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**AERO HEATING RESULTS FROM
THE RFD-2 FLIGHT TEST**

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Re-entry Flight Demonstration No. 2 (RFD-2) was the second in Sandia Corporation's series of operational safety flight tests of Systems for Nuclear Auxiliary Power (SNAP). The SNAP generator flown on RFD-2 was an inert version of a SNAP 19 type isotopic generator designed by the Nuclear Division of the Martin Company. The safety criteria used in the design of this isotopic generator by Martin provided for release of the isotopic fuel and burnup at altitudes above 100,000 feet in the event of a late abort during the ascent phase or following orbital departure.

The RFD-2 was launched on a 3-stage NASA SCOUT vehicle from Wallops Island, Virginia, on a re-entry trajectory leading to impact about 150 nautical miles southeast of Bermuda. The launch occurred at 12:04 A.M. Eastern Daylight Time on October 9, 1964. Injection conditions at 401,066 feet altitude and 293 seconds after launch provided a velocity of 18,910 feet per second and a re-entry angle of -6.8° . Figure 1 shows the trajectory actually flown and the events that occurred during the flight test. Optical and electronic instrumentation systems on Bermuda and on ships and aircraft near Bermuda recorded the events occurring during re-entry. The re-entry system shown in Figure 2 consisted of the simulated isotopic generator, an external fuel capsule experiment, and a re-entry vehicle with its associated sub-systems including a telemetry system. The principal functions

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of the re-entry vehicle were (1) to provide an aerodynamically stable support for the experiments, (2) provide thermal protection to the re-entry system components which required it, (3) provide ejection of the fourth stage adapter and despin of the system, and (4) provide a recovery system.

The RFD-2 flight test was conducted to study the response of the isotopic generator during the re-entry portion of the flight. The primary objective of this flight test was to study generator disassembly and fuel capsule burnup as a result of re-entry heating. In order to accomplish this, it was necessary to determine the local aerodynamic heating inputs to the various locations on the generator. The generator instrumentation for this flight test consisted of 29 thermocouples located to provide temperature profiles throughout the generator (see Figures 3 and 4), and 4 switches mounted at the aft end of the fuel cavity.

The quality of the thermocouple data obtained during the flight test was excellent permitting a detailed analysis to be made of heating rates, internal heat paths, and modes of disassembly. Figures 5, 6, and 7 are typical plots of temperature versus time measured by the thermocouples on the radioisotopic generator. Dissassembly times of the vessel segments were indicated by the thermocouples reaching the melting temperature of the vessel, followed by an open reading as the part melted. Complete generator disassembly was indicated by the opening of all remaining thermocouples as the leads broke. Failure times of the various parts of the vessel as

indicated by the various thermocouples are shown in Table I below:

TABLE I
FAILURE TIMES BASED ON
THERMOCOUPLE DATA

<u>Part and Thermocouple</u>	<u>Failure Time (sec from launch)</u>
Center of cover (T1, 2, 4)	364 to 368
Cover webs (T3, 5)	362 to 367
Cover between webs (T6)	364
Cover flange (T7, 8)	367 to 368
Side rib (T11, 13)	375
Vessel wall under rib (T14)	381
Aft wall (T16)	381

The temperature data was next used to determine heating rates to the generator during the re-entry. This was done with the QAERO digital computer program used on the CDC 3600 computer. The QAERO program computes local, net, hot wall aero heating rates, given the temperature of each node and the material properties as a function of temperature. Radiation and conduction heat losses are accounted for. No provisions are made for ablation of the surface or for heat blockage due to mass injection into the boundary layer from some point upstream. Therefore, the output of this program is net aerodynamic heating and not the cold wall input to a non-ablating body. Typical results of the heating rate study are shown in Figures 8, 9, and 10. The heating rates are plotted against free stream density as well as time from launch. Also shown are the reference free molecular heating rates equal to $1/2 \rho_{\infty} V_{\infty}^3$ and reference continuum

heating rates equal to stagnation point heating rates to a 1-foot radius sphere. Continuum laminar heating rations (F_q) can be read directly from these plots by the ratio of the flight heating data to the reference continuum heating curve. Gross hot wall heating rates are given ~~before~~ before the area in question is affected by transpiration cooling. After that time, net hot wall heating rates are shown. Free molecular heating rates on the RFD-2 flight were too low to cause any appreciable temperature rise of the generator. As a result, free molecular heating rates could not be computed. However, some transition heating was computed. The beginning of the continuum flow regime can be found by noting when the flight heating data forms a line parallel to the reference continuum heating line. The upper limit of continuum flow in attached regions was defined by a Knudsen number of .080, and for separated flow regions by a Knudsen number of .012 where the Knudsen number is based on diameter and the mean free path of the molecules at the surface of the generator.

The net reduction of aero heating rate caused by transpiration cooling was also evident from this analysis. Net heating was reduced by as much as a factor of 2.5 when a section of the magnesium vessel melted upstream. The heat blockage was intermittent and of short duration. Although transpiration cooling did delay disassembly, it did not have the effect of a continuously ablating body.

Tables II, III and IV show a comparison of heating ratios obtained from flight data as well as preflight analytical and tunnel predictions. The heating ratio (F_q) is defined as the ratio of the local heating rate to the stagnation heating rate to a one foot radius sphere. Table II presents the data for the initial configuration before any melting occurs. Table III presents similar data after the cover flange has melted off and Table IV after the side rib has also melted off.

TABLE II
HEATING RATIOS (F_q) FOR THE RFD-2 GENERATOR
INITIAL CONFIGURATION

<u>Location</u>	<u>Analytical Study</u>	<u>CAL Tunnel Tests</u>	<u>R&B Tunnel Tests</u>	<u>Flight Data</u>
Stagnation Point	1.01	0.925	1.7	1.4
Cover Webs	-	-	2.4	0.40
Cover, Between Webs	-	-	1.2	0.21
Cover Flange	0.61	0.36	0.75	0.44
Forward Sides	0.123	0.023	0.17	0.074
Side Rib	0.110	0.025	0.44	0.053
Aft Sides	0.067	0.023	0.17	0.045

TABLE III
HEATING RATIOS (F_q) FOR THE RFD-2 GENERATOR
AFTER COVER FLANGE IS OFF

<u>Location</u>	<u>Analytical Study</u>	<u>CAL Tunnel Tests</u>	<u>R&B Tunnel Tests</u>	<u>Flight Data</u>
Forward Sides	0.121	0.048	0.26	0.155
Side Rib	0.44	0.45	0.45	0.30
Aft Sides	0.076	0.026	0.13	0.115

HEATING RATIOS (F_q) FOR THE RFD-2 GENERATOR

AFTER SIDE RIB IS OFF

<u>Location</u>	<u>Analytical Study</u>	<u>CAL Tunnel Tests</u>	<u>R&B Tunnel Tests</u>	<u>Flight Data</u>
Aft Sides	0.076	0.048	0.15	0.170

A comparison of this data indicates that the tunnels appear inaccurate in the separated flow regions. Short duration tunnels may not run long enough to allow tunnel starting effects to completely damp out in areas of separated flow before the test is completed. The preflight analytical study appears to come quite close to predicting the failure of several parts of the generator; however, the predicted heating rates to some areas were in error. If theoretical aero heating equations can be derived that match flight data in the more complex areas of the generator, the current methods of analysis will be adequate to analyze similarly shaped SNAP devices.

The heating ratios derived from the RFD-2 test data can be used directly to analyze end-on, stable, SNAP 19 type generators when flow is not disturbed by another part of the space vehicle. This data is also being used to improve the analytical thermal model that will be used to predict burnup of other aerospace nuclear systems.

RFD-2 RE-ENTRY TRAJECTORY .

Figure 1.

Figure 2

RFD-2 THERMOCOUPLE LOCATIONS, TOP VIEW

RFD-2 THERMOCOUPLE LOCATIONS, SIDE VIEW

Figure 4

TEMPERATURE #1

Figure 5

TEMPERATURE #8

Figure 6

TEMPERATURE #16

Figure 7

Figure 8

Figure 9