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## TECHNOLOGY UTILIZATION

# HEAT TRANSFER AND THERMODYNAMICS

## A COMPILATION



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

# Foreword

The National Aeronautics and Space Administration and the Atomic Energy Commission have established a Technology Utilization Program for the dissemination of information on technological developments which have potential utility outside the aerospace and nuclear communities. By encouraging multiple application of the results of their research and development, NASA and AEC earn for the public an increased return on the investment in aerospace and nuclear research and development programs.

This document is one of a series intended to disseminate such information. The Compilation is arranged in two sections. Section one presents a group of devices that have been developed to provide more efficient means of heat transfer between components within a system and between systems and the ambient. Additionally, studies on certain theories and mechanical considerations in the transfer of heat are covered. The second section includes various items involved in the thermodynamic properties of matter and the causes and effects of certain interactions.

Additional technical information on individual devices and techniques can be requested by circling the appropriate number on the Reader Service Card included in this Compilation.

Patent Statements reflect the latest information available at the final preparation of this Compilation. For those innovations on which NASA and AEC have decided not to apply for a patent, a Patent Statement is not included. Potential users of items described herein should consult the cognizant organization for updated patent information at that time.

Patent information is included with several articles. For the reader's convenience, this information is repeated, along with more recently received information on other items, on the page following the last article in the text.

We appreciate comment by readers and welcome hearing about the relevance and utility of the information in this Compilation.

Jeffrey T. Hamilton, *Director*  
*Technology Utilization Office*  
*National Aeronautics and Space Administration*

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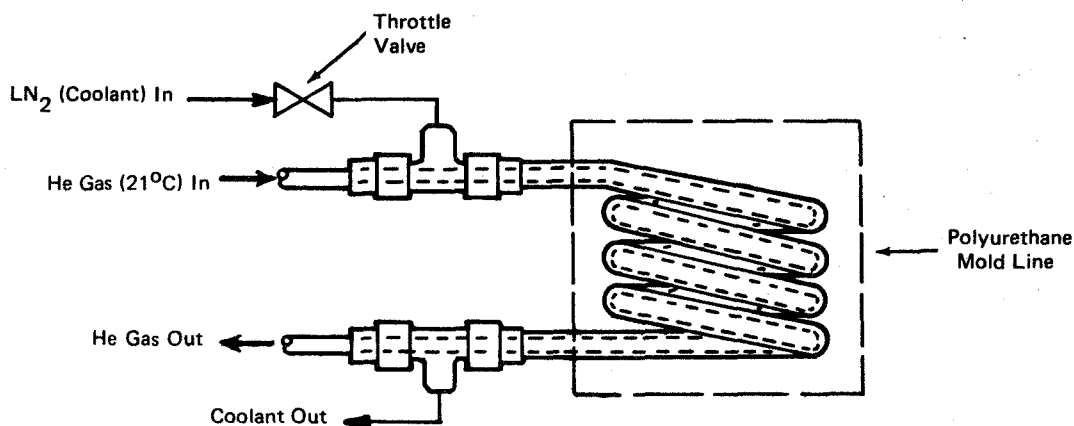
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# Section 1. Techniques and Related Devices for Heat-Transfer Applications

## HEAT EXCHANGER



This is a simplified heat exchanger consisting of a tube within a tube (see fig.) and formed into a coil that is surrounded by a block of foamed-in-place polyurethane. The polyurethane block acts as an insulator to maintain the desired heat exchange rate in the presence of severe ambient temperature fluctuations.

Many test systems require regulation of gases at a sustained, fixed temperature. Commercially available heat exchangers are expensive, require complex con-

trols, and are slow in establishing steady state temperatures. This heat exchanger is inexpensive, requires only simple control valving, and also features rapid response and stability.

Source: D. G. Keys and F. E. Smith of  
Rockwell International Corp.  
under contract to  
Marshall Space Flight Center  
(MFS-16483)

*Circle 1 on Reader Service Card.*

## COMPILATION OF HEAT TRANSFER DATA ON LIQUID HYDROGEN AT SUPERCRITICAL PRESSURES

These data present the results of a research investigation, based on 62 experiments, which provides valuable information on heat transfer to liquid hydrogen at supercritical  $12.97 \times 10^5 \text{ N/m}^2$  ( $>188 \text{ psia}$ ) pressures in turbulent flow inside electrically heated, circular cross-section, straight tubes.

Heat fluxes were as high as  $3.9 \times 10^3 \text{ J/cm}^2\text{-sec}$  ( $24 \text{ Btu/in}^2\text{-sec}$ ) with test section inlet pressures to  $172.50 \times 10^5 \text{ N/m}^2$  ( $2500 \text{ psia}$ ). Three identical test sections were used to obtain the data. In all cases, the outer-tube wall temperatures were measured by thermocouples insulated electrically from the test

section by a  $0.0025 \text{ cm}$  ( $0.001\text{-in.}$ ) thick sheet of mica. Voltage taps were spot-welded to the tubes.

The content of this data compilation should interest engineers, scientists, and students involved in heat transfer studies and applications for cryogenics.

Source: W. S. Miller, J. D. Sender, and  
D. M. Trebes of  
Rockwell International Corp.  
under contract to  
Marshall Space Flight Center  
(MFS-18727)

*Circle 2 on Reader Service Card.*

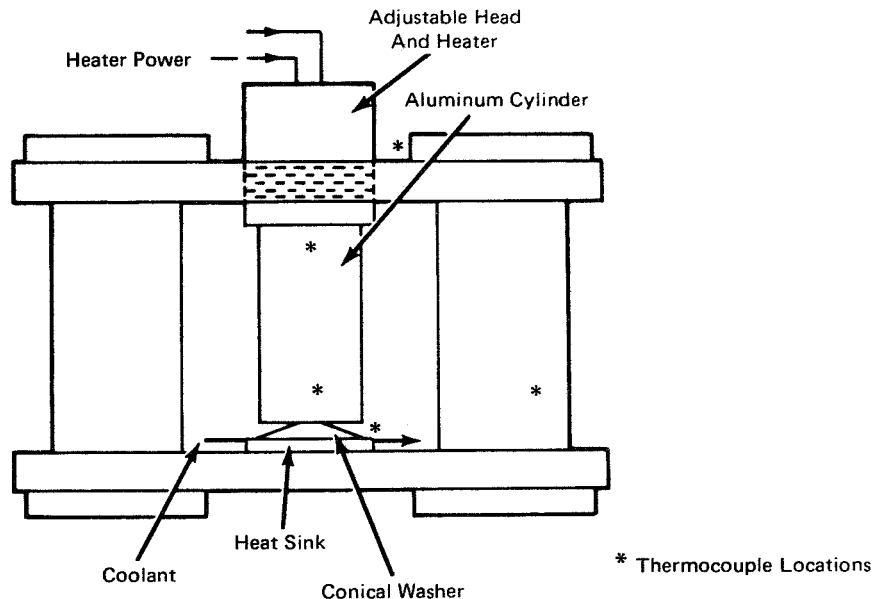
## PASSIVE HEAT TRANSFER CONTROL

The problem of maintaining a preselected temperature in the near vicinity of a variable source of thermal energy has been recently investigated. One typical situation is a solid state power circuit that generates heat, dependent on power requirements, and the stability of which is temperature dependent.

A useful concept has been reduced to an operating prototype stage that exhibits the desired characteristics of passive thermal control. The model used consists of a rigid framework with active elements mounted as shown in the figure. The adjustable head contains a resistance wire heat source operated by 60-Hz ac and has a maximum output of approximately  $2120 \times 10^3$  J/hr (2000 Btu/hr). A solid cylinder of 6061 T6 aluminum exerts vertical motion and force, as a result of thermal expansion on a

This model control is used as the basis for predictions of control temperature as a function of the pre-load, or initial gap at the outer edge of the conical washer with all elements of the control at known temperatures. Heat "leakage" through the two rings of contact at the washer prior to full compression controls heat flow before the control point is reached. Contact conductance between the annular area of the washer and the hot cylinder and heat sink governs temperature of the cylinder after full compression of the washer is accomplished.

Results of two test runs at average cylinder temperatures of 338 and 358 K (150° and 185°F) show positive control especially at the higher-temperature run in which control was achieved well within 2.7 K (5°F) of predicted average cylinder temper-



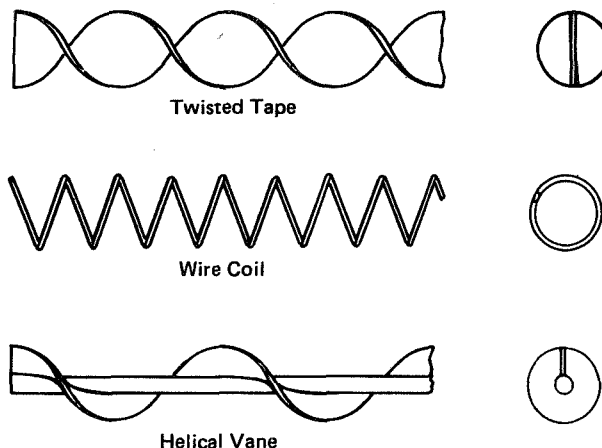
conical washer which rests on a water-cooled heat sink.

Heat input to the aluminum cylinder is controlled by a variable transformer, and a voltage drop across the heater is used to calculate power dissipated in conjunction with the known resistance of the heater. Heat sink temperature is held essentially constant by a large flow of tap water and is monitored by periodic sampling of water inlet and outlet temperature and temperature at a selected point on the heat sink shell.

ature. The thermal conductance behavior of the conical washer appears ideal for this application with the exception of the relatively high initial "leakage" through the circular contact points.

Source: F. A. Fitz of  
Southern Methodist University  
under contract to  
NASA Headquarters  
(HQN-10041)

## HELICAL INSERTS IMPROVE SINGLE-PHASE HEAT TRANSFER IN TUBES



Three Types of Insert

Use of swirl-generating inserts within tubes is a well-established technique for enhancing heat transfer to single-phase fluids. Recently, use of such inserts has been extended to the tubes of high-temperature liquid-metal boilers for electric power plants; the inserts not only improve heat transfer in the all-vapor (superheat) regions but also permit higher rates of transfer in the boiling regions. Use of these devices brings substantial savings in a boiler's size and weight.

Types of insert that have been used in, or are being considered for, boilers are the twisted tape, the wire coil, and the helical vane (see fig.). These may be termed "passive" devices; that is, their enhancement of heat transfer results from the rotational velocity imparted to the fluid, the fin-conduction effect being generally small.

The helical-vane insert has several advantages over the other two configurations; it creates a single, well-defined, helical flow passage. Maldistributions of flow have been observed between the two passages formed by a twisted tape in a tube. Heat-transfer data from the wire coil indicate substantial bypassing of flow. With the helical-vane insert, the bulk of the flow must follow the helical passage; consequently more reliable predictions and extrapolations of the thermal and hydraulic performance of this insert can be expected. The core of the helical-vane insert is not needed to support the vane, but it is a convenient housing for instrumentation (such as thermocouples), which do not disturb the flow.

The single-phase pressure losses and heat-transfer coefficients of a tube containing four full-length

helical-vane inserts differing in ratio of pitch to tube diameter were measured experimentally over a Reynolds-number range from about  $30 \times 10^3$  to  $300 \times 10^3$ . The heat-transfer coefficients and the pressure losses increased with increase in mass-flow rate and with decrease in the insert's pitch-to-tube diameter ratio. A mathematical momentum analysis, based on solid-body rotation, resulted in new theoretically based expressions for the momentum and frictional pressure losses for fully developed flow with these inserts. Helical-vane friction factors and Stanton numbers, computed from the experimental data in accordance with parameters derived from the analysis, correlated with modified plain-tube expressions.

This information may interest designers of single-phase heat-transfer equipment and of forced-convection boilers such as those used in central power plants and Rankine-cycle (low-pollutant emission) engines.

The following documentation may be obtained from:

National Technical Information Service  
Springfield, Virginia 22151  
Single document price \$3.00  
(or microfiche \$1.45)

Reference:

NASA-TM-X-52665 (N70-23224) Augmentation of Single-Phase Heat Transfer in Tubes by Use of Helical Vane Inserts

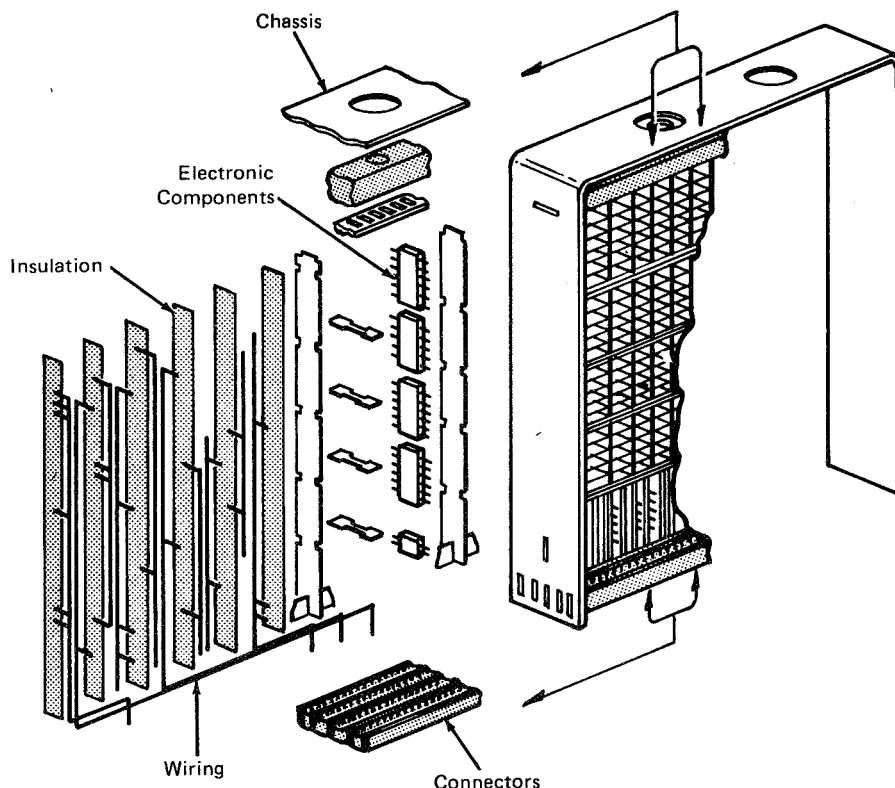
Source: M. U. Gutstein  
Lewis Research Center  
(LEW-11063)

## REPARABLE, HIGH-DENSITY MICROELECTRONIC MODULE PROVIDES EFFECTIVE HEAT SINK

It was necessary to develop a readily reparable modular system, for packaging microelectronic flat packs and miniature discrete components, that will provide an effective heat sink for electric power dissipation in the absence of convective cooling. The package must be light weight, rugged, of simple construction, and be compatible with other miniature, discrete electronic components.

This innovation is a three-dimensional compartmented structure incorporating etched phosphor

each etched part is first coated with solder. The small etched parts are then attached to each other and to a frame for ease in handling. These frames or sheets of etched parts are solder-coated by passing them through a wire mesh solder coater. The resulting thin, uniform coating of solder is sufficient to subsequently join the parts by simply heating the joints to cause the solder to flow together. The completed structure is not only rigid, strong, lightweight, and corrosion resistant, but also affords a good thermal path.



bronze sheets and frames with etched wire conductors.

The module compartments and frame (see figure) are made of etched spring tempered, thin gage, phosphor bronze sheets. A tabs-and-slots method is used to assemble the etched sheets into an easily fabricated and self-jigging rigid structure. The mechanical joints of the module compartments, module frame, and chassis are soldered to solidify the system.

To facilitate the subsequent solder-joining process,

A master wiring comb was developed to facilitate the wiring layout and shorten fabrication time. The master wiring comb is used as a drafting master and the desired wiring runs for each layer of circuitry are colored on transparent acetate sheets. The unused fingers which result from a one-layer wiring run are clipped. Subsequent layers are clipped according to the desired pattern and laminated. The laminated runs are then assembled into the compartmented structure by adhesive bonding. The wiring runs are welded or soldered to the connector.

These flat packs are installed in the modular system by inserting them into the designated compartments. They are aligned with the corresponding flat wire finger which protrudes from the flat wire assembly and connected by pulse soldering to enable later repairs. The individual leads can be pulse-soldered or multiple-soldered by the use of a resistance soldering device, which contacts five leads at a time. The flat packs and flat wiring assembly leads are pretinned to eliminate the need for additional solder or flux in the soldering process.

The round component leads from microminiature components require pretinning for effective use of pulse soldering. Large, bulkier components, such as miniature transformers, can be used in the module by clipping out frame members during assembly.

Source: F. F. Maytone and K. J. Carlson of  
The Boeing Company  
under contract to  
Marshall Space Flight Center  
(MFS-13075)

*Circle 4 on Reader Service Card.*

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## SURVEY OF HEAT TRANSFER TO NEAR-CRITICAL FLUIDS

A survey and analysis was conducted on heat transfer to fluids in near critical conditions. The topics covered include the following: heat transfer boundaries of the near critical region; free, natural, and forced convection experiments; oscillations; geometric effects; parameters which appear to be significant to heat transfer in the critical region; and theories which have been proposed for the region. Although the state-of-the-art is such that completely satisfactory theories or correlations are not available for heat transfer in the critical region, this survey indicates the most promising and widely used correlations and suggests procedures for approaching a critical point heat transfer problem. The survey brings together information on the near critical region, examines these data from a designer's point of view, and examines the flow mechanisms underlying the behavior.

Transport processes, particularly heat transfer, in the near critical region have been of interest for approximately 15 years. Current interest stems from applications which require the use of a fluid in the near critical condition, from information that is too incomplete to produce satisfactory design expressions, and from an inadequate understanding of the mechanics which produce the peculiar behavior in the near critical region.

Current or proposed applications include the use of near critical helium to cool the coils of super-

conducting electromagnets and superconducting electronic or power-transmission equipment, the use of supercritical hydrogen as a working fluid or fuel for both chemical and nuclear rockets, the use of supercritical water in electricity generating plants, and the use of methane as a coolant and fuel for supersonic aircraft.

Theoretical heat-transfer analyses have not, in general, been successful; however, this approach still shows promise for solving questions relating to the near critical region. By contrast, flow oscillations characteristic of this region have been examined analytically and found to be reasonably well predicted by using rather conventional concepts in mechanics.

The following documentation may be obtained from:  
National Technical Information Service  
Springfield, Virginia 22151  
Single document price \$3.00  
(or microfiche \$1.45)

### Reference:

NASA-TN-D-5886 (N71-13035), Survey of Heat Transfer to Near Critical Fluids

Source: R. V. Smith of  
National Bureau of Standards, and  
R. C. Hendricks and R. J. Simoneau  
Lewis Research Center  
(LEW-11289)



## RADIATOR DEPLOYMENT ACTUATOR

This invention is designed to deploy a cooling system radiator smoothly and positively from its retracted position in an aircraft or aerospace vehicle surface recess. Upon actuation, fluid under pressure is introduced into the fluid inlet (Figure 1). This causes the coil made up of the fluid line to move circumferentially within the housing. The outlet end of the fluid line is firmly anchored to the movable end plate and thus causes the end plate to rotate in a clockwise direction as shown in Figure 2. This causes the movable mounting bracket, which is affixed to the end plate and to which the radiator

is attached, to deploy the radiator  $90^\circ$  from its retracted position in the surface recess.

Action of the device is held in control for prevention of too-rapid deployment of the radiator by a damping bellows assembly. The assembly consists of a left-hand and a right-hand bellows separated by a movable partition, equipped with a feed-through orifice and a check valve. The bellows are filled with fluid which passes back and forth through the movable partition orifice as the actuator operates. This bellows device is provided with a closed toroid charged with a compressible fluid to effect a con-

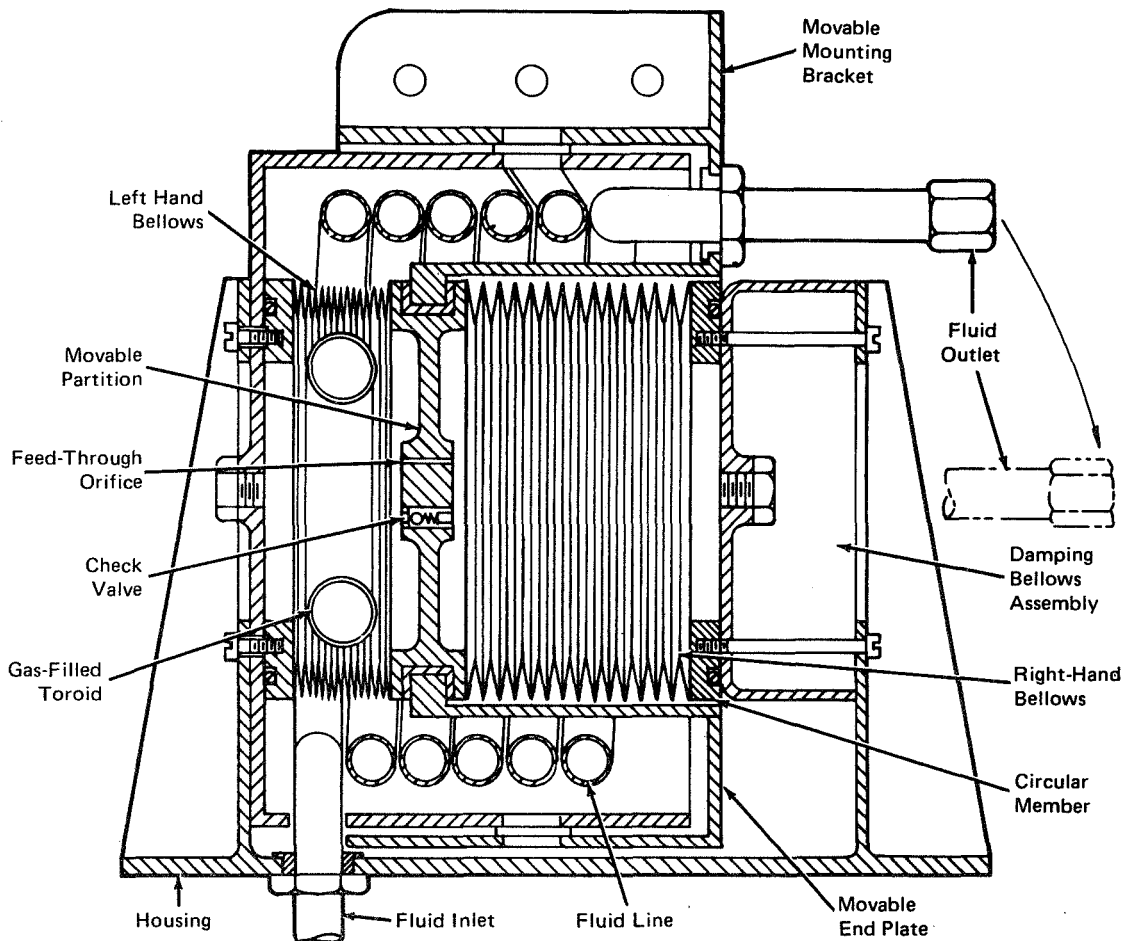


Figure 1.

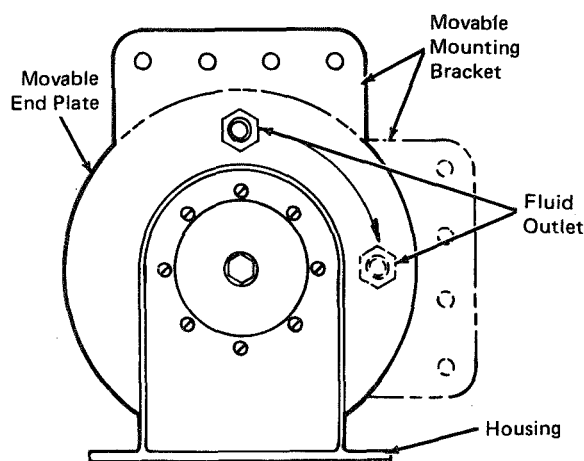


Figure 2.

stant condition within the bellows during temperature gradients. The size of the movable partition orifice is such that flow between the two bellows is restricted sufficiently to dampen but not prevent the desired deployment rate of the actuator.

This invention has been patented by NASA (U.S. Patent No. 3,563,307). Inquiries concerning non-exclusive or exclusive license for its commercial development should be addressed to: Patent Counsel, Code AM, Lyndon B. Johnson Space Center, Houston, Texas 77058, U.S. Patent No. 3,563,307 is available at the U. S. Patent Office, Washington, D. C. 20231, Price \$0.50.

Source: H. M. Koistee and W. E. Simpson of  
Grumman Aerospace Corp.  
under contract to  
Johnson Space Center  
(MSC-11817)

*No further documentation is available.*

## FLAME SPRAYED DIELECTRIC COATINGS IMPROVE HEAT DISSIPATION IN ELECTRONIC PACKAGING

Present electronic packaging applications require the transfer and dissipation of heat from heat-generating components while maintaining the components electrically isolated. The usual approach is to mount the components to an aluminum heat sink which has been coated with an electrically insulating material. The use of an anodized (aluminum oxide) coating has been found to be inadequate because of its low electrical resistance when exposed to a high humidity environment.

The heat sinks are flame sprayed with coatings of alumina ( $\text{Al}_2\text{O}_3$ ) or beryllia ( $\text{BeO}$ ) and then finished off with an organic sealer.

Beryllia ( $\text{BeO}$ ) and alumina ( $\text{Al}_2\text{O}_3$ ) were examined for possible application as heat sink coatings. Magnesia was eliminated from consideration because it was found to be very hygroscopic. The materials applied to aluminum test panels for examination were high purity 325 mesh alumina and 200 mesh beryllia coatings. A controlled atmosphere chamber was used for the flame spraying of beryllia since it is a toxic material.

After the oxide coatings were flame sprayed onto the test panels, organic heat sealers were brushed on

the coatings to inhibit moisture from penetrating into the pores of the coating. Three sealers were tested: an epoxy resin, an insulating varnish, and a phenolic sealer. The coatings exhibited the best shock resistance with the epoxy resin sealer.

Flame sprayed alumina and beryllia coatings with an organic sealer brushed over them can be used from room temperature to 477 K (400°F). They have electrical resistivities of approximately  $10^{15}$  ohm-cm at room temperature to  $10^{12}$  ohm-cm at 477 K (400°F) with no dielectric breakdown at 500 volts. The thermal conductivity of alumina is about one-sixth of that for beryllia. Both coatings (with the epoxy sealer) withstood a thermal cycle test from 477 K to 208 K (400°F to -85°F) with a transition period of approximately three minutes.

Source: T. L. Mackay, J. B. Vanaman, and  
A. N. Muller of  
McDonnell Douglas Corp.  
under contract to  
Marshall Space Flight Center  
(MFS-13569)

*Circle 5 on Reader Service Card.*

## HEAT PIPE IS SIMPLE, VERSATILE, EFFICIENT HEAT TRANSFER TOOL

The heat pipe is a self-contained, closed system capable of transporting large quantities of heat from a source to a sink with only a small temperature drop. Thermal energy may be transferred to and from the heat pipe by any combination of conduction, convection, or radiation heat transfer. Open flames, nuclear sources, and electronic equipment are among the heat energy sources whose energy has been transported by heat pipes. Thermal energy may be added at a high flux over a relatively small area and removed over a large area at a low flux, and conversely.

The heat pipe has no moving parts, requires no energy input other than the heat which it transfers, and does not rely on gravity for its operation. It consists simply of a sealed container lined with a wick and charged with a working fluid which is the primary heat transfer medium.

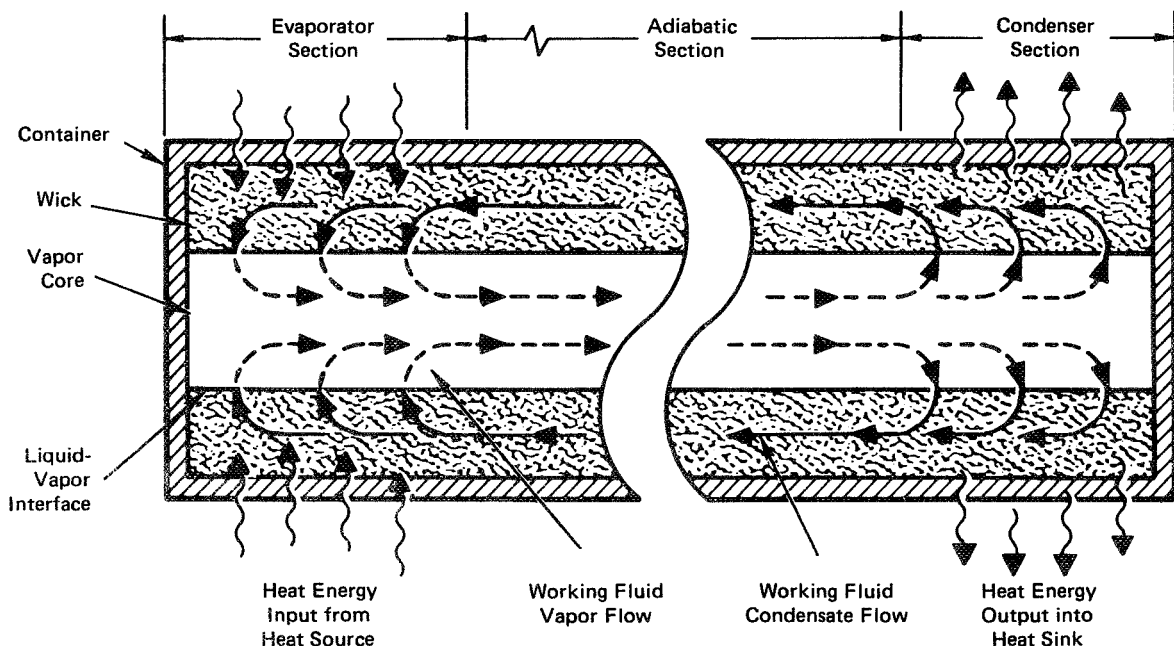
The container is usually a tube made of a metal which is compatible with the wick material and the working fluid. The wick may be metal, such as wire screens, sintered metal powder or fiber, or perforated metal sheets; or it may be a nonmetallic material, such as felt, cloth, or fiberglass. Water, ammonia, acetone, freons, alcohols, and various liquid metals have been used as the working fluid. Only enough fluid to saturate the wick is introduced into the heat pipe. The choice of a particular com-

bination of container, wick material, and working fluid is based on the operation and design criteria of the heat pipe.

In the evaporator section, heat energy from the source is transferred by conduction through the container wall and the saturated wick to the liquid-vapor interface, where the working fluid vaporizes. The vapor flows through the vapor core to the condenser section, where it condenses at the vapor-liquid interface. Heat is transferred by conduction from this interface through the saturated wick and the container wall, and is dissipated into the heat sink in the condenser section. The working fluid condensate moves through the wick by means of capillary action to the evaporator section, where the cycle is repeated.

The container should be capable of withstanding high internal pressure loads due to variations in vapor pressure of the working fluid during operation. The material of the container must exhibit a high thermal conductivity, must be capable of long term operation, and must be compatible with the wick material and the working fluid.

Selecting the wick material usually involves a compromise between capillary pumping capability and minimum pressure drop in the wick. High thermal conductivity is also desirable in order to provide a heat path parallel with the vapor path and the con-



tainer wall. The wick must be readily wetted by the working fluid and it must be compatible with the container material and the working fluid.

The working fluid should have high purity, surface tension, heat of vaporization, and liquid density, and have small liquid viscosity. Toxicity, flammability, ease of handling, compatibility with the other materials, and ability to wet the wick must also be considered.

Although the theory of heat pipes has been formulated, correlation of empirical data with theory is essentially nonexistent. For all practical purposes, therefore, one must resort to trial-and-error techniques in designing a heat pipe for a given set of operating conditions.

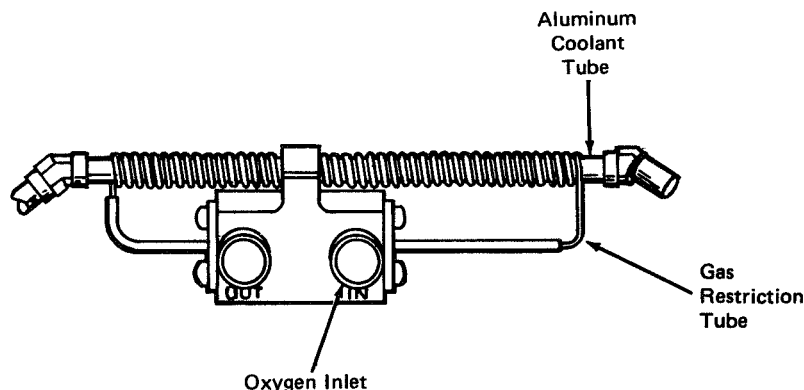
The performance map is an important design tool presenting a collective set of heat pipe data, such as heat transfer capabilities, lower and upper performance limits, and temperature distributions essen-

tially over its entire operational range. The usefulness of the performance map is especially appreciated when a number of heat pipe designs are compared for the same set of conditions. This extends to heat pipes having the same working fluid but with dimensional variations, as well as those with a variety of working fluids. Data from wick permeability and rise test studies may eventually be instrumental in correlating theoretical results with the performance map data for effective heat pipe designs.

Source: J. Schwartz, formerly of  
Caltech/JPL  
under contract to  
NASA Pasadena Office  
(NPO-11598)

*Circle 6 on Reader Service Card.*

## OXYGEN RESTRICTOR CONTROLS TEMPERATURE AND FLOW RATE



In the operation of an environmental control system for a spacecraft test installation, large quantities of oxygen are required. The oxygen flow both upstream and downstream must be maintained at a given rate, and temperature. Additionally, no liquid oxygen can be permitted into the test installation.

A stainless steel capillary tube (see fig.) is wrapped around an aluminum coolant tube and attached to it by aluminum plasma-arc welding. Length and inside diameter of the capillary tubing are sized to effect the desired flow rate and heat transfer rate.

This restrictor controls the flow rate by friction as well as by the size of the orifice. As the gas passes through the long spiral tube, friction makes the flow resistance greater for a given-diameter passage. This

allows a larger orifice to be used, which reduces the chances of clogging.

The oxygen gas is cooled as it passes through the stainless steel capillary. The temperature of the emerging gas depends upon the heat-transfer rate. The heat-transfer rate is controlled by the particular coolant and the diameter of the capillary.

Source: E. Green and D. D. Gromberg of  
Rockwell International Corp.  
under contract to  
Johnson Space Center  
(MSC-17146)

*No further documentation is available.*

## SOLDERING IRON TEMPERATURE INDICATOR

In the fabrication of flight-qualified electronics hardware, soldered-joint integrity is a firm requirement. Long practice in quality control procedures has shown that optimum results can be obtained only when the soldering iron tip temperature is maintained within close tolerances.

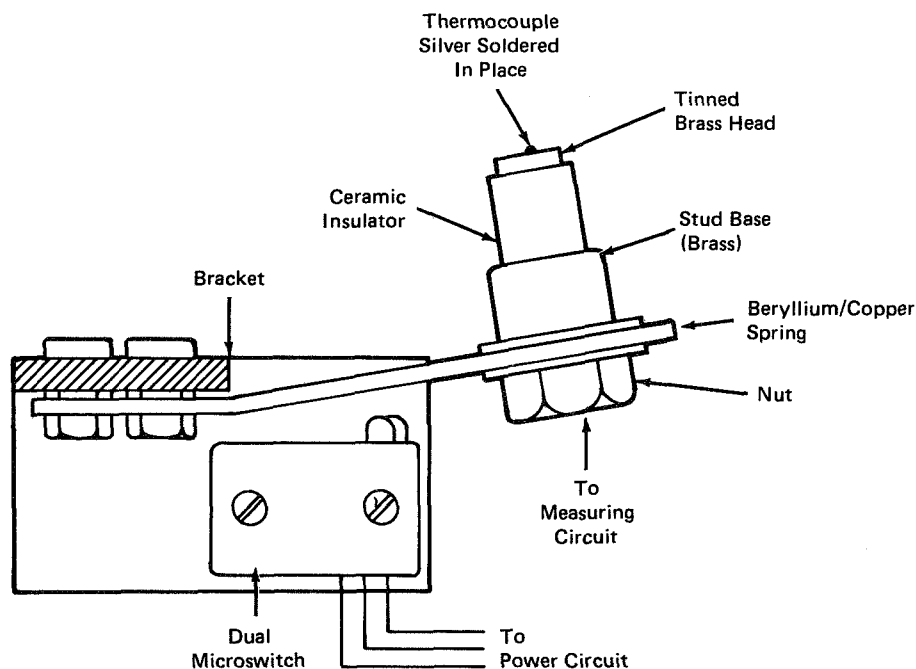
This innovation permits the operator to observe, by a system of warning lights, the tip temperature throughout a continuous assembly operation.

A Chromel-Alumel thermocouple is silver-soldered into a brass receptacle of a mass which has a heat transfer characteristic equivalent to a typical connection that is soldered in the course of assembly. The brass is tinned and then mounted on a ceramic insulator which in turn is cemented to a threaded stud, as indicated in the diagram. The stud is fastened to a leaf spring which operates micro-

switches which is applied to operate the microswitches is very similar to the pressure applied in a normal soldering operation. Thus, when the tip of the soldering iron is touched to the brass thermocouple head and pressed down, the microswitches activate measuring circuits and the temperature of the soldered "joint" is indicated.

Temperature is indicated by white, green, amber, and red light bulbs. If the white bulb lights, the temperature is 25°F (14°C) below the desired temperature. The proper temperature is indicated by a green light; the amber light means the temperature is too high by 25°F, and the red light, that it is 50°F (28°C) too high.

The electronic circuits for operating the bulbs use integrated-circuit operational amplifiers to compare selected reference voltages with the thermocouple



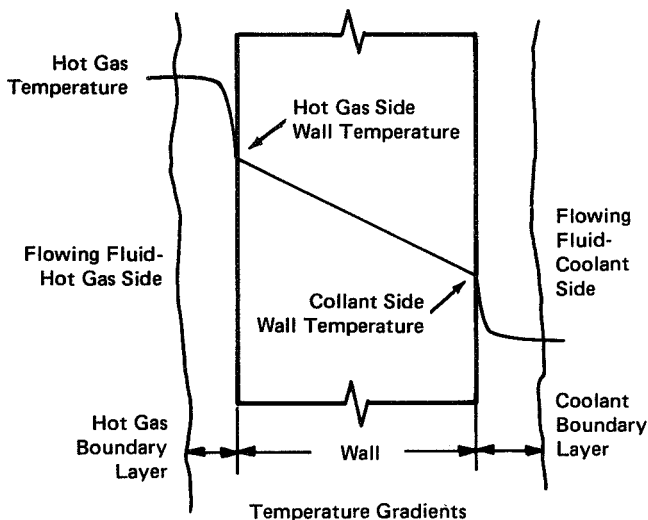
switches when the leaf is depressed by the tip of the soldering iron.

Considerable care must be exercised in the fabrication of the thermocouple brass head, for it is desired that the head simulate the actual soldering conditions as much as possible. The temper of the leaf spring is carefully adjusted so that the pressure

output. Other elements of the circuits ensure that only one bulb is lit at any time.

Source: C. D. Baker and G. A. Wiker of  
Caltech/JPL  
under contract to  
NASA Pasadena Office  
(NPO-11545)

### SIMPLIFIED METHOD FOR DETERMINING CONVECTIVE HEAT-TRANSFER COEFFICIENTS



Convective heat-transfer coefficients on both sides of a wall can now be determined by measuring the temperatures of the hot and cold fluids separated by the wall, and the temperature of the wall at a single point. The method used is generally applicable to heat exchangers and particularly to rocket engines. This simplified transient method requires measurement of the response of the wall temperature to a sinusoidally varied hot gas temperature. Prior, steady-state methods for determining the heat transfer coefficients required measurement of two wall temperatures, and the distance separating them, so that a temperature gradient could be determined for use in the heat conduction equation. When the heat flux is high and the wall thermal conductivity is low, thin walls are necessary to maintain the wall temperature at an acceptable level. Measuring one temperature accurately on a thin wall is possible, but measuring two wall temperatures and determining the temperature gradient accurately is extremely difficult due to the geometries involved. By requiring only one wall temperature measurement, the instrumentation problem is resolved.

The convective heat-transfer coefficients can be determined experimentally if a single wall temperature, the hot gas temperature, and the coolant temperature are known as a function of time. From temperature-time traces of the hot gas, the coolant, and just one location in the wall, the phase lag angle, and ratio of the amplitude of the wall to the hot gas

temperature are determined. Either the phase lag angle or the ratio is used in accordance with an analysis to calculate the convective heat transfer coefficients which exist on the two surfaces of the wall.

An experimental verification of the method is described in NASA-TM-X-1980. An analysis of the method and derivation of the equations for solution of the heat-transfer coefficients can be found in NASA-TN-D-5520.

The following documentation may be obtained from:

National Technical Information Service  
Springfield, Virginia 22151  
Single document price \$6.00 (N69-40789)  
or \$3.00 (N70-21745)  
(or microfiche \$1.45)

#### References:

NASA-TN-D-5520 (N69-40789), Convective Heat-Transfer Coefficients from a Solution of the Conduction Equation for a Wall Separating Two Fluids, One Having an Oscillating Temperature  
NASA-TM-X-1980 (N70-21745), Experimental Evaluation of an Oscillating Temperature Technique for Obtaining Convective Heat-Transfer Coefficients

Source: R. G. Huff  
Lewis Research Center  
(LEW-11156)

## STUDY OF HEAT TRANSFER THROUGH METAL JOINTS IN VACUUM ENVIRONMENT

A study was made to acquire additional information about the transfer of heat across bolted joints and flat metal surfaces in a partial vacuum of less than  $10^{-4}$  torr. Electronic components and other pieces of equipment used on space vehicles develop heat energy as a byproduct of their respective functions. The dissipation of this energy becomes a problem in space because of vacuum conditions and the resulting loss of convection in and around each article. To overcome this problem, conduction into a heat sink is extensively used. However, if the components are clamped or bolted to a heat sink in a high vacuum environment, a problem in heat transfer does remain.

The joining of articles in an environment containing gas at pressures well above  $10^{-4}$  torr will result in good heat transfer from the component to the heat sink or cold plate, since gas molecules between the adjoining surfaces help transfer heat. If the number of molecules per unit volume is reduced below that contained at a pressure of  $10^{-4}$  torr, the heat transfer is effected mainly by direct contact of the two surfaces. The actual contact area of ordinary machined surfaces, either flat or form fitting, is very low at low surface contact pressures because of the roughness caused by tool marks, scratches, etc., and because of a wave variant from absolute flatness. The net result is that temperature differences between the two surfaces tend to be greater than is normally experienced. This study presents information associated with this phenomenon. The conclusions drawn from this study are presented below:

*Temperature Drop across a Bolted Joint.* In a vacuum environment, such as that found in outer space, heat energy transfer across joints bolted together displays several useful and interesting thermal conductivity characteristics.

- (a) If two thin sheets of a metal alloy, for example aluminum alloy 6061-T6, are bolted together, heat energy transfer from one sheet of metal to the other sheet of metal is closely concentrated around the bolt.
- (b) At a given heat energy load, the temperature drop across a bolted joint decreases rapidly as the bolt and nut are tightened to a minimum torque level. Increasing the torque load above this level does not decrease the temperature drop significantly.
- (c) A flange with a large or a small footing area made of thin metal transfers heat energy to a heat sink with equal effect.
- (d) A thick flange with a large footing area transfers heat energy more efficiently to a heat sink having a rigid surface than a thin flange with the same-sized footing area.
- (e) The insertion, between a flange and mounting base, of a soft shim material possessing a low thermal resistance is of very little practical value in increasing heat energy transfer efficiency.
- (f) The temperature distribution around a bolt holding a flange to a heat sink is symmetrical. The temperature drop from a thin flange to a heat sink increases abruptly at a short distance from the perimeters of the bolt head and the nut.

*Temperature Difference of Rigidly Backed Heat Transfer Surfaces.* Rigidly backed flat metal surfaces pressed together in a vacuum environment display a cyclical improvement in heat energy transfer as the interface pressure is increased. This suggests changing the rapidity with which actual contact area increases, through a settling together of the surfaces.

A small rise irregularity on one of the flat surfaces lowers the heat energy transfer efficiency. In the tests described in the report, a small rise irregularity caused the temperature difference of two surfaces to double. Below contact pressure of  $207 \times 10^3 \text{ N/m}^2$  (30 psi), temperature differences increase rapidly and the ratio of two no longer applies.

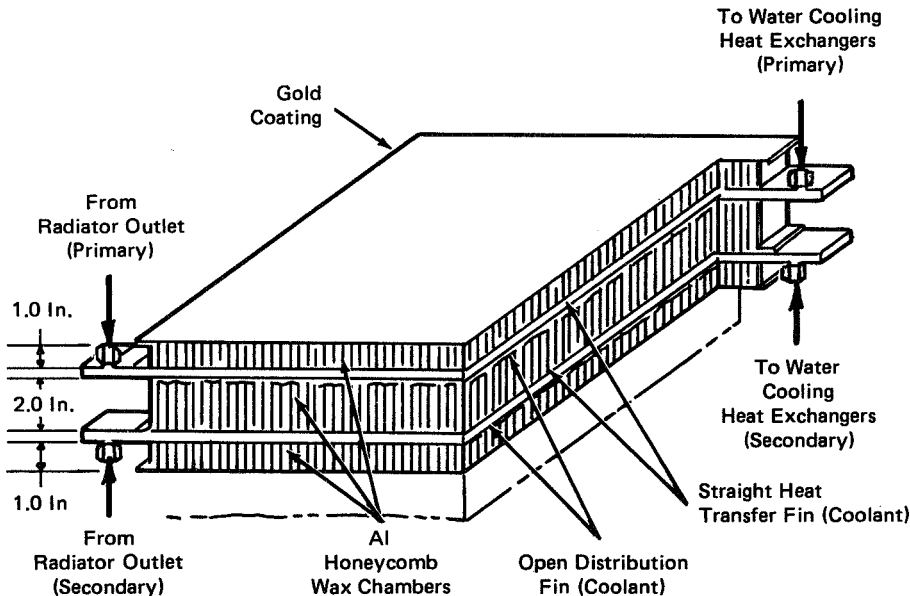
Source: D. H. Elliot of  
Douglas Aircraft Co.  
under contract to  
Marshall Space Flight Center  
(MFS-12534)

## FLUID LOOP THERMAL CAPACITOR

Although this innovation was designed and constructed as a prototype for use in space to dissipate heat gathered during the sunlit portion of an earth orbit, its passive character should make it attractive for earth applications.

Radiator heat rejection limits of the capacitor are determined by the maximum radiator outlet temperature during the sunlit side of the orbit. Peak heat rejection capability is available during the dark side of the orbit. The fluid loop thermal capacitor uses this peak capability to freeze tri-decane wax which then melts during the sunlit

The capacitor (see fig.) consists of three wax chambers and two dual pass, plate-fin heat exchangers (coldplates). The coldplates are sandwiched between the wax chambers. During the charge cycle, coolant fluid enters the unit, and its temperature is raised by the heat of fusion released by the wax as it undergoes a liquid-to-solid phase change. Heat transfer from the wax to the fluid is enhanced by the use of the honeycomb structure containing the wax and by the fins in the heat exchanger. During discharge, fluid entering the unit is cooled by the action of the melting wax.



side of the orbit, increasing the cooling capacity of the radiator. The capacitor is a coolant fluid-to-solid phase-change material heat-exchanger, enabling it to provide temperature control for all the components in the loop.

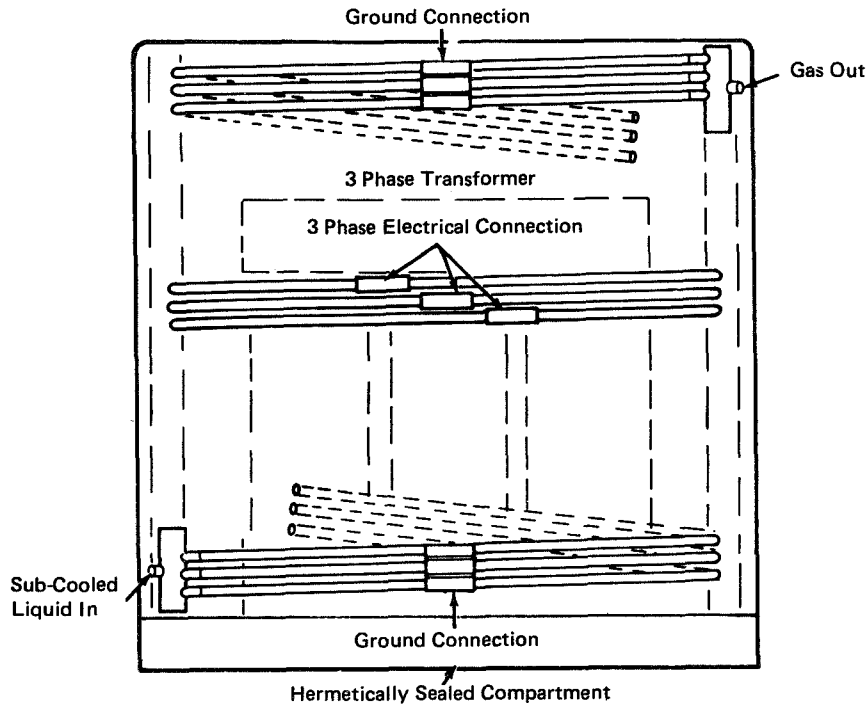
Source: D. W. Richman, G. L. Goedert, and E. A. Pourie of McDonnell Douglas Corp. under contract to Marshall Space Flight Center (MFS-20896)

Circle 9 on Reader Service Card.



## Section 2. Thermodynamic Properties of Matter (Causes and Effects)

### COMPLEMENTARY SYSTEM VAPORIZES SUBCOOLED LIQUID, IMPROVES TRANSFORMER EFFICIENCY



Certain test facilities require large quantities of gaseous hydrogen or nitrogen in their operation. These gases are normally stored in their subcooled liquid state, and it is necessary to apply heat to convert them to the large gaseous volumes required. It is desirable to achieve this conversion as economically as feasible, preferably without conventional heat transfer media.

This complementary system takes advantage of the inherent induction heat losses of an electrical transformer to convert the liquid to a gas. Transformer efficiency is improved in the process.

A parallel arrangement of three heat exchanger tubes is placed within the transformer enclosure in close proximity to the transformer core. The subcooled liquid to be vaporized is passed through the parallel paths of tubing from an inlet header to an

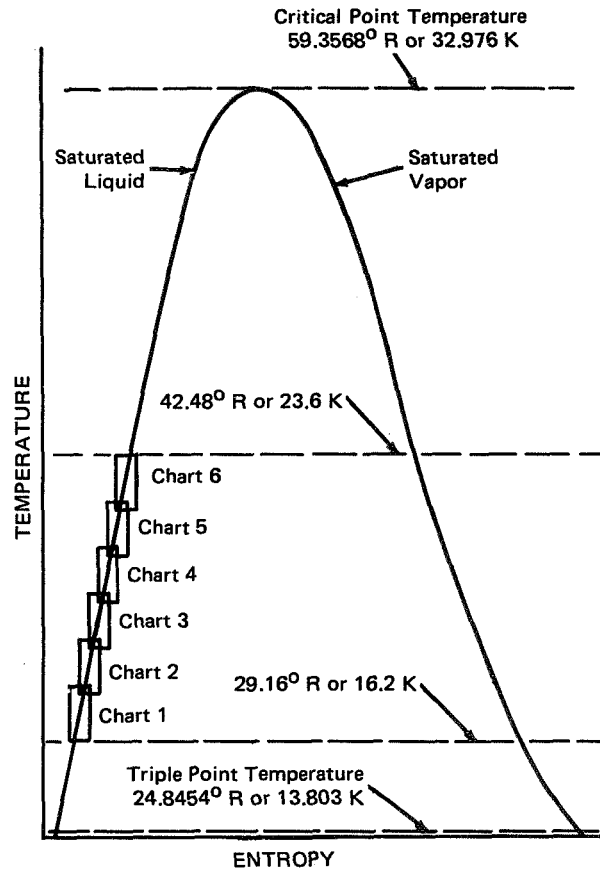
outlet header where it emerges as gas vapor. Each tube is connected as a single phase load on the three phase transformer output. The compartment containing the tubing and transformer core is hermetically sealed to prevent moisture buildup on the tubing.

Transformer efficiency is greatly increased and a given load may be handled with a much smaller core.

Source: E. C. Ketaly of  
Rockwell International Corp.  
under contract to  
Marshall Space Flight Center  
(MFS-550)

*Circle 10 on Reader Service Card.*

## THERMODYNAMIC PROPERTIES OF SATURATED LIQUID PARAHYDROGEN CHARTED FOR SIGNIFICANT TEMPERATURE RANGE



Existing temperature-entropy diagrams for parahydrogen in or near the saturated liquid state, specifically between 16.2 and 23.6 K (29.16° and 42.48°R), are not adequate for some applications. At this state the pressure, density, enthalpy, and quality curves run so close together on a normal scale of plotting that it is impractical to distinguish one curve from another. Therefore, to obtain reasonable accuracy in this range, it was necessary to expand these scales onto large charts.

Data on parahydrogen were developed previously by the National Bureau of Standards, from the triple point to 100 K at pressures to 340 atmospheres.

These data have now been reprocessed, refined, and expanded to create six new entropy diagrams which cover the temperature range from 16.2 to 23.6 K (29.16° to 42.48°R), with pressures to 100 psia (6.8 atm) and mixtures of the liquid and vapor phases to 0.003 quality.

Source: R. D. McCarty and H. M. Roder of  
National Bureau of Standards  
under contract to  
AEC-NASA Space Nuclear Systems Office  
(NUC-10018)

*Circle 11 on Reader Service Card.*

## PROPERTIES OF AIR, AND COMBUSTION PRODUCTS OF FUELS WITH AIR

Thermodynamic and transport properties have been calculated for air, the combustion products of natural gas and air, and the combustion products of ASTM-A-1 jet fuel and air. Properties calculated include: ratio of specific heats, molecular weight, viscosity, heat capacity, thermal conductivity, and Prandtl number. These properties have been calculated for temperatures from 300 to 2500 K and for pressures of three and ten atmospheres. The data for natural gas and ASTM-A-1 were calculated for fuel-air ratios from zero to stoichiometric. Adiabatic combustion temperatures of natural gas burned in air and ASTM-A-1 burned in air were also calculated over this range of fuel-air ratios. The data are presented in the referenced report.

The calculated data for thermal conductivity and Prandtl number were compared with experimental values of these properties available in the literature. Agreement within 5 percent was found between the theoretical and experimental data.

The calculated data presented in the report are for the combustion products of defined fuels. However, it is estimated that the difference between calculated properties of the combustion products of the defined natural gas and the properties of any nominal natural gas composition burned in air will be less than three percent. Likewise, errors of less than three percent will be introduced if the properties of the combustion products of ASTM-A-1 are used for the properties of

the combustion products of any of the typical fuels which were considered.

The analytical investigation described was conducted to determine properties for the gas compositions, pressures, and temperatures encountered in jet engine cooling studies. Accurate values of the thermodynamic and transport properties were not available in the literature and are required when basic heat transfer correlations are being developed to improve the reliability of predicting local turbine blade and vane temperatures.

The data should be useful for general applications in gas turbines and for a variety of industrial combustion processes.

The following documentation may be obtained from:

National Technical Information Service

Springfield, Virginia 22151

Single document price \$6.00

(or microfiche \$1.45)

Reference:

NASA TND-5452 (N69-37936) Thermodynamic and Transport Properties of Air and the Combustion Products of Natural Gas and ASTM-A-1 with Air.

Source: D. J. Pofert, R. Svehla, and

K. Lewandowski

Lewis Research Center

(LEW-11030)

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## THERMODYNAMIC PROPERTIES RELATED TO EXPANSION OF A TWO-COMPONENT GAS

Theoretical equations were derived from basic thermodynamic equations to relate the thermodynamic properties of a two-component gas mixture, consisting of a fixed gas (e.g., helium) and a condensable gas (e.g., nitrogen tetroxide, vaporized from the liquid phase in a tank), to the expansion of the gas during tank ullage blowdown. Experimentally measured values of pressure and temperature were found to be in good agreement with the theoretically predicted data when the effect of heat transfer from the tank wall and liquid surface to the ullage was included in the analysis. The effect of heat transfer becomes

important when the expansion occurs over wide pressure ranges in a heavy tank.

Although the gaseous components were assumed to obey the ideal gas laws, the derivation did not include the assumption that either isentropic or isothermal conditions prevailed during the expansion (blowdown) process.

Source: F. Bizjak of  
Rockwell International Corp.

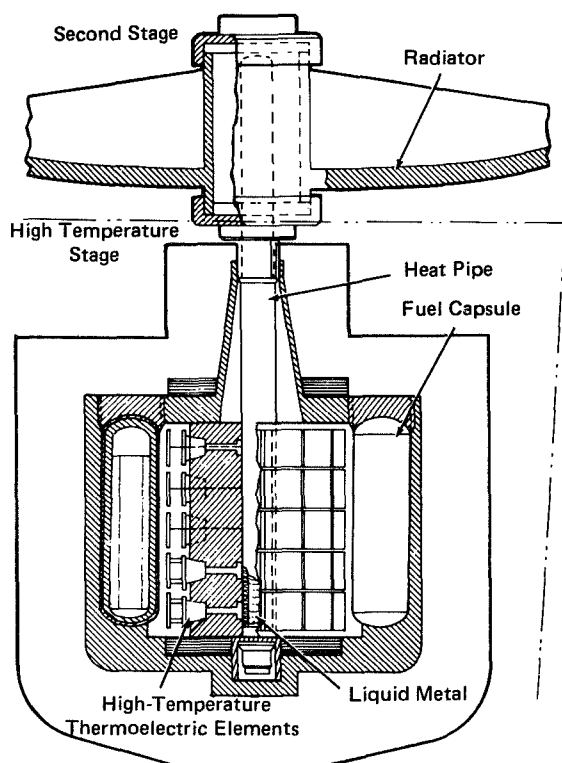
under contract to  
Johnson Space Center

(MSC-1133)

Circle 12 on Reader Service Card.

## THERMALLY CASCADED THERMOELECTRIC GENERATOR

Radioisotope-thermoelectric-generators (RTG) use thermoelectric elements which convert thermal energy to electrical power. It is acknowledged that there is no ideal thermoelectric material; rather, the available materials are each efficient in the conversion of heat into electrical power within specific temperature ranges. It is intuitively apparent that a serial combination of a high-temperature thermoelectric material and a low-temperature thermoelectric material would have a higher conversion efficiency than any single material.



A high efficiency thermoelectric generator has been designed and fabricated which utilizes a high-temperature thermoelectric material in thermal series with a low-temperature material. The provision of a thermally cascaded generator, with two stages connected in thermal series by means of an elongated heat pipe

containing a liquid metal and a wick, increases the overall efficiency of the RTG system.

The thermally cascaded, thermoelectric generator, shown in the figure, consists of a high-temperature stage coupled to a second low-temperature stage by a heat pipe which contains a wick and liquid metal. Heat generated in the isotopic fuel capsules is radiated to the first high-temperature stage located within the cylindrical array of fuel capsules; an array of silicon-germanium (Si-Ge) thermocouples converts a portion of this heat to electrical power. The heat rejected from the first stage is absorbed by the liquid metal (contained in the heat pipe) as latent heat of vaporization. The vapor produced by this energy transformation process travels within the heat pipe to the second stage, where it condenses and transfers the heat to the lower temperature thermoelectric wafers. Lead-telluride (Pb-Te) material is used in this stage to increase the conversion efficiency. The heat input to the second stage is at a temperature of 850 K to 950 K and is rejected by the radiator fins at about 450 K.

The thermal impedances of all the components of the system are carefully matched so that the operating temperature is optimum for the system and not for the individual stages or components. When properly constructed, the system produces approximately 50% more power than could be produced by either stage alone.

The arrangement of the two stages coupled together by the heat pipe and the placement of the Si-Ge thermocouples eliminate direct contact between the generators and the thermocouples; this eliminates the mechanical and chemical stability problems inherent in fabricating a thermally cascaded generator. The heat pipe and radiators are selected to insure that each stage operates in a temperature range where it is more thermoelectrically efficient.

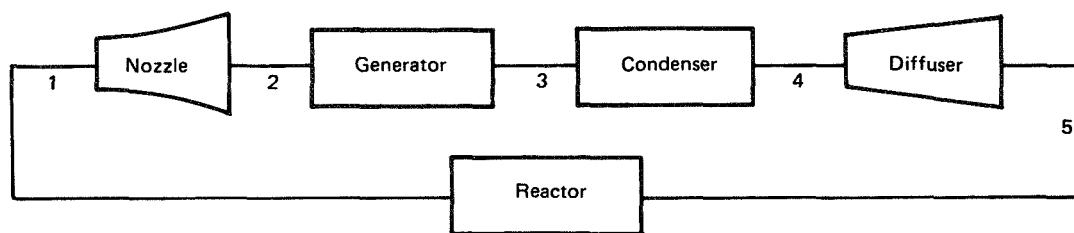
Source: R. Flaherty of  
Westinghouse Electric Corp.  
under contract to  
NASA Pasadena Office  
(NPO-10753)

Circle 13 on Reader Service Card.

## MAGNETOHYDRODYNAMIC GENERATORS USING TWO-PHASE LIQUID-METAL FLOWS

The limits of performance of two-phase magneto-hydrodynamic (MHD) liquid-metal generators have been explored experimentally over extended parameter ranges and preliminary data are reported. Systems incorporating direct-energy-conversion MHD

acceleration cycles are inherently friction-limited and capable of only moderate performance in terms of efficiency, but the two-phase cycle offers the prospect of operation which is relatively high in efficiency; it promises to be highly competitive with not only turbo-



One-component two-phase cycle

generators, coupled to nuclear reactors and conventional steam bottoming plants, are expected to lead to overall cyclic efficiency of about 50% and so to lower costs of electric power. The generators discussed can operate at high efficiencies — about 70%.

In contrast to a Rankine cycle, which employs the vapor phase as the working fluid, liquid-metal MHD cycles must be designed for transfer of the thermal energy of the vapor phase into kinetic energy, or stagnation head, of a fluid of sufficient electrical conductivity to pass through a MHD generator. This constraint in design has given rise to many schemes from which four basic cycles have emerged: (a) the separator cycle, (b) the condensing-injector cycle, (c) the multistage cycle, and (d) the two-phase-generator cycle (see fig.).

These four cycles have two underlying philosophies. In the first three, MHD generators operate on kinetic energy deriving from the conversion of thermal energy prior to entry into the generator; a vapor is used to accelerate a liquid, and then the vapor is either separated or condensed; the generation of electric power from the liquid stream is a separate operation. In the two-phase-flow generator cycle studied at Argonne National Laboratory, the working fluid is compressible and treated as an expanding gas; the thermal-to-electric conversion proceeds in a single interaction region. The expansion process is similar to that occurring in a plasma generator. The liquid-

machinery but also other converters of energy. Either a one- or two-component version of the cycle is possible. Basically, the two-phase mixture passes from the heat source through the MHD generator, where the expansion process takes place and the electrical energy is extracted.

The operation of such a two-phase generator is confined to a specific quality range; however, the feasibility of a second type of generator, a film-flow generator, that potentially can accommodate higher-quality mixtures has also been established. The film-flow generator, if placed immediately adjacent to the separator in the separator cycle, could improve overall efficiency by eliminating the transitional losses; or it can combine the functions of separator and generator. The limits of performance of these two generators have been examined experimentally over extended ranges of parameters.

### Reference:

M. Petrick, SM/74/196 (Argonne National Laboratory, 1968); I.A.E.A. Symp. Magnetohydrodynamic Electric Power Generation, Warsaw, July 1968 (SM-107/20), pp. 1-24.

Source: M. Petrick  
Engineering Division  
Argonne National Laboratory  
(ARG-10168)

Circle 14 on Reader Service Card.

## PLASMA-HEATING BY INDUCTION

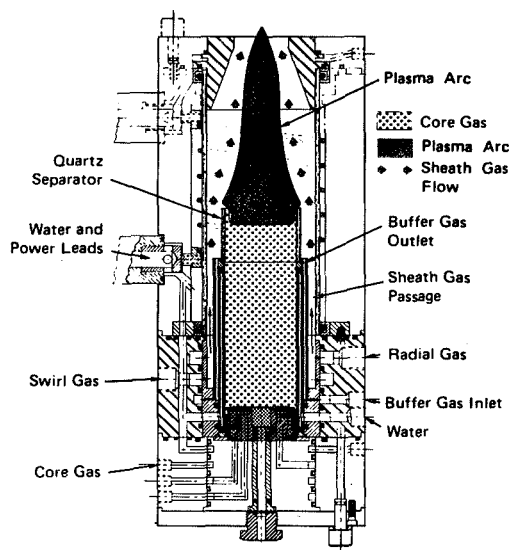


Figure 1. Plasma Torch

An induction-heated plasma torch (Figure 1) has been operated with an input of 1 MW of direct current of which 71% was transferred to the plasma; the remainder was consumed by electrical losses in the system (Figure 2). This power load is about ten times greater than had previously been achieved.

Heating of the plasma was induced by passage of 450-kHz alternating current through a copper coil wrapped around it. The plasma was formed in a central jet of core gas; a surrounding flow of "sheath" gas cooled the torch walls. Nitrogen, oxygen, air, and argon were used in various combinations for these two gas flows. The inside diameters of the torch were 11.4 and 15.24 cm (4.5 and 6 inches). An exhaust enthalpy of  $97.2 \times 10^6$  J/kg (41,700 Btu/lb) in air was achieved at a power level of 700 kW. No over-heating problems occurred. Continuous operation of the torch should be possible for as long as 5,000 hours, as required for power-supply maintenance.

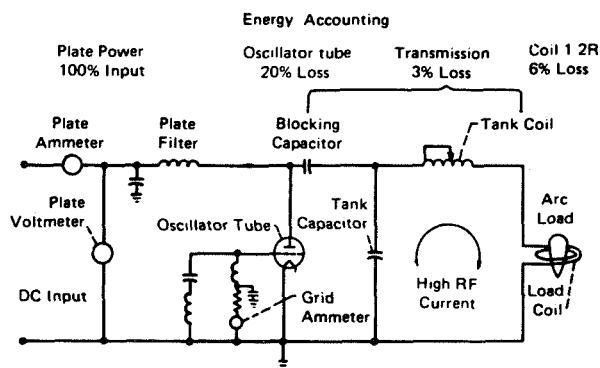


Figure 2. Sites of Losses of 29% of the Power Input

Operation of an induction-heated plasma torch, with pure hydrogen as both the core gas and sheath gas, was achieved at a frequency of 4 MHz at power levels of up to 185 kW. The torch's inside diameter was 2.79 cm (1.1 inches). Exit-gas enthalpies were estimated to be at more than  $2.3 \times 10^9$  J/kg ( $10^6$  Btu/lb).

Title to this invention has been waived, under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457 (f)], to the Humphries Corporation, 180 North Main Street, Concord, New Hampshire 03301.

Source: K. Harrington and M. L. Thorpe of  
Humphries Corp.  
under contract to  
Lewis Research Center  
(LEW-10528)

Circle 15 on Reader Service Card.

## STABILIZATION OF ARCS IN RADIATION SOURCES

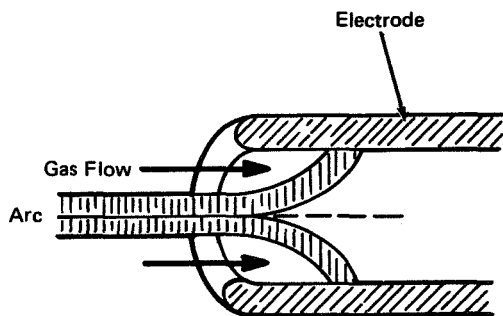


Figure 1

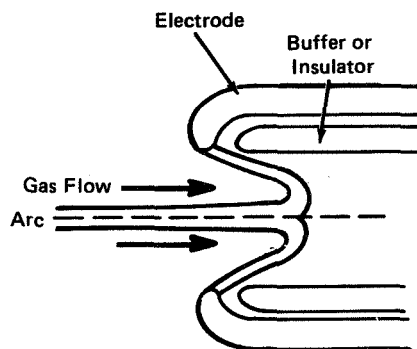


Figure 2

The design of high-power arc radiation sources and arc gas-heaters is frequently based on some form of hollow electrode configuration with the electrode surfaces inside a substantially cylindrical passage in which an arc is confined by a flow of gas (Figure 1). Typically, the hollow electrode may consist of a single ring, multiple rings, segmented rings, or a series of circularly disposed pins directed toward the central axis.

In high-power lamps (more than 200 kW), large rings or segmented electrodes must be used to keep heat loads at tolerable levels, and high flow rates of gas are necessary to provide the arc constriction and

stabilization needed for intense source brightness. However, the actual length of the arc in a given operating mode is difficult to control, for the length is a complex function of the arc current, the gas flow rate, externally applied or self-induced magnetic fields, electrode temperature, and surface conditions, etc. Even when the actual arc attachment points are largely fixed by suitably disposed buffers, the arc length can be stretched by the gas flow, as indicated in Figure 2.

The arrangement depicted in Figure 3 permits adjustment of the arc length within the large electrodes needed for operation at high gas flow rates. In

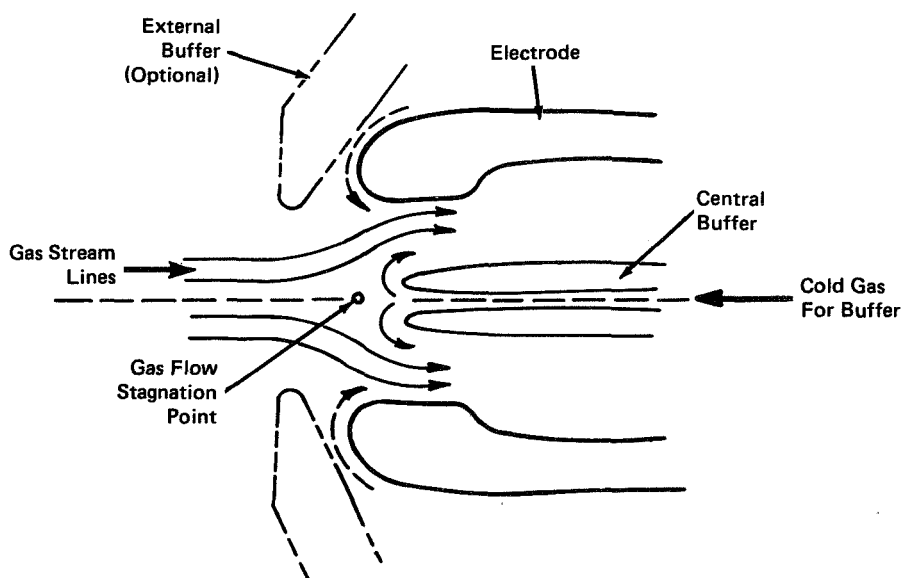


Figure 3

the figure, a central buffer is shown positioned axially inside a conventional hollow electrode duct; a selectively variable amount of cold gas is ejected upstream from the central buffer orifice into the central core of the main gas flow through the hollow electrode. The gas ejected by the central buffer forces the main gas stream to flow closer to the inner circumference of the hollow electrode and maintains a fixed zone for arc attachment. Moreover, the location of the stagnation point(s) and deflected-gas flow around the buffer can be adjusted either by altering the position of the buffer within the hollow electrode, by varying the amounts of gas ejected by the buffer, or both. Thus, the gas flow pattern controls the arc length and the position of attachment. For each operating condition (current and gas flow rate), the position of the central buffer and the rate at which it injects gas can be selected to provide

maximum efficiency and stability of the radiation source.

The brightest region of the arc should be in the vicinity of the stagnation point. Since this region can be readily maintained in position by the central buffer, it may be useful for some novel applications of radiation sources. As indicated by the dotted lines in Figure 3, external buffers may be positioned to induce controlled secondary gas flows which further aid to confine the location of attachment points and to stabilize the stagnation point.

Source: R. D. Buhler of  
Electro-Optical Systems, Inc.  
under contract to  
Ames Research Center  
(ARC-10182)

*No further documentation is available.*

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## DAMPING OF THERMOELASTIC STRUCTURES

A report is available which ascertains the effect of thermoelastic damping on the propagation of longitudinal waves in cylindrical rods. A review of classical results of wave propagation in unbounded elastic solids and in elastic cylinders precedes consideration of thermal modification of elastic properties. Effects upon the purely elastic wave motion consist of a change in propagation velocity and addition of a damping effect upon the mechanical energy of the elastic wave due to heat conduction.

This report shows and concludes that thermoelastic effects on an assigned frequency wave are small in terms of the propagation velocity. However, in comparison, the thermoelastic damping effect is large for very high frequency waves traveling in small diameter bars. There is a linkage of the behavior of the thermoelastic damping coefficient to the "thermo-

elastic bar number,"  $d \nu \chi$ , where  $d$  is a thermoelastic material constant;  $\nu$  is Poisson's ratio; and  $\chi$  is reduced frequency. Developed approximations, based upon the value of the thermoelastic bar number, predict the behavior of the thermoelastic damping coefficient as a function of frequency.

Research engineers may use this work as a basis for investigating thermoelastic effects on other structural elements.

Documentation is available from:

National Technical Information Service  
Springfield, Virginia 22151  
Price \$3.00  
Reference: TSP69-10467

Source: W. M. Gillis  
Marshall Space Flight Center  
(MFS-20002)



## CONTINUOUS, CONTROLLED, CONDENSED DETONATION OPERATES REACTION ENGINE

A reaction engine operating on the principles of a controlled condensed detonation rather than on the principles of gas expansion has been conceived. The controlled condensed detonation results in reaction products that are expelled at a much higher velocity than are the gaseous products resulting from a controlled burning as in a conventional reaction engine. In any detonation reaction, a shock wave is produced as well as gaseous products of combustion. The shock wave and gaseous products resulting from the detonation are vectored in a symmetrical pattern and are codirectional. Thus, the exit velocity of the reaction products approaches the velocity of the shock wave.

The engine includes an outer housing, enclosing a pair of inner walls, that defines an oval or elliptical continuous channel. This channel has one open side and forms a detonation reaction chamber in which a continuous detonation reaction is generated. Each inner wall has a series of orifices or injector ports through which fuel and oxidizer are injected into the chamber. The engine also includes an oxidizer manifold and a fuel manifold connected to the injector orifices formed in the inner walls. The injector orifices are canted at an angle and arranged in pairs so that fuel and oxidizer pass through the orifices and form impingement points of propellant mixture at spaced intervals around the channel shaped detonation reaction chamber.

A detonation wave generating device is included in the housing and positioned so that when actuated it will initiate operation of the engine. The detonation wave generator is an explosive device capable of generating a detonation wave that will detonate the fuel and oxidizer mixture at the first of the impingement points in the detonation reaction chamber.

The shock-wave and detonation products resulting from the reaction at the first impingement point will follow a direction toward the rear or discharge end of the engine that is oriented at an angle to the longitudinal axis of the engine. The angular direction of the reaction is controlled by the injection angle of the propellant mixture. Thus, the reaction at each impingement point provides a pulse of power that can be broken into two vectorial components, one of which

is directed to the rear of the engine to generate a thrust and the other directed towards the next successive impingement point to reinforce the detonation wave generated by the detonation wave generating apparatus and thus detonate the fuel and oxidizer at the next point. The reaction is then repeated and the next impingement point of fuel and oxidizer is detonated, and so on. Thus, after the initial detonation by the detonation wave generating device, the reactions within the detonation reaction chamber are continuous and self sustaining since the original detonation wave generated by the detonation wave generator is reinforced at each impingement point.

Since the detonation reaction at each impingement point has a resultant direction having one component perpendicular to the longitudinal axis of the engine, a torque moment will be generated which tends to rotate the engine about its longitudinal axis. This moment is very undesirable if the engine is to be used in a free bodied vehicle like a rocket, and the torque moment must be countered to prevent rotational motion of the rocket. A proper geometrical arrangement of a group of engines with opposite direction of detonation wave travel is one solution. However, in an application where it is desirable to use a single engine, the unbalanced force can be balanced by using an engine employing a multiplicity of coaxial and coplanar detonation reaction channels in one engine. The number of channels used would be an even number with the traveling detonation wave going in opposite directions in alternate channels.

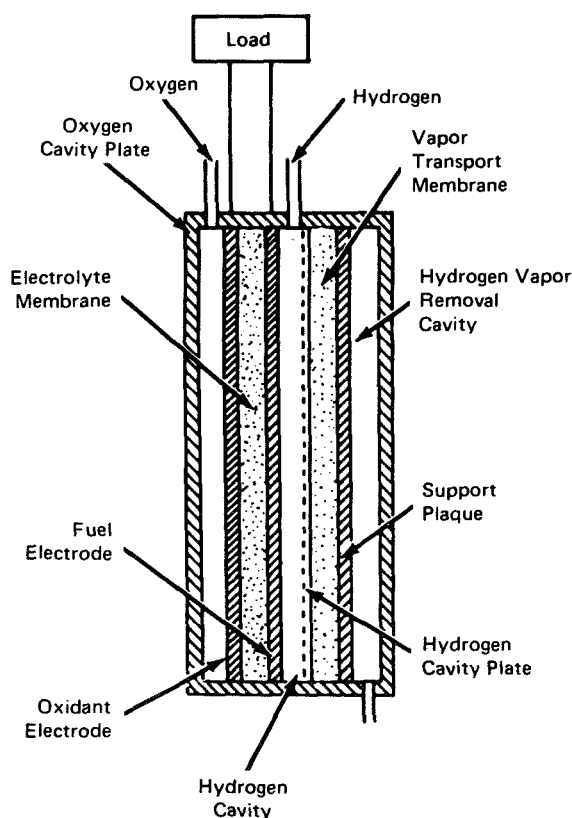
Additional information is contained in U.S. Patent No. 3,336,754 obtainable from the United States Patent Office, Washington, D.C. 20231. Price \$0.50.

This is the invention of NASA employees, and U.S. Patent No. 3,336,754 has been issued to them. Inquiries concerning license for its commercial development may be addressed to the inventors, O. H. Lange, R. J. Stein, and H. E. Tubbs, at Marshall Space Flight Center.

Source: O. H. Lange, R. J. Stein,  
and H. E. Tubbs  
Marshall Space Flight Center  
(MFS-14019)

## REACTION HEAT USED IN STATIC WATER REMOVAL FROM FUEL CELLS

In hydrogen-oxygen fuel cells, more water is formed at the hydrogen fuel electrode than is needed for cell reactions. If not removed as rapidly as formed, this excess water causes electrode flooding, a decrease in cell output, and ultimate cell failure. In the past, many arrangements of pumps and condensers have been used to remove this water with varying results. Such equipment requires sufficient power to seriously penalize the high efficiency of the fuel cell.



This system uses a portion of the heat inherent in the fuel cell current generation reaction to transform excess water into water vapor and cause it to be exhausted from the cell by means of a porous vapor transport membrane adjoining a vapor removal cavity maintained at low pressure.

As an electrical load is applied to the fuel cell, oxygen enters the oxygen cavity and hydrogen enters the hydrogen cavity and both come in contact with the electrolyte in the electrolyte membrane through the oxidant and fuel electrodes, respectively. The gases have relatively free access to the electrolyte membrane for production of the required chemical reaction. The oxygen at the oxidant electrode reacts with the electrolyte (an aqueous solution of potassium hydroxide) and is electrochemically reduced to hydroxyl ions. The hydrogen reacts with the hydroxyl ions and is electrochemically oxidized to water, releasing electrons to the load circuit. For every unit of hydrogen oxidized, two units of water are formed at the fuel electrode. One unit of this water migrates into the electrolyte membrane to replenish the water used in the oxygen reduction. The other unit of water is waste product and must be removed from the cell.

In both of these reactions, heat is produced. Some of this heat is absorbed by the product water formed at the fuel electrode and transforms the water to a vapor. This vapor diffuses into and through the vapor transport membrane where heat from the cell causes evaporation of the water from the vapor transport membrane into the vapor removal cavity. The vapor removal cavity, through the water exhaust line, is maintained at a suitable low pressure so that the water is removed from the cell structure at a rate consistent with its generation at the fuel electrode.

The requirement for fins or other cooling media on the cell is minimized by use of some of the generated heat in removal of the waste water. The invention provides a compact fuel cell having high energy-to-weight and energy-to-volume ratios and requiring a minimum of auxiliary equipment.

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457 (f)], to the Allis-Chalmers Manufacturing Company, Box 512, Milwaukee, Wisconsin, 53201.

Source: J. L. Platner of  
Allis-Chalmers Manufacturing Co.  
under contract to  
Marshall Space Flight Center  
(MFS-532)

## BIMETALLIC EMF CELL SHOWS PROMISE IN DIRECT ENERGY CONVERSION

At the present time, nuclear power is used to produce steam, which is converted to electricity via conventional turbogenerators. A direct energy conversion process would eliminate the expensive, bulky, and inefficient steam interface.

This innovation is a concentration cell, based upon a thermally regenerative cell principle, and produces electrical energy from any large heat source. This experimental bimetallic EMF cell (without a thermal regenerator) uses a sodium-bismuth alloy cathode and a pure liquid sodium anode. The cell has been operated for 17 months without failure, exhibiting reliability, corrosion resistance, and a high current density performance. Although there are presently material problems related to the regenerator, when these are solved, the regenerative bimetallic EMF cell system should be a promising direct energy conversion device.

The experimental bimetallic EMF cell for a Na-Bi system, shown in the figure, is constructed of type 18-8 stainless steel. The electrodes are cylindrical and have a 76.2 mm i.d. Spikes, 2 mm in diameter, at the anode act as electron collectors.

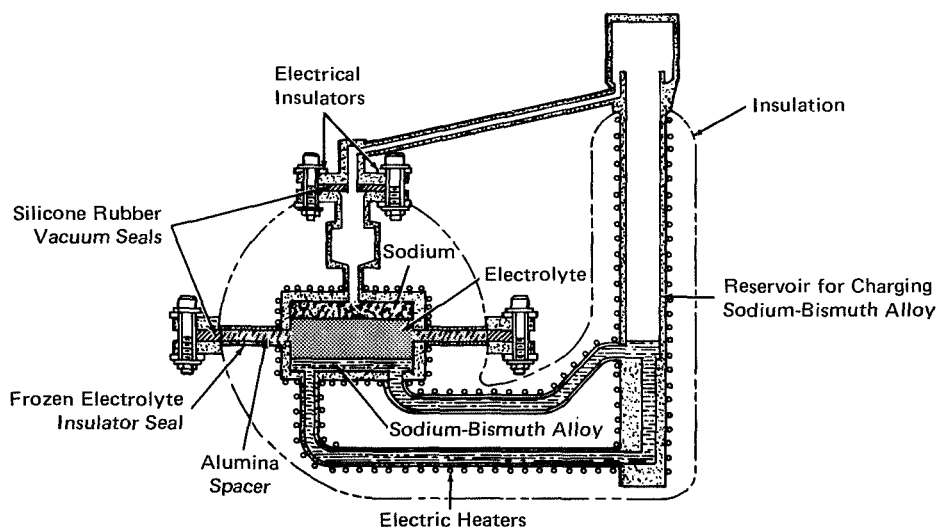
The anode and cathode are electrically insulated by a high purity alumina disc. A portion of the molten salt penetrates into gaps between the alumina spacer and the stainless steel flange and freezes. This frozen electrolyte, together with a silicone rubber gasket, provides a vacuum and pressure seal. Nichrome heater wires, insulated with alumina powder and sheathed by

stainless steel, are used for the heaters. A high temperature insulating material covers the heaters.

The cell is charged under an inert gas atmosphere since the sodium alloys are highly reactive and the salt mixtures are hygroscopic. To charge the cell, first the cathode material, 20 at/o Na-Bi alloy, is charged into the cell under argon atmosphere and melted. After freezing the alloy (the electrolyte) a eutectic mixture of NaI-NaCl-NaF is charged. The alloy and salt mixture are then melted in an argon atmosphere. At each step, the liquid levels of metal and salt must be checked, since bismuth expands upon freezing, which raises the metal level and may short-circuit the cell.

The cell was electrically charged every 48 hours. The cell temperature was varied up to 923 K (650°C); however, for a major portion of the time the temperature was kept at approximately 823 K (550°C). The melting point of the salt is 808 K (535°C). The cell current was varied by external resistance and loaded up to 10 amperes, and the charging current ranged from 1 to 2 amperes.

Cell discharge current densities of 90 and 110 mA/cm<sup>2</sup> at 0.5 and 0.45 V, respectively, were achieved at an anode fuel efficiency of approximately 87%. The internal resistance was about 0.05  $\Omega$  at 823 K (550°C), which decreases with increasing temperature and increases very rapidly when cooled to near the melting point.



Bimetallic EMF Cell

After 17 months of operation, the cell, including the frozen electrolyte insulator seal, showed no signs of failure. An interior inspection revealed little corrosion, with only 0.05 mm dissolution of stainless steel at the electrodes. X-ray analysis of the molten salt showed no signs of dissociation.

Users and producers of electricity may develop or employ sufficiently inexpensive heat sources and suitable use conditions to permit further development in this area. The significance of this item is

dependent upon the further development of regeneration system materials to withstand the boiling sodium and molten sodium-bismuth alloy environment.

Source: H. Shimotake and J. C. Hesson  
Chemical Engineering Division  
Argonne National Laboratory  
(ARG-10183)

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## THERMALLY INDUCED OSCILLATIONS IN FLUID FLOW

Advanced technology in such areas as nuclear power generation and sea water desalinization demands high-efficiency working fluids. This has increased interest in thermodynamic systems designed to operate at or near the fluid's critical pressure, in order to maximize such desirable parameters as specific heat and coefficient of thermal expansion. However, experiments have shown that unstable flow conditions are frequently encountered in such systems. Oscillations of pressure, temperature, and flow velocity occur which may cause mechanical or thermal fatigue failure of various system components.

A theoretical investigation was undertaken to distinguish the various mechanisms responsible for oscillations, to derive a quantitative description of the most troublesome mechanisms, and to develop a capability to predict the occurrence of unstable flow.

Three types of thermohydraulic oscillations were identified: the first caused by rapid change of the heat transfer coefficient in the vicinity of the temperature of maximum specific heat (the transposed, or pseudo-critical point); the second due to high fluid compressibility in the critical pressure region; and the third caused by local variations in flow characteristics and fluid density (pseudo-boiling) brought about by temperature changes in the fluid in contact with the vessel walls.

The first two mechanisms produce relatively high-frequency oscillations which, although bothersome, do not represent a great hazard; the third causes low frequency "chugging" oscillations which are harmful to the apparatus and furthermore, appear to be the most prevalent in systems of practical interest. The third mechanism, therefore, is discussed in detail,

and a quantitative description is derived — a characteristic equation in the form of a third-order exponential polynomial with two time constants, expressed in terms of fluid parameters, system geometry, and operating conditions. This equation is used to obtain stability maps and criteria not previously available in the literature.

The similarity between a reduced form of this equation and one derived previously to describe "chugging" oscillations in combustion systems leads to a prediction that a servo-control mechanism, similar to that found successful in overcoming the combustion system oscillations, will also reduce "chugging" oscillations in thermodynamic systems.

Information on a related investigation involving unstable flow in liquid nitrogen may be found in: NASA TSP69-10541 (N69-74548), Investigation of the Nature of Cryogenic Fluid Flow Instabilities in Heat Exchangers.

The following documentation may be obtained from:  
National Technical Information Service  
Springfield, Virginia 22151  
Single document price \$6.00  
(or microfiche \$1.45)

### Reference:

NASA-CR-84801 (N67-28778), An Analysis of Thermally Induced Flow Oscillations in the Near-Critical and Super-Critical Thermodynamic Region.

Source: N. Zuber of  
General Electric Co.  
under contract to  
Marshall Space Flight Center  
(MFS-20449)

## Patent Information

The following innovations, described in this Compilation, have been patented or are being considered for patent action as indicated below:

**Radiator Deployment Actuator (Page 6) MSC-11817**

This invention has been patented by NASA (U.S. Patent No. 3,563,307). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to:

Patent Counsel  
Lyndon B. Johnson Space Center  
Code AM  
Houston, Texas 77058

**Thermally Cascaded Thermoelectric Generator (Page 17) NPO-10753**

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to:

Patent Counsel  
NASA Pasadena Office  
Mail Code I  
4800 Oak Grove Drive  
Pasadena, California 91130

**Magnetohydrodynamic Generators Using Two-Phase Liquid-Metal Flows (Page 18) ARG-10168.**

This invention has been patented by AEC (U.S. Patent No. 3,636,389). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to:

Assistant General Counsel for Patents  
U. S. Atomic Energy Commission  
Washington, D. C. 20545

**Plasma-Heating by Induction (Page 19) LEW-10528**

Title to this invention has been waived, under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457 (f)], to the Humphries Corporation, 180 North Main Street, Concord, New Hampshire 03301.

**Continuous, Controlled, Condensed Detonation Operates Reaction Engine (Page 22)**  
**MFS-14019**

This is the invention of NASA employees, and U.S. Patent No. 3,336,754 has been issued to them. Inquiries concerning license for its commercial development may be addressed to the inventors, O. H. Lange, R. J. Stein, and H. E. Tubbs at The Marshall Space Flight Center, Marshall Space Flight Center, Alabama 35812.

**Reaction Heat Used in Static Water Removal from Fuel Cells (Page 23) MFS-532**

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457 (f)], to the Allis-Chalmers Manufacturing Company, Box 512, Milwaukee, Wisconsin 53201.

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## Notes:

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