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SANDIA LABORATORIES QUARTERLY REPORT
AEROSPACE NUCLEAR SAFETY PROGRAM
JULY 1 THROUGH SEPTEMBER 30, 1969

MASTER

AEROSPACE NUCLEAR SAFETY DEPARTMENT 9510

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SANDIA LABORATORIES

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SANDIA LABORATORIES QUARTERLY REPORT
AEROSPACE NUCLEAR SAFETY PROGRAM
JULY 1 THROUGH SEPTEMBER 30, 1969

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October 1969

ABSTRACT

This report describes research, development, support, and test activities in Sandia Laboratories Aerospace Nuclear Safety Program from July 1 through September 30, 1969.

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SUMMARY

TRANSIT

Work is continuing on the first phase of the solid propellant burn tests; the burn rate for the annular cylinder was approximately 0.33 inch per second, and for the solid cylinder it was approximately 0.06 inch per second.

ADVANCED FUELS SAFETY

A similarity analysis was conducted of the temperature and thermal stress distributions occurring in a finite cylinder heated from one end; the results of this analysis enable one to correlate the test results obtained from different specimen sizes, materials, and/or heating signatures, provided the mechanical and thermophysical properties of the materials involved are known and provided the tests were properly scaled to provide similarity.

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RADIOISOTOPE SYSTEMS SAFETY SUPPORT

SNAP-27

GLFC Trajectory Documentation (H. R. Spahr)

Sandia Laboratories research report SC-RR-69-296, GLFC Orbital Decay Trajectories and Reentry Environments for Different Aerodynamic Models, Specified Distribution Only, was published. This report documents the analysis, conducted at the request of the SNAP-27 Reentry Panel, which defined the effects of different GLFC and lunar module aerodynamic models and different lunar module disassembly attitudes on the GLFC trajectory and reentry environment.

PIONEER RADIOISOTOPE THERMOELECTRIC GENERATOR

Drop Tests (J. L. Entrekin)

A series of drop tests was completed in which four different Pioneer RTG heat source configurations proposed by Isotopes were dropped. The primary objective of the tests was to obtain terminal velocity data on the four different configurations. A secondary objective was to obtain photographic coverage of the impact crater, measurement of the crater depth, and brief general information about soil conditions at the impact point.

The four different configurations consisted of simulations of the Pioneer RTG heat source hexagonal capsule, ablated hexagonal capsule, bare fuel capsule, and a special Isotopes heat source. The Pioneer simulations were fabricated to duplicate the actual size, shape, weight, and center of gravity, but not the moments of inertia, of the genuine heat source. Moments of inertia were not duplicated because motion during reentry was not necessary for this drop test program.

The Pioneer hexagonal heat source was a ballasted aluminum body with sharp corners; it measured 3.5 inches across the flats, 6.75 inches in length, and nominally weighed 9.1 pounds. The ablated hexagonal heat

source was also a ballasted aluminum body but had rounded corners which duplicated the postreentry shape; it measured 3.45 inches across the flats, 6.75 inches in length, and nominally weighed 8.8 pounds. The bare fuel capsule was a brass cylindrical body with a 2.47-inch diameter at its center tapering down to hemispherical ends with a 1.18-inch radius; its length was 5.9 inches and its nominal weight was 5.7 pounds. The special Isotopes heat source was a graphite box-shaped body 4.76 inches square by 10 inches long; it weighed 8.6 pounds.

All of the drops were made from a fixed wing aircraft (D-18) at altitudes varying from 10,000 to 11,000 feet above terrain at a forward speed of approximately 165 fps. The drop test specimens were tracked with a C-band radar for trajectory data and a Mitchell camera for documentation and backup trajectory data. The Yucca target area at Tonopah Test Range was used for the drops. The results are summarized in Table I.

In addition, complete reduced trajectory data were acquired. These data included drag coefficient, velocity, Mach number, Reynolds number, and altitude as a function of time.

TABLE I
Results of Pioneer RTG Drop Tests

<u>Terminal Velocities (fps)</u>	
<u>Hexagonal Heat Source</u>	<u>Ablated Hexagonal Heat Source</u>
237	337
243	307
246	319
240	327
242	341
238	No Data
<u>Bare Fuel Capsule</u>	<u>Special Isotopes Heat Source</u>
455	128
No Data	
440	
445	
460	
450	
464	
460	

The secondary objective of obtaining photographic coverage of the impact craters, measurement of crater depth, and a brief definition of the soil was only partly attained since not all of the samples were found after impact and time did not allow exact measurement of the craters. Generally, the craters from the hexagonal heat sources, ablated hexagonal heat sources, and special Isotopes heat source were so small as to not warrant measurement. However, the bare fuel capsules penetrated the surface and made craters ranging from 10 to 12 inches deep. The soil at the target was defined as being a firm, dry, sandy soil impregnated with rocks.

A comprehensive formal report, including complete reduced trajectory data and pretest and posttest photographs, is in preparation.

TRANSIT

Solid Propellant Burn Tests (F. L. Baker)

Work is continuing on the first phase of the solid propellant burn tests. The principle objectives of these burn tests are to:

1. develop suitable instrumentation for measuring the heat flux,
2. select instrumentation for measuring flame temperature,
3. gain experience in handling, igniting, and testing solid propellants, and
4. characterize the thermal environment of burning solid propellant.

To date, five burn tests have been conducted at Sandia on solid propellant samples. Four of the tests were conducted with UTP-3001, while the fifth was with Algol IIB.

To measure the solid propellant heat flux, three types of calorimeters were tried. These are designated (1) slug calorimeter (Figure 1), (2) heat flux gage (Figure 2), and (3) cylinder calorimeter (Figure 3). The slug calorimeter and the cylinder calorimeter seem to be providing reliable data, but the heat flux gage has not been satisfactory. The noise picked up in the heat flux gage recordings has made

the data unreadable. The heat flux gage has been redesigned and is now in fabrication. A typical setup of the slug calorimeter and the cylinder calorimeter is shown in Figure 4.

Pyrometric photography is being used to measure the flame temperature. This system appears to be satisfactory. Pyrometric photography data from two of the tests are shown in Figures 5 and 6.

Figure 1. Slug calorimeter

Material - copper, oxygen free, high conductivity
4-inch round per QQ-C-502, 1/2 hard

Figure 2. Heat flux gage

Material - copper, OFHC, 1-inch round, SN 509478

Figure 3. Cylinder calorimeter

Figure 4. Typical calorimeter setup

NOTE: Temperature area above the top ring calorimeter (see Figure 4).

Figure 5. UTP-3001 annular cylinder pyrometric photography data

NOTE: Temperature area approximately 20 inches above the burning propellant surface.

Figure 6. UTP-3001 solid cylinder pyrometric photography data

Documentary film of the UTP-3001 burn tests has provided some information on the burn rate. The burn rate for the annular cylinder could be determined only from the time of ignition to the time of fuel burnout, and it has been determined to be approximately 0.033 in./sec. The burn rate for the solid cylinder was determined by drilling 0.25-inch holes at a 1-inch spacing in the cylinder wall inhibitor. The burn rate was determined from the film to be approximately 0.06 in./sec.

As a part of one of the tests, observations were made on the flame residue deposit on a hot versus cold simulated capsule. Firerod heaters (Inconel case) were used with the hot unit electrically heated to 1300°F prior to flame ignition. A visual examination of the units after the tests revealed no significant difference in the residue deposit on the heaters.

SAFETY TECHNOLOGY

ADVANCED FUELS SAFETY

Reentry Ablation Testing in a Hyperthermal Arc Tunnel (I. B. White)

Two LASL fabricated ThO_2 specimens were exposed to simulated reentry heat fluxes in the Sandia 40-kW arc tunnel. The specimens were cylindrical in shape and were approximately 0.316 inch in diameter by 0.345 inch long. Their densities were 8.66 g/cc. The theoretical density of ThO_2 is 9.69 g/cc.

Specimen 12746 was exposed to a heat flux of $87 \text{ Btu/ft}^{3/2}\text{-sec}$ for 30 seconds. The specimen began to break up in large pieces immediately upon exposure to the plasma; approximately 65 percent was sheared away during the test. The remaining portion crumbled during the demounting process. Specimen 12747 was exposed to a heat flux of $72 \text{ Btu/ft}^{3/2}\text{-sec}$ for 30 seconds. Breakup of this specimen also began upon exposure to the plasma, and it was completely ablated within 1 second.

An additional two specimens, 12748 and 12749, were x-rayed to determine if any cracks were present in them as a fabricated condition. No cracks were visible on the x-ray films. These two specimens will be preheated to the operating temperature of an isotopic generator and then immediately exposed to the same test conditions as specimens 12746 and 12747 to determine the effects of preheating on thermal stress.

The Sandia 40-kW hyperthermal arc tunnel is being calibrated to determine the heat flux profile across the plasma stream. This information will be used to calculate the input heat flux to the test specimen at points other than the stagnation point and the total heat flux to the specimens. Currently, we are establishing positions for the calorimeter across the jet with the aid of a cathetometer. Accurate and repeatable positioning of the calorimeter at various positions is proving difficult with the existing facility setup.

A resistance type heating element is being developed for use in the arc jet. This device will be used to preheat the specimens to the operating temperature of an actual heat source at reentry prior to insertion into the arc jet plasma stream. The purpose of this exercise is to gain information on the thermal stress problem experienced in many of the previous tests of fuel candidates.

Aerothermal Analysis (D. E. Randall)

A preliminary approximate analysis to estimate solid solution cermet fuel impact temperatures was conducted. This analysis indicated that the fuel temperature at impact will not have cooled to ambient but may be significantly above this level.

An evaluation of the effect of substituting niobium for molybdenum in the solid solution cermet overcoat for the fuel simulant test samples was undertaken. Property differences, particularly thermal conductivity and emissivity, could result in differences in the thermal response for these two materials.

The aerodynamic characteristics of the solid solution cermet configuration are being evaluated.

Similarity Analysis (R. E. D. Stewart/F. C. Wessling)

The limitations of existing test facilities and considerations of time, expense, and/or safety often make it impractical, if not impossible, to perform full-scale 1:1 tests on real materials of interest. These limitations and considerations make it highly desirable to be able to evaluate a given fuel candidate configuration by performing at least a majority of the tests with the real material replaced with a simulant material and with the actual specimen size and heat flux scaled to a more convenient size. Ideally, the simulant would be a relatively inexpensive, easily fabricated, nonradioactive material whose general behavior would not differ grossly in some critical manner from that of the real material. However, in order that such test results be meaningful, it is imperative that one be able to translate or scale the results to apply to the actual size, material, and heating signature of interest.

A case in point is the hyperthermal arc tunnel testing at Sandia which is used to evaluate the thermal shock and ablation resistance of various radioactive fuel candidates and container materials to reentry heating and/or certain plausible abort situations. Of necessity, these arc tunnel tests departed in varying degrees from full-scale 1:1 tests. In most cases, the test variables had to be individually scaled to suit the particular test parameters.

As a first step in rectifying the above situation, a similarity analysis was conducted of the temperature and thermal stress distributions occurring in a finite cylinder heated from one end. This is essentially the situation that exists when a cylindrical specimen is heated end-on in a plasma arc tunnel. The analysis shows that a relatively small number of nondimensional similarity parameters govern the temperature and stress distributions in the cylinder. Equating these similarity parameters for a model and a prototype results in scaling relationships which dictate how the initial temperatures and heating rates of a model and a prototype must be scaled in order that the temperature and thermal stress distributions of the model and the prototype be similar. The results of this analysis enables one to correlate test results obtained from different specimen sizes, materials, and/or heating signatures, provided the mechanical and thermophysical properties of the materials involved are known and provided the tests were properly scaled so as to provide similarity.

For instance, the behavior of a full scale radioactive fuel cylinder subjected to a given end-on heating pulse can be determined by performing properly scaled tests on a small cylinder of inexpensive nonradioactive material. Furthermore, plots of certain nondimensional similarity parameters versus others allow one to see immediately how sensitive the temperature and stress distributions are to inaccuracies in material properties. This type of information not only tells one which of the basic material properties are most critical and which are relatively unimportant, but it also tells quantitatively just how accurately the various material properties must be known in order to be able to predict temperatures and thermal stresses with a given accuracy.

To date, consideration has been restricted to temperature and thermal stress distributions in an end-on heated right circular cylinder. However, the same procedure and basic principles can easily be

applied to a side-on heated right circular cylinder or to some other basic shape such as a sphere or cone.

The next step planned for the immediate future is a similarity analysis of ablation phenomena. This presents a somewhat more formidable task than analyzing thermal stress because a number of basically different ablation modes are possible. For example, a material may or may not react chemically with the flow. It may char, it may sublime, or it may melt with subsequent liquid layer stripping, etc. However, the analysis is expected to be no more difficult in principle.

At this point, it must be emphasized that certain basic property data are required in order to realize the power of similitude; and notice should be taken of the fact that good basic property data over the temperature range of interest are very seldom available when they are needed for purposes of analysis and evaluation. This is particularly true as new and more exotic materials become available and allowable temperature extremes are pushed higher and higher. Lack of good basic property data represents a serious handicap and often results in extended time scales and lack of confidence in theoretical predictions. Facilities are sorely needed which would permit accurate, reliable, rapid, routine measurement of such critical basic material properties as thermal conductivity, specific heat, emissivity, shear and tensile strengths, vapor pressure, etc., over the entire temperature range of interest.

Material Properties (R. E. D. Stewart)

In recent months, many radioactive fuel forms and encapsulation materials have come under consideration for use in nuclear power supplies. It is anticipated that future research and development programs will continue to result in the introduction of new and more exotic fuel forms, encapsulating materials, fabricating processes, and treatments. In order to predict accurately the behavior of these materials when they are subjected to various reentry or abort environments, one must have reliable material property data. Material properties of interest include: (1) thermophysical properties such as density, specific heat, thermal conductivity, emissivity, coefficient of thermal expansion, heat of fusion, surface tension, viscosity, vapor pressure, etc.;

(2) mechanical properties such as modulus of elasticity, Poisson's ratio, tensile and shear strengths, etc.; and (3) chemical and thermodynamic properties such as solubility, diffusion coefficient, oxidation rates, etc.

Heretofore, reliable material property data, especially at high temperatures where the need is most critical, were limited; in some cases, data were practically nonexistent. Facilities are needed which would permit rapid and timely measurement of these basic material properties at the temperatures of interest. As a step in this direction, apparatus, instrumentation, and experimental techniques are currently being investigated for the purpose of establishing a capability for measuring the monochromatic emissivity of materials as a function of temperature and wavelength. It is anticipated that the facility will permit emissivity measurements of both radioactive and nonradioactive materials for wavelengths between 0.1 and 100 μm where appreciable thermal emission occurs, and for temperatures ranging from ambient to well above the melting point of most materials (3000°C).

One technique which appears promising for high temperature emissivity measurements, particularly at temperatures near the melting point and beyond, involves measuring the radiant energy emitted by a small particle or molten droplet in free fall in either a vacuum or inert gas atmosphere. An apparatus for generating small molten droplets which can be observed during free fall in a controlled environment was developed previously at Sandia in connection with studies of energy and mass transfer mechanisms, nucleation, and oxidation reactions. With some modifications, it is expected that this apparatus can be adapted to measure emissivity, and possibly also to measure specific heat and thermal conductivity.

Preliminary experiments using materials of known emissivity are planned initially to test the feasibility of the technique and develop the necessary instrumentation. An emissometer which inductively heats a specimen containing a small hole with sufficient depth to diameter ratio to provide a black body reference cavity is also being designed for making routine emissivity measurements below the melting point of the specimen material.

TRACKING, SEARCH, DETECTION, AND RECOVERY

Infrared Search and Detection (J. L. Entrekin)

An evaluation of the U. S. Forest Service's Project Firescan Infrared System as an RTG heat source detection system was performed near Missoula, Montana. The U. S. Forest Service provided the Project Firescan aircraft and aircrews plus personnel who helped man the test site and analyze the results.

Two different detection systems were used. Both systems use similar electronics and the same film processor. The electronic system has a discriminator that separates the hot targets from other heat sources such as automobile exhausts, light bulbs, etc., and automatically causes the photoprocessor to print a blip beside the hot spot and another blip on the side of the film strip in line with the hot spot, plus the image of a 24-hour clock showing the exact time at which the target was detected. The film is processed by a continuous, in-flight wet processor which gives the operator results on a black and white positive only a few minutes after flying over an area. The differences between the two systems occur mainly in the detectors. One detector is of the two-color type and has a filtered indium antimonide element A channel with a 3 to 6 μm wavelength response and a filtered mercury-doped germanium B channel with an 8 to 14.5 μm wavelength response. The other detector is of the one-color type and has an unfiltered indium antimonide element with a 1 to 6 μm wavelength response. Both detectors are cryogenically cooled by a liquid nitrogen system.

Target layouts were similar for flights made with both systems. The targets were composed of banks of one to eight Watlow Firerod* heaters in 6 or 12 inch lengths at different temperatures, either exposed or buried; exposed light bulbs; and an exposed Globar** heater. In addition, the U. S. Forest Service provided two 4-square-foot charcoal arrays, one 500 feet from each end of the target setups for marking purposes, plus some smaller charcoal arrays in 1, 0.5, and 0.25 square foot sizes for targets. All charcoal arrays burned at temperatures ranging from 1000° to 1200°F.

*A commercial Inconel, sheathed Ni-chrome wire resistance heater 3/4 inch in diameter.

**A commercial silicon carbide resistance heater.

The two-color system was flown first, once in the afternoon and once at night. Results were poor due to equipment problems that were discovered just prior to the tests and which could not be corrected before the tests. Since the equipment was not operating correctly, the results are not presented.

The one-color system was flown once at night. The results from this flight were relatively encouraging and were as follows:

1. at 4,000, 8,000, and 12,000 feet above terrain, all heater setups and charcoal arrays were detected and automatically marked on the film, with the exception of the four exposed 12-inch Firerods at 500°F and the 1000-watt light bulb;
2. at 18,000 feet above terrain, only the four exposed 12-inch Firerods at 1500°F and all the charcoal arrays were detected and marked on the film.

The U. S. Forest Service is still working on the system to improve its discrimination ability and to correct the previously mentioned problems. At a later date, another evaluation test may be made on the system should improvements seem to warrant such a test. Figures 7 through 10 show the different layouts.

FLIGHT TEST STUDY

Reentry Simulation (A. C. Bustamante)

A preliminary study was conducted to determine the feasibility of aerothermodynamically simulating a severe Transit capsule reentry abort by an Athena flight test. The results of this study showed that it is possible to obtain this simulation through the use of an Athena H alternate 3-stage configuration. Three different types of payloads were selected for the study (Figure 11). The heating parameters were obtained for each of the payloads and are compared with the parameters for the Transit capsule in Figures 12, 13, and 14. Favorable agreement exists between the heating parameters of payloads A and B and the Transit capsule. For payload C, the agreement is not as good since the heating rate and the integrated heating rate for the RV exceed those of the Transit capsule; on the other hand, these heating parameters for the capsule are below those of the Transit abort condition. However,

it is believed that for payload C, better correlation between heating parameters can be obtained by proper tailoring of the Athena trajectory. As an example, in order to obtain a higher heating rate on the payload C capsule, an additional rocket motor could be used to propel the capsule to a higher velocity. Also, in order to achieve time matching of parameters, the RV could be released at a much higher altitude.

Figure 7. Setup No. 1 - 4000 feet above terrain, two-color system

Figure 8.

Setup No. 2 - 4,000, 8,000, and 12,000 feet above terrain, two-color system

Figure 9.

Setup No. 3 - 4,000, 8,000 12,000, and 18,000 feet above terrain, one-color system

Figure 10. Setup No. 4 - 12,000 and 18,000 feet above terrain, one-color system

Payload A - one capsule

Payload B - two capsules

Payload C - RV and three capsules

Figure 11. Payloads used in simulating Transit capsule reentry abort

Figure 12. Heating parameters for payload A and Transit

Figure 13. Heating parameters for payload B and Transit

Figure 14. Heating parameters for payload C and Transit

ABORT MODEL

Autorotation Studies (A. C. Bustamante/G. W. Stone)

Using data obtained from Edgewood Arsenal and University of Notre Dame wind tunnel tests, and NACA water tests, two correlation equations were obtained which relate the subsonic steady state tip ratio of an autorotating rectangular plate to its aspect ratio. Either of the two equations is adequate; however, the polynomial equation gives a little better fit of the data (Figure 15), while the other equation is easier to use. The two equations are shown below.

$$\left(\frac{wC}{2V}\right)_{ss} = K_0 + K_1 AR + K_2 AR^2 + K_3 AR^3 \quad (1)$$

where

AR = aspect ratio

For AR $\geq$ 0.15

$$K_0 = 0.2555$$

$$K_1 = 0.1283$$

$$K_2 = -0.00995$$

$$K_3 = 0.0005359$$

For AR < 0.15

$$K_0 = 0$$

$$K_1 = 2.55$$

$$K_2 = -4.0$$

$$K_3 = 6.5$$

$$\left(\frac{\omega C}{2V}\right)_{ss} = \frac{AR^2}{3.14 - 2e^{-1.57AR}} \quad (2)$$

Figure 15. Steady state tip speed ratio data for autorotating rectangular flat plates

Experimental Investigation of Thermal Stress Failure in Graphite (D. E. Randall)

The results of an analytical study indicate that it appears feasible to conduct an experimental investigation of graphite thermal stress failure in severe reentry environments. The high enthalpy environment (corresponding to escape velocities) will be provided by an RF induction-heated facility operated under contract to NASA Lewis Research Center. A NASA report describing the facility's capability for thermal testing under reentry environments was coauthored with NASA Lewis personnel. A test plan for the experimental phase of the thermal stress investigation is in preparation.

Cylindrical Thermal Model (D. E. Randall)

A generalized thermal model for calculating the two-dimensional heat flow, both radial and peripheral, in an arbitrarily sized homogeneous circular cylinder was constructed. The size and number of nodes are selected by the user as part of the input data. The model is used with the CINDA thermal analyzer program.

Soil Burial (J. L. Entrekin)

Soil burial tests are continuing on a reduced scale. A test was made with a heated alumina spherical shape in bentonite soil during July. A temperature of 2500°F was achieved on the surface of the heated shape, and the soil was melted for a thickness of approximately 1 inch completely around the spherical shape. New equipment is being assembled to investigate the theory that a heated spherical shape will sink in soil.

General Computer Code Development (H. R. Spahr)

The following computer codes were submitted to and accepted by the Computer Software Management and Information Center (COSMIC), at the request of AEC/ALO.

- HRS004 - Computes initial trajectory conditions for objects decaying from circular orbits.
- HRS015 - Computes the transition flow hypersonic ballistic coefficient of blunt objects.

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