This report was prepared
under Contract AT(30-3)-217
with the U. S. Atomic Energy
Commission.

MND-P-2953
Distribution C-92A

MND-P-2953

SNAP PROGRAMS-UPPER ATMOSPHERE

EXPERIMENTAL RE-ENTRY STUDY

FINAL SUMMARY REPORT

April 1963

MASTER

MARTIN COMPANY
NUCLEAR DIVISION

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Facsimile Price \$ 8.10
Microfilm Price \$ 278

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

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FOREWORD

This report summarizes the effort and reports the results of the study performed under Contract AT(30-3)-217, Task 7, Radiological Safety Studies for Space Power. It is the final summary report issued for this program.

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ERRATA

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<u>PAGE</u>	<u>AS WRITTEN</u>	<u>CORRECTED</u>
Title Page	"Distribution C-92A"	"Distribution C44D"
x, last paragraph 5th line from bottom	"little or no tubmling"	"little or no tumbling"
I-1, 4th paragraph last line	"success was achieved"	"success achieved"
II-27, Instr. Nos. 6, 8, 10, 12, 14	"Bausch & Lamp"	"Bausch & Lomb"
II-27, Instr. No. 9	"Film RSP-8" x 10""	"Film RXP-8" x 10""
II-37, 2nd paragraph, 3rd line	"Figure A-1 of this report"	"Figure A-2 of this report"
II-38, 2nd paragraph, 1st line	"A time of telemetry capsule ejection"	"At time of telemetry capsule ejection"
II-38, last paragraph, 1st line	"each streak reentry and"	"each reentry streak and"
II-46, 2nd paragraph, 12th line	"numbers 5 and 6 which contained"	"numbers 5 and 6 by capsules which contained"
II-51, 1st paragraph 5th line	"telemetry capsule using. The"	"telemetry capsule using the least squares techniques outline in Appendix II of this reference. The"
A-1, 4th paragraph 3rd line	"to re-entry with"	"to re-enter with"
A-1, 4th paragraph 6th line	"that no further decrease"	"that little further decrease"
A-3, Abscissa of Curve	"Time-Sec"	"Time from 400,000 feet- Sec"
B-3, Eq. 5	" = - C _{Mq} $\left(\frac{Ad^2}{2} \right)$ "	" = - C _{mq} $\left(\frac{Ad^2}{2} \right)$ "

SUMMARY

An experimental flight test program was conducted as part of a program of safety analyses of SNAP generators designed for space use. The test program designated AMR Test 102, was flown piggyback in a GD/A Scientific Passenger POD (SPP) 24A aboard an Atlas R&D missile from AMR on 13 August 1962. A series of test specimens simulating components of isotopic-powered generators were placed in ballistic trajectories by this Atlas vehicle.

The primary purpose of the experiment was to verify and improve the methods and techniques used to predict the aerothermodynamic effects on re-entering SNAP devices. An indication of the amount of aerodynamic heating as a function of body shape, size and mode of entry was sought. Test specimens were designed to yield trajectory, aerodynamic heating data, heat distribution and heat transfer of known bodies.

The test procedure and methods of calculating aerodynamic heating and heat transfer for this program are described in Reference 1 and are summarized later in this report. IBM 7090 digital programs were utilized and so constructed that one digital code complemented the other, i.e., at any time during the re-entry period, the complete thermal history of the body is known. It is to verify this technique, along with the equations and their modifications, that this experimental test was conducted.

This program is unclassified except for Atlas performance data. References are made in the body of the report to appropriate documents containing this information.

The test specimens consisted of lead bodies containing alkali metals, used as flaring material, and a larger titanium cylinder containing telemetry equipment. The latter body was instrumented so as to monitor the exterior and interior wall temperatures during re-entry. By judicious placement of transducer sensors, aerodynamic heating rates and mode of entry, i.e., tumbling, spinning and/or stabilized, could be determined. The lead bodies were designed to burnup at high altitudes whereas the telemetry capsule was to survive re-entry.

Optical, telemetry and radar equipment located at several stations downrange about the re-entry area were used to acquire and identify the bodies, the altitude of burnup, the trajectory and the temperature history of the telemetry capsule.

Almost complete success was experienced in obtaining the optical data. There were four groups of lead bodies, each with a specific wall thickness and loaded with a characteristic alkali metal; sodium, lithium, rubidium or cesium. All of the test specimens were photographed and positive identification was made concerning the sodium and lithium loaded bodies. Rubidium and cesium were identified with less certainty with the result that their correlation to specific lead bodies is considered tentative. However, this tentative correlation is corroborated by predicted results.

No useful telemetry information was obtained. As a result, the mode of entry of the bodies could not be positively deduced, but rather is surmised-on the basis of optical data alone.

Prior to the flight test, a study was performed to predict the altitude of destruction of each lead body as a function of the mode of re-entry. Modes of re-entry investigated were:

- (a) tumbling and spinning
- (b) stable, major axis normal to air stream
- (c) stable, major axis at 45° to air stream
- (d) stable, major axis parallel to air stream

The best estimate was that the bodies would assume the re-entry mode of the SPP, i.e., with some tumbling in the pitch or yaw plane. The measured altitudes of destruction of the lead bodies best correlates with those predicted for re-entry with little or no tumbling with major axis normal to the air stream, mode (b). The following table compares the predicted altitudes of destruction of each group of specimens for mode (b) re-entry, with those measured.

<u>Group No.</u>	<u>Specimen Description</u>	<u>Altitude of Destruction (ft.)</u>	
		<u>Predicted</u>	<u>Measured</u>
1	Cylinder, wall thickness of 0.25 inch, sodium flare	183,000	194,000 to 204,000
2	Cylinder, wall thickness of 0.375 inch, lithium flare	192,000	181,000 to 190,000
3	Cylinder, wall thickness of 0.500 inch, rubidium flare	179,000	175,000 to 191,000
4	Cylinder, wall thickness of 0.625 inch, cesium flare	165,000	163,000 to 175,000

Several factors can be readily deduced from this flight test program.

- (1) It was concluded that, during this test program, bodies simulating SNAP components entered with little or no tumbling and that the longitudinal axis of cylinders were most probably normal to the air flow.
- (2) Prior to this test program, some uncertainty existed as to how best to treat aerodynamic heating generated at the stagnation point of stable bodies. It is now felt that the surface averaging technique described in Reference 7 provides the best fit to measured data. As a result, this technique has been adapted for use in re-entry analysis of SNAP devices.
- (3) It was also concluded that the use of alkali metals as flare materials is an excellent method of re-entry testing. This fact is substantiated since all four alkali metals were observed and optical data reduction was estimated to be accurate to ± 300 feet.
- (4) The methods developed for this program can be readily adapted to assess the nuclear safety aspects concerning re-entry analyses of large reactor power systems and nuclear rocket engines. The ranges at the Atlantic Missile Range or Wallops Island are ideally suited for these

programs and both sites have adequate equipment and experienced personnel.

The following agencies participated in the execution of this program:

- (1) Air Force Special Weapons Center acted as test coordinator, designed and built the ejection mechanism and the electronic components of the telemetry capsule, acquired the optical data via aircraft, reduced the telemetry data and performed range support during launching.
- (2) Air Force Office of Aerospace Research provided range support concerning the Scientific Passenger Pod and assisted in establishing schedules and obtaining post-flight trajectory data.
- (3) Air Force Space Systems Division provided the Atlas vehicle, assisted in range support and in scheduling.
- (4) Instrument Corporation of Florida performed the bulk of the optical data reduction and provided consulting services to the Martin Company in the area of photographic equipment, films and filters.
- (5) General Dynamics-Astronautics supplied vehicle performance data, range support and aided in the post-flight analysis.
- (6) The Air Force Missile Test Center had the responsibility for handling the missile launching and range data reduction.

I. INTRODUCTION

The re-entry history of radioisotope generators designed for space use must be determined to assess the effects of aerodynamic forces on the bodies. The ultimate fate desired for the radioisotope fuel, either to be released at high altitude in aerosol particles or to be contained and survive re-entry, is dependent upon several factors. These include the type of mission specified for the satellite, the type of radioisotope (α , β or γ -emitter), the quantity of fuel and the selection of launch point and initial launch azimuth. Re-entry from orbit and from an abort during the launching sequence are studied. The effects of aerodynamic heating on bodies entering in a random or unknown mode are then evaluated.

Empirical and analytical data concerning aerodynamic heating have been determined for hemispherically shaped bodies while lesser amounts of data have been developed for cylinders and flat plates at various angles of attack. SNAP generators do not employ these convenient shapes. As a result, in-flight tests of simulated models were conducted to verify the techniques used to evaluate the aerothermodynamic analyses and to substantiate the conclusions concerning their ultimate fate.

Five flights were scheduled and conducted for this program. The first four flight tests were planned in two phases, each designed to solve a particular aspect of the problem. The fifth flight was conducted because both flights carrying Phase II experiments aborted.

Phase I was designed to investigate the effects of body shape and mode of re-entry on the generation of aerodynamic heating. Lead capsules, loaded with alkali metals, and a telemetry capsule were the test specimens. The lead capsules were a group of spheres and three groups of cylinders, with a variation in the length to diameter ratio of the latter. The telemetry capsule was very similar to the one used for the fifth flight and described in this report. Two flights were conducted with only partial success was achieved.

Phase II was designed to verify the heat transfer code used to calculate the wall temperature gradient and, subsequently, the ablation rates of re-entering bodies. Four groups of cylindrical lead bodies, loaded

with alkali metals, were designed with identical external dimensions and a variation in wall thickness. A telemetry capsule similar to that used in Phase I testing was also flown. The two flights carrying this phase of the program aborted and no information was received.

The program plan is fully described in Reference 1 and the results of the first four flights are documented in References 2 and 3.

The test described in this report was launched on August 13, 1962, and a near-nominal trajectory was flown. The four groups of lead cylindrical capsules, each group containing seven bodies, and the telemetry capsule were ejected from the passenger pod and monitored during re-entry. The observation instruments located aboard the downrange aircraft and Ascension Island obtained nearly 100% coverage of the re-entry.

This report covers in detail the analyses concerning the re-entry of the telemetry capsule, location of downrange aircraft, type and function of instruments and optical data reduction techniques.

II. DESCRIPTION OF TEST PROGRAM

Reference 1, a report issued prior to the first flight, gives a detailed discussion of the methods of analyses of each phase of the program, i.e., aerodynamic heating, heat transfer, trajectory, physics of reentering bodies and structural evaluation of the telemetry capsule. The discussion in this section will briefly summarize these subjects and will cover the fifth flight test.

A. TEST CARRIER AND EJECTION HARDWARE

An Atlas Series F vehicle was used as the test carrier. The test specimens were carried within a Scientific Passenger Pod which was in turn mounted exterior to the Atlas. Figure 1 shows the launch configuration. During proof testing of the Atlas, little payload other than the re-entry vehicle is carried and, as such, additional test programs may be conducted on a non-interference basis. The two pods shown in Figure 1 were so utilized.

The SPP contained a programmer which sequenced events occurring prior to reentry. At a predetermined time, the pod ejected itself from the Atlas and then controlled the ejection of the test specimens. The pod was separated from the Atlas shortly after sustainer engine cut off. Its relative velocity was normal to the Atlas tankage at approximately 4 feet per second. The SNAP telemetry capsule ejected as programmed at 22:23:27.6 Zulu. The four groups of lead "flare" specimens were subsequently ejected at 25 seconds intervals. All the test articles were released prior to 400,000 feet altitude during the reentry portion of the trajectory. A near nominal trajectory for the Atlas lofted R&D mission, as specified in Reference 1, was flown.

Figure 2 shows the test specimens and ejection mechanism. The test specimens are described in the next section. The ejection mechanism consisted of five eject cylinders which contained each group of lead capsules and the telemetry cylinder. The lead bodies were mounted on wooden blocks and so positioned that all of seven specimens within each group could be ejected simultaneously. Lock pins retained the articles under spring tension. Electrical signals from the pod programmer activated solenoids, retracted the pins and allowed the forced ejection of the

FIG. 2 - TEST SPECIMENS AND EJECT MECHANISM

lead specimens and telemetry canister. The velocity of separation was 4 fps (+2 fps).

B. TEST SPECIMENS

Two types of test specimens were designed and built for this test program. The lead bodies were designed to be destroyed at high altitude exposing the alkali metal to indicate the time and altitude of burnup. The telemetry capsule was designed to measure the temperature profile of the reentering body; subsequent proper data reduction was to convert this temperature history to an aerodynamic heating flux.

1. Lead Test Specimens

Four groups of lead specimens, each loaded with a characteristic alkali metal - sodium, lithium, rubidium and cesium were flown. The bodies were all cylindrical in shape, length of 5 inches and diameter of 2½ inches. Each group consisted of seven units of characteristic wall thickness. Figure 3 shows the specimens. Figure 4 is a photograph of one of the specimens in the process of being loaded with the alkali metal. Since liquid rubidium and cesium will react violently with lead, these metals were encapsulated in polypropylene containers prior to insertion into the test specimens.

All liners and capsules were designed with void space to allow for volumetric thermal expansion. These internal spaces were filled with argon gas, pressurized to 0.050 psia.

Table 1 illustrates the physical characteristics of the specimens.

2. Telemetry Capsule

The telemetry capsule was instrumented to measure, record and transmit canister exterior and interior wall temperatures during reentry. It was a hollow cylinder constructed of titanium alloy (5% Al, 2.5% Sn) 9.5 inches in diameter, 19.5 inches in length, and 0.292 inches in wall thickness. Temperature during reentry was intended to be measured by 23 transducers mounted on the exterior surface and three located on the inside wall.

NOTE:
All dimensions in
inches.

Fig. 3. Re-entry Capsules, SNAP Hazards Tests

FIG. 4 - LOADING OF TEST SPECIMEN

TABLE 1
CHARACTERISTICS OF LEAD TEST SPECIMENS*

Group No.	Wall Thickness	Total Weight (per specimen)	Aerodynamic Ballistic Coefficient ($W/C_d A$)	Alkali	Alkali Weight	Total Weight 7 Capsules
1	1/4	4.70	57.3	Na	0.442	32.90
2	3/8	6.15	75.0	Li	0.174	43.40
3	1/2	7.50	91.5	Rb	0.207	52.50
4	5/8	8.46	103.0	Cs	0.144	<u>59.50</u>
						188.30

*All dimensions in inches and weights in pounds.

Temporell 1500 insulation, one inch thick, was placed inside the titanium shell to provide thermal protection for the internal electronic gear. A fiberglass cylinder 1/8 inch in thickness was fitted to the inside diameter of the insulation to provide annular support and alignment for the internal package.

The internal electronic and electrical systems include a battery power supply, voltage oscillators, power amplifiers, a commutator, a magnetic tape recorder and reproducer and a transmitter.

A transmitter antenna was attached to one end plate. All sensed temperatures were intended to be transmitted twice to the receiving stations, the first transmission occurring the instant the temperature was sensed and the second transmission 30 seconds later. The delay was to be effected through the use of recorder/reproducer which stores all sensed temperature data for 30 seconds prior to playback, to circumvent the effects of telemetry blackout during re-entry. The transmission frequency was 244.3 megacycles.

The capsule weighed approximately 85 pounds, 40 pounds comprised the shell, insulation and end plates. The tumbling aerodynamic ballistic coefficient $\frac{W}{C_D A}$ was approximately

70.3.

Figures 5 and 6 show the unit. A spin rocket was attached to the capsule at the end opposite the antenna to impart a high velocity tumbling motion to the body. This spin rocket was used only on the fifth flight and here, only as a hedge to the analysis which showed the body to reentry intact without it.

Appendix A summarizes the analyses conducted to determine the maximum tumbling rate required to assure that the aerodynamic heating flux would be distributed uniformly about the surface of the body. It is shown that a tumbling rate of 2 rpm is adequate, a rate believed imparted by the SPP. The rocket induced a motion of about 100 rpm.

Appendix B describes the effect of pitch damping coefficients on the tumbling rates of the telemetry cylinder. This study shows that if an initial rate of 100 rpm is imposed on the capsule, then it will not damp out to 2 rpm until at least 50,000 feet altitude, well below the altitude where aerodynamic heating is terminated. Curves are also shown

FIG. 5 - TELEMETRY CAPSULE

Fig. 6. Re-entry Telemetry Capsule

for initial tumbling rates of 50, 16.66 and 10 rpm. In each case, pitch damping to 2 rpm was not reached until approximately 50,000 ft.

C. METHODS OF ANALYSES

This section discusses the methods of computing aerodynamic heating, heat transfer and trajectories of reentering bodies. These methods were used in the pre-flight analyses and in evaluation of test data.

1. Aerodynamic Heating*

Reentry of the capsules into the sensible atmosphere was assumed to occur at an altitude of 400,000 feet. The approximate locations of the various flow regimes were determined on the basis of the comparison of the local or free stream mean free path and the body radius as defined by Probst in Reference 4. It is estimated that continuum flow was encountered at 240,000 feet altitude and above this altitude, slip flow, transitional flow and free molecular flow were experienced.

The method by which the time variation of stagnation point heating rate and the distribution of heating flux were calculated is given in Reference 5. The laminar heating rate at the stagnation point on a hemispherical nose is:

$$q_{\text{stag}} = \frac{17,600}{\sqrt{R}} \sqrt{\frac{\rho}{\rho_0}} \left(\frac{V}{V_c} \right)^{3.15} \left[\frac{h_{s,i} - h_{ws}}{h_{s,i} - (h_{ws})_{300}} \right] \quad (\text{Btu/ft}^2\text{-sec})$$

where:

R = nose radius (ft.)

ρ = mass density

V = flight velocity (fps)

h = enthalpy per unit mass

* George I. Nielsen, Appendix C, Reference 1

Subscripts

o = sea level conditions

c = velocity required for circular orbit at altitude under consideration

s = stagnation point

w = body surface

δ = edge of boundary layer

300 = evaluated at 300°K

Since the heating equation as it appears above is applicable only to hemispherical noses, a correction factor must be employed in modifying the equation to fit the case being investigated. Stoney, in Ref. 6, shows that, at Mach numbers greater than 5, the stagnation point heat flux on a flat-faced vehicle at zero angle of attack is one-half that on a hemispherical nose at the same flight conditions. Similarly, to calculate the heat flux at the stagnation line on a cylinder normal to the flow, a correction factor of $\frac{1}{\sqrt{2}}$ is applied to the heat-

ing rates calculated by this equation (Reference 7).

Surface averaging techniques were used in calculating the surface distribution of the heating rates. The surface distribution of heating rates, in which the local heating rates around the body are defined in terms of the stagnation heating rate was determined from test data and from the theory of Lee (Reference 7). The distribution of heating rates for spherical or cylindrical bodies can be shown by a single curve since there is little change in the ratio of local-to-stagnation heating rate with change in Mach number. Figure 7 shows the distribution of heat fluxes as a function of body central angle.

The stagnation line heating rate on a cylinder is also a function of yaw angle (Figure 8), the heating rate being a maximum when the cylinder is normal to the flow. Correlation of heating data from Refs. 8 and 9 indicate that the variation in stagnation line heating rate is approximated by the $(\cos \alpha)^{3/2}$.

FIGURE 7. HEAT FLUX DISTRIBUTION ON A SPHERE AND CYLINDER

FIGURE 8 VARIATION OF HEAT TRANSFER RATE WITH YAW ANGLE FOR A CYLINDER

Table 2 shows the modification factors to the hemispherical body stagnation heating equations that are used to analyze non-spherical bodies. The integral average of the local heating rate with respect to the stagnation values are also shown. These are the factors which are used to determine the surface average heating rate of bodies of revolution entering the atmosphere in a random mode.

TABLE 2
MODIFICATION FACTORS TO HEMISPHERICAL
STAGNATION HEATING EQUATION

<u>Condition</u>	<u>Stagnation Heating Rate</u>	<u>Surface Average Factor</u>
Sphere	1.0	0.312
Cylinder (Normal to Air Flow)	0.707	0.321
Flat Plate, (Cylinder Parallel to Air Flow)	0.500	1.20
Cylinder (Tumbling)	0.584	0.321

Therefore, a right circular cylinder, entering the atmosphere tumbling in the pitch plane, will experience aerodynamic heating as determined by the relationship below:

$$q_{\text{surface ave. cylinder, tumbling}} = q_{\text{stag. sphere}} \times 0.707 \times 0.321 \times 0.584 = 0.132 q_{\text{stag. sphere}}$$

2. Heat Transfer and Trajectory Calculations

The aerothermodynamic analysis conducted on reentering bodies required the simultaneous solution of trajectory and aerodynamic heating equations. After the rate of external heating is known, a heat transfer and, subsequently, ablation study was performed. The methods of solution are programmed on the IBM 7094 Digital Computer.

The two digital programs used in this study were:

- (1) N-Stage Three-Dimensional Point Mass Trajectory, Ref. 10
- (2) Transient Heating Digital Analysis for Structural Design, Ref. 11

a. Three-dimensional, Three Degree of Freedom Point Mass Trajectory Digital Program

This program was used to determine the spatial position of the reentering bodies, and for calculating aerodynamic heating rates and mode of reentry of the bodies. All forces were assumed to act through the center of mass of the body, and the path of the center of mass was computed over a rotating oblate earth under the influence of gravity, thrust, and aerodynamic forces. The gravitational force varied as a function of the geocentric latitude and the distance from the center of the earth. The ARDC model 1959 atmosphere was used.

b. Transient Heating Digital Program

This program handles arbitrarily arranged and selected elements of structure with temperature-dependent material properties. Facets considered were: conduction in three dimensions; radiation to infinity; radiation across infinite, parallel plates; heat flow to a cooled element; and ablation. Equations of curves of enthalpy versus temperature were utilized in handling variable specific heat and phase changes such as melting or boiling. The temperatures were calculated for finite increments in time; and to increase accuracy, the heat balance equations were written as functions of the average temperature gradients over a time interval rather than the temperature gradient at the beginning of the interval. Simultaneous equations were solved for each interval of time. An iteration procedure was used with a technique to accelerate convergence, force convergence in diverging cases, and handle the non-linearity introduced in the radiation and ablation problems. The stagnation heating flux and conversion factors (for orientation and configuration) were entered into this program to determine aerodynamic heating effects on the test capsules.

D. DATA ACQUISITION

The primary equipment for data acquisition were optical and electronic instruments mounted aboard two aircraft and at Ascension Island, Station 12, of the Atlantic Missile Range (Reference 12).

The optical equipment located at the re-entry zone were designed and indexed so as to be switched to the operating mode prior to the time when the test specimens reached 400,000 feet during re-entry. The time that the re-entry vehicle would be at 400,000 feet was determined at the launch site based on trajectory data at vernier engines cut-off, sent to Ascension Island and then retransmitted to the aircraft. The aircraft's camera operators then initiated action of their equipment so that all units were operating during the entire period that the test specimens were between 400,000 and 80,000 feet.

1. Method of Identification of Flare Materials

Identification of the particular lead body producing the light was dependent on the light spectrum produced by the flaring material. The light produced in the spectra of every element is unique and can be analyzed by spectrographic or by filter methods.

Instruments used for flare identification were photometers filtered to pass light produced by rubidium, cesium and lithium and operated by Cambridge Research Laboratory and Barnes Engineering; a Hulcher 70 mm. sequence spectrometer operated by Barnes Engineering; and K-24 cameras operated by Air Force Special Weapons Center personnel.

The K-24, a war surplus aerial camera having an f/2.5 aperture and 7-inch focal length lens, has an effective field of view of 24 degrees (total field of 37.5 degrees, but with tangential distortion). Eight of these cameras were filtered, two each to pass selectively the light from each flare.

The Instrument Corporation of Florida, under subcontract to the Martin Company, determined the best means of selective photography. Their first progress report, dated 21 May 1962 and authored by J. Sibol (Ref. 13), discussed this problem.

The relative energy outputs of all the flare materials considered were plotted, with wavelength as the abscissa, and the relative strength on the M.I.T. scale as the ordinate. Figures 9 and 10 show the curves for sodium and lithium elements. Other materials which are components of the missile, the SNAP pod and the capsules, will also oxidize and emit electromagnetic radiation.

A large variety of filters were available. The transmission curves of some of the filters which were used in this program are shown in Figures 11 and 12.

The spectral sensitivity curves for the films are shown in Figures 13 and 14. Because the spectral sensitivity of films is very dependent upon conditions beyond their control, film manufactures are reluctant to assign absolute figures to these curves.

To ascertain what will happen when certain flare materials, filters, films, and the atmosphere are used in combination, it is necessary to combine their various curves. The combined curves are shown in Figures 15 and 16. The overall values of the ordinates of the filter, film, atmosphere curves are based upon the factors 1, 1.5, and 4 for HSIR, Tri-X and Royal-X pan films respectively, to compensate for variation in film sensitivity, and twice the atmospheric transmission at 8,000 angstroms as at 4,000 angstroms.

2. Method of Determination of Altitude of Burn-Up

Photographs obtained from BC-4 ballistic cameras located aboard the aircraft and at Ascension Island were the principle data used to accurately determine the position of the flaring images as a function of time.

3. Additional Optical Equipment

Table 3 lists the equipment used for this program and indicates the location, operator and the validity of the data obtained from each unit. The handling and operation of the optical equipment was primarily the responsibility of AFSWC. The Instrument Corporation of Florida calibrated the K-24 cameras and selected the film type and filter required to discern the various light spectra.

61-II

MIT SCALE - ARC

II-20

MIT SCALE-ARC

FILM SENSITIVITY - ARBITRARY SCALE

TABLE 3

List of SNAP Re-entry Test 102 Optical Instrumentation

Instr. No.	Operator	Instrument Description	Filter or Grating	Lenses and Angular Field	Film	Exposure	Developer	Remarks
1	CRL	Photometer RCA	Li	Aero-Ektar 7" f/5.6 3°	N/A	Continuous	N/A	a,d,h,v,w,x
2	CRL- AFSWC	Vought 16 mm Model No. VDR-5T	None	Telate 3" f/4 5.6° x 7.8°	Tri-X Rev. (ASA 200)	100 fps	-	a,b,h,k
3	CRL	Photometer RCA	Rb	Aero-Ektar 7" f/5.6 3°	N/A	Continuous	N/A	f,h,t,w,x
4	Barnes	Bell & Howell 16 mm GSAP	None					a,b,g,w,x,y
5	Barnes	Barnes Dual Channel Photometer	Cs & Rb	2°	N/A	Continuous	N/A	a,e,f,h,w, x,y
6	Barnes	Hulcher 70 mm Model 100	Bausch & Lamp 33-53-63-65 400 grooves/mm	Aero-Ektar 7" f/ 18° x 20°	HSIR			e,f,h,s,w,x
7	AFSWC	Mitchell 16 mm Model No. 16	None	Telate 3" f/4 5.6° x 7.8°	DuPont 4-Type 928A Neg. (ASA 320)	48 fps	DK-76, 68°F 8 min.	b,g
8	AFSWC	Eastman Kodak Co. A/C Type K-24	Bausch & Lamp 33-53-63-55 600 grooves/mm	Aero-Ektar 7" f/2.5 39° x 39°	Tri-X Type 18 Class N (ASA 250)			c,d,h,s,u
9	AFSWC	Avco-Everett Ballistic	None	Metrogan 6" f/5.6 67° x 79°	RSP-8" x 10" (ASA 1250)	Random Chop 0.04-0.065 seconds	DK-50, 68°F 3½ min, 1 min. agitation	b,h,r,z

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TABLE 3 - Continued

Instr. No.	Operator	Instrument Description	Filter or Grating	Lenses and Angular Field	Film	Exposure	Developer	Remarks
10	AFSWC	Eastman Kodak Co. A/C Type K-24	Bausch & Lamp 33-53-63-55 600 grooves/mm	Aero-Ektar 7" f/2.5 39° x 39°	IR, Type 1A, Class K (ASA 125)			a,e,f,j
11	AFSWC	Avco-Everett Ballistic	None	Metrogon 6" f/5.6 67° x 79°	RXP-8"x10" (ASA 1250)	Random Chop 0.04-0.065 seconds	DK-50, 68°F 7 min, 1 min. agitation	b,i,g,z
12	AFSWC	Avco-Everett Ballistic	Bausch & Lamp 33-53-38-55 600 grooves/mm	Metrogon 6" f/5.6 67° x 79°	IR-8" x 10" (ASA 25)	Random Chop 0.04-0.065 seconds	DK-50, 68°F 7 min, 1 min. agitation	a,e,f,i,p
13	AFSWC	Milliken, 16 mm Model DBM-5	None	Raptar 2" f/2.5 8.4°x11.7°	Tri-X (ASA-250)		D-76, 68°F 8 min. Processed Neg.	b,i
14	AFSWC	Hulcher, 70 mm Model 102	Bausch & Lamp 33-53-63-77 300 grooves/mm	Aero-Ektar 7" f/2.5 18° x 20°	Tri-X (ASA 125)	15 fps	-	a,c,d,i,l
15	AFSWC	Mitchell 35 mm Model "B"	None	Baltar 100mm f/2.5 9.0° x 12.4°	Ansco Ultra Speed Color (ASA 500)	32 fps		a,b,i,n
16	AFSWC	Mitchel 35 mm Model "B"	None	Baltar 152mm f/2.7 6.0° x 8.3°	Ansco Ultra Speed Color (ASA 500)	48 fps		b,i
17	ICF- AFSWC	Eastman Kodak Co. A/C Type K-24	None	Aero-Ektar 7" f/5.6 39° x 39°	RXP (ASA 650)		DY-19	A
18	ICF- AFSWC	Eastman Kodak Co. A/C Type K-24	None	Aero-Ektar 7" f/5.6 39° x 39°	RXP (ASA 650)		DK-19	A

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TABLE 3 - Continued

Instr. No.	Operator	Instrument Description	Filter or Grating	Lenses and Angular Field	Film	Exposure	Developer	Remarks
19	ICF-AFSWC	Eastman Kodak Co. A/C Type K-24	Wratten # 90	Aero-Ektar 7" f/4.5 39° x 39°	RXP (ASA 650)		DK-19	A
20	ICF-AFSWC	Eastman Kodak Co. A/C Type K-24	Wratten # 92	Aero-Ektar 7" f/4.5 39° x 39°	Tri-X, Type 1B, Class N (ASA 200)		DK-19	A
21	ICF-AFSWC	Eastman Kodak Co. A/C Type K-24	Baird-Atomic Mono-Pass (7800 Å°)	Aero-Ektar 7" f/4.5 39° x 39°	IR, Type 1A, Class K (ASA 125)		DK-19	A
22	ICF-AFSWC	Eastman Kodak Co. A/C Type K-24	Wratten # 87-C	Aero-Ektar 7" f/4.5 39° x 39°	IR, Type 1A, Class K (ASA 125)		DK-19	A
23	ICF-AFSWC	Eastman Kodak Co. A/C Type K-24	None	Aero-Ektar 7" f/5.6 39° x 39°	RXP (ASA-650)		DK-19	A
24	ICF-AFSWC	Eastman Kodak Co. A/C Type K-24	None	Aero-Ektar 7" f/5.6 39° x 39°	RXP (ASA-650)		DK-19	A
25	ICF-AFSWC	Eastman Kodak Co. A/C Type K-24	Wratten # 90	Aero-Ektar 7" f/4.0 39° x 39°	RXP (ASA-650)		DK-19	A
26	ICF-AFSWC	Eastman Kodak Co. A/C Type K-24	Wratten # 92	Aero-Ektar 7" f/4.0 39° x 39°	Tri-X, Type 16, Class N (ASA-200)		DK-19	A
27	ICF-AFSWC	Eastman Kodak Co. A/C Type K-24	Baird-Atomic Mono Pass (7800 Å°)	Aero-Ektar 7" f/4.0 39° x 39°	IR, Type 1A, Class K (ASA-125)		DK-19	A

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TABLE 3 - Continued

Instr. No.	Operator	Instrument Description	Filter or Grating	Lenses and Angular Field	Film	Exposure	Developer	Remarks
28	ICF-AFSWC	Eastman Kodak Co. A/C Type K-24	Wratten # 87-C	Aero-Ektar 7" f/4.0 39° x 39°	IR, Type 1A, Class K (ASA-125)		DK-19	A
29	AFSVC	Bell & Howell 16mm Model B1A	None	Cine Ektanon 152mm f/4.5 2.8° x 3.9°	Tri-X (ASA-250)	32 fps	DK-19	b,g
30	RCA-ICF	Wild BC-4-251 Ballistic, Sta 12.1 ICF I.D. #1	Wratten # 35 & 2C	Aviator 210mm f/16 46° x 46°				A
31	RCA-ICF	Wild BC-4-253 Ballistic, Sta 12.1 ICF I.D. #2	Wratten # 38 & 2E	Aviator 210mm f/16 46° x 46°				A
32	RCA-ICF	Wild BC-4-245 Ballistic, Sta 12.2 ICF I.D. #3	Wratten # 25A	Aviator 210mm f/32 46° x 46°				A
33	RCA-ICF	Wild BC-4-250 Ballistic, Sta 12.2 ICF I.D. #4	Wratten # 47	Aviator 210mm f/32 46° x 46°				
34	RCA	IGOR 70 mm Flight Research IGOR Site	None	18" aperature 90" E.F.L. 1.4° x 1.6°	Eastman Rev. Hi Speed Ektachrome	30 fps		b,h
35	RCA	Wild BC-4-267 Ballistic Sta 12.1	None	Astrotar 300 mm f/? 33° x 33°				b,z
36	RCA	Wild BC-4-268 Ballistic Sta 12.2	None	Astrotar 300 mm f/? 33° x 33°				b,z

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- a - No data
- b - SNAP package documentary
- c - Na flare identifier
- d - Li flare identifier
- e - Cs flare identifier
- f - Rb flare identifier
- g - No timing
- h - AMR timing
- i - AFSWC timing
- j - Film broke due to gummy roller
- k - Motor ran backwards due to reverse polarity
- l - Inoperative due to camera wiring short
- m - Slight light leak
- n - Film fogged by timing light leak
- o - Camera operated at only 18 fps, possibly due to low voltage
- p - Too low film speed
- q - Film overdeveloped
- r - Chop constant at 0.04 second due to wrong switch made.
- s - Na, Li, Rb, Al, O₂ identified
- t - Questionable Rb data
- u - Timing on Barnes visicorder paper
- v - Incorrect Li filter - manufacturer's mistake
- w - Final report not received
- x - Preliminary data received by telephone
- y - Reason unknown
- z - SNAP package spacial relationships
- A - Final Report, ICF support to Martin Marietta Corp. in the Reduction and Interpretation of Photographic Records of SNAP Tests, Jerome Sibol, 27 Dec 1962

4. Aircraft and Ground Observation Platforms

The aircraft were manned by Air Force Missile Test Center and Air Force Special Weapons Center personnel. Figure 17 shows the type of equipment and their position within the AFMTC C-54G A/C 556 and the AFSWC C-54G A/C 461.

The specifications of the equipment, and other data pertaining to data acquisition, were published by the Special Weapons Center under separate cover and are summarized in Table 3.

Figure 18 shows the ground installation of the photographic equipment. In addition to the battery of K-24 cameras supplied specifically for this program, some data was obtained by the BC-4 star cameras, 16- and 35-mm cinecameras, and a Hulcher 70- mm sequence spectrometer.

5. Aircraft Flight Plans

The aircraft flight plans during the re-entry period are shown in Figure 19. The aircraft were located at distances of 70 to 100 n. miles from the re-entry zone whereas Ascension Island was approximately 70 to 120 n. miles away.

It was decided early in the program to fix mount all optical equipment, except those with small viewing angles, to negate the requirement of aiming and, thereby, moving the mounting rig during this short period. As such, the aircraft positions were selected so that:

- (a) All instrument can view the event,
- (b) Aircraft are within radar sight of Ascension Island, and
- (c) Other bright objects, such as spent carrier tankage, do not obscure the bodies of interest.

Table 4 summarizes pertinent data concerning the location of each aircraft and the various ground stations. It can be seen that the base line used for triangulation from Ascension Island is approximately 3 miles; short yet sufficiently long to enable accurate position determination. The Instrument Corporation of Florida (ICF) used data obtained from the two ground stations as the

AIRCRAFT CAMERA MOUNTS

TEST NO. 102

FIGURE 17

ASCENSION ISLAND GROUND MOUNT

TEST NO. 102

FIGURE 18

AIRCRAFT FLIGHT PLANS

Test No. 102

FIGURE 19

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TABLE 4

Location of SNAP Re-entry Test 102 Instrumentation

Instr. No. or Description	Location	Latitude	Longitude	Elevation
1-10	AFSWC C-54G A/C 556 ^{1,2}	6.893° S	14.632° W	9720'
10-22	AFMTC C-54G A/C 461 ^{1,3}	7.288° S	14.403° W	8720'
23-29	TLM-18 Radar Site Ascension Island	7° 58' 29.28" S	14° 23' 21.89" W	753'
30-31	BC-4 Site 12.1 Ascension Island	-	-	-
32-33	BC-4 Site 12.2 Ascension Island	-	-	-
34	IGOR Site Ascension Island	7° 57' 04.07" S	14° 24' 44.35" W	280'
35	BC-4 Site 12.1 Ascension Island	7° 55' 47.64" S	14° 24' 21.84" W	475'
36	BC-4 Site 12.2 Ascension Island	7° 58' 32.93" S	14° 23' 36.42" W	505'
Mod II Radar	Ascension Island	7° 55' 53.30" S	14° 24' 10.47" W	868'
Mike-Hercules Radar	Ascension Island	7° 54' 25" S	14° 24' 11" W	103'

¹Determined at T+1909 seconds.²Located by extrapolation of Mod II Radar data.³Located by interpolation of Mod II Radar data.

primary source of position information. Information obtained and reduced by the Air Force Special Weapons Center was used to substantiate and improve the results contained in the ICF report.

E. DATA REDUCTION

The items of interest in data reduction were:

- (a) Identification and trajectory of the test specimens, with an accurate determination of the location (x,y,z) and velocity ($\dot{x}, \dot{y}, \dot{z}$) of all the bodies.
- (b) The time and altitude of the instantaneous burning of the flare material, with identification of the specimen, and
- (c) Temperature data from the large telemetry capsule.

1. Telemetry Capsule

The expected temperature levels at various locations of the telemetry capsule during the reentry period was reported in Reference 1. Figure A-1 of this report summarizes that temperature distribution as a function of reentry time. The maximum temperature expected on this, the fifth shot, was 1900°R since tumbling was induced by a solid propellant rocket mounted on one end of the unit. Although the unit was expected to tumble due to tumbling of the SPP inclusion of the rocket apparatus was deemed a safeguard warranted by the uncertainties of the SPP initial conditions at reentry and of forces associated with ejection from it.

AFSWC reported in Ref. 13 that the telemetry capsule was ejected as programmed at 22:23:27.6 Zulu and the signal strength increased linearly from a noise level of 3 mv to a satisfactory level of 70 mv at 22:23:38.0 Zulu. Thereafter, it varied sinusoidally from 10 mv to 80 mv with a null period varying from 0.5 to 1.0 seconds. Center frequency deviation held at a constant - 20 KC up to blackout. Loss of signal occurred at 22:31:52.3 Zulu and was never reacquired.

The period of the signal strength null indicated that the spin-up mechanism operated satisfactorily and imparted a tumble rate of 60 to 120 rpm to the telemetry capsule.

Discrimination of the telemetry tape showed information to be present on all three sub-carrier channels, i.e., 40 KC + 15% (direct data), and 3.6 KC + 40% (delayed data) and 10 KC + 15% (tape speed reference) up until blackout. The signal-to-noise ration of the 10 KC and 40 KC channels was very good, but the 3.6 KC channel was extremely noisy and useless from a data reduction standpoint.

A time of telemetry capsule ejection, the temperature at several locations on the surface of the unit approached 1000°R. These values are much higher than anticipated for this period of time, thereby suggesting external heating prior to pod separation (during the ascent portion of the trajectory). Further available temperature data shows that there was no temperature decline which would be expected in the 7 minutes, from the time of telemetry capsule ejection to the time of capsule arrival at 400,000 feet. In addition, no temperature rise was detected from this time (400,000 feet altitude) to time of telemetry blackout (approximately 240,000 feet). These discrepancies tend to invalidate the data obtained from the telemetry unit. It is presumed that either sensors or other electronic circuitry failed to operate properly.

2. Lead Test Capsules

The four groups of test capsules, each comprising seven units, contained sodium, lithium, cesium and rubidium alkali metals, respectively, as "flare" materials. Figures 20, 21, 22 and 23 show enlargements of the ballistic camera photographs of the re-entry phenomena. Reference 15, published by the Instrument Corporation of Florida, (ICF), was the primary source of reduced optical data and pertinent discussions from it are included in this section.

a. Flare identification (Ref. 15)

Drawings numbering each streak reentry and each ballistic camera checkpoint read by ICF from BC-4 photographs are shown in Figure 24. By comparing streak No. 1 on Ballistic Camera photograph ID #2 (filtered to pass sodium and cesium light), Ballistic Camera ID #1 (filtered to pass rubidium and lithium light) and Ballistic Camera photograph ID #4 (filtered to pass rubidium and cesium light), it was determined that streak number one was made by the capsules which contained sodium. By examining the first photograph of Ascension K-24 camera location no. 3-1, Figure 25 and realizing that this unfiltered camera will

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FIGURE NO. 20
B.C.I.D. #1

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FIGURE NO. 21
B.C.I.D. #2

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FIGURE NO. 22
B.C.I.D. #3

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FIGURE NO. 23
B.C.I.D. #4

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FIGURE 24
OPTICAL DATA POINTS
REF 14 FIG 11

TEST 102
AIRCRAFT 461 K-24 CAMERA PHOTOGRAPHS

LOCATION 1-1
CAMERA NO. 1
R-XP FILM
NO FILTER
f 5.6

LOCATION 1-2
CAMERA NO. 5
R-XP FILM
NO FILTER
f 5.6

LOCATION 1-3
CAMERA NO. 3
R-XP FILM
WRATTEN 90 FILTER
f 4.5

LOCATION 1-4
CAMERA NO. 8
XXX FILM
WRATTEN 92 FILTER
f 4.5

LOCATION 1-5
CAMERA NO. 4
HSIR FILM
MONOPASS FILTER
f 4.5

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03 02 01 22:31:00 59 58 57 56 55 54 53 52 51 22:31:50

FIGURE 25 ZULU TIME

TEST 102
ASCENSION K24 CAMERA PHOTOGRAPHS

LOCATION 3-1
CAMERA NO. 6
R-XP FILM
NO FILTER
f 5.6

LOCATION 3-3
CAMERA NO. 10
R-XP FILM
WRATTEN 90 FILTER
f 4.5

LOCATION 3-4
CAMERA NO. 2
XXX FILM
WRATTEN 92 FILTER
f 4.5

LOCATION 3-5
CAMERA NO. 9
HSIR FILM
MONOPASS FILTER
f 4.5

LOCATION 3-6
CAMERA NO. 12
HSIR FILM
WRATTEN 87C FILTER
f 4.5

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04 03 02 01 22:32:00 59 58 57 56 55 54 53 52 22:31:51

FIGURE 25 ZULU TIME

more readily pass sodium light, it was confirmed that number 1 contained the sodium capsules. Further confirmation was obtained from the 70 mm IGOR film, where individual sodium flares were seen to ignite and the times of flaring were accurately obtained.

Reference 15 further states that in a manner analogous to the above, when streak number 2 from the photographs from Ballistic Camera ID #1 and ID #3 are compared with streak number 2 from the photograph from Ballistic Camera ID #4, it was concluded that streak number 2 was caused by the flares which contained lithium. Confirmation that streak number 2 was made by the capsules which contained lithium can be found in the second photograph of K-24's, locations numbers 1-4 and 3-4. Confirmation was also obtained from a review of the IGOR Camera photographs.

Some uncertainty exists in the identification of the other two alkali metal streaks. The IGOR camera did not photograph these streaks. It is felt that this camera did not have the rubidium and cesium capsules in its field of view since these capsules reentered below the sodium and lithium-filled bodies. The Ballistic camera photographs show, by process of elimination, that the rubidium and cesium flares are contained in streaks 4, 5, and 6. It is most possible that streaks 5 and 6 were caused by the same family of capsules. Reference 15 concludes that streak No. 4 was caused by the capsules which contained rubidium flares and streaks numbers 5 and 6 which contained cesium flares. The rubidium flares ignited near the beginning of streak number 4 and the cesium flares ignited close to the end of streaks 5 and 6. The best confirmation can be found in the first reproduced photograph of aircraft K-24 camera, location 1-5. This camera used the Baird-Atomic rubidium monopass filter. The brightness of streak No. 4 in this photograph indicates that it was caused by the flaring of rubidium.

This frame also indicates that the flaring of rubidium started at approximately 22:31:54.72, closing time of the shutter when the photograph was taken, and extended past 22:31:55.48, the opening time of the next photograph. The second photograph, K-24 camera location 3-6, lends support to the assumption that cesium flaring occurred later, between 22:31:56 and 22:31:58.

b. Camera orientation

The mathematics used to determine the orientations of the cameras; the determination of X, Y, Z data from the ballistic camera plate readings; and transformation of the X, Y, Z data to latitude, longitude, and height are described in Ref. 16.

Nineteen star trail breaks, clustered around the area of the SNAP package, were chosen. The breaks were caused by the openings and closings of the camera shutters in prescribed sequences and times, before and after the missile test. The star trail breaks were then read and used in the calculation of the camera orientation parameters. The residuals from the control points were small and were randomly distributed about zero, indicating a good fit of the data. Essentially, what this means is that, if the accuracy of the reading of the breaks in the SNAP package can be considered to be of the same accuracy as the readings of the breaks in the star trails, then the accuracy of the directions from the cameras to the data points would be the mean error divided by the focal lengths of the BC-4 cameras, or 3.5 and 3.8 arc seconds, respectively. In actual practice, however, the reading of the breaks in the images of the SNAP package was not as accurate as reading the breaks in the star trails, because of the use of different filters on the two cameras, and because of the rapid fluctuation of the light intensity output of the SNAP flares. An educated guess as to the accuracy of the directions to the SNAP data points is about 7 seconds.

c. Reduction to X, Y, Z

At the same time the star trail breaks were measured, the SNAP package image breaks were also read. After the orientations of the cameras were computed, the X, Y, Z positions of the SNAP package image breaks were calculated, using Coordinate System No. 4. It is in this routine that the corrections for optical refraction are made. In addition to the actual X, Y, Z coordinates, the routine computes the standard deviations of the coordinates based upon a nominal reading accuracy of 3 microns. These quantities are normally referred to as the G.D.O.P.s or the Geometrical Dilutions of Precision, and they ranged from 289 to 686 ft. in X, 71 to 116 ft. in Y, and 65 to 204 ft. in Z. If the average reading error of the SNAP package image breaks is considered to be 7 microns instead of 3, these figures should be multiplied by the factor

7/3. Another set of data computed in the X, Y, Z reduction routine is the residuals from triangulation expressed in microns in the original ballistic camera plate coordinate systems.

In addition to the SNAP package image breaks, a number of points where the SNAP package images seemed to flare were read, under the assumption that they might be points of alkali ignitions. These points are listed as flares in Table 5, which correlates the numbers of the points read with their times. After the IGOR films were scrutinized and the actual times of the flares were determined, it was realized that some of the images noted on the ballistic camera plates were truly the flares, but that others must have been caused by the shells of the lead spheres turning and glinting after flaring had occurred. For this reason, and because the IGOR film times of flaring were available, (see table 6), it was decided to eliminate these glint points from further consideration. Because of the following reasons, points 19 through 22, were eliminated: they appeared to have derived from some source other than the capsules; the paucity of breakpoints, the timing pattern, and therefore the times of these points, could not be determined with any degree of reliability, they obviously occurred after the other flares had ignited.

d. Orbital Plane Fit

After the X, Y, Z data had been fit to an orbital plane for the first time, a clearer pattern of what had happened emerged. With so many capsules being ejected at one time, the flaring of the capsules occurred within very close proximity to each other, and the images from the individual flares, tended to co-mingle. What is termed the "adjacency effect" became a consideration.

From the pamphlet, Kodak plates and films for science and industry, the adjacency effect is defined as follows: "At the boundary of a dark image with a light background, the reaction products diffuse from the dark image into the region of light density and restrain development in this region near the dark image. Likewise, fresh developer from the light region diffuses into the dark image and, after it has penetrated a short distance, loses its original activity so that the image density is lower inside the image than at the extreme edge where the density is higher". Combining the proximity of the individual flare images with the adjacency effect, it is easy to understand

POINT NO.	TIME	POINT NO.	TIME
1	22:31:53.86	48	22:31:56.50
2	22:31:54.04	49	22:31:56.70
3	22:31:54.75	50	22:31:56.90
4	22:31:54.89	51	22:31:57.03
5	22:31:55.04	52	22:31:57.75
6	Flare	53	22:31:54.75
7	Flare	54	22:31:54.89
8	22:31:55.76	153	22:31:55.04
9	22:31:55.90	154	22:31:55.76
10	22:31:56.04	55	22:31:55.90
11	Flare	56	22:31:56.50
12	22:31:55.76	57	22:31:56.70
13	22:31:55.90	58	22:31:56.90
14	22:31:56.04	59	Flare
15	22:31:56.50		
16	22:31:56.70	60	22:31:54.75
17	22:31:56.90	61	22:31:54.89
18	22:31:57.03	62	22:31:55.04
		63	22:31:55.76
30	22:31:55.90	64	22:31:55.90
31	22:31:56.50	65	22:31:56.04
32	22:31:56.70	66	22:31:56.36
33	22:31:56.90	67	22:31:56.50
34	22:31:58.48	68	Flare
35	22:31:58.68	69	Flare
		70	22:31:57.03
40	22:31:54.75	71	22:31:57.75
41	22:31:54.89	72	Flare
42	22:31:55.04	73	22:32:05.35
43	Flare	74	22:32:05.83
44	22:31:55.90	75	22:32:06.495
45	22:31:56.04	76	22:32:06.695
46	Flare	77	22:32:06.895
47	22:31:56.36	78	22:32:07.45

Table 5 Ballistic Camera Break Time Table

ZULU Time	COMMENTS
22:31:54.31	Sodium Capsules enter field of view
22:31:54.605	1 Sodium flare starts
22:31:54.639	Sodium flare ends
22:31:54.708	1 Sodium flare
22:31:55.039	1 Sodium flare
22:31:55.140	1 Sodium flare)
22:31:55.241	2 Sodium flares) seen on Ballistic Camera plates - pts 6 & 7
22:31:55.407	2 Sodium flares
22:31:55.607	1 Sodium flare
22:31:55.903	1st Lithium flare
22:31:56.041	Lithium flare
22:31:56.174	Lithium flare
22:31:56.207	Lithium flare
22:31:56.274	Lithium flare
22:31:56.474	Lithium flare
22:31:56.774	Lithium flare
22:31:56.807	Lithium flare

Table 6 IGOR Flare Time Table

why it was difficult to determine what are individual capsules within each of the streaks composing a family of capsules. This problem could have been alleviated by using longer focal length cameras, which would further separate the images on the plate. Because one point in a family of capsules at, say, a thousand feet from the other points could severely distort the orbital plane, it was necessary to reject the points one at a time and note the effects of the rejection before considering the rejection of other points in the family. Therefore, the orbital-plane fit program was run a number of times for each family of capsules, the telemetry pod, and the telemetry capsule, before it was decided that further rejection would not give a substantially better orbital-plane fit.

e. Position and Velocity by Polynomial Smoothing

After the data had been edited by determining those data points within each SNAP package image which fit an orbital plane, the regression line of X, Y and Z, on time, were simultaneously determined for each family of capsules and the telemetry pod and telemetry capsule using. The residuals from the regression line of each data point were computed, and, in most instances were substantially below the desired goal of plus or minus 300 ft. The polynomials of the sodium and lithium regression lines are evaluated at the times the sodium and lithium flares were seen to ignite on the IGOR films, to obtain the positions of flare ignition. The best estimate of the times the rubidium and cesium flares ignited was derived from the K-24 films. The appropriate polynomials for the regression lines of the rubidium and cesium capsule images were evaluated at these times to give the locations of the rubidium and cesium capsules at flaring.

In one instance (streak Number 7 the telemetry capsule), because of the severe glinting of the capsule as the capsule tumbled, it was exceptionally difficult to determine what were the end points of the images caused by the openings and closings of the camera shutters. By the time the orbital-plane fit editing was completed, only three points of data remained. These three data points, of course, fit the second degree polynomial perfectly and the residuals from the fit were, except for rounding errors, zero.

III. COMPARATIVE ANALYSIS

The significant data obtained during this test program concern only the lead test specimens. A comparison is given in this section of the predicted altitude of burnup of each configuration with that observed and reported by Reference 15.

Figure 26 shows the altitude of first release of the flare as a function of time. This figure corresponds with the streaks shown in Figure 24 and indicates the relative position and, thus, timing of the flaring portion of the re-entry phenomenon with respect to the entire image. Figure 26 specifies that streaks No. 1, 2, 4 and the combination of 5 and 6 are, respectively, the sodium, lithium, rubidium and cesium bodies.

Because of the close proximity of the seven individual bodies within each group, the altitude of burnup of each configuration is reported as an altitude span. The largest span, that of the rubidium-filled group, streak No. 3, was 16,500 feet, corresponding to a re-entry time span of only 1.5 seconds. It is felt that this span can be reduced by noting the start and stop times of the K-24 film images shown in Figure 25, location 1-5. It can be seen that the rubidium flaring existed at the time of the lens opening at 22:31:55.60 and terminated at approximately 22:31:56.56. The image of the previous lens opening does not include the rubidium light so that it can be said that at time of 22:31:54.86 the rubidium did not exist. Therefore, the initial time of rubidium ignition occurred between the closing and opening of the lens at this time interval, a period of 0.6 seconds. If it is assumed that flaring initiated at the instant of shutter opening, the altitude span of rubidium visibility is reduced to approximately 8,000 feet and time span of approximately 0.75 seconds. The summary plot of Figure 27 does not show this refinement.

Various modes of re-entry were assumed for the lead test specimens and aerodynamic heating rates were calculated by methods previously described. A right circular cylinder such as the specimens can enter either in a stable mode, with its longitudinal axis randomly orientated to the air stream, or in a tumbling mode. The analysis of Appendix A shows that a tumbling rate of greater than 2 rpm is sufficient to distribute the aerodynamic heating about the entire surface of the body. In all cases, the heating was distributed in a surface averaging fashion.

FIG 26
REENTRY HISTORY
OPTICAL DATA REDUCTION
(REF. 14 FIG 16)

Figure 27 shows the predicted altitude of initiation of surface melting of the lead test specimen and of the point of release of the flare material. The heat transfer and ablation analysis assumed uniform ablation of the body wall and, as such, complete melting of the lead material prior to exposure of the alkali "flare" material.

Also shown in Figure 27 are the optically measured altitudes of flare ignition as shown in Figures 20-26. It can be seen that the photographed altitudes of destruction correspond very nearly to that assumed mode of re-entry of a stable body. The analytical procedure used to calculate the point of flare release was as follows:

- (1) The cylindrical test specimen was assumed to enter relatively stable, longitudinal axis normal to the air flow,
- (2) The semi-empirical equations used to compute aerodynamic heating on hemispherical bodies were modified to accommodate the right circular cylinder,
- (3) The aerodynamic heating was calculated using the surface-averaged technique previously described.

The lack of telemetry data from the instrumented capsule presents a missing link in the overall analysis of this program. It was planned to use the data depicting temperature rise as a function of re-entry time and sensor location on the capsule as an indication of the amount of aerodynamic heating experienced by this re-entering body. This information would have given us a firm indication of the validity of the aerodynamic heating equations and the various modifications that were used to make these equations applicable to bodies simulating SNAP devices. While not trying to solve the aerodynamic heating problem, per se, the information planned to be obtained from the telemetry capsule would have increased our confidence in the use of these equations and would have aided in the interpretation of the data obtained from the lead test specimens.

It can only be concluded that the cylindrical lead test specimens entered in a relatively stable mode and that the longitudinal axes were normal to the air flow. Figure 27 shows the relationships between the predicted altitudes of destruction and the measured altitudes. The specimens, other than the sodium-filled bodies, were

COMPARISON OF TEST AND COMPUTED DATA
ALTITUDES OF BURNUP
OF
LEAD TEST SPECIMENS
SNAP REENTRY TEST 102
FIGURE 27

TEST SPECIMEN E
MODE OF REENTRY
(COMPUTED)

GROUP 1 (No FLARE)
SPINNING & TUMBLING
STABLE ~ NORMAL
STABLE ~ 45°
STABLE ~ PARALLEL

GROUP 2 (L FLARE)
SPINNING & TUMBLING
STABLE ~ NORMAL
STABLE ~ 45°
STABLE ~ PARALLEL

GROUP 3 (R FLARE)
SPINNING & TUMBLING
STABLE ~ NORMAL
STABLE ~ 45°
STABLE ~ PARALLEL

GROUP 4 (C FLARE)
SPINNING & TUMBLING
STABLE ~ NORMAL
STABLE ~ 45°
STABLE ~ PARALLEL

ALTITUDE (1000 FEET)
260 240 220 200 180 160 140

LEGEND
○ CALCULATED START
OF LEAD ABLATION

□ CALCULATED RELEASE
OF FLARE MATERIAL

TEST DATA -
OBSERVATION OF
FLARE MATERIAL

260 240 220 200 180 160 140

predicted to be destroyed at altitudes bracketed by those measured. The sodium bodies were predicted to be destroyed at an altitudes slightly less than those measured. It should be noted that for these trajectories, the altitude change in one second is approximately 8,000 feet. Aerodynamic heating for a period of one second at the altitude where the sodium was destroyed is only 2.5% of the total integrated heating.

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APPENDIX A*

AERODYNAMIC HEATING ON TUMBLING CYLINDERS

A study was conducted to determine the aerodynamic heating rate that would be generated by the telemetry capsule during atmospheric re-entry under various tumbling rates.

Several authors (Beckwith and Gallagher, Cunningham and Kraus, and Goodwin, Marcies and Wenkler) have presented stagnation heat transfer rates for right circular cylinders at various angles of attack for a re-entry period of approximately 50 seconds. The results of these studies were used to compile composite stagnation heating rate curves to reflect the effects of various tumbling rates. The curves were adjusted so that the peak heating rates, experienced at zero angle of attack, occurred at identical times during the re-entry trajectory.

References A-1 and A-2 indicate that for small spin rates of cylinders and spheres, stagnation temperature distribution may be reduced by approximately 50%. Reference A-1 cites that a spin rate of only 1 rpm is required for spheres to achieve the reduction while Reference A-2 indicates that cylindrical body require spin rates of from 1 to 10 rpm. These references also state that beyond these relatively low spin rates, no further appreciable decrease in stagnation temperature can occur.

Figure A-1 shows the integrated heating rate that would be experienced by the telemetry capsule if assumed to re-entry with tumbling rates of 0, 1, 2, 5, 10 and 100 rpm. The aerodynamic heating was surface averaged about the body as summarized in the body of the report. Examination of Figure A-1 shows that no further decrease in heating can be expected for the telemetry capsule for tumbling rates exceeding 5 rpm.

Figure A-2 shows the temperature history expected for the telemetry capsule. The methods of predicting aerodynamic heating and heat transfer through bodies have been detailed in References 1, 2 and 3 and summarized in the body of this report.

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TOTAL AERODYNAMIC HEATING
ON THE
TELEMETRY CAPSULE
AS FUNCTION OF
TUMBLING RATE

FIGURE A-1

TEMPERATURE HISTORY
OF
TELEMETRY CAPSULE
DURING REENTRY

FIGURE A-2

REFERENCES

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APPENDIX B*

EFFECTS OF PITCH DAMPING COEFFICIENTS ON TUMBLING RATES OF THE TELEMETRY CAPSULE

Results

The dynamic motion of the telemetry capsule was analyzed during its re-entry period to determine its mode of stability. Previous study (Appendix A) showed that, if the capsule is tumbled at a rate of 2 rpm, the aerodynamic heat would be sufficiently dispersed about the body so that the maximum temperature at any point on the body would be less than that necessary to yield the material. The kicker rocket attached to the telemetry capsule imparted an initial tumbling rate of about 100 rpm.

Figure (B-1) shows a summary of the tumbling motion of the body during the re-entry period as a function of its initial rate. It can be seen that the body, if its initial rate is nearly 100 rpm, will not damp out to 2 rpm until at least 50,000 feet altitude, well below the height where aerodynamic heating is terminated. Curves are also shown for initial tumbling rates of 50, 16.66 and 10 rpm. In each case, pitch damping to 2 rpm is not reached until approximately 50,000 feet.

Thus, any initial tumbling motion imparted to the telemetry capsule upon ejection would not be damped out to zero (become stable) until well below 50,000 feet.

Discussion

In this experimental re-entry study, a telemetry canister of similar configuration and ballistic coefficient as that of the other test specimen was ejected as part of the experiment. The telemetry canister was instrumented to measure, record, and transmit the canister wall temperature history during re-entry.

The analysis of the tumbling problem was done by the use of the Martin Company Pershing Three Dimensional Trajectory Program (UØ 003). With initial aerodynamic data and tumbling rates as input for a re-entering body (cylinder), the program gives the corresponding trajectories and damped tumbling rates.

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SNAP PROGRAM
T/M PACKAGE RE-ENTRY STUDY
EFFECT OF PITCH DAMPING COEF.
ON TUMBLING RATE

FIGURE B-1

This program was selected since it was capable of a six degree of freedom analysis and its ability to handle a re-entering body that is tumbling through 360 degrees.

The re-entry body (telemetry canister) considered for the analysis was a right circular cylinder of a l/d ratio equal to 2.105. Estimated values for the moments of inertia were calculated using the latest modifications to the telemetry canister. The kicker rocket package's design permits for separation from the canister before re-entry. Therefore, it was not included with the canister weight or inertia calculations.

Other input parameters to the program which were considered consisted of (1) damping in pitch coefficient, (2) axial and normal force coefficients, and (3) center of pressure.

The damping in pitch coefficient is defined as:

$$C_{mq} = \frac{1}{q_0 A d} \frac{\delta m}{\delta \left(\frac{\dot{\theta}}{ZV} \right)} \text{ per radian}$$

Eq. 1
Ref. B-12

Other formulas expressing the damping in pitch coefficient obtained from the references are:

$$C_{mq} + C_{m\dot{\alpha}} = - \frac{2.772 I_{yy} V}{q_0 A d^2} \left(\frac{1}{t_{1/2}} \right) \text{ per radian}$$

Eq. 2
Ref. B-10

$$C_{mq} = 2 \left(\frac{k}{d} \right)^2 \left[\frac{u d}{V} \lambda_0 + C_{n\dot{\alpha}} \right] \text{ per radian}$$

Eq. 3
Ref. B-11

The UØ - 003 program expresses the damping in pitch coefficient by the term:

$$\dot{q} = \frac{(C_{MQ})_q q_0}{I_{yy} V} \frac{\text{rad}}{\text{sec}^2}$$

Eq. 4

where

$$C_{MQ} = - C_{mq} \left(\frac{A d^2}{2} \right) \text{ meters}^4$$

Eq. 5

A check was made to determine the correctness of the term $(\frac{Ad^2}{2})$. Since the program was written for the Pershing missile, Pershing data was substituted into Eq. 5 to obtain values of (C_{mq}) . The values checked relatively close to given reference values of C_{mq} for a conical shape. With this check, Eq. 5 was assumed correct.

Reference (B-10) gives a $C_{mq} = -0.5/\text{rad}$ for a flat-nosed object evaluated at the flat area. Reference (B-13) has a very small C_{mq} for a cylinder of an $l/d = \sim 1/2$ at an angle of attack of 90° . Using these values as a guide, equation 3 was used assuming $\lambda_0 = 0$. λ_0 is the non-rolling pitch damping constant. Equation 3 now becomes:

$$C_{mq} = -2 \frac{I_{yy} C_{N\alpha}}{md^2} \text{ per radian} \quad \text{Eq. 6}$$

Substituting our values into this equation gives $C_{mq\text{ave}}$ of $-1.5/\text{rad}$ or $C_{mq\text{ave}} = .0025(\text{meter})^4$. The subscript ave denotes the use of an average $C_{N\alpha}$ over an angle of attack range of 0 to 90° . Because of the size of C_{mq} compared to that of reference B-13, equation 6 seems conservative.

Because our interest is in that portion of the re-entry where maximum heating occurs, i.e., 250,000 to 80,000 feet in altitude and greater than 5,000 feet per second in velocity, C_{mq} was loaded into the IBM program as a constant versus Mach Number. There is little variation of $C_{N\alpha\text{ave}}$ with Mach Numbers above 3; thus there is little variation in C_{mq} .

1. Axial and Normal Force Coefficients

After reviewing several reports on right circular cylinders, it was decided to use the unpublished data obtained from the Marshall Space Flight Center at Huntsville, Alabama. References for this data are Ref. B-1 through B-7. This data is the most complete, giving axial and normal force variations with Mach Number, l/d , and angles of attack through 90° . Some center of pressure variations were also

given. The hypersonic data was Newtonian modified for Mach effects. Normal force coefficients were taken at an $\ell/d = 2.105$.

2. Center of Pressure

Little data is available concerning center of pressure location for cylinders with an ℓ/d of 2. The best information available again is the unpublished data from Huntsville. This information and that of Ref. B-9 were used to obtain the c.p. variation with angle of attack and Mach number. This data is not well defined for angles of attack in the order of 10 to 30 degrees and for ℓ/d of 2 for all Mach numbers. Some data were available for an ℓ/d of 5 and this was used to determine approximate shape of our curve.

3. Variation of Pitch Damping Coefficient

Figure B-2 illustrates the effect of the pitch damping coefficient (C_{MQ}) on the initial pitching velocity of 600 deg/sec (100 rpm) with a nominal altitude profile. From previous work (Reference B-4) it was indicated that a pitching rate of 2 rpm is sufficient to prevent the telemetry canister from being possibly damaged upon re-entry. Applying this information to Figure B-2, resulted in obtaining Figure B-1. Figure B-3 illustrates altitudes at which initial tumble rates are damped to 2 rpm by various pitch damping coefficients.

Symbols

ℓ = body length -- ft. or meters

d = body diameter -- ft. or meters

C_{mq} = damping in pitch coef. -- per radian

C_{MQ} = damping in pitch coef. -- meters⁴

$\dot{\theta}, Q, q$ = pitching rate (tumble) -- deg/sec, rad/sec,
rev/sec, rev/min

Q_0 = initial tumbling rate -- deg/sec, rad/sec,
rev/sec, rev/min

FIGURE B-2
SNAP PROGRAM
TLM PACKAGE REENTRY STUDY

q_o = dynamic pressure -- lbs/ft² or kgms/m²
 A = cross-sectional area (ref.area)-- ft² or m²
 V = velocity -- ft/sec or m/sec
 I_{y-y} = moment of inertia in pitch -- slug-ft²
 $t_{1/2}$ = time to damp to half amplitude -- sec
 k = radius of gyration = -- ft or meters
 M = mass -- slugs
 $u = \frac{4M}{\rho A d}$
 ρ = density -- slugs/ft³
 q = pitching acceleration -- deg/sec² or rad/sec²
 $C_{N\alpha}$ = normal force slope -- per rad
 λ_o = non-rolling pitch damping constant

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