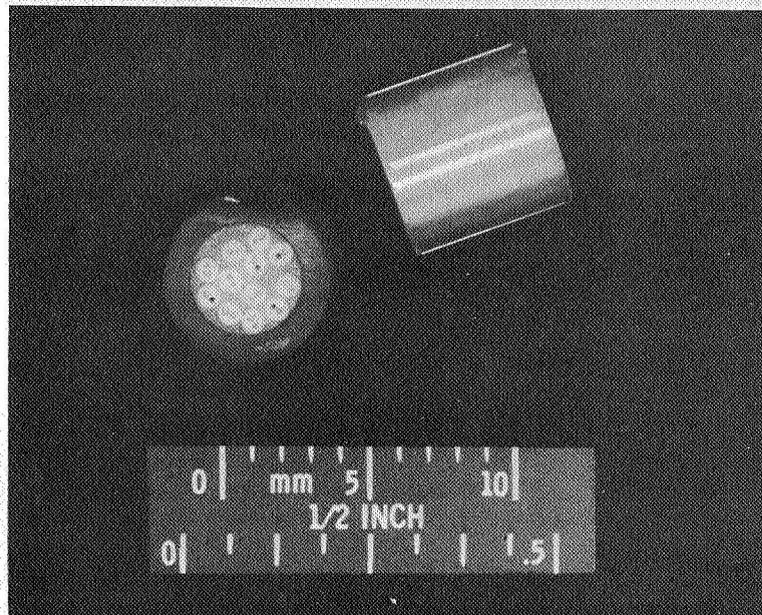


Figure 4

L-69-5212

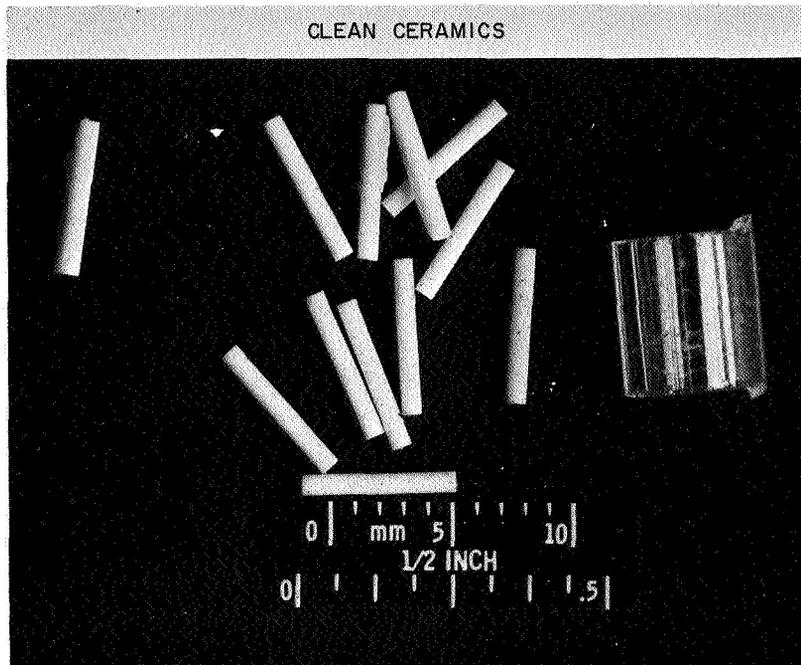


Figure 5

L-69-5213



## 15. A NEW LIGHTWEIGHT RADIOMETER

By Howard B. Miller  
Langley Research Center

### INTRODUCTION

A radiometer is a device for detecting and determining the amount of radiant energy coming from some source (the sun, for example) and striking a surface. Such a device was required to measure steady-state and time-varying total irradiances at the surfaces of spacecraft and models of spacecraft under vacuum conditions. When the radiative and conductive components can be separated at the test surfaces, the results of thermal tests can be more rapidly evaluated. This separation is particularly beneficial for complex configurations where multiple reflections and emissions occur. For this research a radiometer having the following characteristics is desirable:

- (1) Small physical dimensions to minimize shadowing effects
- (2) Low thermal mass to minimize thermal disturbances to the test surfaces
- (3) Capability of indicating irradiances when the mounting-surface temperature is appreciably different from that of the radiometer
- (4) Capability of maintaining a constant calibration irrespective of the mounting method
- (5) Good constancy of calibration between radiometers

Inasmuch as a radiometer meeting all these requirements could not be found, a suitable disk radiometer has been developed at the Langley Research Center for space thermal-vacuum environmental studies.

### RADIOMETER COMPONENTS

The 2.3-cm-diameter, 0.5-cm-high disk-type radiometer is shown in figure 1. The radiometer components include a sensing element with a thermocouple attached, a thermocouple-instrumented shield, and a plastic chassis.

The plastic chassis was pressure molded from a material that is dimensionally stable and highly resistant to thermal conductivity. The chassis was designed to provide a long thermal path between the sensor attachment point and the mounting feet. The parts of the chassis facing the mounting surface were vapor deposited with gold to minimize radiant heat transfer between the chassis and the mounting surface. The remaining parts of the chassis were left uncoated to promote rapid cooling or heating.

The side of the sensor facing the shield was gold-plated to minimize radiant heat loss. The top surface of the sensor was painted with flat black epoxy paint to increase sensitivity to heat sources. The disk was embossed to increase its rigidity. The thermocouple leads were routed across and close to the top surface where they would be warmed by the source radiation. Thus, the leads would be essentially the same temperature as the sensor and conduction loss would be minimized.

The shield was mounted between the chassis and the sensor. The top surface of the shield was also painted black. Because it is larger than the sensor, the shield blocks most of the radiant heat transfer between the sensor and the mounting surface, receives part of the irradiance to be measured, and seeks to attain temperature equilibrium with the source. As a result, error-producing thermal gradients between the sensor and shield are small. Another important function of the shield is to provide temperature information indicative of the magnitude of unwanted heat transfer between the sensor and mounting surface.

The unique feature of this disk radiometer is the instrumented shield. Complete details of this radiometer are given in reference 1.

## RADIOMETER APPLICATIONS

In spacecraft research, energy travels by radiation to and from a surface and by conductance through the structure. Spacecraft thermal design is frequently verified by model tests. Although such models may be heavily instrumented with thermocouples, thermocouples cannot distinguish whether the energy present is radiative or conductive or where it is coming from. When these radiometers are used in conjunction with thermocouples, rapid analysis of model data becomes possible because the solving of complicated simultaneous equations is practically eliminated.

Figure 2 illustrates how thermocouples and radiometers can be arranged to determine the thermal balance in the vicinity of a star tracking device mounted on the side of a spacecraft. From the multiple radiations involved, a purely analytical approach to such a situation could be impractical.

An experiment performed in a space simulator is shown in figure 3. Twenty radiometers were mounted on a support bar across the 3-foot diameter of a scale model inflatable spacecraft. An additional radiometer was used to monitor the energy source (a solar simulator). The purpose of the experiment was to determine the effectiveness of a balloon in providing a uniform internal radiation.

Although this radiometer was designed for thermal-vacuum environmental studies, it is believed that this device can be mass produced and serve many useful purposes in industry, particularly if the radiometer is placed in a vacuum tube or case. Since the

radiometer generates an electrical signal, it may be wired to turn on a warning light or ring an alarm bell if a change in radiation intensity occurs. Also, the device may be focused on an object or be made sensitive to specific radiations by the addition of suitable lenses and filters. Weather stations could use the radiometers for daily measurements of solar radiation.

In figure 4 are shown sketches of two industrial applications for which inquiries have been made.

### CONCLUDING REMARKS

A disk radiometer has been designed for space thermal-vacuum environmental studies. Because this radiometer is small in size and constant-temperature references are not required, it effects a minimal thermal disturbance to the test surface. The major feature of this device is a shield between the sensor and mounting surface. This shield is instrumented so that an empirical correction can be applied to the radiometer measurements to compensate for unwanted heat transfer between the sensor and mounting surface. From research thus far, indications are that this new disk radiometer has many possibilities for industrial application.

### REFERENCE

1. Sweet, George E.; and Miller, Howard B.: A Radiometer for Use in Thermal Studies of Spacecraft. NASA TN D-4925, 1968.

### DETAILS OF RADIOMETER

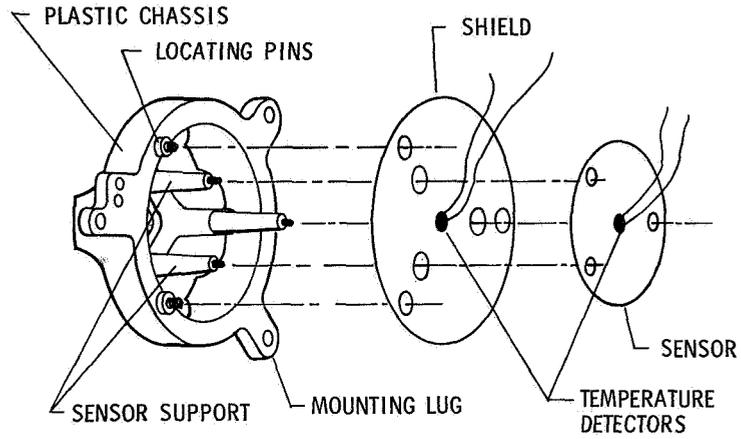


Figure 1

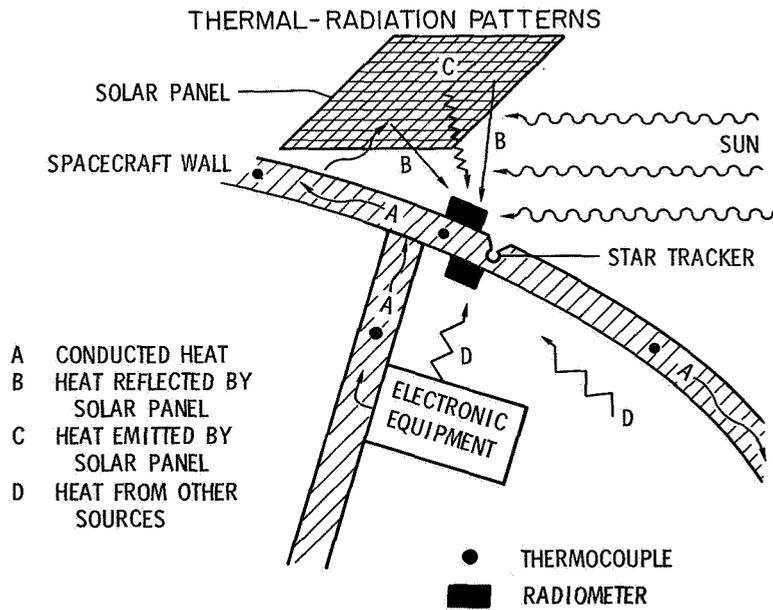


Figure 2

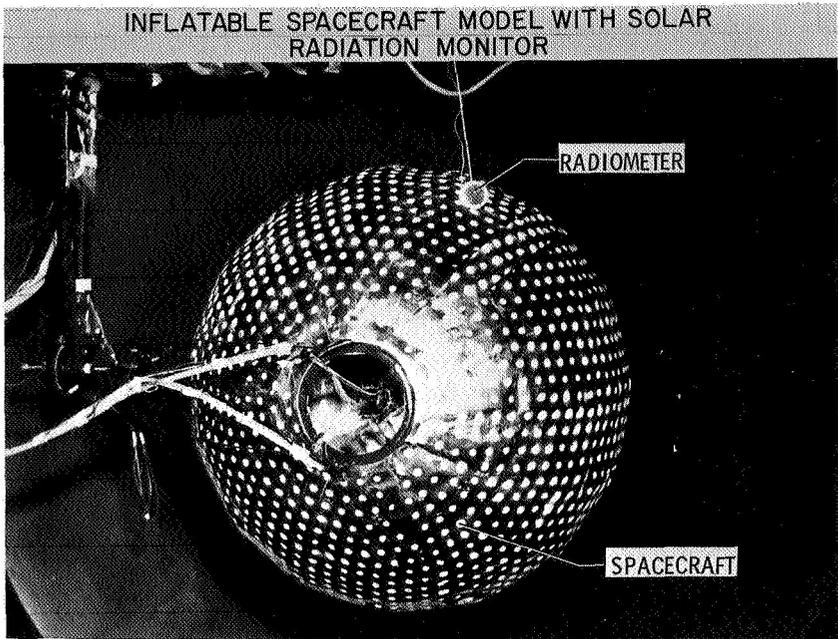
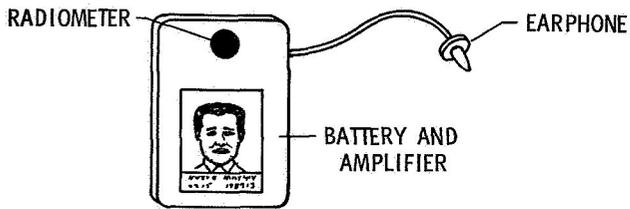


Figure 3

L-3248-4

**SOME POSSIBLE APPLICATIONS**

PERSONNEL SAFETY WARNING



PORTABLE RADIATION MONITOR

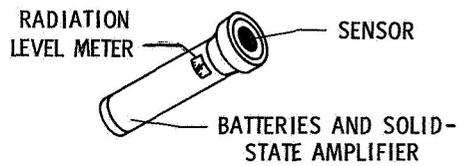


Figure 4



## 16. COLOR-CODED AREA SENSITIVITY MAPS OF PHOTOMULTIPLIERS

By Otto Youngbluth, Jr.  
Langley Research Center

### INTRODUCTION

A technique was developed to display three-dimensional data in a two-dimensional form. The three-dimensional data are obtained from mapping the sensitive area of a photomultiplier (PMT). Because the PMT is a very sensitive light detector, it is used widely in the fields of nuclear science, spectroscopy, astronomy, and so forth. Unfortunately, the PMT has an undesirable characteristic – the per unit area sensitivity is not the same over the entire face of the detector.

### DISCUSSION

A brief description of the PMT operation may present an insight into the cause of the area sensitivity variations. If a small light spot (less than 0.03 mm) is focused on the upper portion of the photocathode as shown in figure 1, electrons are emitted and focused electrostatically by the focus electrode on the first dynode. For each electron that strikes the first dynode, usually two or more electrons are emitted. These electrons are focused on the second dynode, and in turn, for each impacting electron two or more electrons are emitted. This chain reaction or avalanching of electrons is called electron multiplication. Finally, the avalanche of electrons is collected at the anode and an output is measured at the load resistor. However, if the light spot were moved to the lower portion of the photocathode, a different output would be measured. The major factor that controls the sensitivity variations is the focus electrode. The voltage on this element controls the collection efficiency, or in other words, how well the electrons are collected from the entire surface of the photocathode and focused on the first dynode. Even with the focus electrode set at a fixed voltage, the output varies when the light spot is moved from one point to another.

Variations of the per unit area sensitivity as measured at the anode of a 541-A PMT are displayed as a color-coded map in figure 2. Each color represents a different sensitivity. For example, orange represents the maximum response (100 percent) and corresponds to the light spot illuminating the lower portion of the photocathode as shown in figure 1. Dark blue represents 70 percent of the maximum response and corresponds to the light spot illuminating the upper portion of the photocathode.

Thus, if a light spot is focused in the orange area (see fig. 2) and if during the course of the experiment the light spot is allowed to drift into the dark-blue area, the output will

drop 30 percent. The experimenter reading the data assumes that the light intensity has dropped 30 percent. However, this is a false assumption because the light spot moved to a less-sensitive portion on the detector face. An immediate solution would be not to let the light spot move. In many applications this is not possible. An alternative solution would be to diffuse the light or to use optics to flood the sensitive area. These methods work well in some cases, but there are disadvantages in using them. Finally, the experimenter might correct the data. With the assumption that the path of the light spot is known, the experimenter can correct for the variations in sensitivity, that is, if a map of the area sensitivity were available.

Many PMT users know that the sensitivity varies over the detector face. However, in the past to obtain a map of the sensitivity was a tedious, time-consuming, and costly job. Although this paper does not include a means for alleviating the sensitivity variation over the detector face, it presents a relatively fast means for measuring these variations. For example, if the old mapping method presented 1000 data points, one map per day could be obtained. This paper describes a technique that presents more than 10 000 data points and one map could be obtained in less than 3 minutes using Polaroid's Polarcolor, Type 108. The technique requires a system to scan a light spot across the entire face of the PMT and to record the output variations as shown in figure 2.

A block diagram of the system used in the mapping process is shown in figure 3. A raster generator, which supplies a staircase and a triangular wave, drives the light spot of the two oscilloscopes simultaneously to obtain the scanning pattern. The lens focuses the pattern on the face of the PMT. As the light spot scans the entire face of the PMT, the output is amplified and applied to two level detectors. The level detectors are set so that when the signal lies between the two settings, an output is obtained and brightness modulates the display scope. Other color-coded maps such as a weather map could be obtained by supplying the longitudinal and latitudinal data at the x-axis and y-axis, respectively, and by supplying the pressure and temperature data in place of the PMT signal. The next step is to obtain the color coding. At this point it may be important to realize that only one color at a time is recorded per entire scan. Therefore, if six different colors were used, the PMT would have to be scanned six times, with a different color filter for each entire scan.

Figure 4 illustrates the sequence of exposures on the color film. The first exposure was made with the level detectors set so that only the maximum signal would lie between the two settings. Therefore, when the signal level reached the lower setting, the light spot of the display scope was brightened and turned off at the upper level as shown in the first picture of the sequence in figure 4. An orange filter was placed in front of the scope and an exposure was made. The second exposure was made with a green filter and the settings turned down an appropriate amount. When the signal reached the new lower level,

the spot would brighten and turn off at the new upper limit as shown in the second picture of the sequence in figure 4. Similar adjustments were made until the six exposures produced the entire picture. The camera shutter was opened six times exposing a different portion of the film each time.

When the constant-intensity light spot is scanned along the diameter of a 7265 PMT, the output amplitude varies as shown in figure 5. This figure was obtained with the photographic sequence described above. Figure 5 indicates how the different amplitude levels are represented in the color contour maps which follow, with orange representing the maximum response. The single line scan was taken along the horizontal diameter of the PMT as shown in figure 6, which is a color-coded area sensitivity map. This map was made at the optimum setting of the focus-electrode voltage, that is, the setting which produces the largest areas of uniform sensitivity without markedly reducing the gain. This voltage setting can drastically affect the relative area sensitivity map. When the focus electrode was set at one extreme of the voltage range (i.e., at the first-dynode voltage), a map was obtained as shown in figure 7. This map shows that the maximum sensitivity has moved to the lower edge. When the focus electrode was set at the other extreme of the voltage range, or near the cathode potential, the map reversed itself and the maximum sensitivity was located at the upper edge as shown in figure 8. These three maps (figs. 6, 7, and 8) illustrate the influence of the focus electrode on the area sensitivity maps of PMT's.

Figures 9 and 10 are included to demonstrate a different type of presentation. Figure 9 is an area sensitivity map of a 7264 PMT; however, a three-dimensional type of presentation is sometimes more useful. Figure 10 is a "mesa" or three-dimensional type of presentation of the same PMT at the same settings as in figure 9. This type of map is obtained by adding the PMT signal to the raster at the vertical axis of the display scope.

#### CONCLUDING REMARKS

A technique was developed for obtaining color-coded area sensitivity maps of photomultipliers. These maps are needed to indicate just how nonuniform the area sensitivity can be, to indicate what parameters affect the area sensitivity, and to demonstrate how the maps can be optimized. These maps provide the user with new information about PMT's. Therefore, the area sensitivity should be another factor in selecting a PMT for a specific task. These maps provide a challenge to the engineer to devise schemes to compensate for the nonuniform area sensitivity and to the manufacturer to design new focusing elements to produce a PMT with a uniform area sensitivity. Finally, this technique has other applications besides testing PMT's and other photodetectors. For

example, it can be used to color-code any type of mapping data, such as weather or topographical maps, thermal or pressure distributions on reentry surfaces, or any other three-dimensional data to be displayed in a two-dimensional form.

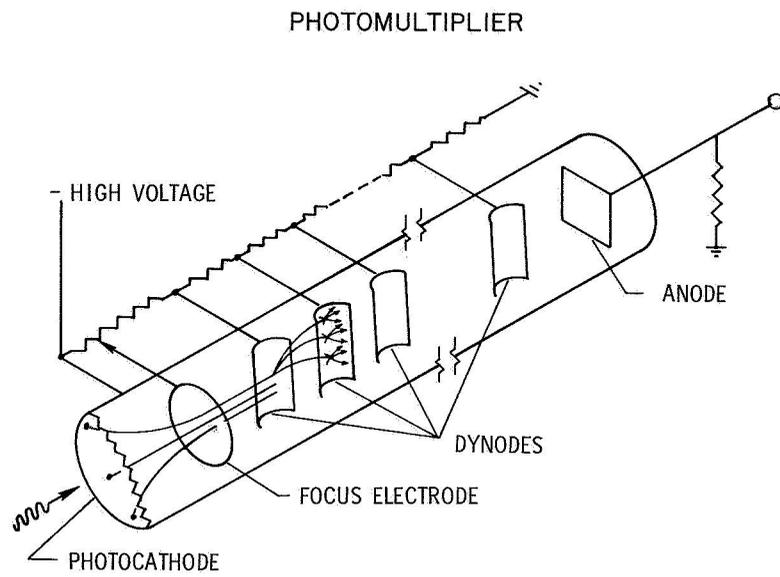
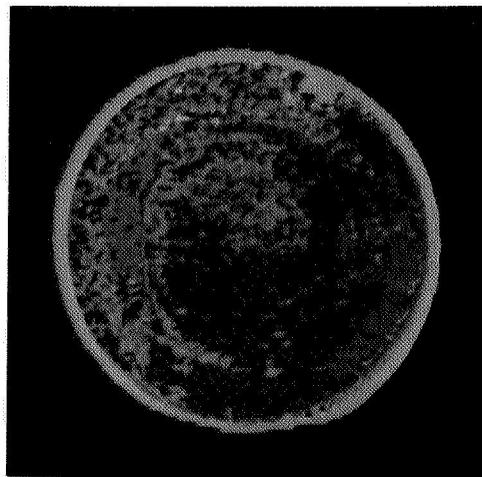


Figure 1



L-69-5200

Figure 2

### SETUP FOR MAKING SENSITIVITY CONTOURS

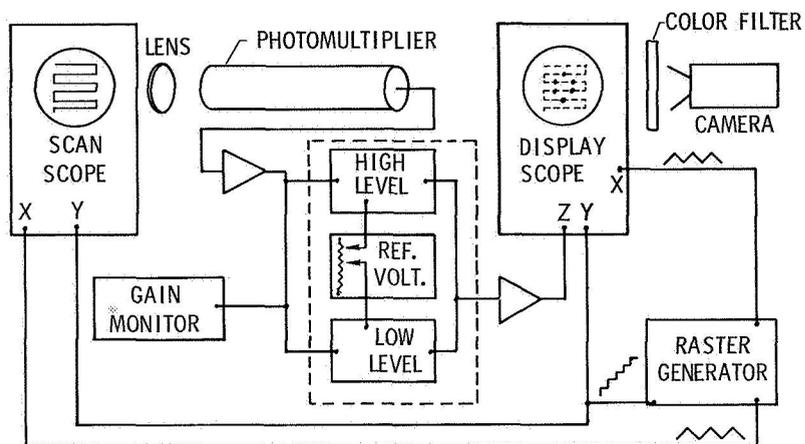


Figure 3

### SEQUENCE OF PHOTOGRAPHING SENSITIVITY CONTOURS

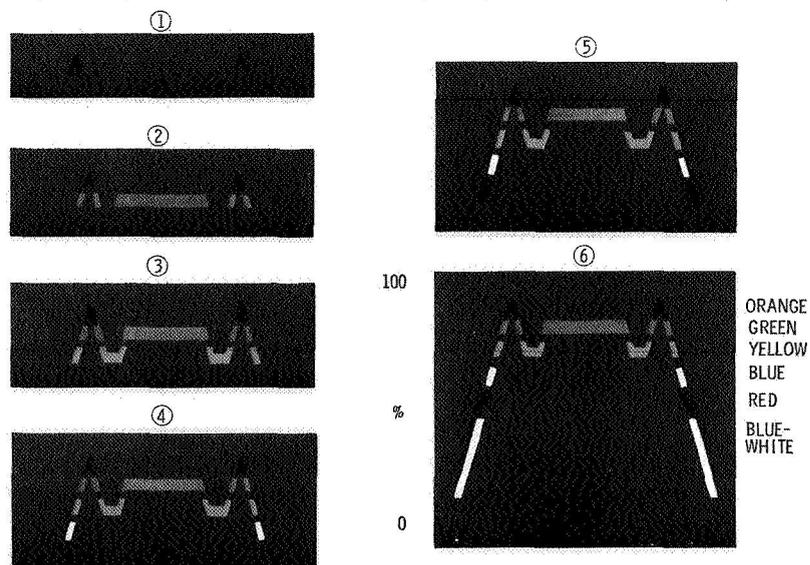
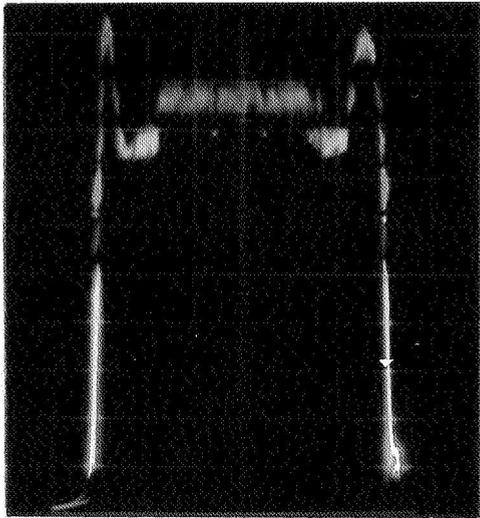


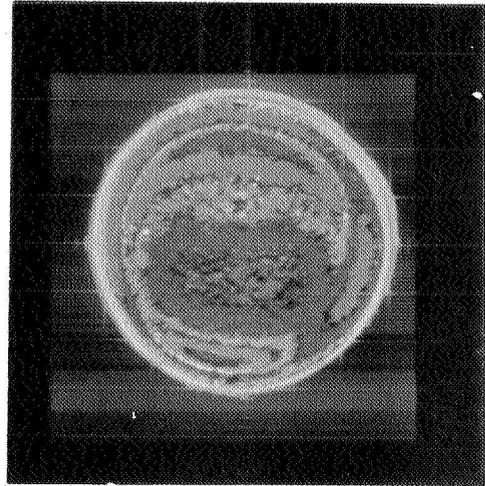
Figure 4

L-69-5201



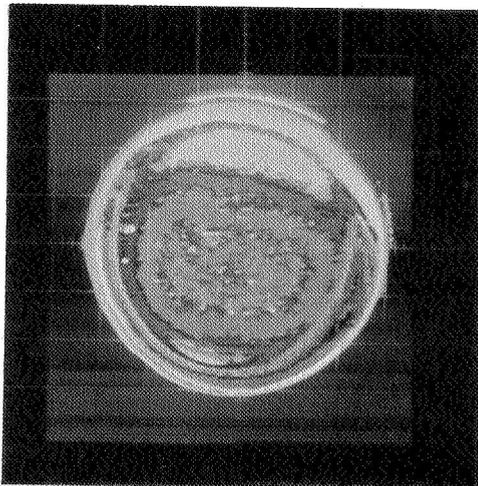
L-69-5202

Figure 5



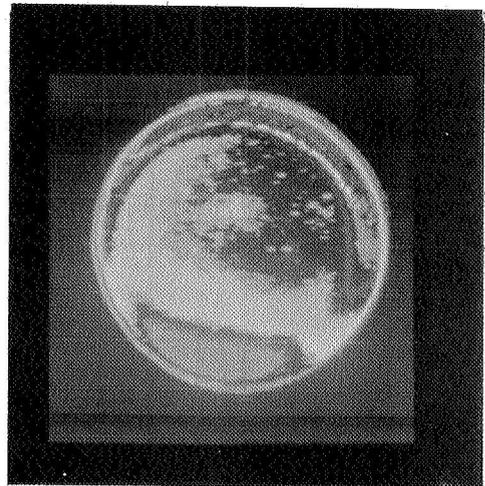
L-69-5203

Figure 6



L-69-5204

Figure 7



L-69-5205

Figure 8

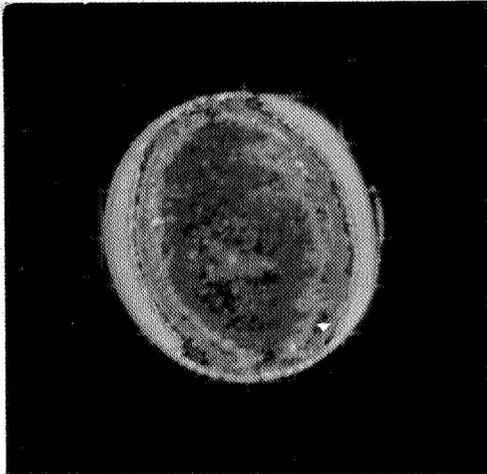


Figure 9

L-69-5206

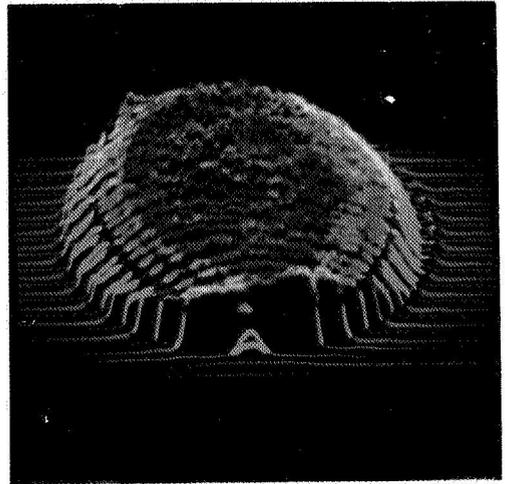


Figure 10

L-69-5207

## 17. SCREENED-CIRCUIT PROCESSING

By Robert L. Stermer, Jr.  
Langley Research Center

Since the early work at Langley Research Center, a number of manufacturers have incorporated screened-circuit technology into their production lines. Because of the basic simplicity and low capitalization of this technology, small business can also compete profitably in the production of screened circuits.

As a research center, Langley's interests were mostly in low-volume production and as such were developed along lines suited for small-business applications. This interest included the developments of tools, materials, and processes which may be directly applicable.

As a review of what a screened circuit is, a typical circuit is shown in figure 1. The conductors, resistors, capacitors, and insulators are printed and fired onto a substrate. To complete the circuit, the active components are bonded in place. The technology required to fabricate this circuit consists of a compatible set of process steps. The word compatible is important. For example, there are four separate firings on this substrate: the conductor material, insulation material, dielectric, and resistor. The firing order must be designed so that the materials may be fired in order of decreasing firing temperature.

There are several points in the film supplement to this paper which may be of particular interest. First, there are the capacitor dielectric materials which are formed in two basic types: the recrystallized ferroelectric and the colloidal suspension of a ferroelectric.

The recrystallized ferroelectric material is essentially a barium titanate ( $\text{BaTiO}_3$ ) glass. Its exact composition is shown in table I. Its characteristics are shown in figure 2. (The curve labels A and B refer to the mixtures in table I.) It is characterized by very high dielectric constants and excellent temperature stability. The batch weights for the colloidal suspension dielectric are shown in table II. This material does not have the very high dielectric constant that the recrystallized material has but is easier to work with and does have good temperature stability as shown in figure 3.

Other points of interest may be some of the tools designed for the process, for example, the screen press shown in figure 4. This machine uses a vacuum chuck to hold the substrate. The height of the screen is very important and micrometer adjustments are supplied to make this setting. A second parameter is the squeegee pressure which is set by using a micrometer adjustment mounted on the squeegee carriage.

It was found that after resistors were trimmed by conventional techniques, they tended to drift. This problem can be overcome by an arc-type trimming in which a pair of closely spaced electrodes are used to localize the arc. After trimming, a subsequent annealing prevented further drift.

A motion-picture film "Thick-Film Microelectronics," serial number L-1013 (16 mm, 18.3 min, color, sound), which shows screened-circuit technology as a compatible set of process steps, is available on loan. Requests should be sent to

NASA Langley Research Center  
Att.: Photographic Branch, Mail Stop 171  
Langley Station  
Hampton, Virginia 23365

TABLE I

COMPOSITION OF RECRYSTALLIZED DIELECTRIC

Component	Percent by weight for -	
	Mixture A	Mixture B
Barium titanate glass	20	80
Barium titanate monocrystals	80	20

\* Barium titanate glass

Constituent	Percent by weight
BaO	54.7
BaF <sub>2</sub>	3.2
TiO <sub>2</sub>	24.0
Al <sub>2</sub> O <sub>3</sub>	7.9
GeO <sub>2</sub>	2.0
SiO <sub>2</sub>	8.2

TABLE II

BATCH WEIGHTS FOR COLLOIDAL SUSPENSION DIELECTRIC

Material	Formula	Percent by weight
Lead monosilicate	PbO · 0.67 SiO <sub>2</sub>	65.0
Barium titanate	BaO · TiO <sub>2</sub>	22.5
Lead zirconate titanate	$\left\{ \begin{array}{l} 0.9281 \text{ PbO} - 0.4737 \text{ TiO}_2 \\ \frac{0.0719}{1.0000} \text{ SrO} - 0.5349 \text{ ZrO}_2 \end{array} \right\}$	10.0
Calcium stannate	CaO · SnO <sub>2</sub>	2.5

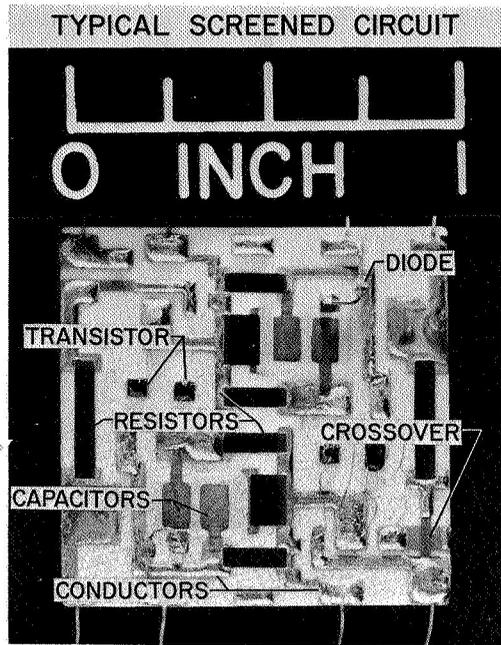


Figure 1

L-2763-1

TEMPERATURE DEPENDENCE OF THE DIELECTRIC CONSTANT  
AT 10kHz

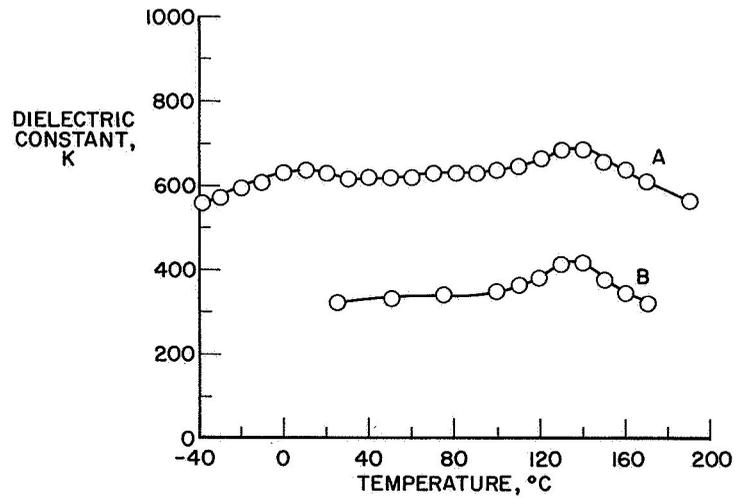


Figure 2

### COLLOIDAL SUSPENSION DIELECTRIC CAPACITANCE & DISSIPATION VS TEMPERATURE

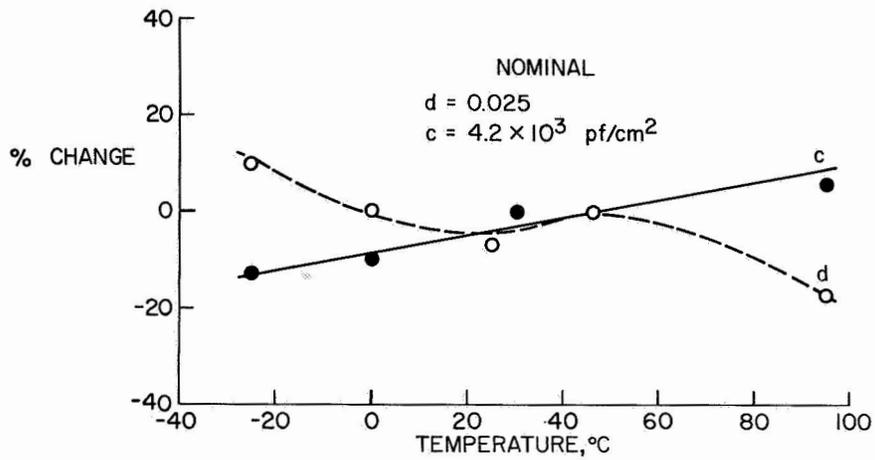


Figure 3

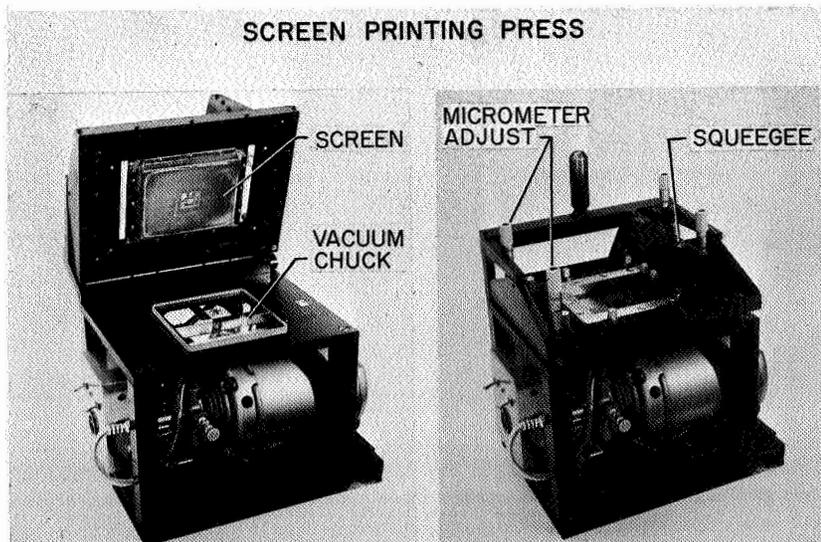


Figure 4



## 18. DIGITAL-SENSING TECHNIQUE FOR INTERFEROMETERS

By K. C. Romanczyk and W. E. Howell

Langley Research Center

### SUMMARY

A technique has been developed for digital readout of interferometer displacements, which offers advantages over those presently available. This technique makes use of a mirror oscillated by a piezoelectric wafer in one arm and a single photomultiplier tube as a sensor. Direction and magnitude of the displacement are displayed on a standard up-down counter to an accuracy of  $\pm 1/8\lambda$ ; this sensitivity can be extended electronically without modification of the interferometer to  $1/16\lambda$  and possibly to  $1/32\lambda$ ,  $1/64\lambda$ , or greater depending upon available signal-noise ratios. The major advantage of this technique is that at each level of sensitivity ( $1/8\lambda$ ,  $1/16\lambda$ ,  $1/32\lambda$ , etc.) the output is inherently digital. An interferometer using this readout technique has been constructed and evaluated, and typical data from this fringe-counting interferometer are presented.

### INTRODUCTION

In an increasing number of operations precise measurements of linear displacements are required; reliability and an accuracy of a few millionths of an inch, or better, is demanded. Basic requirements for a device to make high accuracy measurements include (1) fundamental accuracy – the system should have a self-contained reference, one that can be traced to the National Bureau of Standards; (2) ease of application – ease with which to apply the system to make precision measurements on a wide variety of equipment in relation to other devices having a comparable accuracy; and (3) automatic readout – an output for computer operations, preferably digital. Making use of some form of laser interferometer is one way of meeting these requirements. The purpose of this paper is to determine the feasibility of this approach.

### SYMBOLS

- |   |  |
|---|--|
| A | amplitude of piezoelectric oscillation, quarter wavelengths                |
| a | constant dependent on laser power output                                   |
| d | difference in path length between reference and unknown paths, wavelengths |

I	intensity at any point on fringe (or output of photomultiplier tube)
$J_n$	Bessel function of order n
k	unknown value of motion, wavelengths
$P_0$	photomultiplier-tube output
t	time
$\lambda$	wavelength of light
$\omega$	frequency of oscillation, 6280 radians per second
$\theta, \alpha, \beta$	arbitrary angles

#### DISCUSSION

A diagram of the fringe-counting interferometer used in this investigation is presented as figure 1. In most respects, this interferometer is fairly conventional with a laser source, beam splitter, reference mirror (mirror 1), and a second mirror (mirror 2) attached to the object whose position is to be monitored. The reference mirror is mounted on a piezoelectric wafer which is driven by a 1000-Hz oscillator. The length of the reference arm can therefore be varied at a frequency of 1000 Hz with the amplitude dependent upon the oscillator output. With a slight angle between the two mirrors, the output pattern is a set of fringes that oscillate across the face of the single light sensor, which in this system is the photomultiplier tube. This signal is processed by an electronics system to extract the amount and direction of motion of mirror 2. To understand what goes on downstream requires some analysis of the photomultiplier-tube output. The intensity distribution for a fringe is given as the familiar cosine-squared function:

$$I = 4a^2 \cos^2 \frac{2\pi d}{\lambda} \quad (1)$$

Since the reference path length is being varied,  $d$ , a function of time, is given as

$$d = \frac{A}{4} \lambda \sin \omega t$$

Another factor which influences  $d$  is the motion of mirror 2 from any initial setting. This influence can be represented by adding an unknown motion  $k\lambda$  to the preceding equation; thus,

$$d = \frac{A}{4} \lambda \sin \omega t + k\lambda \tag{2}$$

It is this unknown  $k$  which must be determined in both magnitude and direction. If equation (2) is substituted into equation (1) and the identity

$$\cos^2 \theta = \frac{1}{2} + \frac{1}{2} \cos 2\theta \tag{3}$$

is applied, the resultant photomultiplier-tube output is

$$P_o = 2a^2 + 2a^2 \cos (A\pi \sin \omega t + 4\pi k) \tag{4}$$

Applying a second identity

$$\cos \alpha + \beta = \cos \alpha \cos \beta - \sin \alpha \sin \beta \tag{5}$$

to equation (4) gives

$$P_o = 2a^2 + 2a^2 [\cos (A\pi \sin \omega t) \cos 4\pi k - \sin (A\pi \sin \omega t) \sin 4\pi k] \tag{6}$$

Using the Bessel expansions

$$\cos (A\pi \sin \omega t) = J_0 A\pi + 2J_2 A\pi \cos 2\omega t + 2J_4 A\pi \cos 4\omega t + \dots \tag{7}$$

$$\sin (A\pi \sin \omega t) = 2J_1 A\pi \sin \omega t + 2J_3 A\pi \sin 3\omega t + \dots \tag{8}$$

in equation (6) gives

$$\begin{aligned} P_o = & 2a^2 + 2a^2 J_0 A\pi \cos 4\pi k \\ & - 4a^2 J_1 A\pi \sin 4\pi k \sin \omega t \\ & - 4a^2 J_3 A\pi \sin 4\pi k \sin 3\omega t - \dots \\ & + 4a^2 J_2 A\pi \cos 4\pi k \cos 2\omega t \\ & + 4a^2 J_4 A\pi \cos 4\pi k \cos 4\omega t + \dots \end{aligned} \tag{9}$$

Note the coefficients of the fundamental and second harmonic terms. The first harmonic term consists of a constant term  $4a^2J_1A\pi$  and a term of the form  $\sin 4\pi k$ . Therefore, for every  $1/4\lambda$  traveled by the second mirror, the first harmonic term varies from 0 to 1 and back to 0. Furthermore, as mirror 2 continues to move from  $1/4\lambda$  to  $1/2\lambda$  ( $1/4\lambda \leq k \leq 1/2\lambda$ ) this term varies from 0 to -1 and back to 0. The total effect of this change is to vary the amplitude of the fundamental and its phase. Similarly the term  $\cos 4\pi k$  varies the amplitude and phase of the second harmonic. As an example of the way the system works, suppose the mirror is moved in one direction at a constant rate, then  $k$  will be proportional to time. The amplitude and phase of the carrier will change as shown in the oscillogram in figure 2. The top trace shows the envelope of the fundamental and the bottom trace shows that of the second harmonic. Although it is impossible to simultaneously show the modulation envelope and the carrier phase, each succeeding maximum is opposite in phase to its predecessor. The remaining factor of importance is that  $\sin 4\pi k$  and  $\cos 4\pi k$  are orthogonal functions; hence, the envelopes of the two frequencies reach maximums at different values of  $k$ . This factor is shown graphically by the oscillogram. The second harmonic peak occurs at the valley of the fundamental and vice versa. By taking advantage of this fact and keeping track of how the phase of the carrier changes, each  $1/8\lambda$  motion of the moving mirror can be detected and recorded. The electronic system which accomplishes this purpose is shown schematically in figure 3. The output of the photomultiplier tube is fed through a preamplifier and to two discriminators (filters) simultaneously. (The equations in fig. 3 represent the equation of the wave forms at their respective points.) The previous oscillograms (fig. 2) were recorded at the output of these discriminators. These signals are fed to the phase-sensitive detectors which derive their reference signals from the original driving oscillator for the fundamental, and through a frequency doubler for the second harmonic. The output of these two detectors are dc signals whose amplitude and sign are determined by the coefficients of the fundamental and second harmonic, respectively. The logic system keeps track of the sign changes and the sequence in which they occur. An output is then generated for the bidirectional counter which displays the displacement of the moving mirror from its initial position in  $1/8\lambda$  increments.

It is possible to significantly improve the sensitivity of the output. For example, the sensitivity would be doubled if the argument of the  $\sin 4\pi k$  term were doubled from  $4\pi k$  to  $8\pi k$ ; this can be accomplished if the output of the photomultiplier tube is electronically squared (multiplied by itself) to yield an equation of the following form. The equation is obtained by setting equation (4) equal to equation (9) and transposing the terms of the first line of equation (9). This removes the dc terms of equation (4) and is accomplished electronically by the preamplifier which passes only ac. The resultant equation in closed form is

$$P_{o,ac} = 2a^2 [\cos (A\pi \sin \omega t + 4\pi k) - J_0 A\pi \cos 4\pi k]$$

The squared output  $P_o^2$  is

$$P_o^2 = 4a^4 [\cos^2 (A\pi \sin \omega t + 4\pi k) - 2J_0 A\pi \cos 4\pi k \cos (A\pi \sin \omega t + 4\pi k) + J_0^2 A\pi \cos^2 4\pi k]$$

By applying equations (3) and (5), the identity

$$\sin \theta \cos \theta = \frac{1}{2} \sin 2\theta$$

and the Bessel expansions (eqs. (7) and (8)), the output can be written, neglecting dc terms introduced by the squaring circuit, as

$$\begin{aligned} \frac{P_o^2}{4a^4} = & -J_1^2 A\pi \sin 8\pi k \sin \omega t - \dots \\ & + 2J_0 A\pi J_1 A\pi \sin 8\pi k \sin \omega t + \dots \\ & + J_2^2 A\pi \cos 8\pi k \cos 2\omega t + \dots \\ & - 2J_0 A\pi J_2 A\pi \cos 8\pi k \cos 2\omega t - \dots \\ & - 2J_0 A\pi J_2 A\pi \cos 2\omega t - \dots \end{aligned}$$

The fundamental and second harmonic terms now have coefficients involving  $\sin 8\pi k$  and  $\cos 8\pi k$ , respectively, which doubles the counting frequency or sensitivity of the system yielding a count every  $1/16\lambda$  of motion.

This concept was mechanized and evaluated as follows. To check the  $1/16\lambda$  counting sensitivity a second interferometer was used. (See fig. 4.) The mirrors 1 and 2 are labeled as in figure 1. In addition, a conventional interferometer has been added with the back surface of mirror 2 in its moving leg. Hence the modulating system can be used on one side and the conventional interferometer on the other. The second interferometer was used to check the first. The center trace in figure 5 is the output of the second (conventional) interferometer recorded by a photocell as mirror 2 was moved at a constant rate. The upper sine wave is the output of the fundamental phase-sensitive detector (fig. 3), which is the envelope of the fundamental frequency. The top square wave is the output of a Schmitt trigger which changes state from 0 to 1 (or vice versa) as the sine wave goes through zero. The lower sine wave and square wave are similar outputs for the second harmonic. A full wavelength of motion of mirror 2 has been marked off on the output of the second interferometer. Counting the changes in Schmitt level during this period will show there were 16 changes – eight from the fundamental and eight from the second harmonic Schmitt.

## CONCLUDING REMARKS

This digital-sensing technique for interferometers has the advantage that the sensitivity is electronically adjustable to  $1/8\lambda$ ,  $1/16\lambda$ ,  $1/32\lambda$ , or more. The output is inherently digital; thus, it is compatible with computer operations. Since this technique employs only one light sensor, the alinement of the components are less critical.

# FRINGE-COUNTING INTERFEROMETER

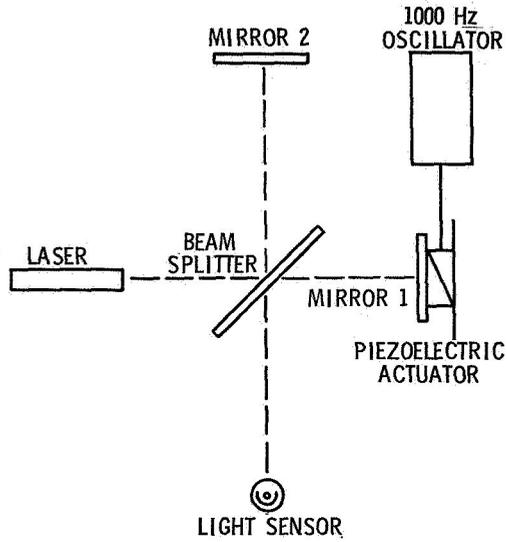


Figure 1

# TYPICAL WAVEFORMS

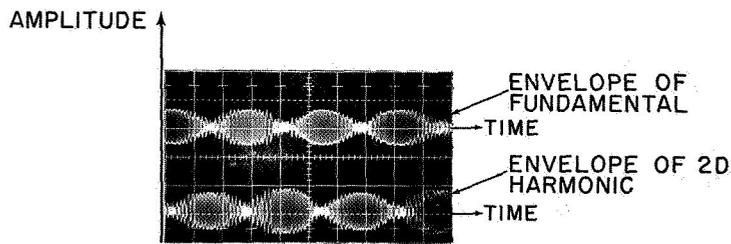


Figure 2

L-2966-3

### ELECTRONICS DIAGRAM OF SYSTEM

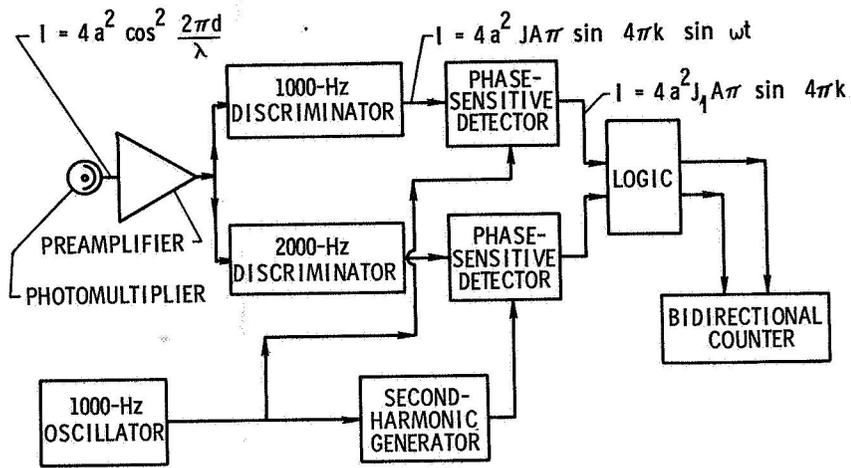


Figure 3

### LABORATORY SETUP SHOWING DUAL INTERFEROMETER

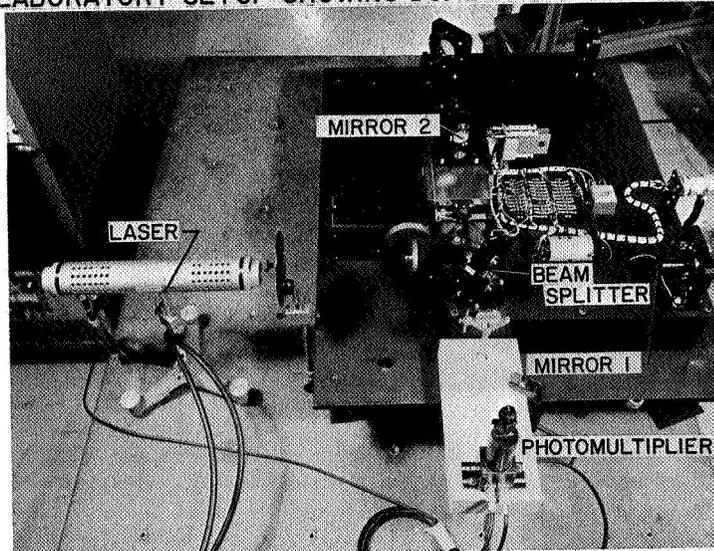


Figure 4

L-2966-6

### 1/16 $\lambda$ COUNTING SENSITIVITY TECHNIQUE

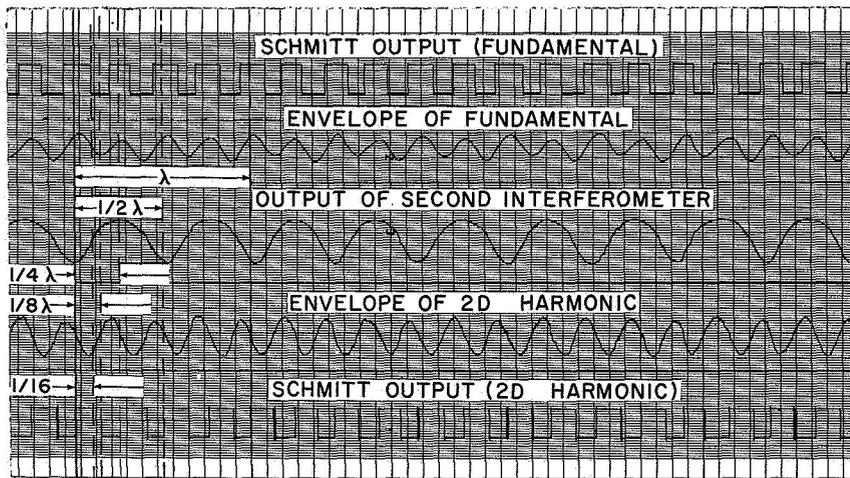


Figure 5



## 19. PROCESSING OF PLASTIC MATERIALS WITH DIELECTRIC HEATING

By Charles B. King  
Langley Research Center

### INTRODUCTION

Ablative heat shields have provided manned spacecraft with reliable protection from severe heating environments encountered as the spacecraft returned from an earth orbit or a lunar mission. The heat shields of Mercury, Gemini, and Apollo were subjected to temperatures from 3000<sup>o</sup> F to 4500<sup>o</sup> F. The feasibility of thermal protection for space vehicles is no longer in question. Future heat-shield technology development must be directed to reducing entry vehicle costs. Heat-shield weight is a major cost factor in an overall flight program. The direct cost of fabricating and applying a heat shield to the vehicle is also a significant item.

The manufacturing procedure for the Apollo heat shields represents the state of the art as it existed several years ago and is fully acceptable on the basis of demonstrated performance of simulated and actual reentry studies. NASA has prepared a motion-picture film<sup>1</sup> entitled "Returning From the Moon" which describes, in part, the manufacturing procedure for the Apollo heat shield.

The Apollo spacecraft was completely covered with honeycomb plastic, adhesively bonded to the spacecraft's metal skin. The honeycomb-clad spacecraft components were positioned on a tape-controlled boring mill outfitted with a special grinding head. The grinder precision machined the honeycomb plastic to the proper height. Next, skilled technicians pressure injected a heated ablation compound into each of the 200 000 honeycomb cells on the large end of the spacecraft. The ablation composition was doughy, fibrous, and required heating to reduce its viscosity. Care was exercised to prevent entrapment of voids as the composition was injected into the cells, and radiographs were taken to determine if voids were present. Excessively large entrapped voids dictated removal of the material from the defective cells, which were then refilled to eliminate the voids. The heat-shield assembly was encased in plastic film to exclude air and moisture since these might have inhibited the cure of the plastic material. A large walk-in oven provided heat to cure the ablation composition at approximately 200<sup>o</sup> F for 24 hours. A repeat grinding operation smoothed the compound to final size.

---

<sup>1</sup>Film No. HQk-SR9 may be obtained on loan from NASA Headquarters, Code FAD, H. Warren Phipps, Chief, Distribution, Washington, D.C. 20546. Any requests must be received 2 weeks in advance of date of showing.

Dielectric-heat processing of ablation materials and heat-shield application concepts are being developed at the Langley Research Center; this technology will permit manufacture of lower cost heat shields on future flight programs.

### REPLACEABLE-PANEL CONCEPT

The basic heat-shield replaceable-panel concept is shown in figure 1. The vehicle is protected by a series of panels. Panel details are shown and the ablator panels are built up as follows: first, a face sheet is shaped to the local vehicle contour; then, a honeycomb panel is bonded to the face sheet; and, finally, the cells are filled with ablation material and cured. The panels are mounted by drilling holes through the ablator at the desired attachment points. Studs are attached to the vehicle surface and the panel is placed on the vehicle skin so that the studs enter the holes in the ablator panel. A nut holds the panel in place, and a plug of ablation material is bonded in the hole.

The principal advantage of this heat-shield configuration is that the panels are easily attached to the vehicle prior to launch, then removed and replaced after the vehicle is recovered. Therefore, vehicle refurbishment and reuse are facilitated. Improved heat-shield materials can be introduced, as their flight qualifications are established, without major program changes. A single vehicle can be used for a variety of different missions by applying different materials or panel thicknesses as appropriate for specific missions.

### DIELECTRIC-COMPRESSION MOLDING

Langley Research Center has processed low-density ablation materials by conventional steam-heated steel molds. Instrumented specimens indicated that very lengthy cure cycles were necessary to affect a complete cure throughout the molded part. Because of the long processing time required for fabrication of these ablative materials, a program was initiated to investigate the direct application of dielectric heating to ablation material processing. Dielectric heating provides a method for uniformly heat curing electrical nonconducting and low thermal conductive organic materials. (See ref. 1.)

Figure 2 is a schematic of a cylindrical dielectric-compression mold that was used in early experiments to mold simple cylindrical billets of ablation compounds 3 inches thick by 10 inches in diameter. The mold assembly consisted of an epoxy-resin glass-fiber filament-wound cylinder. The pistons and shafts of the mold were made of metal, and the shafts serve three purposes: (1) an electrical attachment point, (2) as a vacuum duct so that gases can be exhausted from within the cylindrical mold confines when molding the ablation composition, and (3) to apply compaction force to the compound.

"O" ring seals were provided as required to permit reduction of the pressure within the cavity to approximately 5 millimeters of mercury absolute pressure prior to heating the composition. Infrared transparencies were located in the cylinder wall to permit line of sight between an infrared sensor and the molding composition. Properly mixed powdered ingredients of "B" stage phenolic resin, cured phenolic hollow microspheres, and nylon resin were poured into the cylindrical mold cavity. The top piston was advanced to the vicinity of the composition and the air was exhausted from the mold cavity. The piston shafts were attached to feeders from a 27-megacycle dielectric-heating machine. The entire assembly was within a shielded room to prevent interference with radio communications at the facility. When the capacitor circuit was energized, uniform heating of the ablation composition occurred which was indicated and recorded from the output of the infrared sensor. Phenolic resin cures by a condensation reaction which liberates water vapor that is removed from the mold cavity by a vacuum pumping system through the hollow piston shafts. As sufficient heating causes the phenolic "B" stage resin to become softened the pistons were advanced to apply sufficient pressure to consolidate the ablation powder into a uniformly compacted and cured billet.

The "B" stage phenolic resin remained in a viscous fluid consistency for a short period of time and the dielectric heating of the composition within the mold cavity minimized the delay of the application of pressure to the molding ingredients. The lubricity imparted by the liquefied phenolic permitted geometric consolidation and compaction of the nylon and hollow phenolic microspheres to give a very uniform and homogenous mixture of materials.

## DEVELOPMENT OF DIELECTRIC-PROCESSING TECHNIQUES

Ablation-shield research disclosed applications whereby low-density compositions were very effective ranging from 10 to 20 pounds per cubic foot. The low-density material did not require the molding pressure as had been exerted with piston molding techniques. A vacuum bag capable of exerting from 10 to  $14\frac{1}{2}$  pounds per square inch was found adequate to affect a uniform compaction of ablation compound, and density measurements have shown the density gradient to be at a minimum. The use of a vacuum bag, a low cost structural form, and simple-to-shape aluminum-foil electrodes led to the present processing technique. (See fig. 3.) Fifty-four-inch-diameter phenolic laminate-honeycomb panels could be fabricated by conventional technology with a duplicate metal skin from the vehicle. A structural form composed of glass-fabric reinforced epoxy resin manufactured against the metal skin, aluminum-foil electrodes bonded to the structural form, and use of a flexible vacuum bag sealed to the structural form about its perimeter indicated a very simple and straightforward cure-in-place ablator manufacturing technique.

The honeycomb-laminate assembly was positioned on the center of the ground electrode in the dielectric-heat curing system. The processed ablation compound was introduced into the cell areas of the phenolic honeycomb by pouring the finely divided powdered composition on top of the assembly. A screeding device was then used to level the compound. A vacuum was then created, by using a layer of plastic film, to compact the compound within the cells. Additional compound was introduced and screeded providing an approximate 1/2-inch-thick layer of ablation compound above the phenolic-glass honeycomb to assure complete filling of each honeycomb cell and permit a uniform application of pressure above each cell during the dielectric curing process.

The uncured "B" stage phenolic resin was heated in the dielectric field of the capacitance circuit to yield a viscous fluid; thus, a lubricating action is imparted to the filler particles and permits motion of the fillers to assure a more uniform packing density. Continued heating caused the "B" stage resin to convert to "C" stage, a rigid infusible form. During this process, quantities of water vapor, ammonia, phenyl, and hexamethylenetetramine have been detected. The evolution of these gaseous by-products and their diminishing to a minimal quantity is one method in which the degree of cure can be compared with the cure of phenol formaldehyde resin systems subjected to conventional heating methods such as oven curing. A time-of-flight mass spectrometer was utilized to compare volatile products given off from heated pieces of conventionally cured ablation composition with dielectrically heat cured material. Dielectric-heat curing of ablation compositions posed a serious problem as to the measurement of temperature of the molding composition while in the radio frequency dielectric field. Conventional temperature measurement devices were unsatisfactory, necessitating the use of an infrared sensor calibrated to measure in the temperature range of 170° F to 300° F. The maximum temperature indicated is approximately 270° F. (See fig. 4.) The release of water vapor changes the absolute pressure within the confines of the vacuum bag and can be a simple indication as to the progress of the dielectric curing process and possibly as a method of determining proper cure of the ablation shield.

The largest ablator panel fabricated is the 54-inch-diameter spherical segment shown in figure 5. This size is probably representative of the largest panel that would be required on a manned entry vehicle using the replaceable-panel concept. A photograph of a section of this shield is shown in figure 6. Note the uniformity of compaction of the ablation composition in each individual cell which is typical of all edges exposed of this shield.

## COMPARISON OF SHIELD FABRICATIONS

A comparison of heat-shield technologies is made to point out certain advantages pertaining to dielectric processing of ablative compositions. (See table I.) The Apollo

ablation composition materials and dielectric-process ablation shield material will probably compare in cost. Receipt and inspection of received materials would be required in both technologies to ascertain compliance with materials specifications. The Apollo formulation is a viscous putty which requires heating to facilitate injection of the composition into the individual cells of the heat shield. The heating of the composition will accelerate the hardening or thickening of the composition; therefore, the working life is limited. The dielectric-process ablation composition is formulated as a dry powder and if kept within a reasonable temperature range, has indefinite shelf life; thus the honeycomb filling operation can be performed with an unhurried schedule.

The assembly of the Apollo heat shield necessitates uniting the honeycomb structure to the spacecraft dome by adhesive bonding with resulting spacecraft programing delays. Dielectric processing will use a duplicate metal skin from which the phenolic laminate can be manufactured. The honeycomb would then be adhesively bonded to the phenolic glass laminate. Fiber-glass-reinforced plastic structural forms can be made from the metal skins and equipped with a live electrode to manufacture the refurbishable heat shields independent of spacecraft manufacturing schedules. A comparison in man days to inject the putty-like ablation composition into the cells of the honeycomb heat shield of Apollo was based on 30 seconds to fill each individual honeycomb cell. The 14-foot-diameter shield would contain approximately 200 000 honeycomb cells and this necessitates approximately 208 man days to effect a complete cell-filling operation.

Radiographic inspection techniques are used to determine if the individual cells are completely filled with the ablation composition. These cells which contain composition with voids must be located, ablation composition removed, and the cell refilled to a void-free condition. The removal of material from the cell and refilling of the cell would add to the effort required.

The dielectric-processing method requires introduction of the ablation composition as a powder, an initial evacuation compaction utilizing a vacuum bag, and a second application of ablation powder to assure the powder depth is equal to the honeycomb depth plus 1/2 inch. Additional depth will assure complete filling of each individual cell and uniform compaction within each cell. The effort required to introduce the powder composition into the panels of the refurbishable-type heat shield and to dielectrically heat process the panels would require approximately 24 man days. Radiographic inspection of the heat shield for both the Apollo concept and the dielectric-processing concept would employ approximately the same degree of effort.

One major difference in the systems is based on the concept of working on the heat shield independently of the spacecraft and radiographic inspection would create no additional delay to spacecraft scheduling. The criticality of spacecraft manufacturing schedule makes the refurbishable ablation panel concept attractive. If a refurbishable panel

is found to be defective, it can be discarded or reworked with minor loss of expense or time. The Apollo heat shield, if defective, would require extensive repair involving the spacecraft proper, again necessitating schedule delays. The refurbishable concept permits replacement of ablated panels and a typical ablation environment for low-density shields would be an earth atmospheric entry or a Mars atmospheric entry. The refurbishable-ablator-panel size permits use of small autoclaves and ovens for certain operations, whereas the Apollo shield requires a very large walk-in oven involving large capital outlay. The refurbishable concept also permits a supply of backup parts in the event localized vehicle damage should occur during handling prior to launch; therefore, panels can be immediately replaced. After dielectric curing of the ablation composition in the honeycomb panels, the honeycomb and ablation material are bored and the face sheet drilled to permit mechanical attachment of the panel. It is necessary to adhesively bond ablation material into the cavity where a mechanical attachment is accomplished to the main structure of the airframe or spacecraft.

#### SUMMARY OF DIELECTRIC PROCESSING

It has been shown that large ablation panels can be formed to shape by using dielectric heating to provide the elevated temperature required to cure the ablation material. Dielectric processing requires forms having the desired panel shape, a vacuum bag and vacuum system, a high-frequency-energy source, and a special heat sensor. Conductive sensors and leads cannot be placed in the high frequency field. Possible radio-communication interference may require radio-frequency shielding. Dielectric processing permits the uniform curing of large panels, the use of a powdered-resin system which simplifies the filling of the honeycomb cells, and results in significant savings in both cost and time.

#### REFERENCE

1. Cable, J. Wesley: Induction and Dielectric Heating. Reinhold Pub. Corp., 1954.

TABLE I

COMPARISON OF SHIELD FABRICATIONS

ITEM	APOLLO	DIELECTRIC PROCESSING
MATERIALS COST	-----SAME-----	
TOOLING		DUPLICATE CONTOUR METAL SKINS AND FIBER-GLASS-REINFORCED PLASTIC FORMS
APPLICATION OF COMPOUND	GUNNED INTO EACH CELL (APPROXIMATELY 200 MAN-DAYS)	POWDER Poured INTO CELLS (APPROXIMATELY 24 MAN-DAYS)
CURING TIME	24 hours	2 hours
TESTING	-----NONDESTRUCTIVE-----	

### REPLACEABLE-PANEL CONCEPT

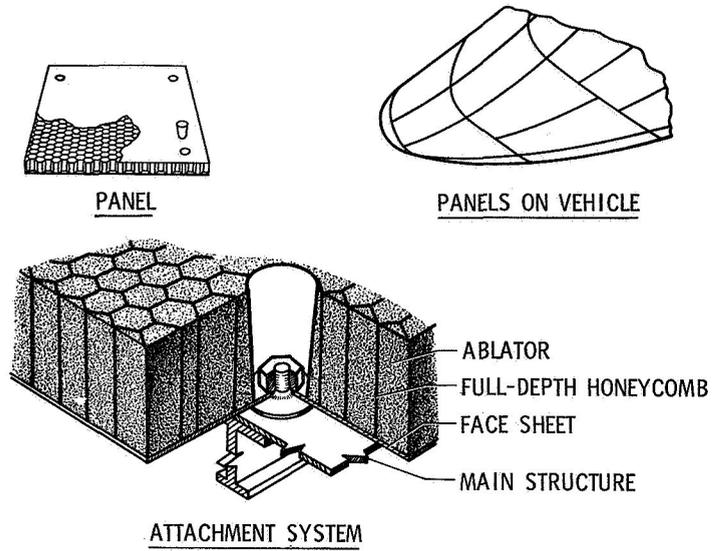


Figure 1

### DIELECTRIC-COMPRESSION MOLDING

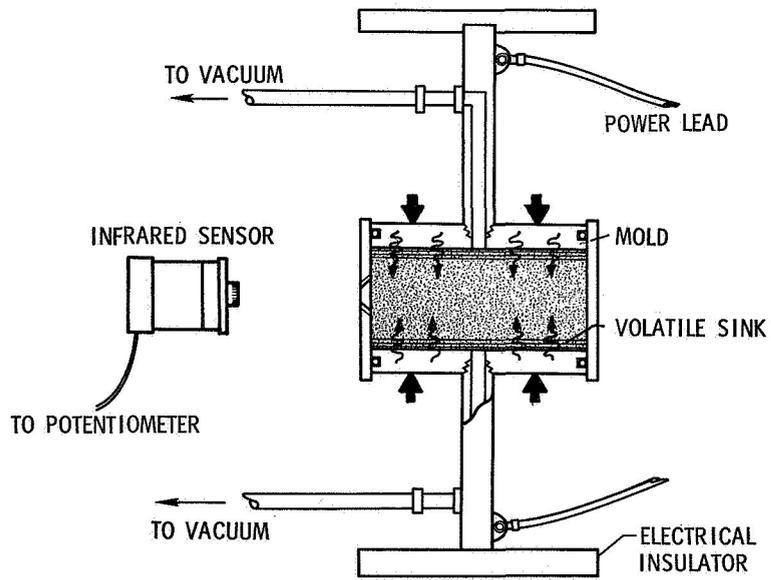


Figure 2

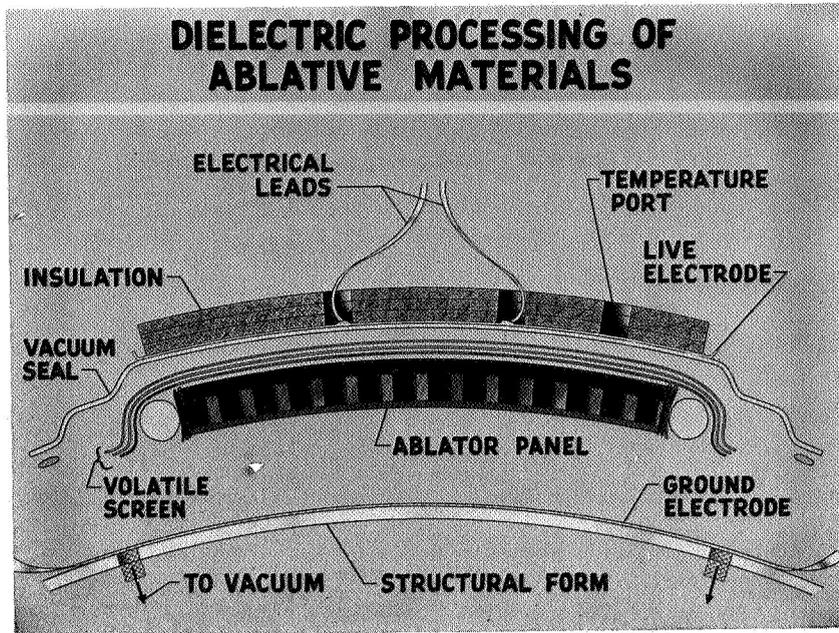


Figure 3

L-2144-A

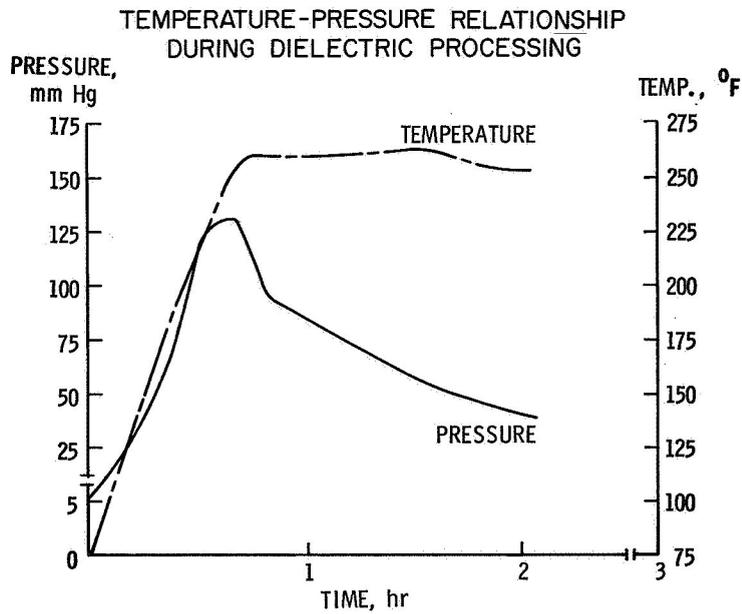


Figure 4

54-inch-DIAMETER HEAT SHIELD

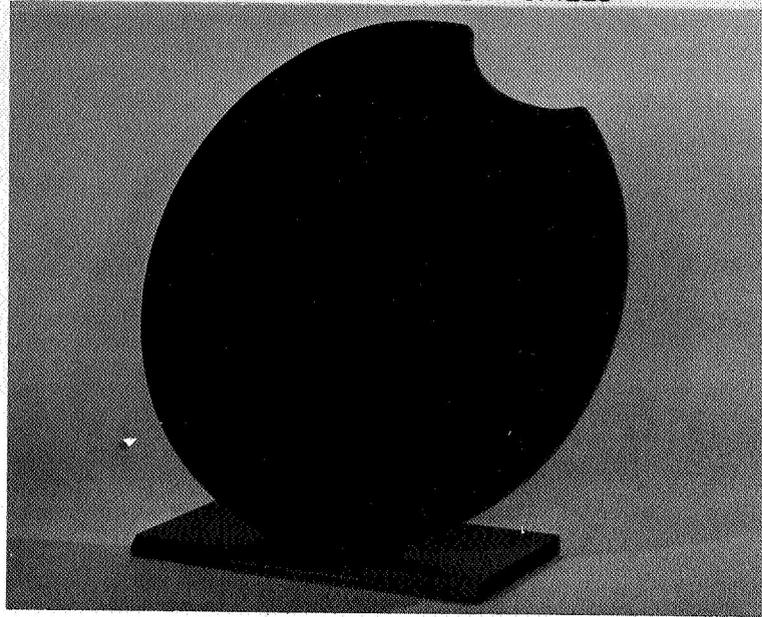


Figure 5

L-3186-13

CROSS SECTION OF 54-in.-DIAMETER HEAT SHIELD

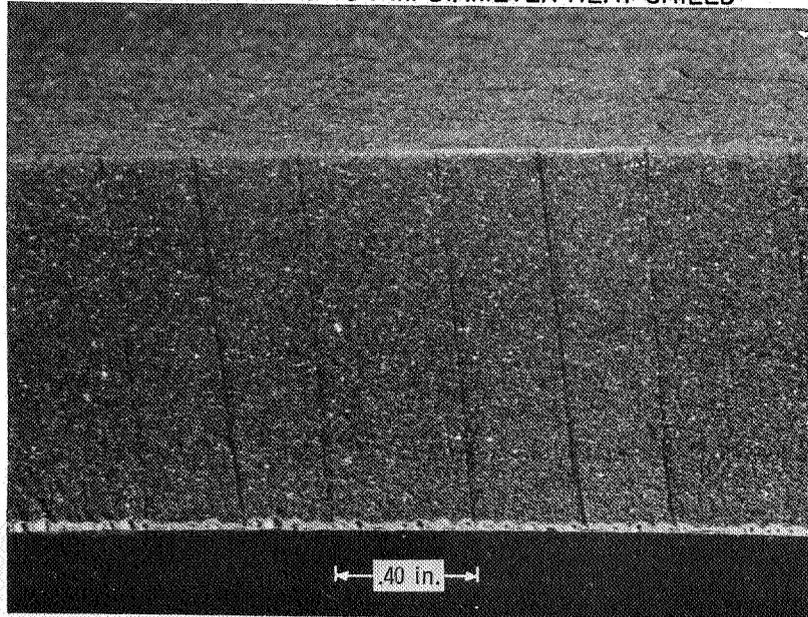


Figure 6

L-3186-12

## 20. PREVENTION OF STRESS CORROSION BY GLASS-BEAD PEENING

By Thomas T. Bales and W. Barry Lisagor

Langley Research Center

### INTRODUCTION

Many of the NASA launch vehicles and spacecraft currently utilize solution-treated and aged Ti-6Al-4V titanium-alloy fuel and oxidizer tanks. During September 1965, several of the tanks failed prematurely during ground tests which simulated actual flight conditions. The result of one such failure is shown in figure 1. Although the failure may appear to have resulted from overpressurization, failure actually occurred at a pressure corresponding to 50 percent of the tank design burst strength. The cause of the failures was not immediately known, but the failures were thought to have resulted from stress corrosion of the titanium alloy when exposed to the oxidizer nitrogen tetroxide ( $N_2O_4$ ).

The Langley Research Center began an immediate investigation to verify that the tanks were failing as a result of stress corrosion from exposure to  $N_2O_4$  and to study various methods of salvaging the existing titanium-alloy tanks. To study this problem, Langley used the typical research approach in that small specimens were used to study and to define the problem and then to alleviate it. Finally, the resultant solution was applied to the actual hardware.

### DISCUSSION

For the reader that may not be familiar with the term stress corrosion, an attempt will be made to explain it by using the schematic diagram in figure 2. Shown in figure 2 is a section of a pressure tank and the requirements necessary to cause stress-corrosion cracking. The three requirements are a susceptible material, such as the tank material, an applied tensile stress, such as exists on the tank wall, and a corrosive environment. As is shown, stress-corrosion cracking occurs when a susceptible material is exposed to the combined action of a tensile stress and a corrosive environment.

#### Determination of Stress-Corrosion Damage

The configuration of the Ti-6Al-4V titanium-alloy specimen that was chosen to study stress corrosion is shown in figure 3. The specimen is fabricated by welding together two strips, approximately 4 inches long, whose ends have been bent to a pre-determined angle. This procedure produces a specimen with a uniformly stressed center section as shown at the upper right in figure 3. The outer surface of such a specimen

is stressed in tension, and it is on this surface that stress-corrosion cracking occurs if the specimen is exposed to a corrosive environment.

If the specimen is tested in compression prior to exposure to a corrosive environment, a certain amount of deflection or shortening  $\delta$  is obtained as is indicated at the lower left in figure 3. If the specimen is tested in a similar manner following exposure during which it has been damaged by stress-corrosion cracking, the shortening  $\delta$  is much less as is shown at the lower right in figure 3. Therefore, the shortening of the unexposed specimen can be used as an indication of zero damage and the shortening of a specimen that has been cracked completely through during exposure can be used as an indication of 100 percent damage.

By utilizing these definitions, Ti-6Al-4V titanium-alloy specimens were exposed to  $N_2O_4$  at  $165^\circ F$  for various lengths of time and were then compression tested unless 100 percent damage had occurred. The data given in reference 1 were obtained and are plotted in figure 4 where stress-corrosion damage in percent appears as a function of exposure time in hours. Stress-corrosion damage is shown to begin between 4 to 8 hours of exposure with complete failure or 100 percent damage occurring after approximately 50 hours. These data helped to verify that the failures of the titanium-alloy tanks occurred as a result of stress corrosion in  $N_2O_4$  but did not answer the question of how to prevent stress corrosion.

#### Prevention of Stress Corrosion

Replacement of the Ti-6Al-4V titanium alloy with a material that was not susceptible to stress-corrosion cracking was not feasible because of the economics and resultant schedule slippage of the Apollo program. Therefore, because of the necessary requirements of stress corrosion mentioned previously in the discussion of figure 2, there were two possible ways to alleviate the problem. First, an attempt could have been made to alter the corrosive environment, which would have meant altering the chemical composition of the oxidizer to make it noncorrosive to the titanium alloy. This approach did not appear promising, however, because of the possibility of affecting the performance of the  $N_2O_4$  in rocket-engine use.

The second approach was to attempt to remove the stress requirement of stress corrosion. Removal of the tensile stresses imposed on the tank wall by pressurization was not feasible. However, it was reasoned that alteration of the stress on the inner surface of the tank which was in contact with the  $N_2O_4$  might be possible. It was determined that residual compressive stresses could be induced in the tank wall by glass-bead peening and that the magnitude of the residual stresses would be sufficient to counteract or cancel the applied tensile stress required for stress-corrosion cracking.

Numerous Ti-6Al-4V titanium-alloy specimens of the type shown in figure 3 were glass-bead peened, were exposed to N<sub>2</sub>O<sub>4</sub> at 165° F for various lengths of time, and were then compression tested. The data obtained are presented in figure 5 along with the data from figure 4. The circular symbols show that the specimens which were peened experienced no stress-corrosion damage after being exposed to N<sub>2</sub>O<sub>4</sub> for up to approximately 170 hours. Consequently, glass-bead peening was considered to be an effective method of preventing stress-corrosion cracking of the Ti-6Al-4V titanium alloy in N<sub>2</sub>O<sub>4</sub>.

The next step was to apply this method to actual hardware. An Apollo reaction-control-system tank was glass-bead peened on contract and was returned to the Langley Research Center for testing. Both the peened tank and an untreated tank were filled with N<sub>2</sub>O<sub>4</sub>, were heated to 105° F, and were pressurized with helium. The test results for the peened tank along with the results for the untreated tank are shown in the following table:

Tank condition	Tensile stress, ksi	Temperature, °F	Time to failure, hr
Untreated	90	105	100
Glass-bead peened	90	105	No failure in 720 hr

The untreated tank failed from stress-corrosion cracking in approximately 100 hours, whereas the glass-bead-peened tank withstood a 30-day (720-hour) exposure. The peened tank was then hydrostatically tested and failed at approximately the same stress as an untreated tank indicating that no degradation resulted from either the peening or the exposure to N<sub>2</sub>O<sub>4</sub>. On the basis of these results, glass-bead peening was considered to be a suitable method for the prevention of stress corrosion of the Ti-6Al-4V titanium-alloy spacecraft and launch-vehicle tanks. However, the equipment and procedures used to peen the tank were not considered suitable for reliable peening of flight-hardware tanks for use in space programs.

#### Equipment and Procedures

In order to meet the schedule requirement of the Apollo program, the necessary equipment and procedures were needed within 30 days. The Langley Research Center, therefore, embarked on a concentrated effort to produce this equipment. Only the basic unit for propelling the glass beads was commercially available. A photograph of the equipment which was designed and built at Langley is shown in figure 6. This equipment consisted of five major units which are

- (1) The bead-propelling equipment for accelerating, sorting, and retrieving the glass beads
- (2) The cradle for supporting and rotating the titanium-alloy tanks
- (3) The lance and carriage for advancing the peening nozzles along the length of the tank
- (4) The lance arm on which the peening nozzles are mounted
- (5) The programing and control equipment for operating the systems

As stated previously, only the basic unit for propelling the glass beads was procured commercially. The cradle was designed for supporting and rotating the tanks and was driven by a variable-speed motor so that the rate of rotation of the tanks could be regulated during peening. The lance and carriage were designed to advance the peening nozzles along the longitudinal axis of the tank. The lance arm was attached to the lance in a manner which permitted it to sweep an angle of  $180^{\circ}$  in the horizontal plane. This angle of sweep was necessary for peening of the hemispherical dome ends of the tanks. Four peening nozzles were mounted on the lance arm in order to peen a larger area per unit time. The lance-arm assembly containing the four peening nozzles is shown in figure 7. The L-shaped shield was lowered in front of the peening nozzles until uniform bead flow was reached and was then raised to allow the glass beads to impinge on the tank wall. Data-track programers, which were housed in the control room shown in figure 6, controlled the variable-speed motors which regulated the rate of tank rotation and lance-arm movement. Thus, these programers made precise control of the peening operation possible.

The flow of beads to the nozzles had to be uniform if the tanks were to be peened uniformly. Therefore, continuous monitoring of the bead flow was necessary. This monitoring was done in a manner that is believed to be unique. The static charge built up on the nonconductive bead line was monitored by a direct-current microvolt ammeter and was recorded on a strip-chart recorder.

Quality control specimens were peened periodically to insure that the established peening parameters did not change. These specimens were standard Almen "N" strips which were peened in the specimen chamber shown in figure 6.

By using this equipment, a total of 26 Ti-6Al-4V titanium-alloy tanks were peened at the Langley Research Center. These tanks were for use in the Apollo spacecraft and service propulsion system, Lunar Module, Saturn S-IVB third stage, and Lunar Orbiter. Half of these peened tanks were for test purposes whereas the other half were intended for use in actual flight vehicles. The size of the treated tanks ranged from 20 inches to 14 feet in length and from 12 to 51 inches in diameter.

Concurrently with the effort of the Langley Research Center on the peening of tanks, several NASA contractors were working on the chemical approach of preventing stress corrosion. One contractor showed that minor additions of nitrous oxide to the  $N_2O_4$  could alleviate the problem. The decision was therefore made by Langley not to peen additional Apollo or Lunar Module tanks. The Marshall Space Flight Center, however, decided to rely on both the peening and the modified oxidizer as a solution to stress corrosion for the Saturn S-IVB third stage. Therefore, the Langley Research Center equipment was transferred to Marshall which, in turn, supplied the equipment to a contractor for the peening of additional tanks.

### CONCLUDING REMARKS

In summary, it has been demonstrated that glass-bead peening can be applied on a large scale to prevent stress-corrosion cracking. As was shown, the glass-bead peening process can be precisely and reliably controlled. Equipment and procedures were established which can be used to peen pressure tanks of various sizes. It is reasonable to suggest that the process can also be used to prevent stress corrosion of metals other than the Ti-6Al-4V titanium alloy, such as stainless steel, various aluminum- and copper-base alloys, or essentially any metal that is susceptible to stress-corrosion cracking. It is therefore hoped that this equipment and the associated peening technology can be utilized by industry. A more detailed description and discussion of this investigation is reported in reference 2.

### REFERENCES

1. Lisagor, W. Barry; Manning, Charles R., Jr.; and Bales, Thomas T.: Stress-Corrosion Cracking of Ti-6Al-4V Titanium Alloy in Nitrogen Tetroxide. NASA TN D-4289, 1968.
2. Bales, Thomas T.; Manning, Charles R., Jr.; and Lisagor, W. Barry (With appendix B by Stephen K. Park): Equipment and Procedures for Glass-Bead Peening Titanium-Alloy Tanks. NASA TN D-4288, 1968.

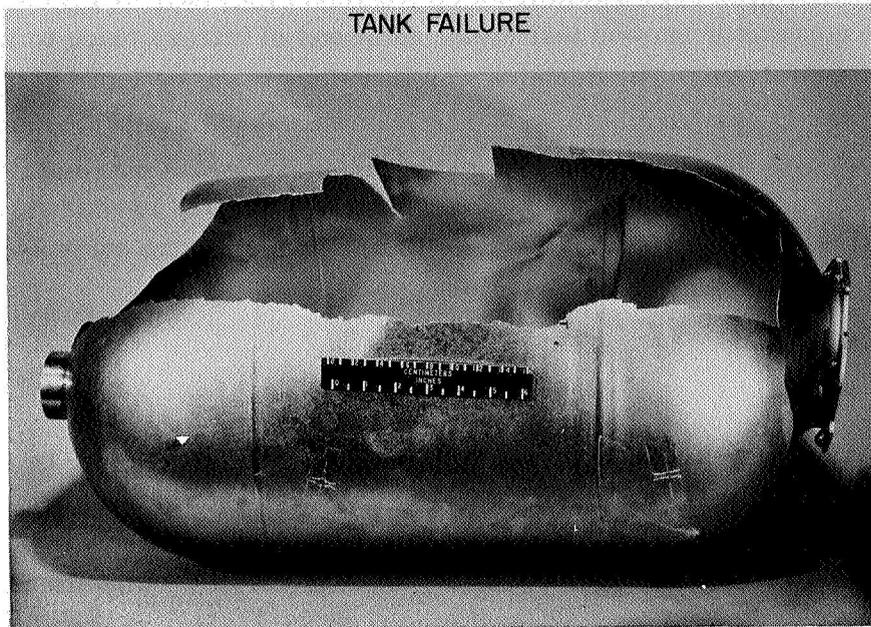


Figure 1

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### REQUIREMENTS FOR STRESS CORROSION

#### PRESSURE-TANK SECTION

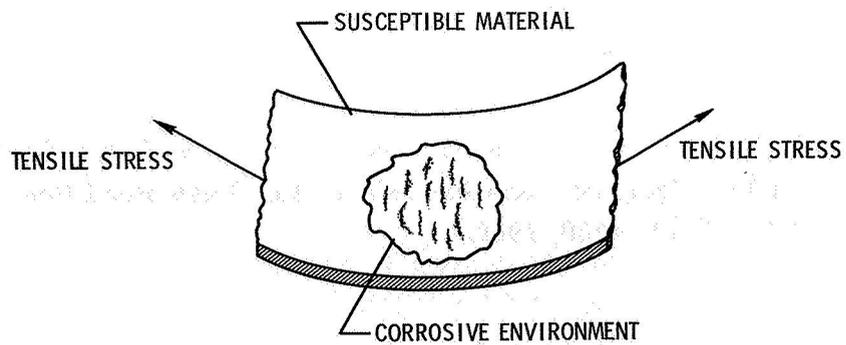


Figure 2

SPECIMEN CONFIGURATION

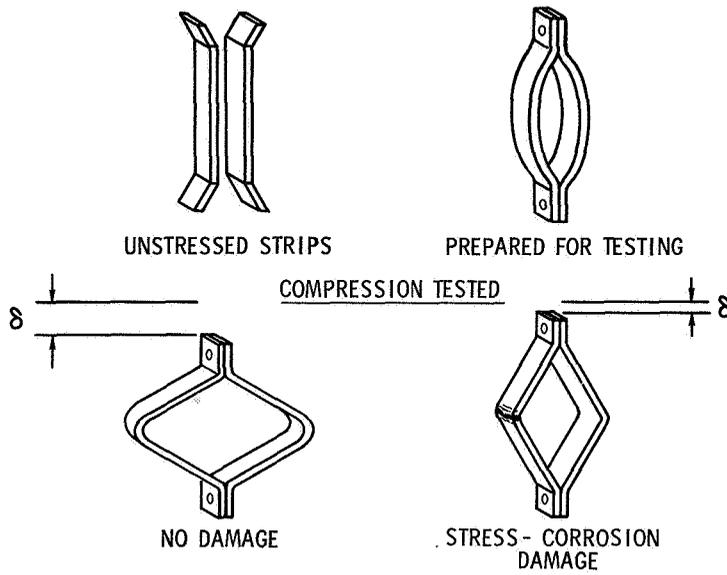


Figure 3

$N_2O_4$  STRESS-CORROSION DAMAGE OF Ti-6Al-4V SPECIMENS

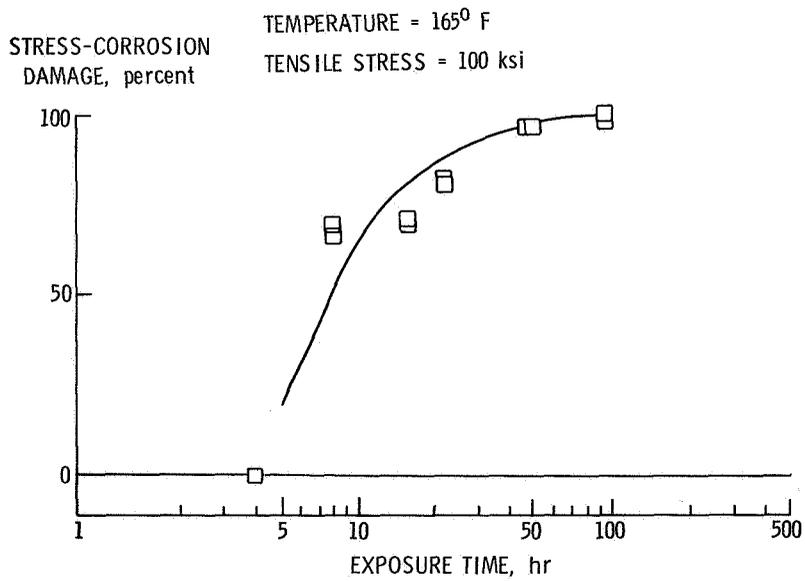


Figure 4

$N_2O_4$  STRESS-CORROSION DAMAGE OF Ti-6Al-4V SPECIMENS

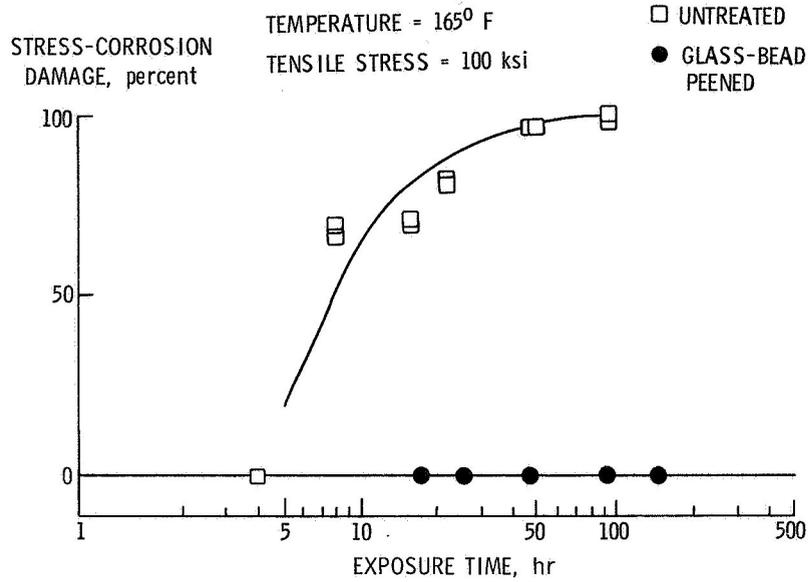


Figure 5

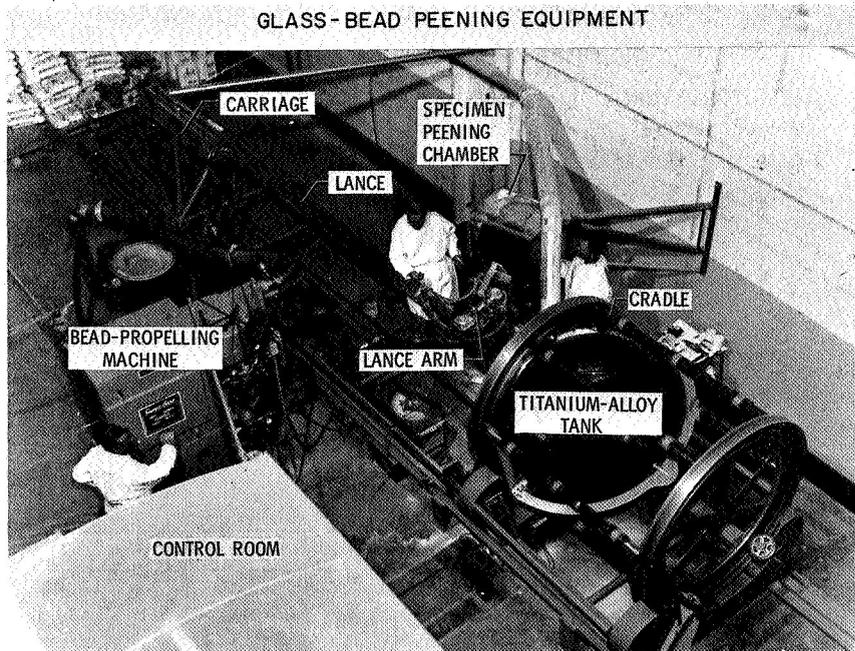


Figure 6

L-66-377

MULTIPLE - NOZZLE ASSEMBLY

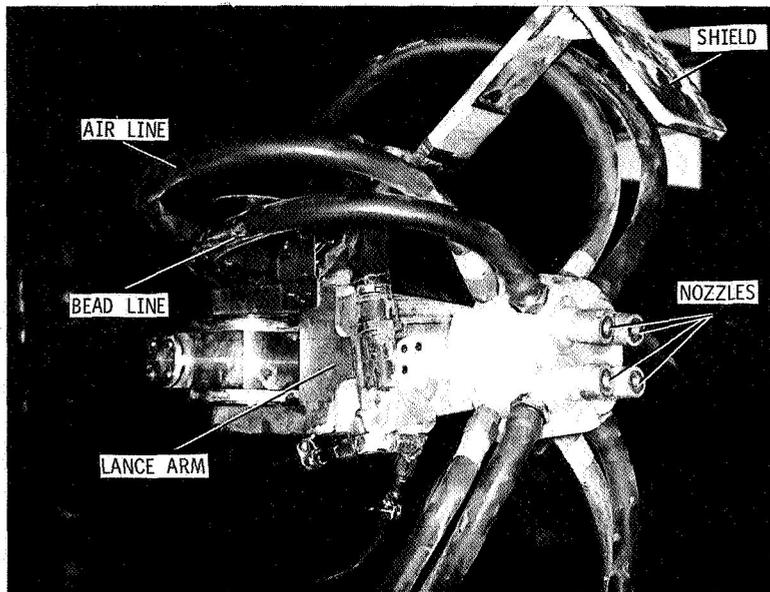


Figure 7

L-67-6667.1



## 21. FABRICATION AND STRUCTURAL APPLICATIONS OF ADVANCED COMPOSITE MATERIALS

By H. Benson Dexter and John G. Davis, Jr.

Langley Research Center

### INTRODUCTION

Considerable interest has developed concerning the potential applications of filament-reinforced composite materials to aerospace structures because of their high strength, high stiffness, and low weight. Results of recent investigations indicate that compressive strengths four to five times greater than in aluminum can be achieved in boron-epoxy composites if all the boron filaments are aligned in the direction of the applied load. A unique fabrication process (ref. 1) is described that was developed for fabricating high quality tubular components with good alignment of the filaments. Fabrication of tubular composite truss structures, typical of unmanned spacecraft is discussed; results of reinforcing metal structural components with composites is also discussed.

### TUBE-FABRICATION PROCESS

Because of handling and fabrication difficulties encountered with single filaments, the filaments are generally impregnated with an epoxy matrix to form a single-ply tape similar to that shown in figure 1. A flow diagram of the process for fabricating both boron-epoxy and S-glass-epoxy tubes is shown in figure 2. The first step consists of cutting and aligning strips of preimpregnated filaments on a teflon rod which serves as a removable mandrel. Care is taken to align the filaments parallel to the longitudinal axis of the mandrel. The width of each strip is equal to the circumference of the tube, and plies are added until the desired wall thickness is obtained. In the second step a heat-shrinkable teflon sleeve is slipped over the mandrel and preimpregnated filaments. The diameter of the teflon sleeve should be just large enough to permit the sleeve to be slipped over the filaments without damaging the outer ply. The third step consists of heating the teflon sleeve with air from an electric heat gun. Shrinkage occurs completely at exposure to temperatures of 350° F with partial shrinkage occurring at exposure to temperatures as low as 200° F. As the sleeve shrinks tightly on the preimpregnated filaments, air entrapped between the plies is squeezed out the end of the sleeve. In addition, the teflon sleeve serves as a mold which forms a smooth outer surface on the filament reinforced tube. Step four consists of inserting the entire assembly in a close-fitting steel tube which prevents the mandrel from sagging while the epoxy resin is cured at elevated temperature. The steel tube and assembly are heated in a circulating-air oven for the final

cure of the epoxy. Step five consists of sliding the assembly from the steel tube, peeling the teflon sleeve from the outer surface of the tube, and extracting the teflon mandrel. Additional details of step three are shown in figure 3. Approximately one-half of the shrinkable sleeve has been heated. Sagging of the mandrel was prevented by applying tension with the aid of a nut on the threaded end of the teflon mandrel. After heating, the sleeve fits tightly on the mandrel and preimpregnated filaments. After complete shrinkage of the sleeve, the assembly is removed from the mandrel support and placed inside the steel tube for curing.

Figure 4 shows typical S-glass-epoxy and boron-epoxy tubes fabricated by utilizing the process as described. The tubes exhibit very smooth inner and outer surfaces which are a result of direct contact of the inner and outer plies with teflon surfaces. The tubes fabricated by using this process exhibit less dimensional variation than the tolerances set for extruded aluminum tubing.

Typical cross sections of both boron-epoxy and S-glass-epoxy tubes are shown in figure 5. A small section of a typical three-ply boron-epoxy tube is illustrated in a magnified view on the left. A rather uniform filament spacing, exhibited by most of the tape used in this investigation, is illustrated. The right photomicrograph shows a small portion of the cross section of an S-glass-epoxy tube. Although the plies are not easily distinguishable, the S-glass-epoxy tube consists of two-ply construction. The boron filaments are about 10 times larger in diameter than the S-glass filaments. The results of void content determinations indicate that essentially void-free composites result when using the fabrication process described.

## TRUSS FABRICATION

The results of compressive and column buckling tests indicate that the tube-fabrication process can produce high quality tubes suitable for structural applications. However, to pursue the structural applications of brittle-like composite materials, an efficient method of joining had to be developed. Figure 6 shows a typical configuration developed for joining tubular components. This configuration utilizes electron-beam-welded tubular aluminum joint clusters. Individual tubes were adhesively bonded to the joint cluster with two-piece split aluminum collars. Some of the collars were stepped on the inside diameter to accommodate differences in component and joint tubing diameters. This joining concept was utilized to fabricate truss structures typical of unmanned spacecraft. (See ref. 2.) A finished boron-epoxy truss is shown in figure 7. The mass placed at the top of the truss was for dynamic testing purposes. The view on the right of figure 7 is a result of rotating the truss 30° clockwise with respect to the left view. Both boron-epoxy and S-glass-epoxy composite trusses were designed and fabricated for comparison with an aluminum truss.

The major objectives of the investigation were to demonstrate that composite trusses could be fabricated and to demonstrate the magnitude of weight savings that could be obtained in practice with the application of advanced composite materials. The design criteria for all the trusses were based mainly on stiffness and vibration requirements. All the trusses were designed to withstand the same static and dynamic loading conditions. The truss configuration selected as the test model is 3 feet wide at the base and approximately  $5\frac{1}{2}$  feet high.

Because of alignment requirements, a precision machined fixture was utilized to fabricate the trusses. The truss-assembly sequence is shown in figure 8. The truss-assembly fixture located the joint clusters. The vertical members were bonded in place first, starting from the top and working down. After the adhesive was allowed to cure overnight, the horizontal members were bonded in place. The completed truss was then lifted from the assembly fixture. Tube requirements for the trusses ranged from  $1/4$  inch to 1 inch in diameter with lengths up to 25 inches. The S-glass-epoxy tubes were three-ply construction, whereas the boron-epoxy tubes were both two- and three-ply construction.

A weight comparison of aluminum, S-glass-epoxy, and boron-epoxy trusses is shown in figure 9. The S-glass-epoxy truss weighs approximately 70 percent as much as the aluminum truss, whereas the boron-epoxy truss weighs only 40 percent of the aluminum truss. The total joint weights for all trusses were approximately equal. Although composite materials are much more expensive than conventional metals, weight savings such as shown in figure 9 make composites very attractive for advanced structural applications.

## REINFORCED METAL STRUCTURAL COMPONENTS

Another area of application of advanced composite materials is selective reinforcement of metal structural components with unidirectional filamentary composites, applied to locations where the maximum benefit can be obtained. Preliminary experimental and analytical results (ref. 3) indicate that considerable weight savings are possible with this reinforced metals approach. The metal structure to which the composite is adhesively bonded retains much of the metal fabrication and joining technology that has been developed for aircraft structures.

Figure 10 shows an aluminum tube reinforced with boron-epoxy. This tube was fabricated by using the process previously described except that the aluminum tube serves as the mandrel. The cross section of the tube wall illustrates uniform filament spacing for a typical five-ply composite.

Figure 11 shows some results of reinforcing aluminum tubes with various amounts of boron-epoxy. The tubes were subjected to compressive loading and shattering of the filaments occurred at maximum load. The experimental results shown are for tubes of approximate equal weight. The equal weight tubes were obtained by chem milling the inside of the aluminum tube a certain amount and adding an equal weight of boron-epoxy to the outer surface. The compressive load-carrying ability varies linearly from 4000 pounds for all-aluminum to 35 000 pounds for an 11-ply all-boron-epoxy composite. The experimental data agree quite well with the rule-of-mixtures calculations. This approach of reinforcing metals with composites is being extended to other structural components. Figure 12 shows some experimental results of aluminum skin-stringer panels reinforced with unidirectional boron-epoxy laminates. As shown on the right of figure 12, boron-epoxy strips were adhesively bonded to the outstanding flanges of the stringers. The aluminum panel reinforced with boron-epoxy exhibits an increase in compressive load capability of 50 percent above the all-aluminum panel for an increase in weight of only about 15 percent. The reinforced metals approach appears to be more attractive than the all-composites approach for immediate incorporation of advanced composites into aircraft structures. The reinforced metals approach is especially attractive because of the use of existing fabrication and joining technology for conventional metal structures.

#### CONCLUDING REMARKS

Increased load capabilities of reinforced metal structural components merit special attention in the future design of structures. A unique tube fabrication process was utilized to produce high quality tubes suitable for truss-type structures. A boron-epoxy truss demonstrated weight savings in excess of 50 percent when compared with an aluminum truss subjected to the same loading conditions.

#### REFERENCES

1. Davis, John G., Jr.: Fabrication of Uniaxial Filament-Reinforced Epoxy Tubes for Structural Applications. Advanced Techniques for Material Investigation and Fabrication, SAMPE Vol. 14, Soc. Aerosp. Mater. Process Eng., c.1968.
2. Davis, John G., Jr.; and Rummler, Donald R.: Application of Advanced Materials to Truss Structures. Materials and Processes for the 70's, SAMPE Vol. 15, Soc. Aerosp. Mater. Process Eng., c.1969, pp. 37-57.
3. Zender, George W.; and Dexter, H. Benson: Compressive Properties and Column Efficiency of Metals Reinforced on the Surface With Bonded Filaments. NASA TN D-4878, 1968.

# BORON-EPOXY COMPOSITE

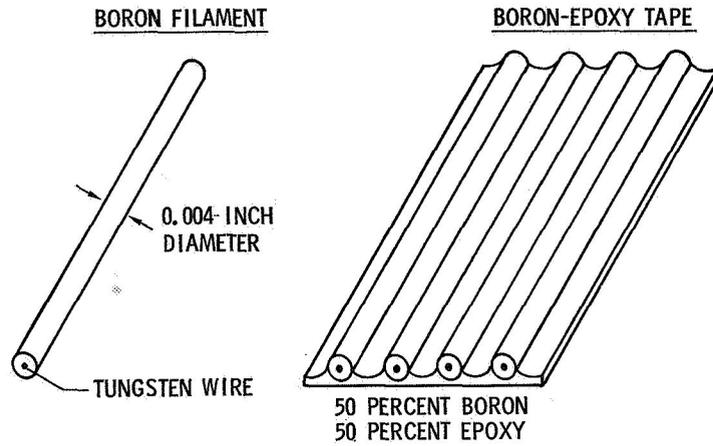


Figure 1

## FLOW DIAGRAM OF FABRICATION PROCESS

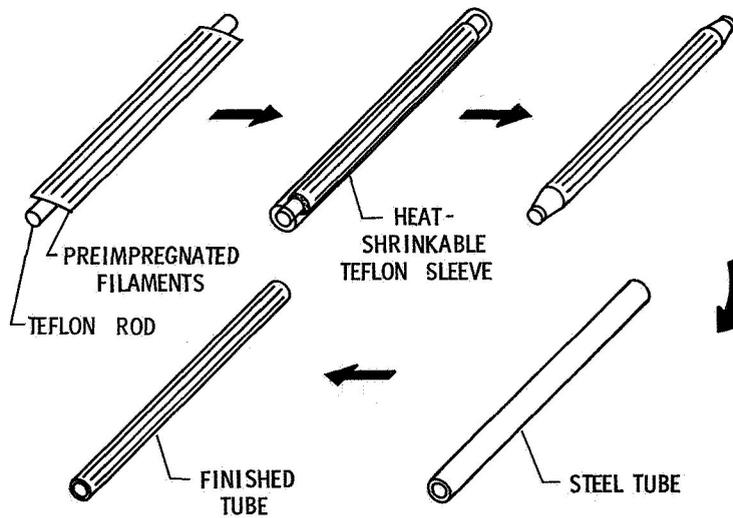


Figure 2

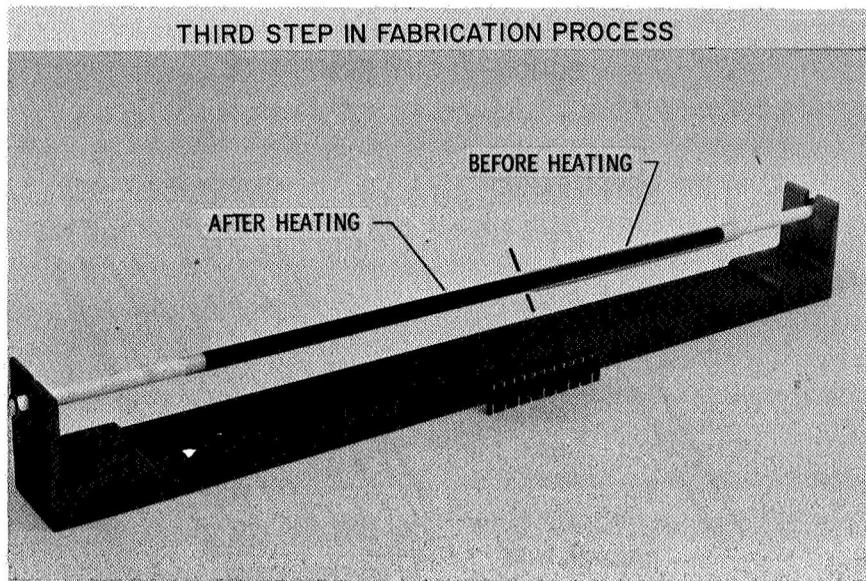


Figure 3

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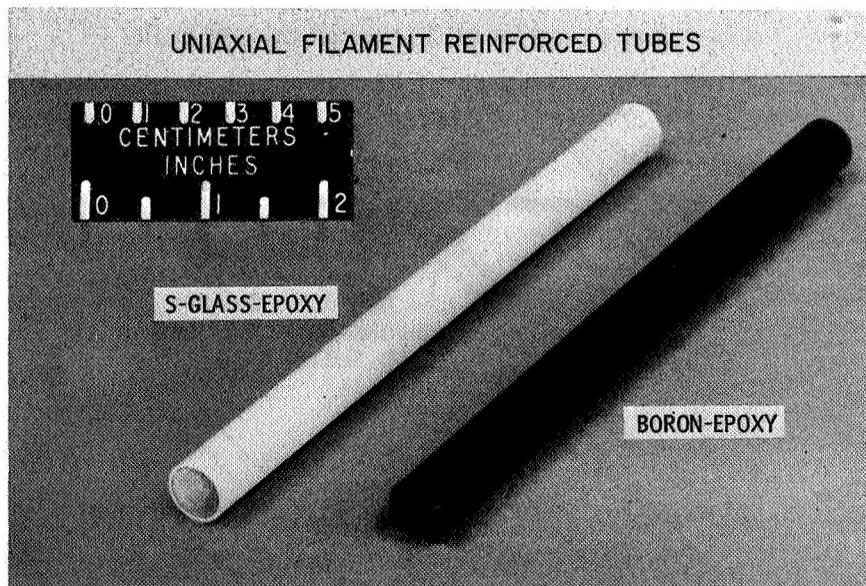


Figure 4

L-3254-4

# TUBE CROSS SECTIONS

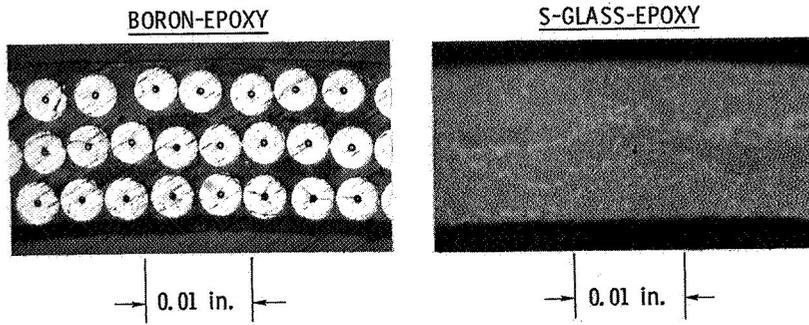


Figure 5

L-3254-5

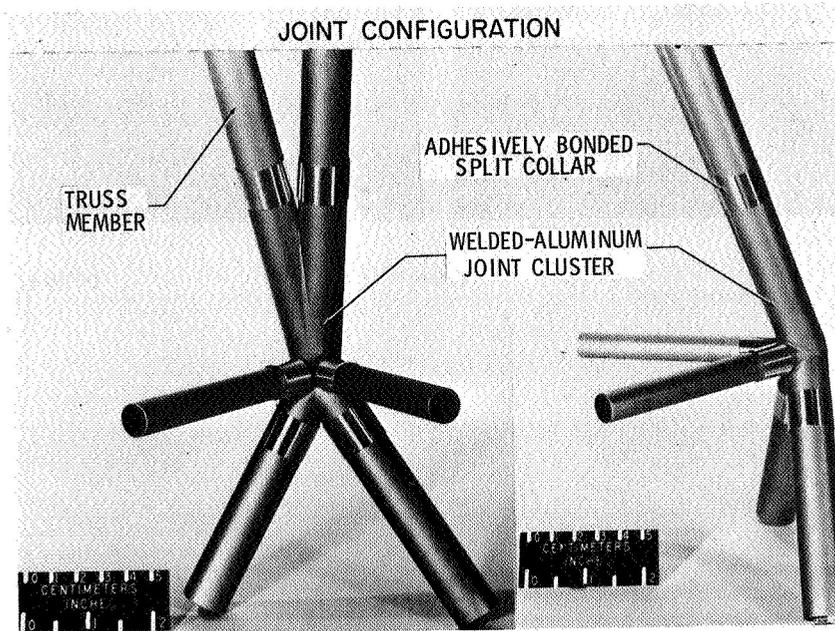


Figure 6

L-3185-3

BORON-EPOXY TRUSS

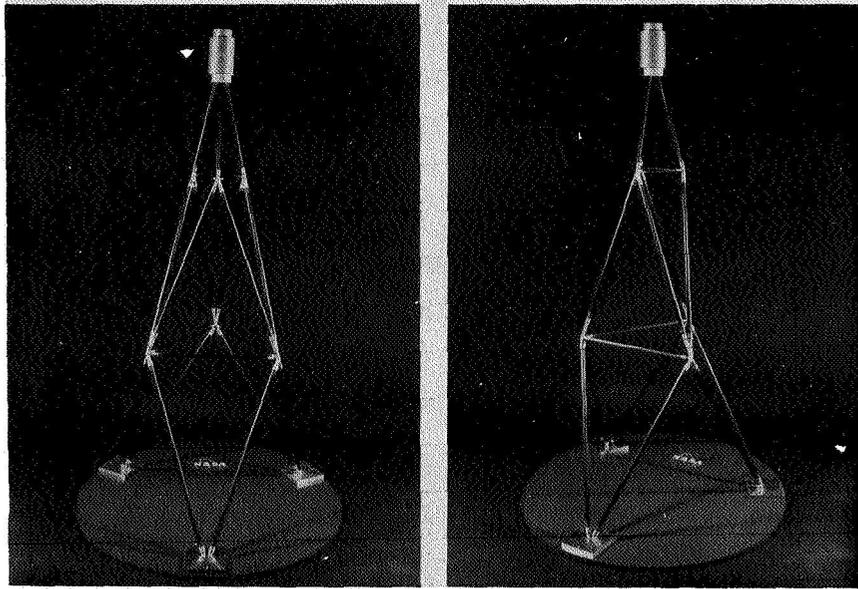
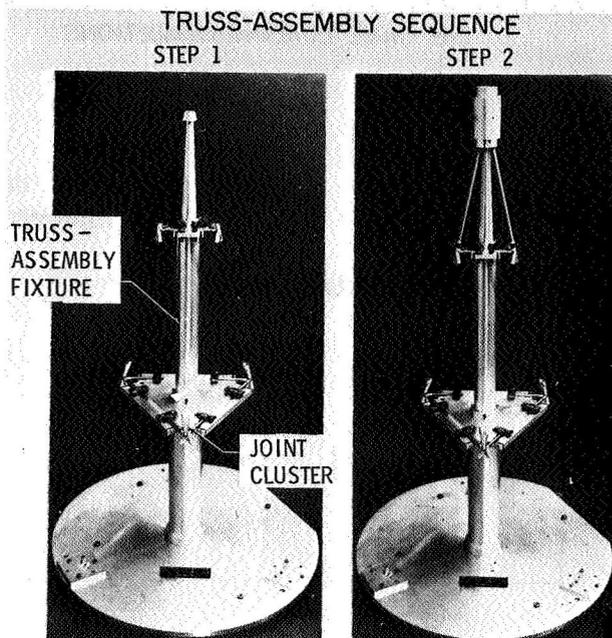


Figure 7

L-3254-6



L-3185-4

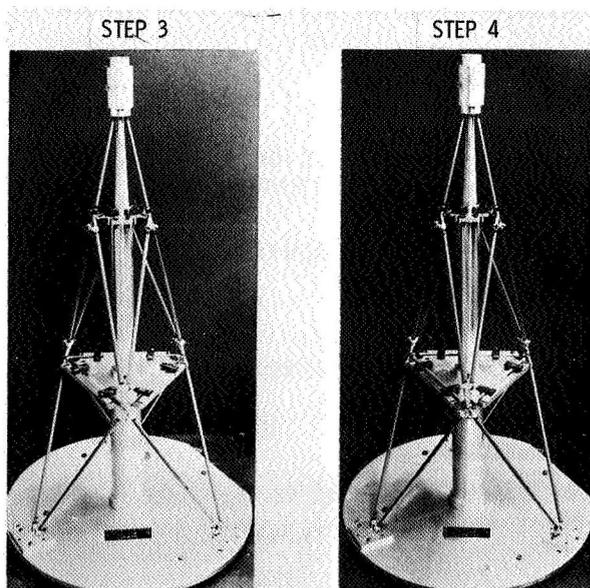


Figure 8

L-3185-5

COMPARISON OF WEIGHTS OF TRUSSES DESIGNED FOR THE SAME LOADING CONDITIONS

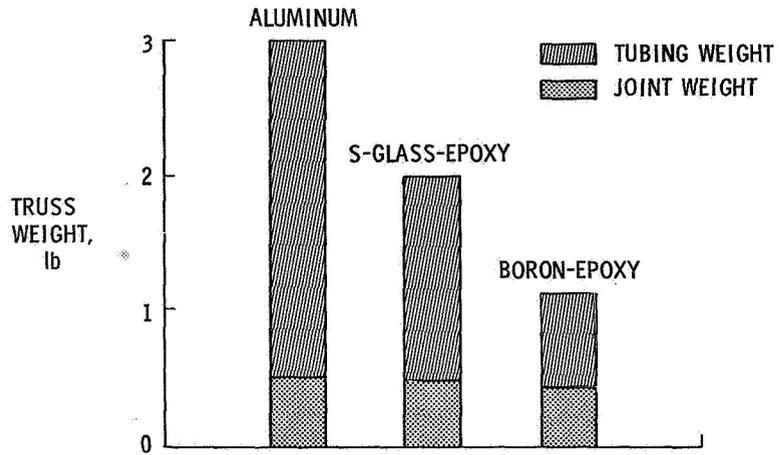


Figure 9

ALUMINUM TUBE REINFORCED WITH BORON-EPOXY

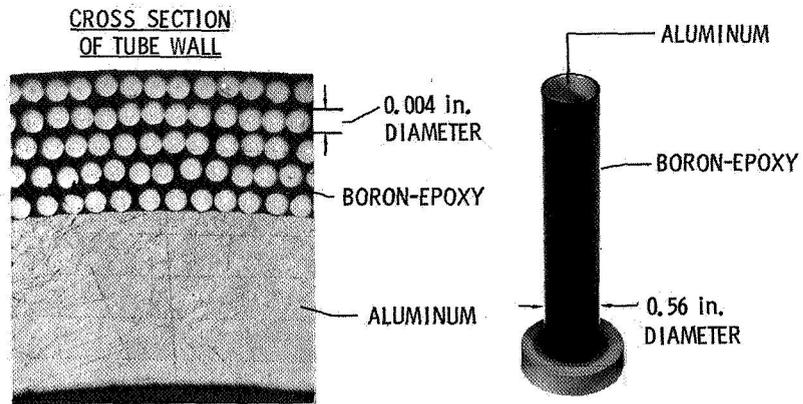


Figure 10

L-3254-11

ALUMINUM TUBES REINFORCED WITH BORON-EPOXY  
 COMPRESSIVE LOAD TESTS

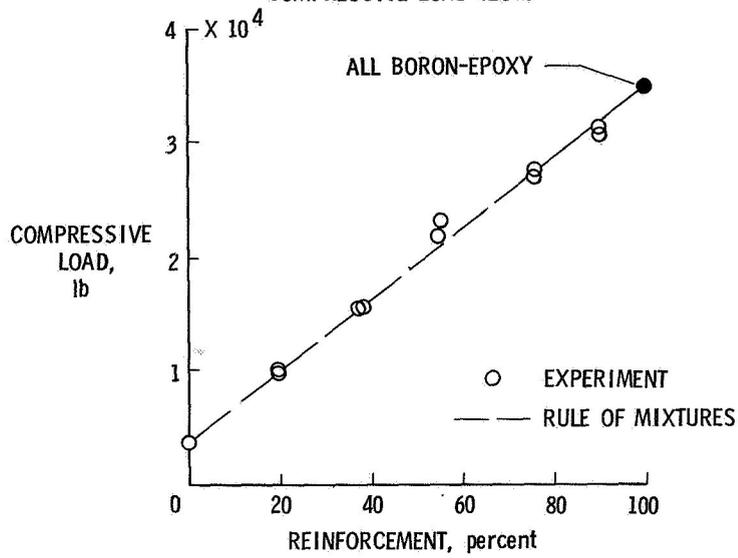


Figure 11

ALUMINUM SKIN-STRINGER PANEL  
 REINFORCED WITH BORON-EPOXY

ALUMINUM  
 ALUMINUM/BORON-EPOXY

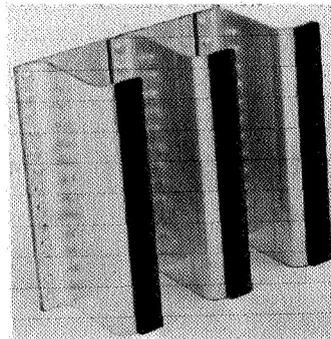
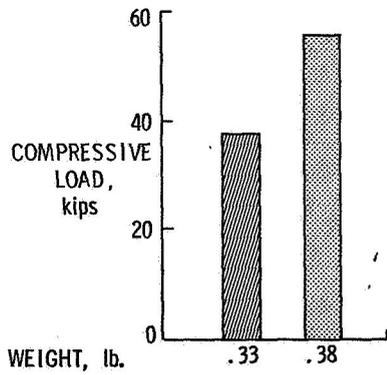


Figure 12

L-3254-12



## 22. DESIGN TECHNIQUES FOR REDUCING OUTGASSING FROM MECHANICAL APPARATUS IN VACUUM

By Vernon P. Gillespie, Gerald L. Gregory,  
and Donald A. Lietzke

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### INTRODUCTION

In the past decade there has been an increased need for the design and construction of mechanical apparatus which can operate in the vacuum environment. In particular the ultrahigh vacuum region,  $10^{-9}$  torr and below, is of prime importance to NASA for the development and evaluation of spacecraft systems. Private industry has also found a variety of uses for ultrahigh vacuum; chemical processes, semiconductors, thin films, and food processing are but a few of the industrial applications. For each application it is necessary to design and construct mechanical apparatus which will function in the ultrahigh vacuum region. In the design and construction of such apparatus, one must rely on techniques and methods compatible with existing vacuum technology. References 1 to 4 are vacuum textbooks and handbooks in which vacuum fundamentals are discussed. In the present paper a brief review of vacuum fundamentals is presented, and several techniques developed at Langley Research Center during the design and construction of mechanical apparatus for vacuum use are discussed.

### VACUUM FUNDAMENTALS

In reviewing the fundamentals associated with the vacuum environment, the unit of pressure is the torr. The unit torr is defined as  $1/760$  of a standard atmosphere and is approximately equal to 1 millimeter of mercury. The generally accepted degrees of vacuum are as follows:

- (1) Low vacuum, 760 torr to 25 torr
- (2) Medium (rough) vacuum, 25 torr to  $10^{-3}$  torr
- (3) High vacuum,  $10^{-3}$  torr to  $10^{-6}$  torr
- (4) Very high vacuum,  $10^{-6}$  torr to  $10^{-9}$  torr
- (5) Ultrahigh vacuum,  $10^{-9}$  torr and lower

## Ultrahigh Vacuum Region

Experience at the Langley Research Center has largely been centered around designing and fabricating mechanical apparatus for use in space simulators. The present requirements of simulating interplanetary space (pressures between  $10^{-9}$  and  $10^{-16}$  torr) dictate that mechanical apparatus operate in the ultrahigh vacuum region. Although the ultrahigh vacuum environment is most frequently characterized by its pressure, the more significant feature is its low molecular density. For example, the molecular density of air at  $20^{\circ}$  C and  $1 \times 10^{-10}$  torr is approximately  $3 \times 10^6$  molecules/cm<sup>3</sup>; whereas, at 760 torr (room conditions) the molecular density is approximately  $3 \times 10^{19}$  molecules/cm<sup>3</sup>. As a result of the low molecular density of a vacuum, materials when placed in vacuum become a continual source of gas. These gases evolve from the surface of a material as well as from the bulk.

In order to attain ultrahigh vacuum in present-day space simulators, it is necessary to reduce the quantity of gas that evolves from a material or apparatus in vacuum. The effect of these gases on the ultimate pressure of a space simulator or vacuum chamber is illustrated in the equation

$$P = Q/S \quad (1)$$

In this equation  $P$  is the ultimate or final pressure in the vacuum chamber,  $Q$  is the total quantity of gas evolving from the chamber construction material and from the mechanical apparatus in the chamber, and  $S$  is the rate of gas removal from the chamber (the vacuum-pump capacity). Therefore, for a given vacuum chamber (fixed  $S$ ), lower pressures are obtained by reducing the quantity of gas evolving from the apparatus in vacuum.

### Major Gas Sources

Gases can originate from various sources associated with a mechanical apparatus in a vacuum chamber. The major sources are (1) material outgassing and (2) virtual leaks.

Material outgassing.- Outgassing is defined as the spontaneous evolution of gas from a surface in vacuum. Therefore, material outgassing is that gas evolving from the materials used in the construction of the apparatus. The quantity and nature of material outgassing is dependent upon the material selected and its surface condition. Foreign or unnecessary materials left in or on the apparatus during fabrication are also sources of material outgassing. Examples of such materials are machinists' dyes, cutting oils, lubricants, rust, and protective lacquers.

Virtual leaks.- A virtual leak is a volume of gas trapped in the apparatus during fabrication and assembly. In most instances virtual leaks slowly release gas and affect

the simulator pressure and molecular density for long times. Common sources of virtual leaks are joints that have been improperly designed or fabricated.

## DESIGN PROBLEMS AND SOLUTIONS

It is the combined responsibility of the design engineers and the fabricators to minimize the quantity of gases originating from a mechanical apparatus in vacuum. The purpose of this paper is to discuss several areas in which attempts are made to reduce the quantity of these gases. These areas are as follows:

- (1) Construction materials
- (2) Surface finish or condition
- (3) Joints
- (4) Bearings and lubrication
- (5) Cleaning and assembly

This purpose is accomplished by considering some particular design features of the tensile-test apparatus shown schematically in figure 1. The tensile-test apparatus was designed and has been used for the storage and tensile testing of materials in the ultra-high vacuum environment. Notable features of this apparatus are the multiple-sample storage capability (30-inch-diameter storage table), rotary motion for positioning of the storage table (rotary feedthrough and gear arrangement), and linear motion for sample testing (loading bar). Figure 2 is a photograph of the apparatus installed in a Langley Research Center space simulator.

### Construction Materials

When selecting the materials for construction of a mechanical apparatus for vacuum use, the designer must consider the vacuum properties of the materials as well as the physical and structural properties. The most significant vacuum property of a material is its outgassing rate. As previously pointed out, the magnitude or quantity of outgassing is dependent upon the material. Stainless steel with its low outgassing rate is the most desirable construction material for vacuum application and hence was the primary material used in the construction of the tensile-test apparatus. However, cost, machinability, and other factors often require trade-offs between physical and vacuum properties. For example, the storage table of the tensile-test apparatus, shown in figure 3, is made of aluminum. The use of aluminum for the top and bottom disks of the storage table is an example of a trade-off, as aluminum has a higher outgassing rate than stainless steel but is much lighter and more easily machined.

Bearings (see fig. 3 for location) and other small parts of the tensile-test apparatus are carbon steel. Although carbon steel has a relatively high outgassing rate, these bearings were selected because they were commercially available. The upper bearing assembly of the tensile-test apparatus is shown in figure 4, and it can be seen that only the bearing itself is carbon steel. The use of carbon steel for the bearings is an example of a trade-off between the availability of the component and its vacuum properties. The higher outgassing rate of the carbon steel is acceptable because of the high pumping speed of the particular space simulator being used.

Certain nonmetallic materials can also be used for the construction of mechanical apparatus for vacuum use if the quantity and application are carefully considered. In general, nonmetallic materials tend to outgas more than metallic materials.

#### Surface Condition

The surface condition of the mechanical apparatus is important for two reasons. First, a smooth surface facilitates the cleaning of the apparatus, and second, a smooth surface tends to reduce the outgassing from the apparatus. The following table illustrates the effect of surface condition on the outgassing rate:

Surface condition	Outgassing rate (relative)
Rusty, anodized, or cast . . . . .	1000
Sand blasted . . . . .	250
Stock . . . . .	100
Polished . . . . .	1

This table is only a guideline for estimation purposes, as outgassing rates of materials are tabulated in the literature in terms of their surface condition.

A variety of surface finishes are used on the tensile-test apparatus. For example, the surface finish on the structural tubing (see fig. 3) and on most of the plate is a stock finish. The most common machined finish has a root-mean-square (rms) average roughness of 63 microinches. This finish is used on both the top and bottom disks of the storage table (see fig. 3) and has been proven as a good basic standard for vacuum use. Smooth surface finishes such as those with an rms average roughness of 16 or 32 microinches are preferred in the vacuum environment, but their use is minimized by the excessive cost of such finishes. The use of these two finishes on the tensile-test apparatus is limited to those applications where normal design criteria, such as a bearing seat, dictate their use. In general, the surface-condition selection is a compromise based on vacuum level desired, vacuum-system characteristics, and economy.

## Joints

Joint design for vacuum application must be considered because mating surfaces trap gas and become a potential virtual leak. From a vacuum standpoint, it is desirable to minimize the quantity of trapped gas and to provide means for trapped gas to be quickly removed by the vacuum pumps. The most significant feature of all joints for vacuum use is a minimum contact area between the two mating surfaces. By reducing the area of contact between the mating surfaces, the quantity of gas trapped in the joint is reduced.

Figure 5 illustrates the minimum-contact-area principle in joint fabrication. This figure shows a typical welded T-joint and a welded T-joint designed by Langley personnel for vacuum use. For the vacuum T-joint, a slot has been machined through the joint area to reduce the area of contact between the two surfaces. A use of a skip weld is also illustrated in figure 5. The skip-weld technique aids the release of any gas trapped between the two surfaces. The skip-weld technique has long been used for vacuum-chamber construction and is just as effective for vacuum apparatus. Figure 6 is a photograph of typical welded T-joints used in the fabrication of the tensile-test apparatus. Figure 7 is a photograph illustrating the use of the skip-weld technique.

Other types of welded joints used in the fabrication of the tensile-test apparatus are shown in figure 8. Note that the lap joint shown in figure 8 makes use of the machined slot to reduce contact area, but does not use the skip-weld technique. The lap joint shown is narrow, and strength considerations require a continuous weld. The full-penetration weld and the fillet weld, as used in corner-joint construction, are also shown in this figure. Both of these corner joints illustrate the minimum-contact-area principle in that there is a minimum of overlap of the two mating surfaces. The full-penetration weld is preferred over the fillet weld for vacuum use. All welds for vacuum use should be made by the tungsten inert-gas arc process. Welds should be sound, clean, smooth, and free of impurities. A single-pass weld is advisable where practical.

Examples of bolted joints are shown in figure 9. Again slots have been machined to reduce the area of contact between the mating parts. The bolted joint presents special problems in that gas is trapped in the screw threads. This problem is solved by machining slots or flats on the bolts (thread slots) as illustrated in figure 9. In the case of a blind tapped hole (see right-hand sketch in fig. 9), a vent hole is drilled to release gas trapped in the blind hole. Both techniques, the thread slot and the vent hole, eliminate sources of virtual leaks for the bolted-joint construction. Figure 10 is a photograph of a bolt used in the tensile-test apparatus and shows the use of the machined flat. With this type of design, each volume of gas between the threads is vented. Figure 11 illustrates the venting of blind tapped holes; in addition, the threads of the bolts in figure 11 have been slotted.

## Bearings and Lubrication

Bearings and their lubrication are complex subjects and each application must be carefully analyzed. Bearing-design and lubrication selection must be made by considering many factors. In addition to the usual bearing-design factors such as load and speed, the designer must consider such factors as chamber pumping speed (vacuum-pump capacity), desired operating pressure, and outgassing. Virtual leaks, as previously discussed with regard to joint design, are also a problem with bearings. The minimum-contact principle can be applied to both the bearing housing and the shaft.

The most convenient solution to the bearing problem, as in the case of the tensile-test apparatus (low-load, low-speed application), is to use dry (unlubricated), unshielded ball bearings. The bearing assembly in figure 4 is typical of those used in the tensile-test apparatus and has operated in vacuum without problems for several months.

The lack of lubrication does induce bearing "noise." Such noise is not generally objectionable in vacuum apparatus; however, commercial ball bearings are now available with polytetrafluoroethylene (TFE), polyvinyl fluoride (PVF), and glass balls. Other types of bearings (for example, journal bearings) can also be obtained in similar types of synthetic materials. The use of plastics as a bearing material eliminates bearing "noise" and the need for lubrication, but generally such bearings will outgas more than unlubricated metallic bearings. Lubricants, when required for a vacuum application, must be carefully selected. Common lubricants are not acceptable for vacuum application. These materials outgas considerably and contaminate the system. The use of the new-technology lubricants (dry films and the like) should be carefully reviewed, as experience with this type of lubricant in vacuum is limited. Lubricant selection, when required, should be based on chamber performance, outgassing rate of the lubricant, possible contamination, and other factors normally considered in lubricant selection.

## Cleaning and Assembly

Proper cleaning and assembly are required for vacuum apparatus. All marking dye and other fabrication aids must be removed or they will become a source of outgassing. It should be pointed out that every nut and bolt, as well as all large components, must be cleaned. An example of steps taken to insure cleanliness can be seen in figure 12. A junction point of the structural tubing on the tensile-test apparatus is shown in this figure. A large hole has been cut in the tubing at the junction point. This hole not only allows the tubing to be evacuated of gas during pump down, but also allows the inside of the tube to be cleaned. For the tensile-test apparatus it was desirable to provide for the cleaning of the apparatus at frequent intervals during its useful life. Other examples of these cleaning provisions can be seen in figure 3.

In general, the proper procedure to follow in the assembly of vacuum apparatus can be summarized by these three "B. C.'s":

(1) BE CLEAN. Although a white room is not required, careful attention must be paid to oil, dirt, and other contaminants. Special clothing, while not essential, does reduce contamination and serves as a reminder to technicians of the nature of their work.

(2) BE CAREFUL. The importance of surface condition has been noted. All parts should be protected during handling and shipment.

(3) BE CONSCIENTIOUS. Much time is saved by attention to detail. Experience at Langley has indicated that it is the small details which cause the problems, such as failure to vent blind tapped holes in a bolted joint.

### CONCLUDING REMARKS

Several problem areas frequently encountered in the design of mechanical apparatus for vacuum use have been discussed. The approach to these problem areas was illustrated by considering particular problems encountered in the design and fabrication of the tensile-test apparatus. Numerous references were made to specific techniques used in the design and fabrication of this apparatus. The techniques considered are new and have been applied at Langley Research Center in the design of mechanical apparatus for vacuum use. In each case, the techniques considered were directed at minimizing or reducing the quantity of gas evolving from the apparatus in the vacuum environment. It was shown that the ultimate pressure of a space simulator is directly dependent on the quantity of gas evolving from mechanical apparatus in the simulator.

### REFERENCES

1. Santeler, Donald J.; Holkeboer, David H.; Jones, Donald W.; and Pagano, Frank: Vacuum Technology and Space Simulation. NASA SP-105, 1966.
2. Steinherz, H. A.: Handbook of High Vacuum Engineering. Reinhold Publ. Corp., 1963.
3. Van Atta, C. M.: Vacuum Science and Engineering. McGraw-Hill Book Co., Inc., c.1965.
4. Dushman, Saul (J. M. Lafferty, ed.): Scientific Foundations of Vacuum Technique. Second ed., John Wiley & Sons, Inc., c.1962.

### TENSILE-TEST APPARATUS IN VACUUM CHAMBER

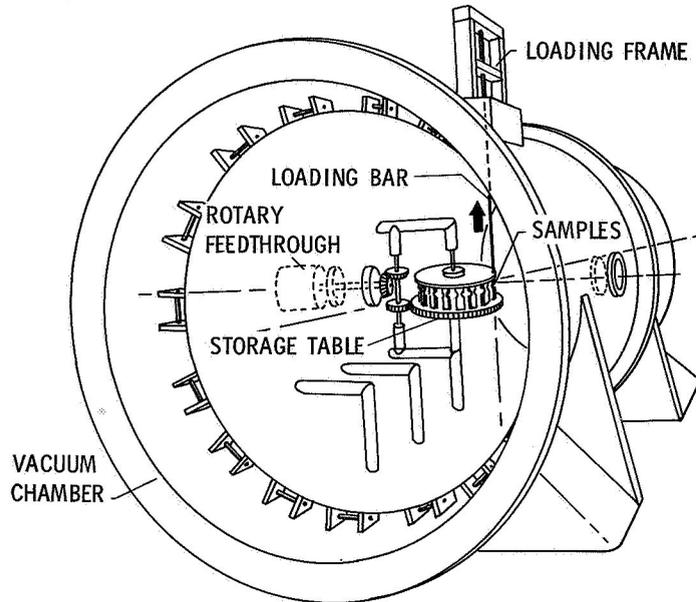


Figure 1

### PHOTOGRAPH OF TENSILE-TEST APPARATUS

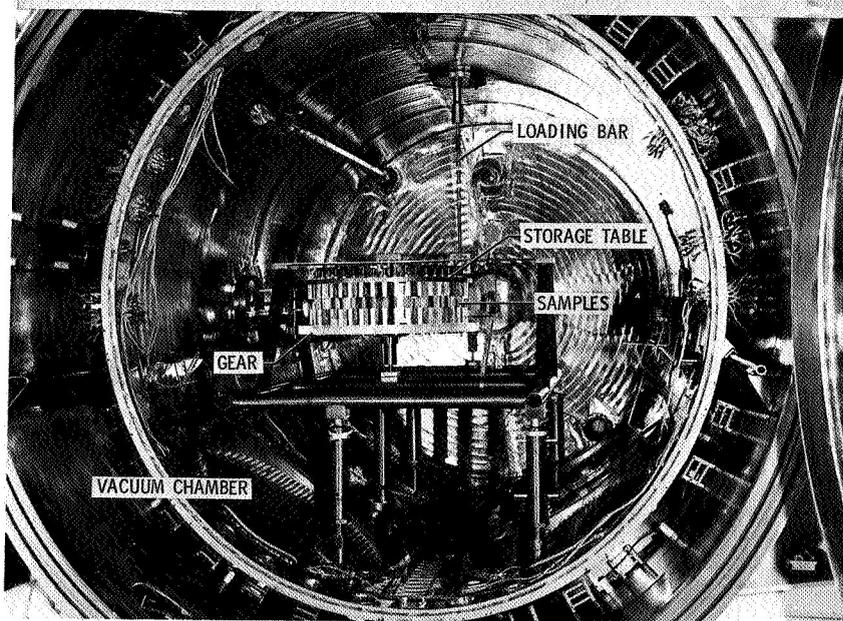


Figure 2

L-67-1578.1

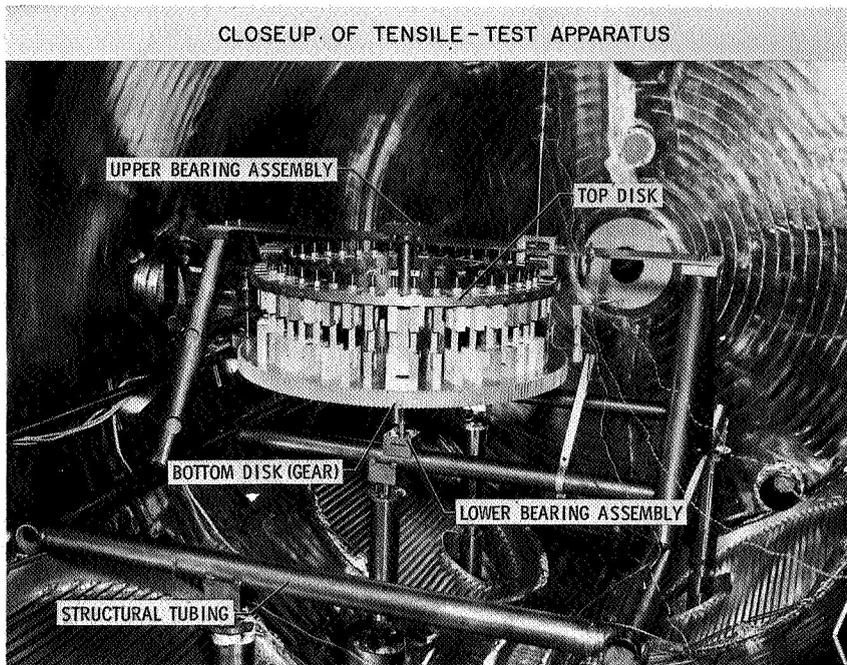


Figure 3

L-67-1579.1

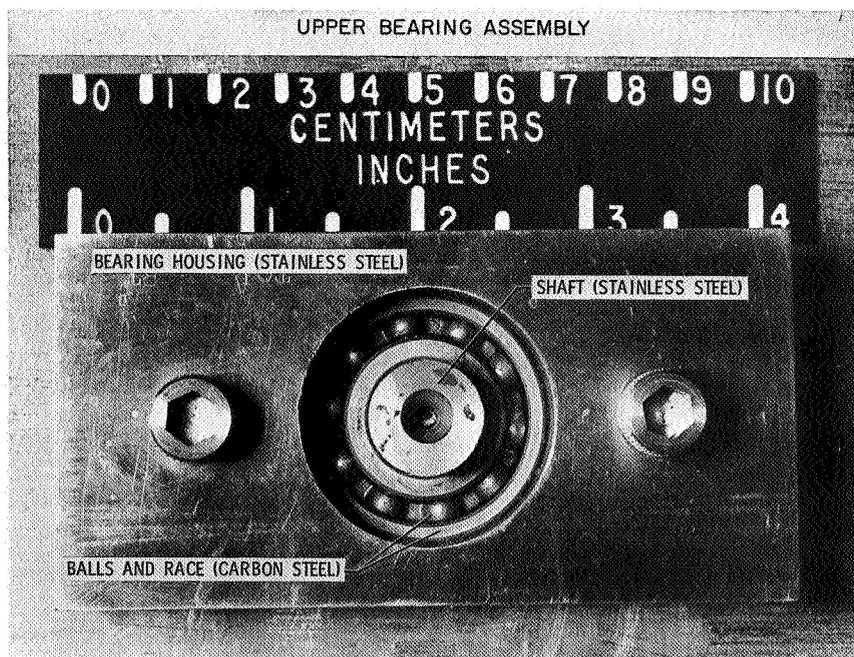


Figure 4

L-69-3503.1

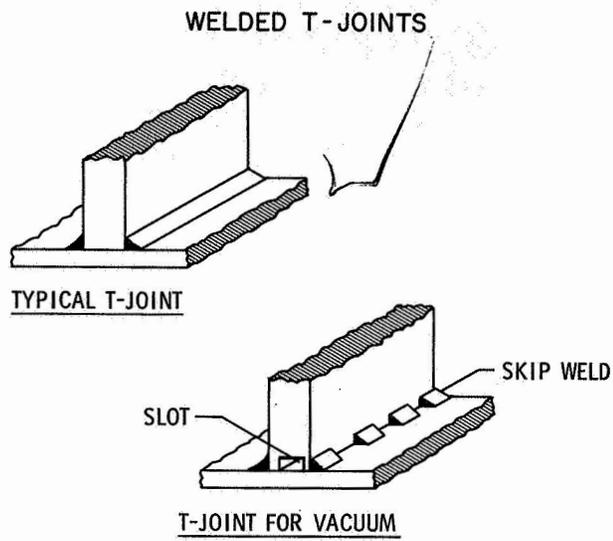


Figure 5

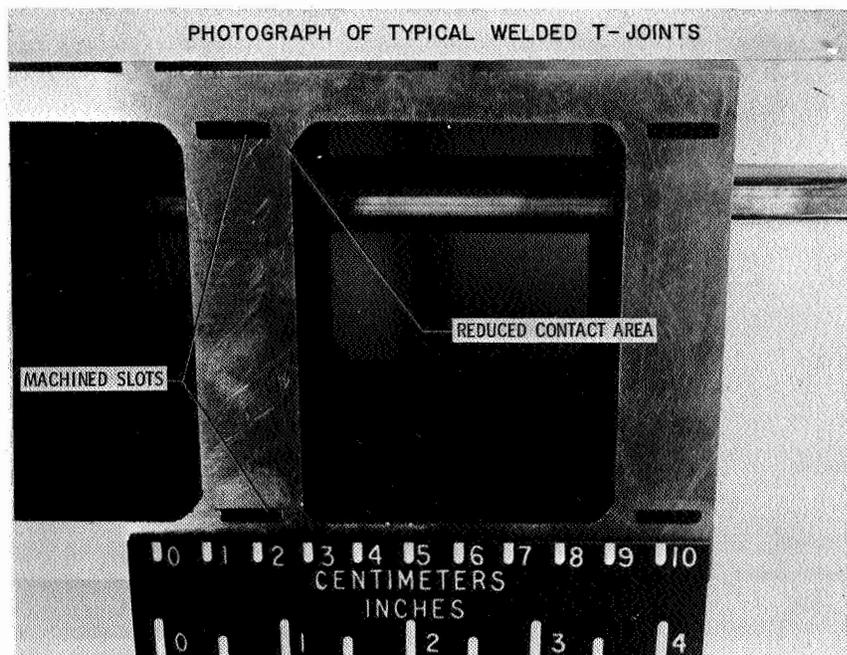


Figure 6

L-69-3501.1

SKIP-WELD TECHNIQUE

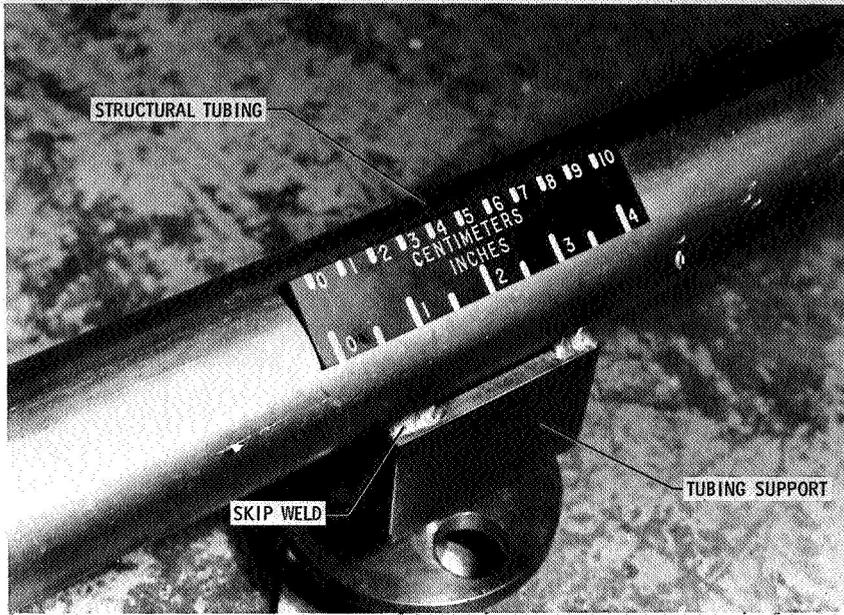


Figure 7

L-69-3502.1

TYPICAL WELDED JOINTS

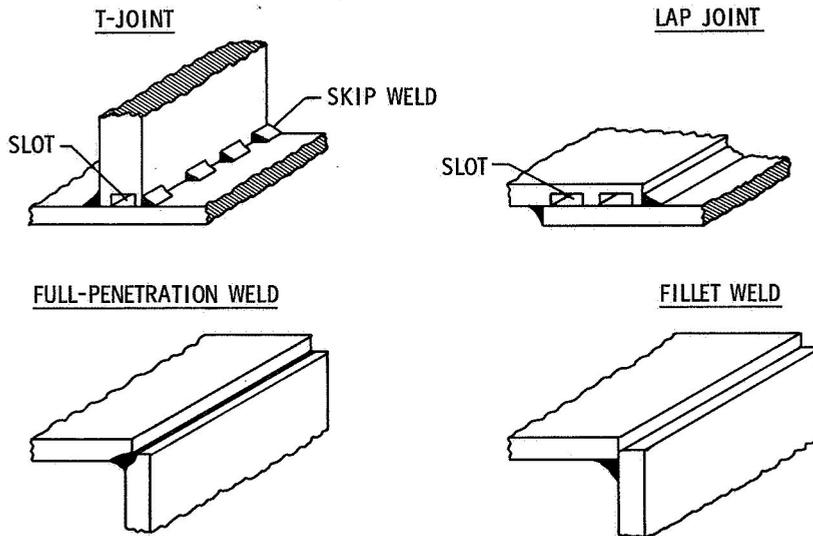


Figure 8

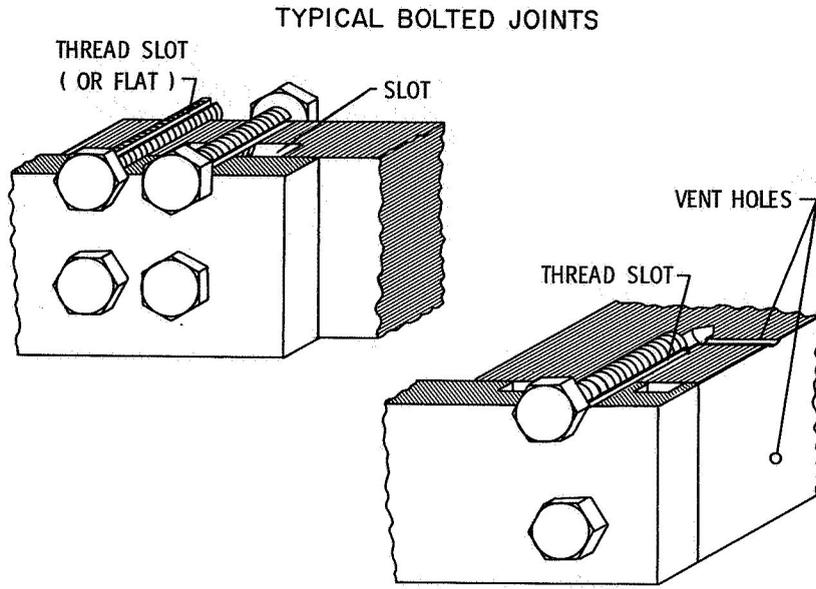


Figure 9

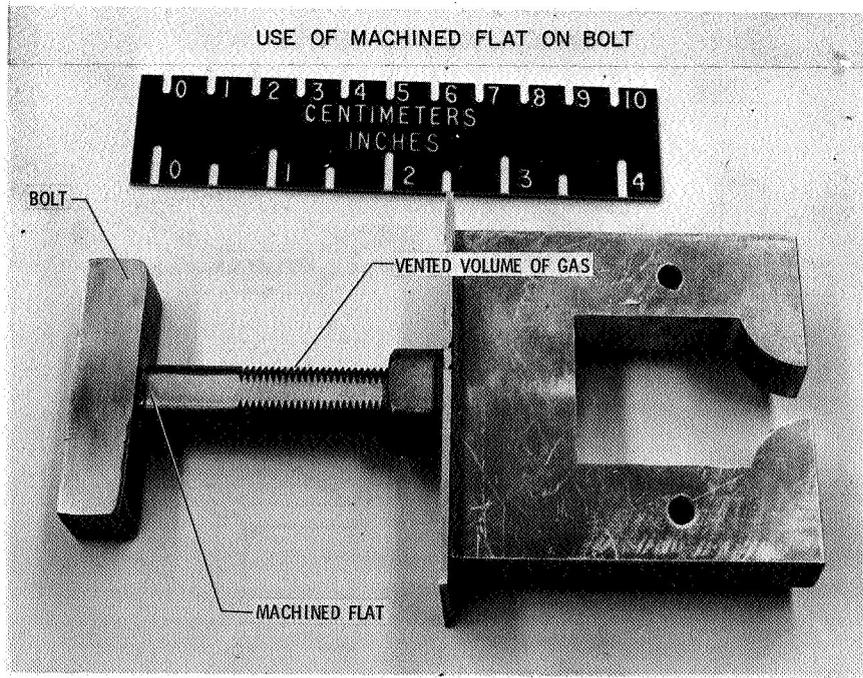


Figure 10

L-69-3506 .1

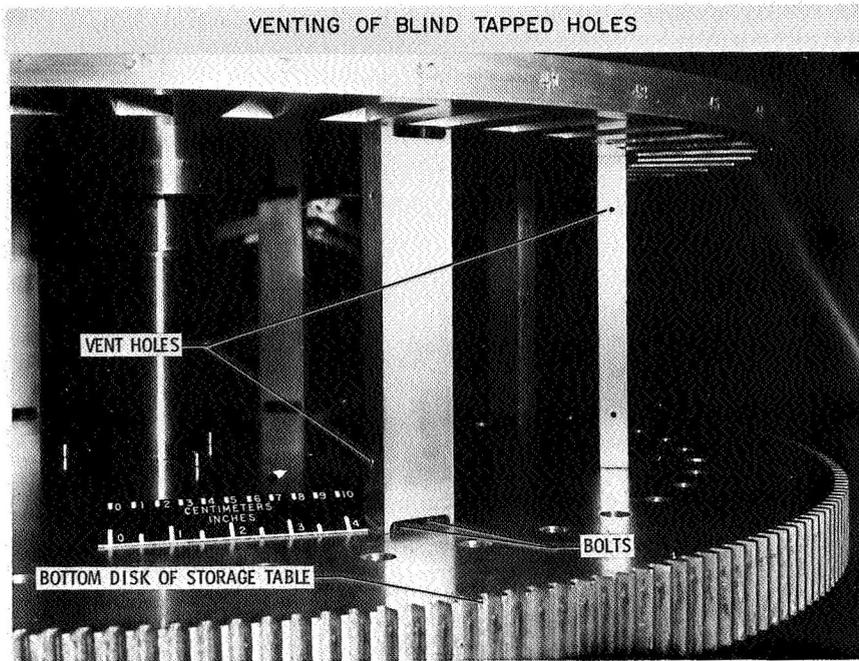


Figure 11

L-69-3504.1

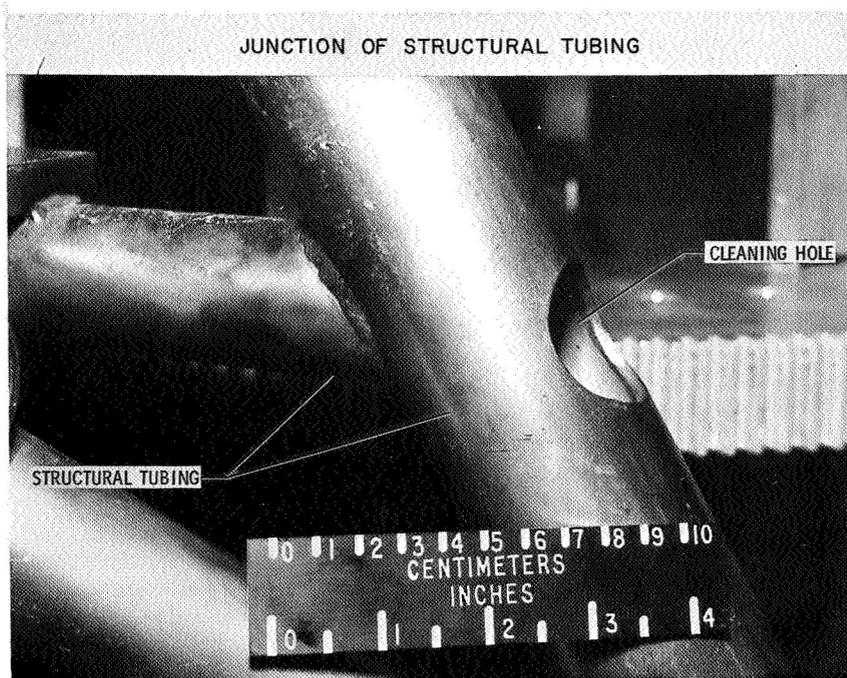


Figure 12

L-69-3505.1



## 23. PRECISION CASTING OF FLUIDIC SYSTEM COMPONENTS

By Richard F. Hellbaum and Albert R. Philips

Langley Research Center

### INTRODUCTION

A new fabrication process developed at the Langley Research Center is described in this paper. This process was developed to facilitate the construction of devices with minute, complex air passages – the so-called "fluidic devices." Fluidic devices utilize the interaction of fluid jets to perform many of the functions commonly assigned to electronic and electromechanical systems. These devices frequently offer advantages in cost, reliability, and tolerance to extreme environments.

### DISCUSSION

Figure 1 is an example of one of these devices. This figure shows a simplified drawing of a bistable fluidic element called a flip-flop. It has a fluid supply input, two control inputs, and two outputs. The passages shown have a rectangular cross section. Fluids used in this type of device can either be liquids or gases.

A flow enters the supply duct. After passing the control inputs, it will attach to one of the two walls and leave by the corresponding output. A small control flow introduced at A will deflect the stream and cause it to attach on the alternate wall and leave by output A. (See fig. 2.) With the removal of the control flow, the stream remains attached to this wall. This flow, of course, may be switched back to the original position by introducing a small control flow at B.

This device is bistable; that is, it is stable in two positions – much like a two-position switch. It amplifies the signal since the output is greater than the control input. This device might be used, for example, in a memory core of a computer since it remembers the position that it has been placed in.

Figure 3 is a photograph of an actual flip-flop. It has a supply duct, two control ducts, and two output ducts which have been previously discussed. The two extra vents have been added to carry off excess fluid. The smallest channels are 0.020 inch wide.

There are numerous other devices which, because of their geometry, perform various functions. These individual components can be utilized with one another to form circuits such as shown in figure 4. This box of "spaghetti" is actually three layers of circuitry that form a fluidic addition circuit. The upper right-hand corner shows a flip-flop similar to that shown in figure 3. This circuit is approximately 4 × 5 inches and 1/4 inch

thick. The smallest channel dimensions are 0.020 inch by 0.040 inch. It is the fluidic equivalent of an electronic printed circuit. This fluidic circuit would replace approximately 35 transistors. The three separate layers of circuitry are internally connected in a nonlaminated sheet of plastic – truly a machinists nightmare. Requirements for this type of construction lead us to seek a method of building it readily.

In order to produce a circuit such as that shown in figure 4 an eight-step process is followed. It can be described as a two-wax investment casting process, which is based on lost-wax techniques. Lost-wax techniques are very old and very well established. Channels and internal cavities are formed by casting around an expendable wax core. The wax is melted out and the desired internal void remains. Previously, it has been difficult to fabricate fragile cores without distortion. This problem has been solved by using two waxes: The nonsoluble pattern wax commonly used in the lost-wax process and a water-soluble wax. Briefly, a water-soluble wax mold is made, which is used to cast the desired lost-wax core of nonsoluble wax. The soluble wax can easily be washed away without pulling or distorting the fragile core. The eight steps outlined take the process from a design drawing to the finished product:

- (1) Exact-size negative made for each layer
- (2) Photosensitive-plastic mold made from negatives
- (3) Injection of water-soluble wax into plastic molds
- (4) Assembly of water-soluble-wax mold layers
- (5) Injection of nonsoluble wax into water-soluble-wax assembly
- (6) Washing of water-soluble wax from nonsoluble wax core
- (7) Encapsulation of core with plastic
- (8) Melting out nonsoluble wax core; finished plastic system remains

The first two steps are shown in figure 5. On the left you see a negative which has the exact silhouette of one of the layers of the circuitry. In step 2, this negative is used to produce the photosensitive plastic mold shown on the right. This mold has raised sections with rectangular cross sections. This photosensitive plastic is commercially used in a printing process. For step 3, the plastic mold is placed in an aluminum housing as shown in figure 6. The pieces on the right and left are the two pieces of the required housing. The piece on your right contains the photosensitive plastic master that has just been made. The piece on your left contains a similar plastic plate for forming the interconnecting holes between layers. The two photosensitive plastic molds are held together by the housing, and the water soluble wax is injected between them; thereby the finished layer of soluble wax shown in the middle is formed. Similarly, the other layers of the circuitry are formed. Figure 7 shows the bottom layer, the middle layer, the layer just discussed, and the plate for covering the top channels.

In step 4 these layers are stacked together and placed in a second housing shown on the right of figure 8. This stack of layers now contains all the channels that make up a complete circuit and are alined by using locating pins. In step 5, the housing is closed and nonsoluble wax is injected under pressure. This wax fills all the channels and the perimeter of the plenum, which forms a core box that will support the delicate core structure after the next step. The wax structure is shown in the center. The sprue shown on the two-wax structure is formed by the channels on the left which are used for proper distribution of wax during injection.

Step 6 is shown in figure 9. The assembly produced in the previous step shows the soluble wax with one corner washed out (for display purposes) to expose the fragile non-soluble wax core. Normally, the entire assembly is washed out at one time. This figure shows the fragile lost-wax core. This core is similar to that used in normal lost-wax processes except that very complicated and fragile cores can now be formed by use of the water-soluble wax. Figure 10 shows the washed nonsoluble wax placed in a box on the left and prepared for step 7, encapsulation. The cover plate is placed on top and the box is filled with an epoxy resin. After the epoxy is cured, the assembly looks like that shown in the center. In step 8, the wax is melted out in a hot kerosene bath. After trimming, the finished product shown on the right is obtained. It has been placed on a dark background for photographic purposes. The finished circuit is shown again in figure 11 in more detail.

#### CONCLUDING REMARKS

With this process, tolerances can be reproduced to within 2 percent. Components and circuits can be miniaturized by photoreduction since a photographic negative is used in the first step. Bonding and laminating problems have been eliminated. A low-cost fabricating technique for producing minute complex passages in a monolithic structure has been shown. The process is equally adaptable to unique components for laboratory testing or to circuit production. Therefore, individual laboratory components may be duplicated in integrated circuits by the same fabrication process.

BISTABLE - FLUIDIC ELEMENT  
FLIP-FLOP

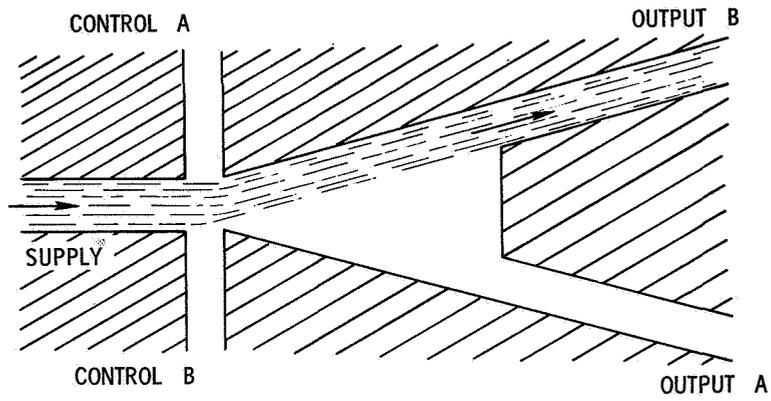


Figure 1

BISTABLE-FLUIDIC ELEMENT

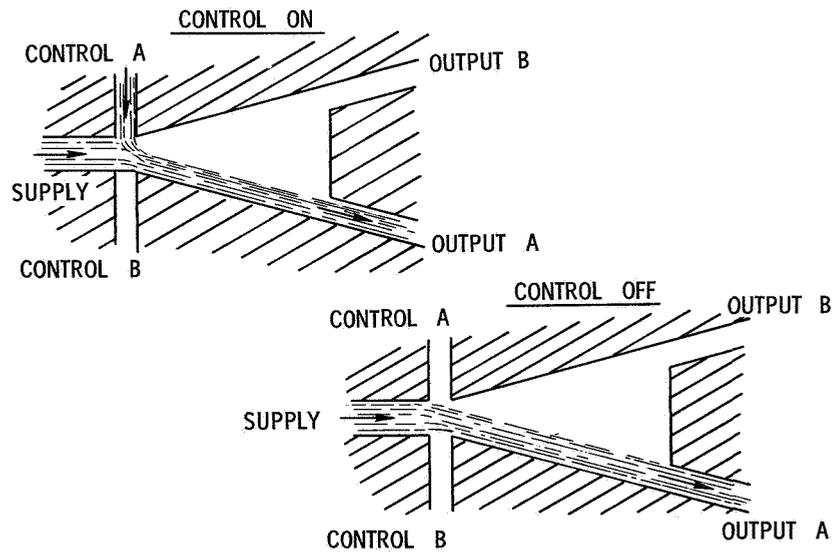


Figure 2

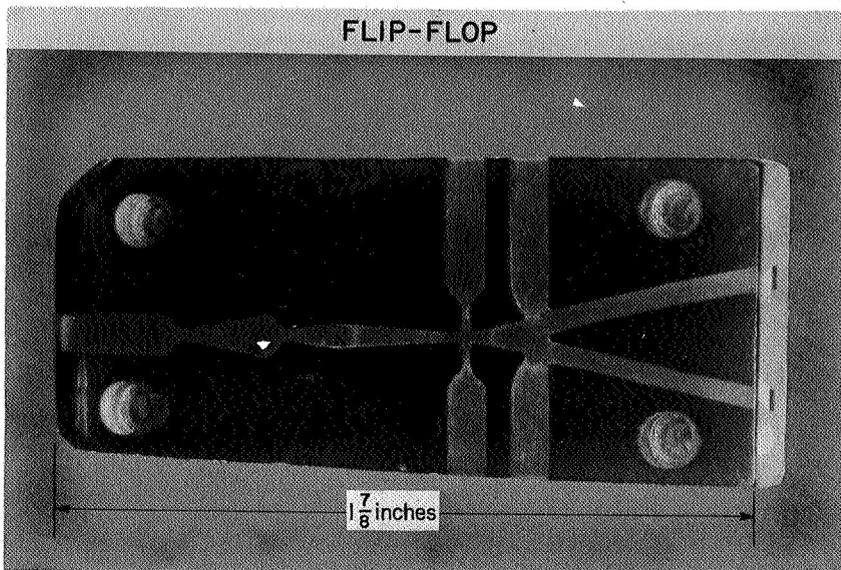


Figure 3

L-3260-3

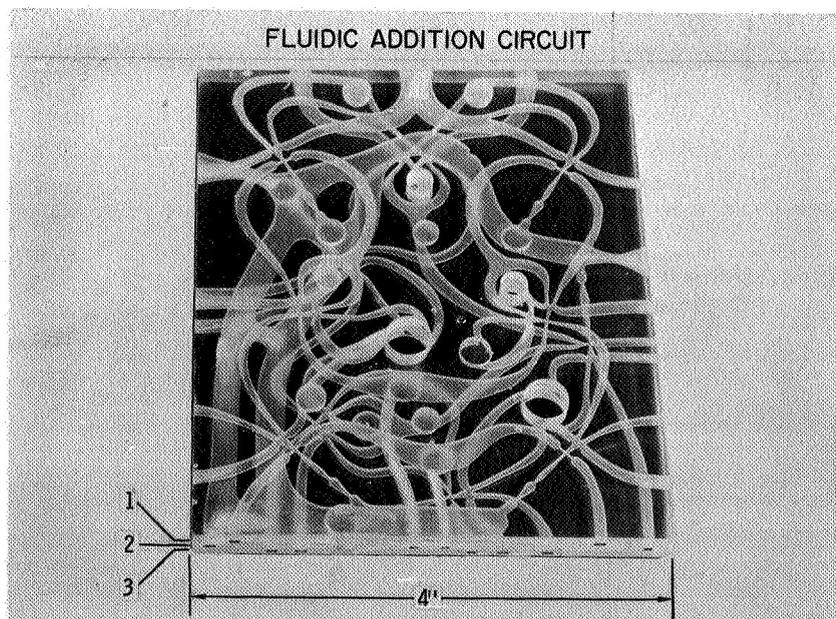


Figure 4

L-3260-4

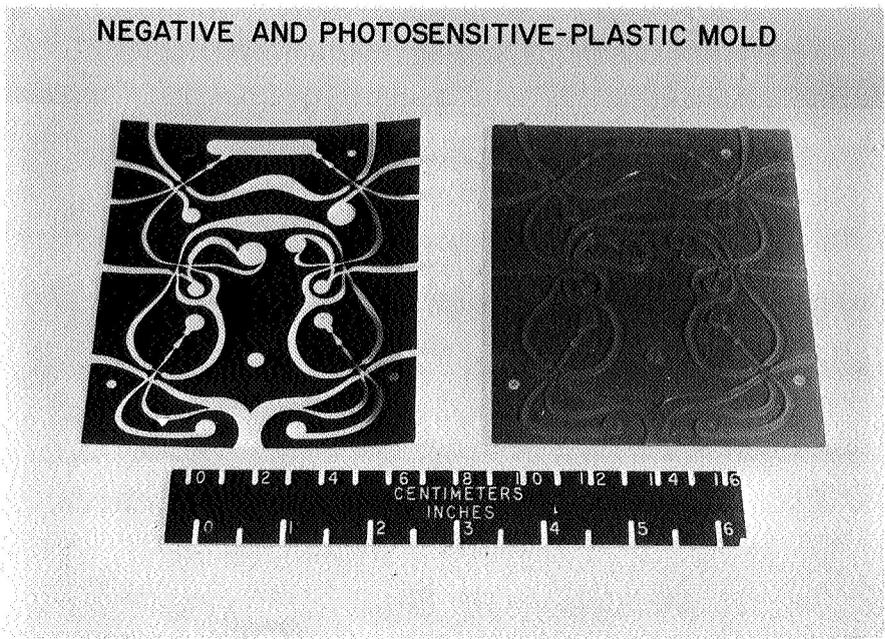


Figure 5

L-3260-6

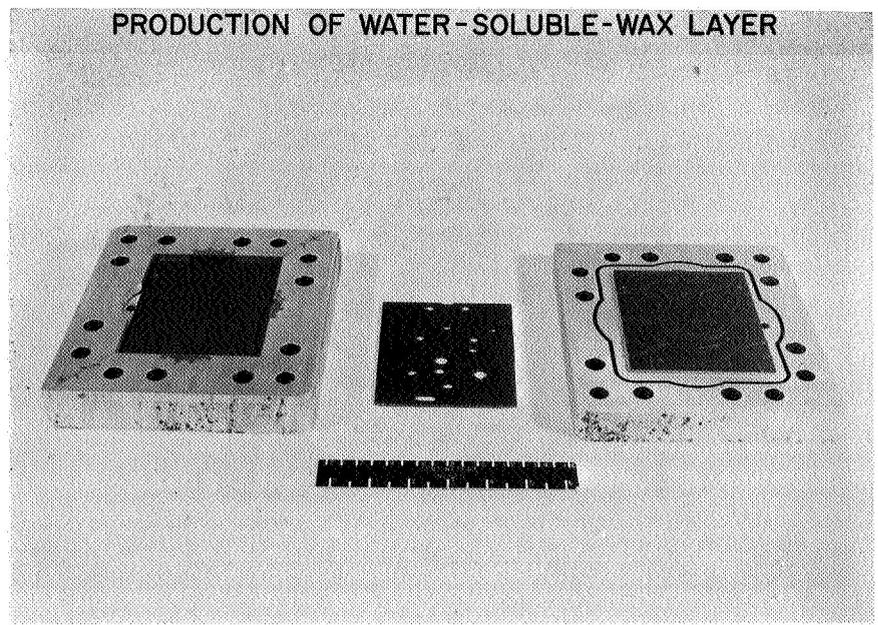


Figure 6

L-3260-7

ASSEMBLY OF WATER-SOLUBLE-WAX LAYERS AND COVER

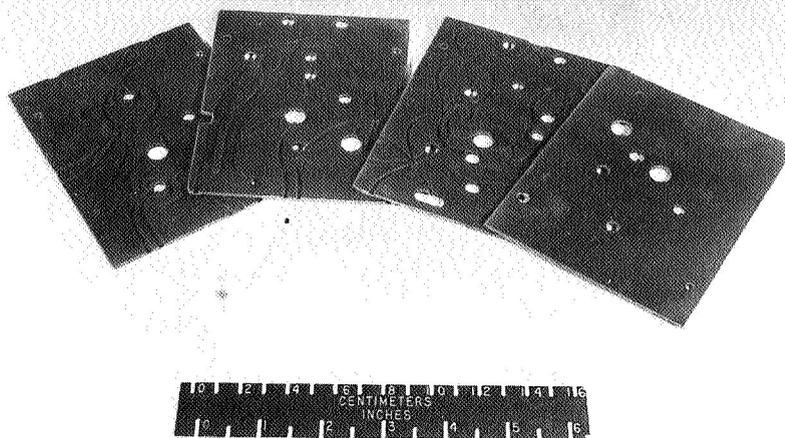


Figure 7

L-3260-8

INJECTION OF NONSOLUBLE WAX INTO ASSEMBLED WATER-SOLUBLE WAX LAYERS

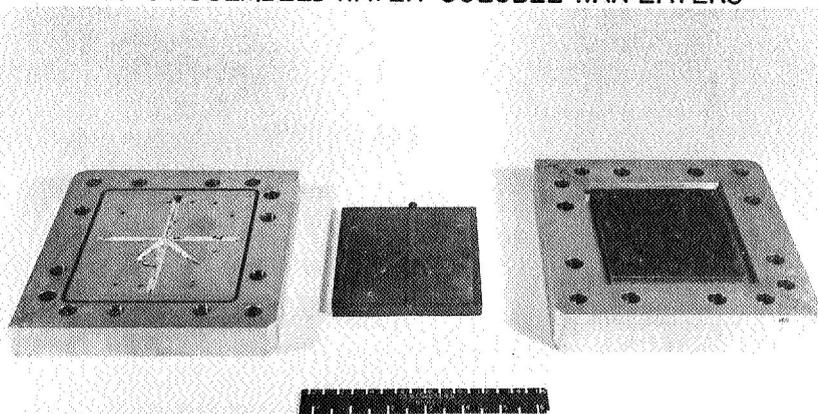


Figure 8

L-3260-9

WASHING OF WATER-SOLUBLE-WAX TO  
EXPOSE NONSOLUBLE-WAX CORE

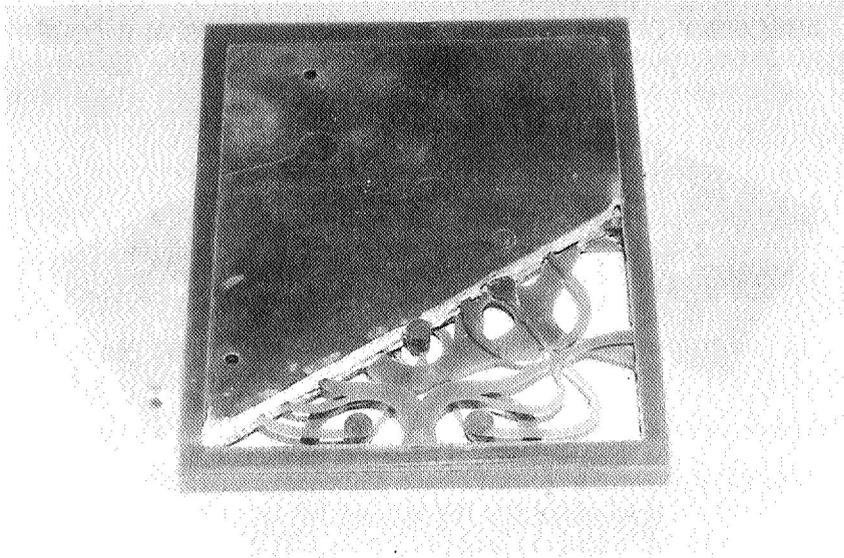


Figure 9

L-3260-10

PLASTIC ENCAPSULATION AND MELT OUT OF CORE

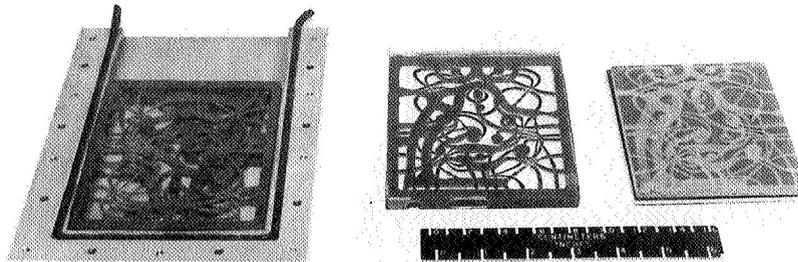


Figure 10

L-3260-11

FLUIDIC ADDITION CIRCUIT

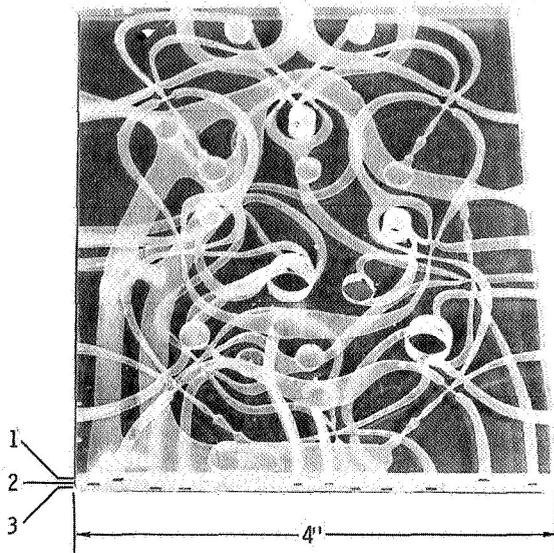


Figure 11

L-3260-4



## 24. PROPERTIES AND POTENTIAL APPLICATIONS OF A NEW HIGH-TEMPERATURE POLYMER, PYRRONES

By Warren C. Kelliher  
Langley Research Center

### INTRODUCTION

The pyrrones are a new class of polymers that have been developed at the Langley Research Center for high-temperature environments. The polymer is a thermosetting-type resin resulting from the reaction of an aromatic tetraamine with an aromatic dianhydride. (See fig. 1.) The two monomers initially react to form an intermediary stage having a nylon type of structure. At this stage the polymer is tractable and forms the basis for fabricating the polymers into useful end products. By use of a thermal-curing process, the polymer loses water, forms initially a polybenzimidazole (PBI) or polyimide (PI) structure, and then fully cyclizes to the pyrrone structure. The PBI and PI are commercially available high-temperature resins and have a step-ladder structure as schematically shown in figure 1. The pyrrones, however, being fully cyclized have a full-ladder type structure, are more rigid, and have different properties than the PI and PBI resins.

The two available forms of the intermediate stage of the polymer are shown in figure 2. The solution form can be obtained by using a variety of solvents and is generally used for producing films and coatings. The solution or varnish, as it is sometimes called, is suitable also for making laminates, since a solids content of 35 percent in the varnish can be obtained. The powder is a fine, free-flowing material used for the production of foams and moldings.

### DISCUSSION

Some of the forms that have been fabricated from the pyrrone intermediate stage are shown in figure 3 and are:

(1) Films – The films have high strength, little elongation, and reflect the rigid nature of the pyrrone polymers. The investigation of the properties of the films has shown a potential application as a membrane or a separator in electrolysis systems.

(2) Coatings – Solutions of the high-molecular-weight pyrrone intermediate stage have a natural film-forming tendency and also have good adhesive properties. As a result, excellent coherent coatings on a variety of substrates can be obtained. The thermal and

chemical stability of the pyrrones suggest potential application of the coatings where high-temperature corrosion resistance is required.

(3) Laminates – Much of the applied research on pyrrone resins has been in the area of fabricating and testing of laminates for high-temperature structural applications. The high rigidity of the pyrrone resin structure results in laminates having high flexural strengths, and the good adhesive properties of the intermediary solution stage results in laminates with high interlaminar shear strengths. At the present time, the long-term high-temperature properties of the pyrrone laminates are being investigated in combination with different reinforcing agents.

(4) Foams – Because of the volatiles given off during the thermal curing process, the pyrrones have a natural tendency to foam. This property presents some difficulty in producing quality laminates and moldings. Because of the high-temperature stability and high strength of these foams, they are currently being evaluated for use as ablative materials and as a structural core material. Foams with densities as low as 15 lb/ft<sup>3</sup> that possess good mechanical strength properties have been obtained.

(5) Moldings – Unfilled moldings have been produced at the Langley Research Center and are being used as a means to evaluate the properties of the cured resin system. An investigation of filled moldings has just begun and good results have been obtained with 50 percent loading levels of aluminum, mica, molybdenum disulfide, and graphite in pyrrone.

For comparison with other polymers, the more significant strength properties of different fabricated forms of pyrrone resins are presented in figure 4:

(1) Films: For 1 mil thickness film – high tensile strengths, 20 000 psi; low elongation, 6 percent.

(2) Laminates: For 12 ply, glass-reinforced laminates – high flexural strength, 90 000 psi; high modulus strength,  $5 \times 10^6$  psi; good horizontal shear strength, 5000 psi. When tested at 600° F, retains 80 percent of room-temperature strengths.

(3) Foams: For unreinforced 30 lb/ft<sup>3</sup> density foams – high compressive strength, 2000 psi; high modulus strength,  $1.3 \times 10^5$  psi.

(4) Moldings: For unreinforced moldings – high flexural strength, 18 000 psi. When tested at 600° F after 100 hours at 600° F, they had 15 000 psi flexural strength and 3000 psi flexural strength at 1000° F.

The general properties of the pyrrone polymers are:

(1) Nonflammable – It can be heated to incandescence without flammable combustion

(2) Outstanding radiation resistance – Although most polymers suffer degradation after 5000 Mrads of radiation, the pyrrone were subjected to 50 000 Mrads of radiation and had no detectable degradation of properties

(3) High-temperature stability – Pyrrones have long-term stability to at least 500° F and potentially to 600° F; short-term stability to 1000° F

(4) Good adhesion, coatability, and corrosion resistance – Pyrrones have excellent potential as high-temperature corrosion-resistance coatings; 1000 hours at 150° F in 40 percent sulfuric acid and potassium hydroxide had little effect on the resin

(5) Easy to machine – Because of rigid nature of the polymer, it is very easy to perform normal milling, cutting, and sanding operations on the cured resin.

### CONCLUDING REMARKS

It must be emphasized that the pyrrones are a new class or family of polymers and these polymers have different chemical and mechanical properties depending on the starting monomeric materials. At Langley Research Center the polymers are being developed and their properties are being investigated from the standpoint of space and aeronautical utilization. The polymer does, however, have some very interesting and useful properties that could have commercial applications. Its development for these purposes and potential usage is left to the initiative of private enterprise. The polymer is available in research quantities from the Langley Research Center and from two contractors, Hughes Aircraft and Avco Corp., who are assisting in the optimization of the mechanical properties of the polymer. Additional details on these polymers can be obtained from the Langley Research Center.

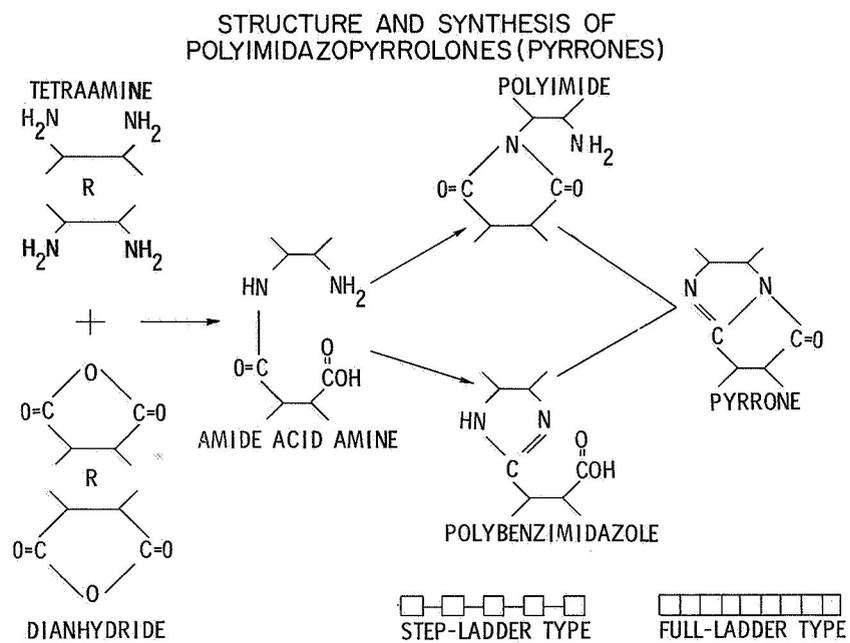


Figure 1

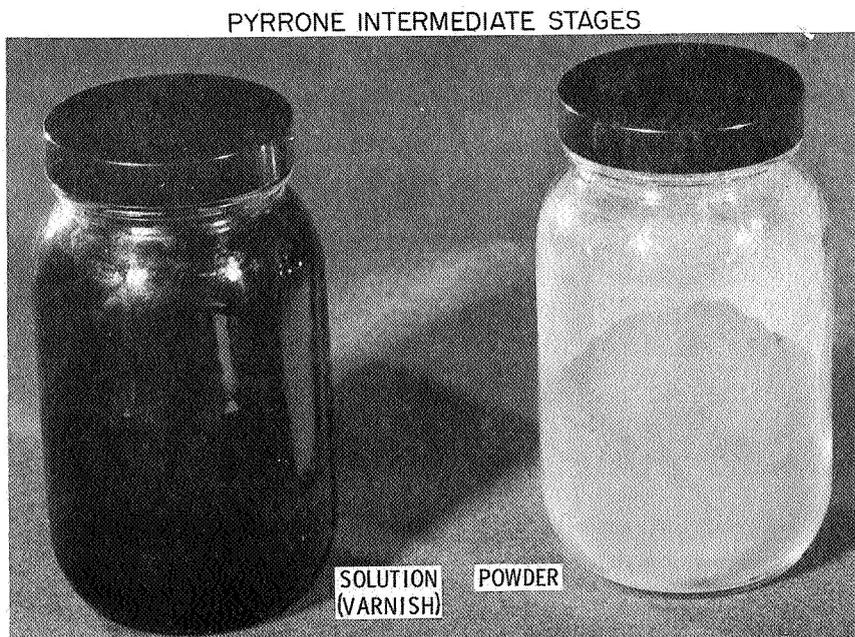


Figure 2

L-3257-2

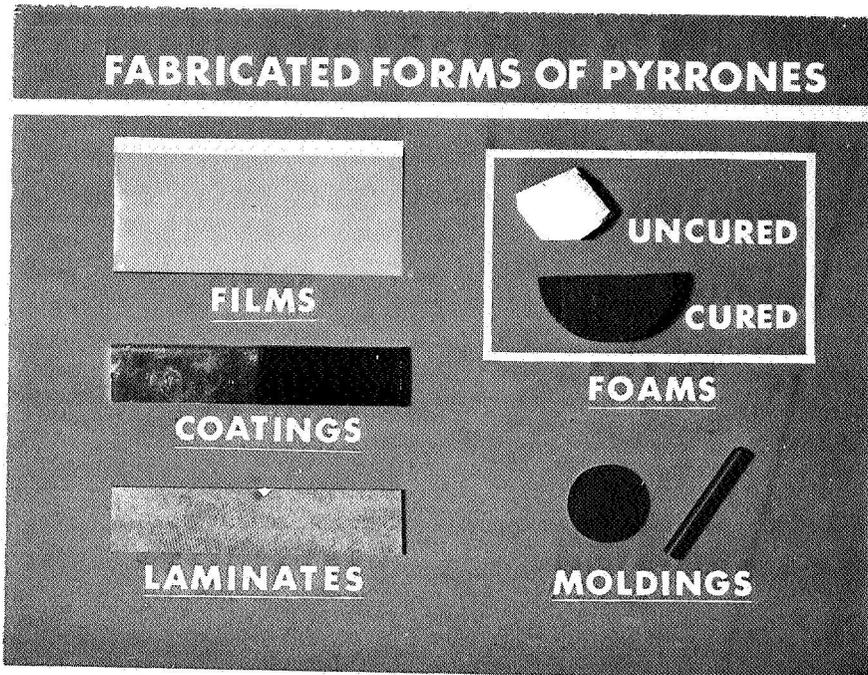


Figure 3

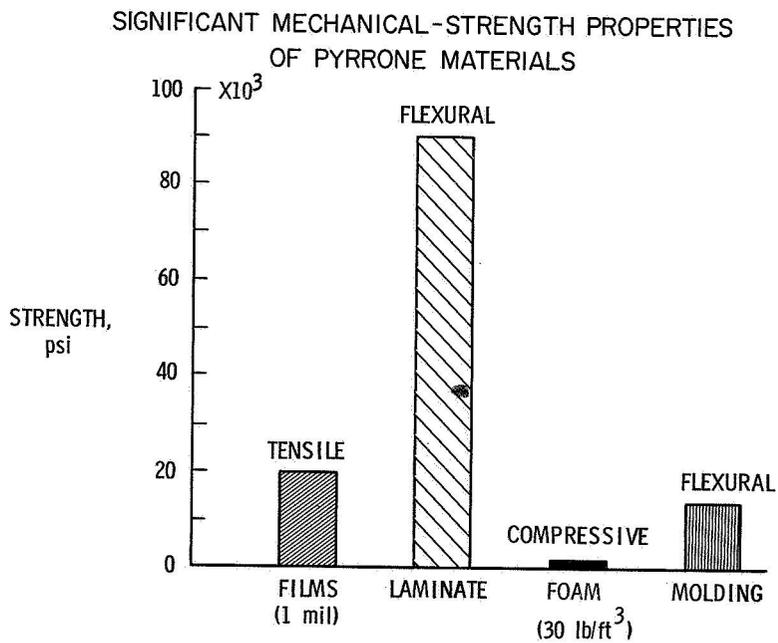


Figure 4



## 25. A PROCESS FOR IMPRINTING MICRO LAGOON FIELDS IN PLASTIC

By Edward N. Fleenor, Jr., and Clarence D. Cone, Jr.

Langley Research Center

### INTRODUCTION

During a recent investigation of abnormal cell growth at the Langley Research Center, it became necessary to isolate tiny colonies of cells in one plastic petri dish so that the scientist could observe the behavior of individual tiny colonies of cells in a time-lapse series of microphotographs. The tiny colonies of cells were to be isolated by means of small indentations, or micro lagoon fields, in the bottom of the plastic petri dish, and the bottom of the petri dish had to be transparent so that microphotographs could be made. Thus, a process had to be devised for imprinting micro lagoon fields in the bottom of the plastic petri dish without disturbing the transparent finish.

### DISCUSSION

Since such a process was not commercially available, a considerable amount of experimentation was necessary. Conventional machining methods of milling the micro lagoons were tried, but the small sizes and the resulting poor finish made this technique fail. Finally, a photographic method, similar to that used to produce printed circuit boards, was investigated and proved to be successful. By means of this imprinting process, a large number of petri dishes can be imprinted rapidly with micro lagoons of almost any size and geometry.

The micro lagoon field is imprinted in the plastic petri dish by a photoetched die. A typical photoetched die and imprinted petri dish are shown in figure 1. The processing of the die begins with the preparation of a negative of the micro lagoon field which is 20 times the actual size. The negative is then photographically reduced to the actual size. A typical micro lagoon field appears in figure 2.

The surface of a 0.032-inch sheet of beryllium-copper alloy is coated with AZ-340 Photo Resist and is then dried. This sheet is sweat soldered to the face of a larger cylindrical copper block called the impression plate. The prepared negative is applied to the beryllium-copper surface and is exposed to ultraviolet light. After exposure, the metal is placed in an AZ-300 developer solution, is dried, and is then placed in a PEMCO spray etcher until enough metal is removed to reveal the little "islands" that eventually make the indentations in the plastic. The exposure time in the spray etcher depends on the desired height of the islands. For the micro lagoon field shown in figure 2, these islands range in height from 0.001 to 0.0035 inch and in diameter from 0.004 to 0.040 inch. It

should be noted that the etching solution acts on the sheet in the horizontal direction as well as in the vertical direction. The solution etches the sides of the islands as they become exposed and causes a reduction in diameter that is dependent on the exposure time. This reduction in diameter must be taken into consideration when the negative of the micro lagoon field is prepared.

The side of the impression plate is then drilled to receive a conventional soldering iron for heating. A similar copper block without an impression, called the press plate, is prepared for heating in the same way. The petri dish is placed between these two blocks, and the blocks are heated and pressure is applied. This process is shown in figure 3. The proper combination of heat, pressure, and time which produces the ideal finished product was found by experimentation. Heat was varied by using Variac rheostats.

### CONCLUDING REMARKS

Since this imprinting process does not disturb the transparent finish of the plastic petri dish, microphotographs of colonies of cells can be made. Using micro lagoons prepared by this process to study cancer cells, a Langley Research Center scientist has discovered that one dividing cell can induce adjacent connected cells to divide also in a chain reaction. This stimulation could be the means by which cancer cells divide so rapidly.

## MICRO LAGOON FIELD IMPRINTED IN PLASTIC PETRI DISH

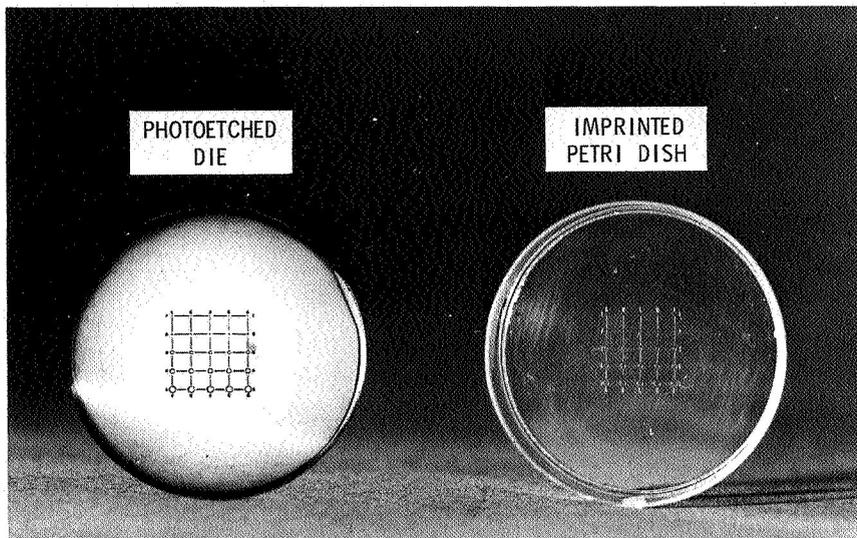


Figure 1

L-3245-1

## MICRO LAGOON FIELD AND SIZE

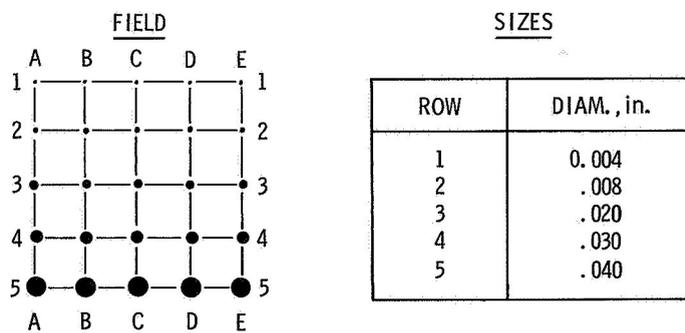


Figure 2

### PROCESS OF IMPRINTING MICRO LAGOON FIELD

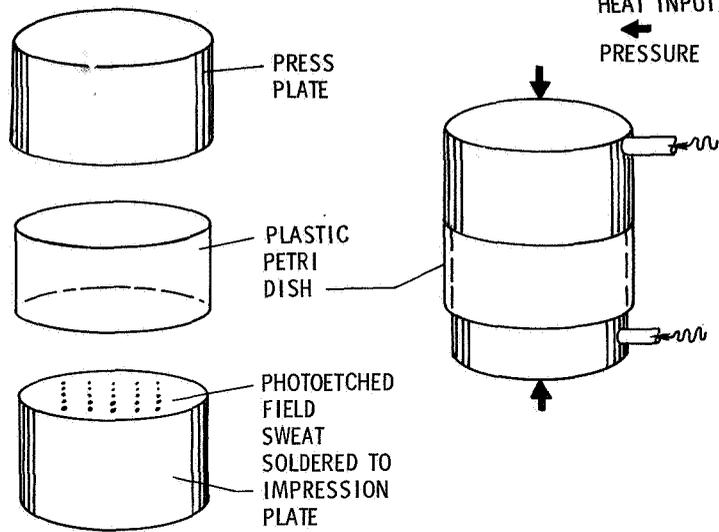
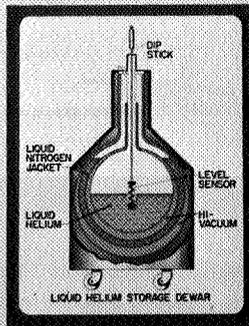
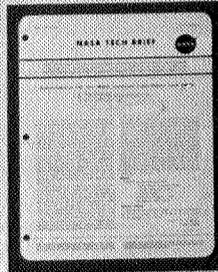


Figure 3

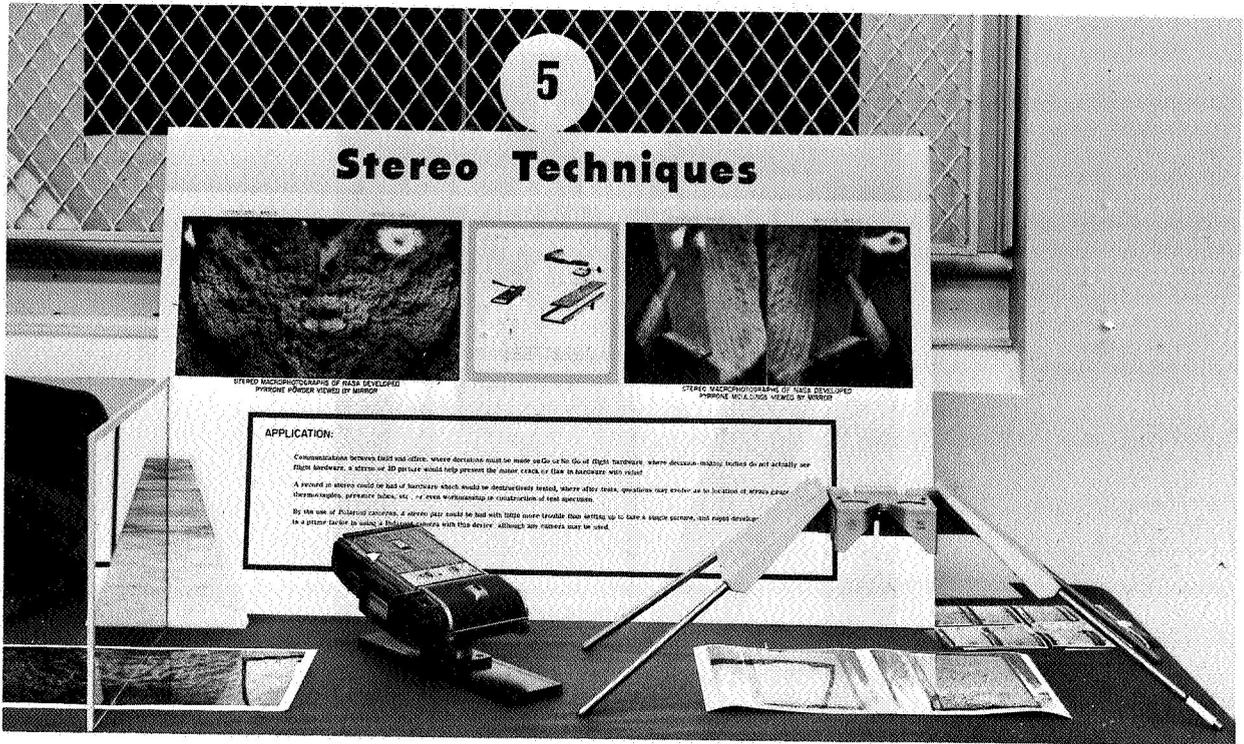
3

# LIQUID HELIUM LEVEL SENSOR

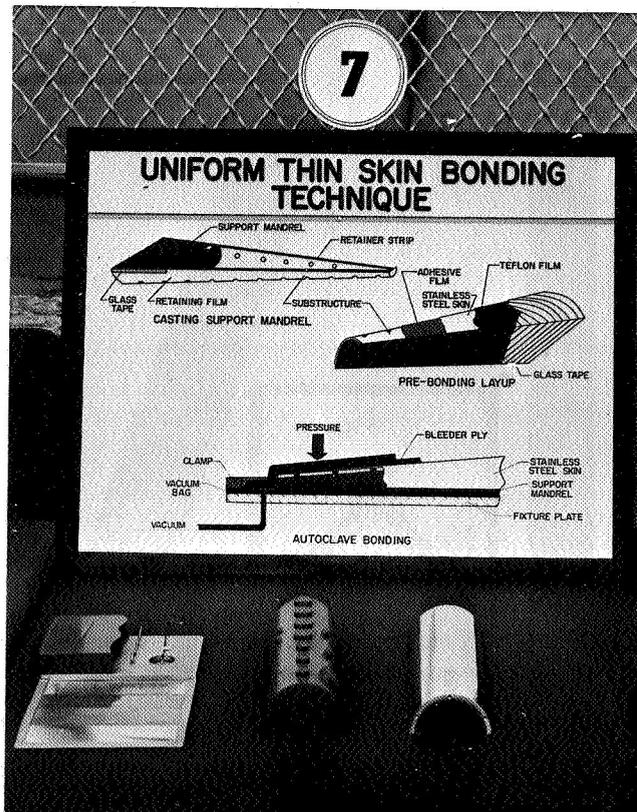


Additional Displays

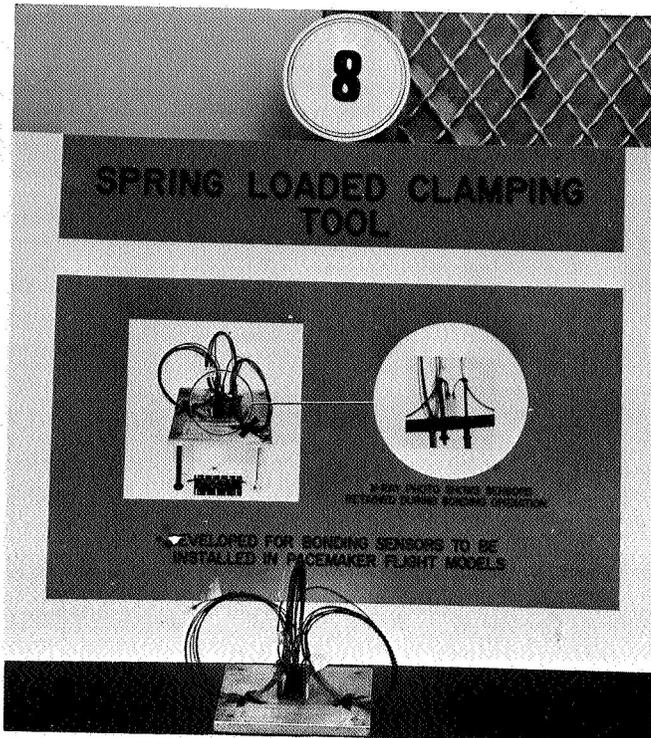
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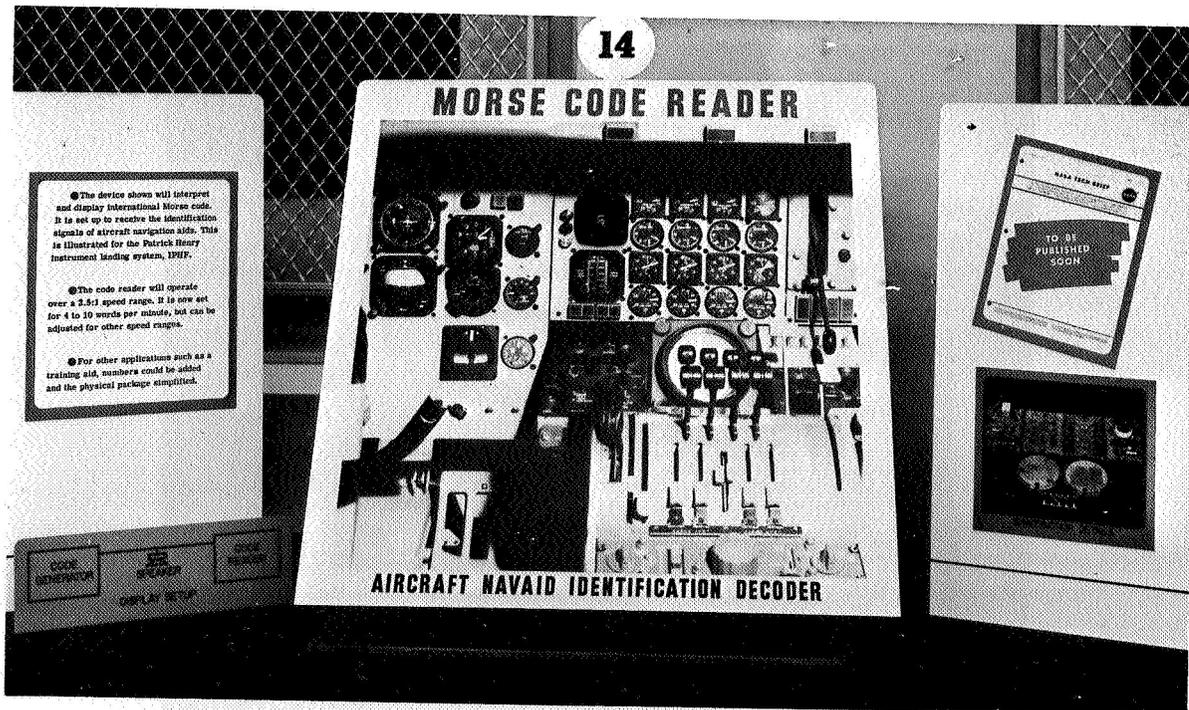
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L-69-3878



L-69-3872

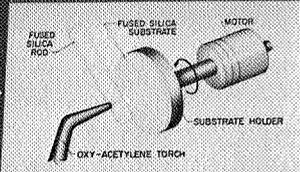
## IMPROVED ULTRAVIOLET DIFFUSER

**NEED:**  
To obtain a uniform distribution of ultraviolet light from a diffusing surface.

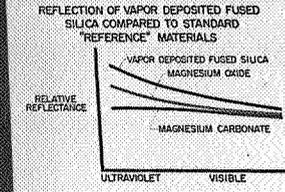
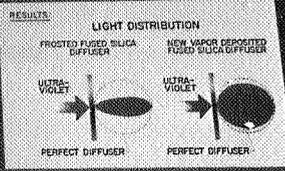
**APPLICATION:**  
To calibrate an ultraviolet light sensor for recent fluid use.

**PROBLEMS:**  
1) Diffusers which work well in the visible do not transmit ultraviolet (e.g., flaked opal glass, milk glass, crown glass).  
2) Present ultraviolet diffusers (treated fused silica) do not give uniform light distribution.

**SOLUTION:**  
Adjust particle size and shape of the ultraviolet diffusing materials used previously to better scatter ultraviolet.

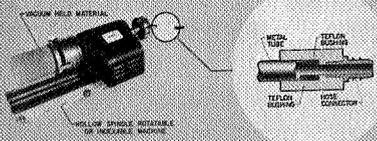


**HOW IT'S DONE:**  
Dry-acetylene torch produces a vapor of fused silica. This vapor condenses on a substrate of high quality fused silica, which rotates the substrate as vapor withers deposition.

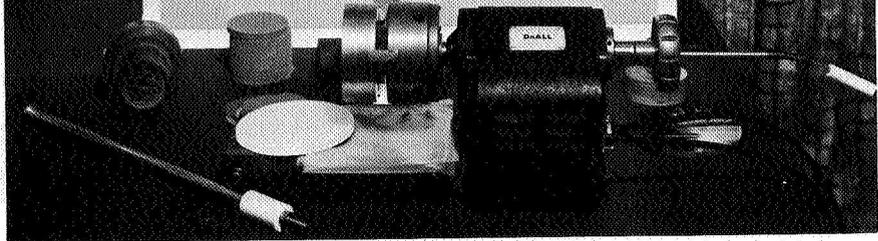


L-69-3871

## SIMPLIFIED ADAPTATION OF VACUUM HOLDING TO ROTATING MACHINERY



- ADVANTAGES:**
- SIMPLE, INEXPENSIVE CONSTRUCTION
  - ADAPTABLE TO DIFFERENT MACHINERY AND MATERIALS
  - SELF LUBRICATING
  - SELF SEALING

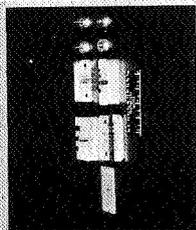
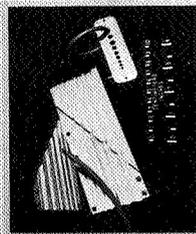
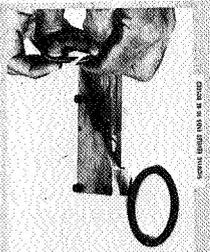
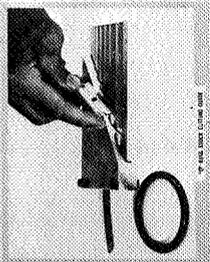


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23

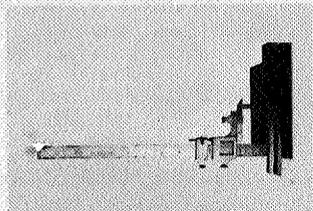
### SPlicing TECHNIQUES FOR MAKING CUSTOMIZED "O" RINGS



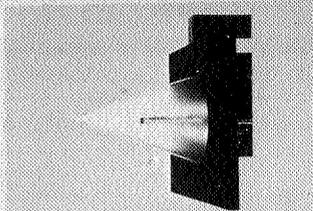
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24

### INTERNAL LAY-OUT SCRIBING TOOL



SETTING THE GAGE



SCRIBING

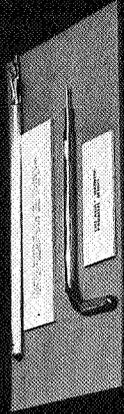
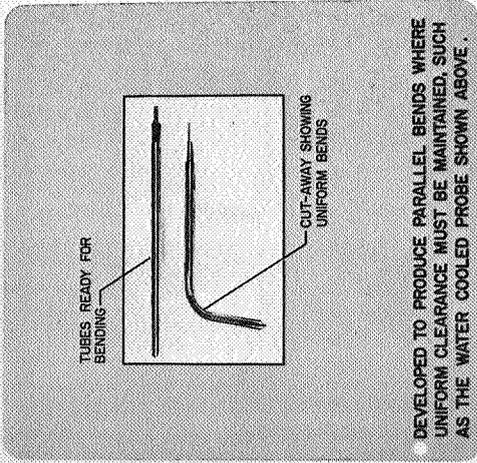
DEVELOPED FOR SCRIBING OBJECTS OF UNCONVENTIONAL GEOMETRY SUCH AS CONES OR TUBING



L-69-3862.1

26

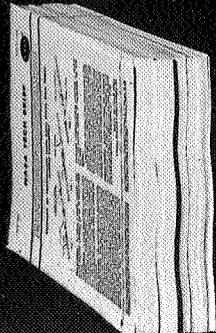
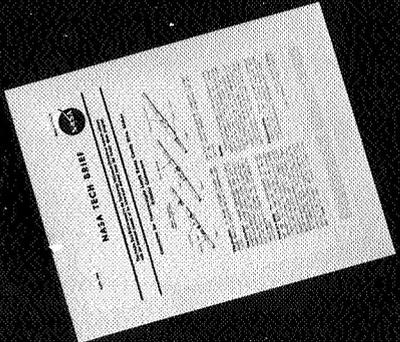
### BENDING TECHNIQUE FOR NESTED TUBING



L-69-3858A.1

27

### ELECTRICAL CONNECTOR, SWAGED TO FLEXIBLE LEADS



L-69-3858A.2

**28**

**BASKET WEAVE TECHNIQUE**  
FOR SOLDERING SMALL TUBES

THE FIRST STEP IS TO SOLDER THE TUBES TOGETHER AT THE POINTS WHERE THEY MEET. THIS IS DONE BY SOLDERING THE TUBES TOGETHER AT THE POINTS WHERE THEY MEET.

THE SECOND STEP IS TO SOLDER THE TUBES TOGETHER AT THE POINTS WHERE THEY MEET. THIS IS DONE BY SOLDERING THE TUBES TOGETHER AT THE POINTS WHERE THEY MEET.

THE THIRD STEP IS TO SOLDER THE TUBES TOGETHER AT THE POINTS WHERE THEY MEET. THIS IS DONE BY SOLDERING THE TUBES TOGETHER AT THE POINTS WHERE THEY MEET.

THE FOURTH STEP IS TO SOLDER THE TUBES TOGETHER AT THE POINTS WHERE THEY MEET. THIS IS DONE BY SOLDERING THE TUBES TOGETHER AT THE POINTS WHERE THEY MEET.

THIS PIECE OF TUBES CAN BE USED TO SOLDER SMALL TUBES TOGETHER AT THE POINTS WHERE THEY MEET.

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**29**

**FURNACE BRAZING TECHNIQUE**

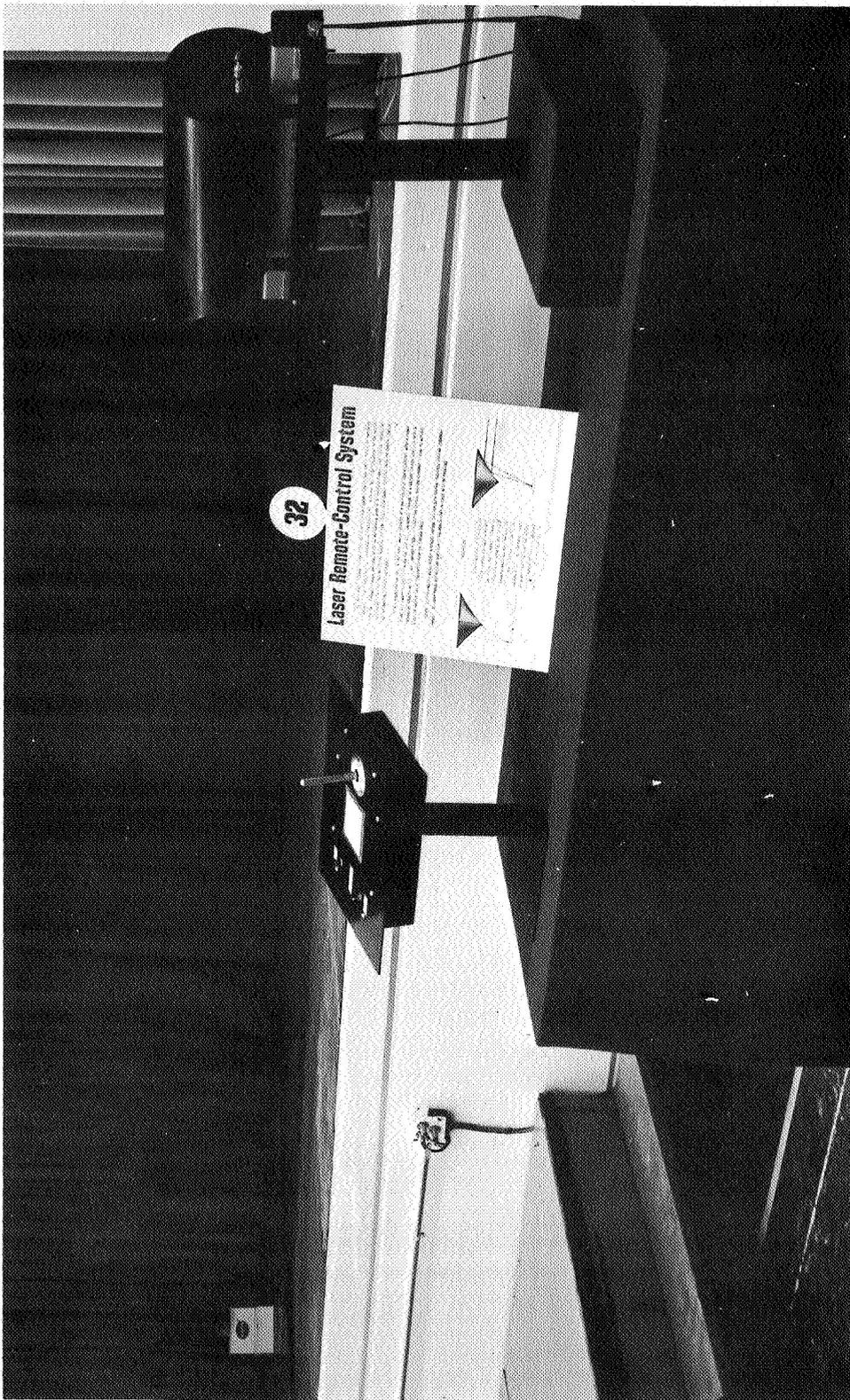
THE FIRST STEP IS TO SOLDER THE TUBES TOGETHER AT THE POINTS WHERE THEY MEET. THIS IS DONE BY SOLDERING THE TUBES TOGETHER AT THE POINTS WHERE THEY MEET.

THE SECOND STEP IS TO SOLDER THE TUBES TOGETHER AT THE POINTS WHERE THEY MEET. THIS IS DONE BY SOLDERING THE TUBES TOGETHER AT THE POINTS WHERE THEY MEET.

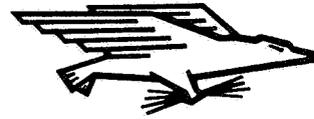
THE THIRD STEP IS TO SOLDER THE TUBES TOGETHER AT THE POINTS WHERE THEY MEET. THIS IS DONE BY SOLDERING THE TUBES TOGETHER AT THE POINTS WHERE THEY MEET.

THIS PIECE OF TUBES CAN BE USED TO SOLDER SMALL TUBES TOGETHER AT THE POINTS WHERE THEY MEET.

L-69-3861.2



L-69-3858.1



*"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."*

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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