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February 3, 1965

To: G. A. Fowler - 9000

From: A. Y. Pope - 9300 RC Mayden for

Re: Aero Projects Capabilities as Related to Sandia Responsibility for R/V Research and Development

A. Responsibility of 9300

Aero Projects would provide (in support of the R/V project group) the thermodynamics and aerodynamics information necessary to design the ballistic case, including ablation material. This would include 6-degree of freedom programs for CDC 3600 re-entry trajectory calculations, vehicle static forces and moments, vehicle dynamic stability characteristics and local aerodynamic heating rates to the R/V for selection of ablative materials. The aerodynamic parameters would be determined from theory and wind tunnel tests. In addition, Aero Projects would furnish estimates of electron density distribution about the R/V (for radar-fuzing window studies) and in the wake (for radar cross-section studies). Information on baro-probes for fuzing (if needed) at hypersonic Mach numbers and parachute and/or other R/V recovery systems would be furnished. Aerodynamic inputs for structural case design and dispersion analysis for hardening R/V systems against nuclear blasts would be furnished.

B. Accomplishments Relative to R/V Research and Development

1. R/V Design Experience

The Aerospace Nuclear Safety Department, 9310, has been responsible for the conduct of two re-entry burnup flight tests, RFD-1 and RFD-2. These tests were designed to examine in detail the heat-up, meltdown, and disassembly of simulated SNAP power supplies. This responsibility included design, evaluation, and fabrication of the re-entry vehicle, and telemetry and fuzing system used to re-enter the SNAP units, range launch coordination, and downrange optical and telemetry systems. Each test required about 60 manyears of effort and cost around five million dollars. These R/V's were fabricated at Bendix, Kansas City; BKC subcontracted some of the ablative materials fabrication to Goodyear.

The design effort required a significant capability in three and six degree of freedom trajectory analysis, heating calculation, and aerodynamic calculation and measurements. RFD-1 was flown in May 1963, and RFD-2 was flown in October 1964. The data return from both tests was excellent.

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1. Wolney, W., "Heat-Transfer and Pressure Measurements on the Full-Scale SNAP-2/10A at M=19," AEDC-TDR-63-84, April 1963 (U).

2. Bustamante, A. C., "Aerodynamic Analysis and Characteristics of the SNAP-10A Re-entry Test Vehicle for the RFD-1 Re-entry Flight Test," SC-4927(RR), October 1963 (U).

3. Klett, R. D., "Re-entry Flight Demonstration No. 1 (RFD-1): Pre-Flight Disassembly Analysis & Observed Disassembly of the Simulated SNAP-10A Reactor," SC RR 64-515, June 1964 (U).

4. Jacobs, J., "Re-entry Flight Demonstration No. 1 (RFD-1): Design, Development, and Performance of the Re-entry Vehicle," SC-RR 64-511, May 1964 (U).

5. SC-RR-65-13, "Re-Entry Flight Demonstration Number Two Interim Flight-Test Report."

2. ASP

The ASP re-entry power supply converts the heat energy developed by aerodynamic heating to electrical energy in a process similar to the plasma diode. If the front portion (emitter) of the R/V skin is electrically insulated from the aft part (collector) of the R/V, a potential and consequent current flow is produced. Currents of 30 amperes per square inch of emitter surface area have been produced experimentally.

Since the ablative or surface material must conduct electricity, Sandia has investigated such esoteric materials as pyrolitic graphite, copper-impregnated porus tungsten and graphite-impregnated phenolics. A model R/V (for testing on Polaris missiles) has been fabricated of pyrolitic graphite. A Sandia design of an R/V model of graphite was unusually successful in withstanding the extreme heating environment of the Cornell Wave Superheater.

References:

Touryan, K. J., "The Hypersonic Plasma Converter, I and II", SC 4960(RR) and SC-RR-64-979.

3. R/V Hardening

Organization 9320 has a coordinated theoretical and experimental program designed to yield methods for predicting the aerodynamic loads induced on a re-entry vehicle by an intercepting nuclear blast. This work is being done experimentally by firing rocket boosted model R/V's through an H.E.-generated blast in the IBIT

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program. Other experimental work is being conducted in laboratory shock tube hypersonic wind tunnel facilities. A theory for predicting shock inter-action loads is being developed with the assistance of the Lockheed Missile Systems Company and Oklahoma State University.

In addition, a computer program is being developed to predict the rigid body accelerations and the subsequent ballistic dispersion of an R/V as it passes through the free field environment of an atomic blast.

References:

1. Randall, D. E., "Pressure Distributions Determined from the Test of a Cone Model in the AWFL Shock Tube," SC-TM-64-1283.

2. Wolff, W. S., "Transient Flow Field Analysis Around a Conical Body Exposed to a Blast Wave," Lockheed Missiles and Space Co., Report No. 4-70-64-1.

4. Re-entry Plasma Physics

In conjunction with the Plasma Laboratory, spectroscopic methods have been developed for measuring the temperature and electron density of high temperature plasmas which are experienced in re-entry. This is applicable to re-entry discrimination. A computer program has been developed to determine the real gas properties of the dissociated and/or ionized air at re-entry temperatures. Theoretical work has been done on the attenuation of electro-magnetic energy in highly ionized gases, which is appropriate to the R.F. attenuation problem.

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The Sandia Corporation Plasma Laboratory contains a 160 kw and 1 megawatt plasma jet which can be used for testing ablative materials, R.F. attenuation, and magnetohydrodynamic ideas. As an example, lithium hydride was recently evaluated as an ablative material in the Plasma Laboratory. Funds for a 2.5 million larger facility have been approved.

References

1. Shipley, K. L., "Spectrographic Analysis of Plasmajets. Progress Report II," SC-4776(RR)

2. Brooks, W. B. and Reis, G. E., "A Method For Obtaining Radial Distributions From Optical Measurements on Cylindrical Plasmas," SC-4938(RR)

3. Russo, A. J., "Interaction of Plane Electromagnetic Waves With a Fully Ionized Plasma," SCTM-64-64

5. Rocket Experience

The Aero and Thermodynamics Department has participated in rocket programs since early 1957. Solid propellant motors have been used in the single, two stage and three stage systems. Approximately 714 rocket-boosted vehicles (a total of 1349 motors) have been launched to date. The systems used include Deacon-Arrow, Nike-Cajun, Nike-Apache, Nike-Nike, Nike-Tomahawk, Doorknob, Honest John-Nike, XM33/2XM19 and XM33/2XM19-TE442. Sandia is currently involved in developing a 12-inch motor that can be used as a single stage to carry a 200 pound payload to over 600,000 feet. The purpose of these rocket programs has been for scientific measurements in the upper atmosphere, diagnostic measurements, nuclear warhead testing and parachute research and development.

The Strypi rocket system was developed on a crash basis (2 months) during Operation Dominic to carry a nuclear warhead to 492,000 feet msl for detonation. This single-stage system, consisting of an XM-33 sustainer rocket with two XM-19 boosters, can propel a 1240-pound payload up to approximately 674,000 feet msl. The system was used successfully in the Checkmate event and subsequently 5 out of 5 times

Sandia Corporation has the field experience in the use of rockets for R&D aerodynamic heating studies, parachute development and instrumentation tests.

References

1. "Sandia Research Rocket Programs (U)," SC-4939(RR), November 1963, CFRD

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2. Barton, W. R., "Aero Ballistic Development of the Strypi Rocket Vehicle for Operation Dominic," SC-4754(RR)

6. Parachute and Recovery Systems

It may be necessary to recover an R/V after re-entry to examine the ablative shield or recover an instrument package. Sandia has had extensive experience in parachute recovery systems since 1952. A fully-equipped parachute laboratory is used for parachute R and D. Parachute systems have been developed for bombs, test vehicles and rocket payloads.

During Operation Hardtack, where the Doorknob rocket was used, approximately 12 payload recoveries were made. In the Dominic series, with the Nike-Apache system, 13 payload recoveries were completed. Currently a recovery system is being developed to be used on the Nike-Tomahawk systems and six recoveries have been made to date. Flotation bags, dye markers and beacons are used as part of the recovery system.

Parachute research has cumulated in the successful deployment of a 20 ft. diameter ribbon parachute at test conditions of Mach 2 at 13,000 ft. altitude. This represents a unit loading on the parachute of 4000 lbs/ft^2.

References

1. Pepper, W. B., "Test Results Relevant to the Selection of the 12.5-Foot Diameter Ribbon Parachute for the TX-57 (U)," SC-DR-64-18

2. Johnson, D. W., "Design and Evaluation of the 76-Foot Diameter Ribbon Parachute for the TX-53 Laydown Application," SCTM-90-61(71)

7. Baro-Fuzing Probe for Hypersonic Speeds

A study to establish feasibility of a barometric fuzing system for advanced R/V's was initiated in 1964. Various aerodynamic and thermodynamic parameters, necessary to the development of a suitable probe, have been defined for vehicle ballistic parameters from 600 to 3500 psf. Experimental testing of the system is ideally suited to the high speed sled. Therefore, an extension of sled capability to Mach 6 to 8 is underway. A series of six to twelve sled tests for probe development will be conducted during calendar 1965.

Three techniques for providing the necessary probe thermal protection are under consideration by a materials contractor (Battelle Memorial Institute). Included are a) high melting point materials

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such as TaC and HfC (7000°F); b) tungsten matrix materials impregnated with metals such as copper, silver or zinc; c) tungsten impregnated with a metal-hydride combination. Models will be tested in the Sandia Plasma Jet in order to establish the relative merit of each system. Successful development of a barometric fuzing system would remove the limitations currently placed on R/V systems by inertial fuzing techniques.

References

1. Vaughn, H. R., Barton, W. R., and Bennett, M. D., "Theoretical and Wind-Tunnel Calibration of Two Sandia Corporation Stubby Probes for Barometric Fuzing," SC-4304(TR), May 1959

2. Bennett, M. D., "Characteristics of Three Sandia Pressure Probes at Supersonic Speeds," Confidential, SC-4545(RR), February 1961

3. Ducoffe, A. L. and White, F. M., Jr., "An Analytical and Experimental Investigation of Steady and Unsteady Flow in Tubing, With Special Application to Simulated Missile Pressure-Sensing Systems," Sandia Corporation, SC-4544(RR), May 1961

4. Touryan, K. J., "Static Pressures on Cone-Cylinders in Slip to Transition Flows," SC-RR-64-1689, January 1965

5. Rigali, D. J., Budge, T. A. and Clark, G. E., "A Parametric Study of Re-Entry Vehicles," Sandia Corporation Research Report (to be published)

8. R/V Stability, Pressure, Heating Studies

Aero-thermo work related to R/V design has been done in support of project groups since the initial effort on OAK and Winchester. In general, the studies include determination of pressure distribution, aerodynamic force and moment coefficients, trajectory computation, determination of aerodynamic heating rates, dispersion calculations, and base pressure studies.

References

1. SC 4396(WD) and SC 4398(WD), OAK and Winchesters Systems

2. RS 8155/64, "Report of the Integrated Warhead Working Group"

3. SCTM 287-59(51), "Feasibility Report on a Re-Entry Data Playback Capsule"

4. SC-4397(WD), "Preliminary Analysis for a Proposed Class C ICBM Re-Entry Vehicle"

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5. Foster, A. D., "A Compilation of Longitudinal Aerodynamic Characteristics Including Pressure Information for Sharp and Blunt Nose Cones Having Flat and Modified Bases," SC-R-64-1311 and SC-R-64-1312

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C. Personnel

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Personnel in the Aero and Thermodynamics Department (9320) consist of 4 Ph.D (Aerodynamics, Thermodynamics, Plasma Physics), 26 M.S. (Aerodynamics, Physics), 12 B. S. (Aerodynamics), 8 M.S. (Mechanical and Electrical) and 18 technical assistants and support personnel.

D. Aero and Thermodynamics Test Facilities

Wind tunnel facilities at Sandia Corporation include the 12-inch Trisonic tunnel and the 18-inch Hypersonic tunnel. Force, dynamic stability, and pressure distribution tests can be performed at Mach numbers from 0.7 to 3.0 in the Trisonic tunnel. Force, dynamic stability, and heat transfer tests at Mach numbers of 5, 7, and 11 can be conducted in the hot (air temperatures up to 2500°F) Hypersonic tunnel. These facilities are described in SC-4937(M).

External facilities under contract to Sandia include Cornell Aeronautical Laboratory, Ling-Temco-Vought, Inc., and Fluidyne Engineering Corporation. At Cornell Aeronautical Laboratory, the following facilities are available:

a. The 8-foot Transonic tunnel for force, pressure, and dynamic stability tests at Mach numbers from 0.5 to 1.3.

b. The 48-inch and 96-inch Hypersonic Shock tunnels for force, pressure and heat transfer tests at Mach numbers from 4 to 30.

c. The Wave Superheater Hypersonic tunnel for heat transfer, ablation, and dynamic stability tests at Mach numbers from 3 to 12.

At Ling-Temco-Vought, Sandia uses the 4-foot High Speed Wind tunnel for force, pressure and dynamic stability tests at Mach numbers from 1.6 to 5.0 and the 13-inch Hypervelocity Wind tunnel for force and dynamic stability tests at Mach numbers from 14 to 21. The 20-inch Hypersonic tunnel of Fluidyne Engineering Corporation can be used for dynamic stability tests of an ablating model at Mach numbers of 11 and 14.

In addition, a 27-foot diameter high altitude chamber (which can be evacuated to 80μ Hg absolute pressure which simulates 230,000 feet density altitude) is available for environmental tests at Sandia. This chamber is equipped with a spin table for rotating components up to 600 rpm.

Sandia has available a complete environmental capability including a large centrifuge for sustained g loading, temperature and humidity equipment; a complete shock and vibration facility, and a ten megawatt radiant heat facility with programmable heat input for full-scale testing. In FY66, a five megawatt arc-powered plasma tunnel will be available which was designed for re-entry test simulation. This tunnel will be capable of a maximum enthalpy of 15,000 Btu/lb

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at heating rates ($\dot{q}R$) up to 200 Btu/ft^3/2-sec with gas flow rates and composition simulating atmospheric conditions.

The facilities at the Tonopah Test Range which presently include radars (C & S band), tracking and documentary cameras, telemetry (FM-FM) receiving stations, launchers for firing of rocket vehicles, and various other support equipment, provide the necessary facilities for conducting the following types of field tests:

a. Rocket-boosted vehicles to obtain hypersonic Mach numbers to study baro fuzing, aerodynamic heating, and R/V stability at high Reynolds numbers.

b. Develop parachute recovery systems using rocket-boosted vehicles.

c. Decoy deployment and penetration studies.

d. Control system studies for maneuverable R/V's.

E. Applicable Contracting

Outside contracting has included both theoretical and experimental studies in the areas of wind tunnel force and stability testing, pressure studies for use in barometric fuzing, and shock-on-shock interaction studies. As an example, comprehensive wind tunnel tests were conducted for the RFD-2 and Halberd vehicles using the facilities of Ling-Temco-Vought, Cornell Aeronautical Laboratory and Fluidyne. Pressure studies are currently contracted at Oklahoma State University and Space General Corporation while shock-on-shock phenomena have been investigated by Lockheed Missiles and Space Company, Convair, Cornell Aeronautical Lab and the AFWL Shock Tube Facility.

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