Sensor and Simulation Notes

Note 278

17 Arpil 1980

In-Flight Missile Electromagnetic Coupling Tests-- Preliminary Considerations

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Abstract

EM coupling to an inflight missile is a topic of interest to EMP survivability efforts. A particular issue is the possibility of actually doing EM tests while a missile is in flight. This report briefly considers such tests. The rationale for such tests is considered, as are types of inflight tests. Various background information is also included.

electromagnetic fields, inflight missiles, Minuteman, ground based, electromagnetic pulse simulators, coupling

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

SSN 278

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
IN-FLIGHT MISSILE ELECTROMAGNETIC COUPLING TESTS--PRELIMINARY CONSIDERATIONS

5. TYPE OF REPORT & PERIOD COVERED
Technical Note

6. PERFORMING ORG. REPORT NUMBER
DC-TN-1505-3 (FINAL)

7. AUTHOR(s)
Daniel F. Higgins, William A. Radasky
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Santa Barbara, California 93105

8. CONTRACT OR GRANT NUMBER(s)
F29601-79-C-0036

9. PERFORMING ORGANIZATION NAME AND ADDRESS
The Dikewood Corporation
1613 University Boulevard, N.E.
Albuquerque, New Mexico 87102

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Air Force Weapons Laboratory (NTYET)
Air Force Systems Command
Kirtland AFB, New Mexico 87117

12. REPORT DATE
April 17, 1980

13. NUMBER OF PAGES
37

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
This work was completed by JAYCOR under Subcontract No. DC-SC-79-01 for The Dikewood Corporation (JAYCOR Report No. 200-80-218-2148).
This research was supported by the Defense Nuclear Agency under Subtask 637PAXYX957, MX Missile In-Flight Test, Work Unit 20.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
EMP, MX Missile, EM Shielding, In-Flight Coupling

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

CONTENTS

I. INTRODUCTION

The coupling of electromagnetic pulse fields generated by a nuclear burst to an in-flight missile was first considered in the early sixties as part of the EMP hardening of the Minuteman missile system. Interest has recently been renewed as a result of the MX missile program.

Numerous in-flight coupling calculations have thus been carried out over the past 15 years, and various experimental coupling studies have been performed using missile hardware and ground-based EMP simulators. However, no EM coupling tests have been done on a missile while it was actually flying.

A basic reason for considering in-flight tests is that the fundamental electromagnetic configuration of an in-flight missile is different than that of the same missile sitting on the ground. The most dramatic difference is the existence of a long, conducting rocket exhaust plume when the missile is in-flight. This plume can greatly affect the electrical length of the missile and will enhance the low frequency coupling. Besides the plume, there may also be electromagnetic differences due to the motion of the missile. These might include shock wave ionization of the ambient air and shielding degradation due to missile vibration. Estimates of how much such phenomena affect electromagnetic coupling have been made theoretically and a few tests have been performed examining a few of the phenomena separately, but experimental verification of the overall response is presently lacking.

The purpose of this report is thus to present the results of a brief, preliminary investigation of possible in-flight electromagnetic coupling tests. Various rationales for such tests will be discussed first. This is followed by a categorization of possible tests, both in terms of flight vehicles and source/ sensor location. This is followed by a summary of background information collected under this effort and technical discussions of experimental options. As this effort involved a survey of existing technology in the plume phenomenology and missile testing areas, a bibliography is given in Section VI to indicate the sources employed here.

II. POSSIBLE RATIONALES FOR AN IN-FLIGHT EM TEST

1. PLUME RELATED RATIONALE

As mentioned previously, the existence of a long rocket exhause plume, made up of hot, conducting gases, can, at least theoretically, greatly affect the basic electromagnetic configuration of an in-flight missile. In particular, external EM coupling to the missile may be severely modified by the plume (although the effect of a plume on missile survivability depends upon specific design details, such as the amount of EM shielding).

Various plume parameters have been identified as being potentially important to EM coupling. These include: 1) plume length and cross-section; 2) electron density; 3) effective conductivity (impedance); and 4) connectivity between the plume and conductors on the missile. A number of theoretical studies have been carried out to investigate the relative importance of such parameters, but experimental data for confirming various plume models is practically nonexistent.

One reason for an in-flight missile test is thus to try to directly measure the actual plume parameters of interest. A direct measurement of parame-eters such as the electron density at a number of locations within the plume would be very difficult experimentally, however. (Measuring the overall effect of the plume would be easier). One also has the question of why an in-flight missile test is required to investigate plume parameters.

With regards to this last question, it has been suggested that static rocket tests might be a much better way to study plume parameters. Obviously, many experimental problems would be alleviated if the test object were not moving through the air with supersonic velocity. However, various theoretical plume models indicate that the basic plume behavior is a strong function of missile velocity. For example, turbulent mixing at the boundary between the moving plume and the surrounding air is thought to be a prime factor in determining plume electron density. Also, plume lengths are apparently quite long at higher altitudes and pressure chambers large enough for investigating such effects are not available. It thus appears that static plume tests cannot provide valid measurements of plume parameters for a rapidly moving, high-altitude missile.

Because plume parameters are difficult to directly measure on an in-flight missile, one can consider measuring the "effects" of such parameters rather than the actual parameters. In this case, one might measure the resulting current along one part of the missile as a result of some electromagnetic excitation. The response as a function of frequency would depend upon such plume parameters as conductivity, plume length, and plume connection to the rocket nozzle.

Such plume effects tests would be relatively easy to perform on an in-flight missile (compared to direct plume parameter measurements), and the results could be used to check the predictions of existing plume/EM coupling models. Such tests would thus primarily serve as analysis verification experments.

It should be noted that analysis verification tests have certain limitations. For example, if experimental results do not agree with theoretical predictions, it may be very difficult to determine the actual effects of interest. Differences might be due to either plume length, conductivity, or connectivity and effects measurements may be incapable of distinguishing which phenomena caused a given response. Similarly, a theorectical model may be incorrect and still give answers close to those measured under some circumstances. The results of analysis verification tests must thus be carefully interpreted, and such tests must often be iterated along with theoretical model development until results agree.

2. EM SHIELDING RATIONALE

Any missile designed to survive nuclear electromagnetic effects will have a variety of hardening features. A key hardening feature expected in most cases is an electromagnetic shield surrounding all sensitive electronic hardware. No electromagnetic shield is perfect, however, but various apertures, cracks, and imperfectly sealed joints are usually the dominant source of leaks in shielding systems.

It is known that shielding effectiveness can degrade as a result of bending and vibration. Ground based shielding effectiveness tests can examine such degradation to some degree, but such ground tests cannot duplicate all of the mechanical stresses that might be applied to an in-flight missile. One thus reaches the conclusion that an inflight test might be needed to evaluate the performance of EM shielding on an actual missile.

3. OTHER RATIONALES

Other related reasons might be given for an inflight missile test. For example, the goal might be to acquire data for use in guiding ground-level EMP tests. (A plume effects tests might be used to help design a plume simulator for a ground-based EMP test in the ARES simulator.) On the other hand, the goal might be system-specific, such as validation of specific hardness features (e.g., shielding) of an inflight MX missile.

III. TYPES OF IN-FLIGHT TESTS

1. SOURCE/SENSOR LOCATIONS

One method of characterizing various types of in-flight electromagnetic tests is in terms of the locations of the EM source and the EM sensors. Both the source and any sensors can be located either on the missile or on the ground with the resulting matrix of experiment concepts shown in Table 1. Each of these concepts will be briefly discussed.

A. Source on Ground/Sensors on Ground

The idea of having both the EM source and the sensors on the ground greatly simplifies experimental problems because no additional equipment need be installed on the missile. This concept, however, is basically just one of making radar cross-section measurements of an in-flight missile. A great deal of such data already exists (see Section IV and Appendix A.) There is thus already some information on the effective electrical length of plumes at radar frequencies, and more will be generated during future flight tests.

A major problem with such techniques, however, is that little, if any, missile coupling information is obtained. The plume itself tends to dominate the radar cross-section. Plume connection and missile response is thus not directly measurable. Some additional study of existing data might be useful, but further work on this concept would probably be of only limited value.

B. Source on Missile/Sensors on Ground

Another means of investigating the electromagnetic features of an in-flight missile is to install a source on the missile, for example, exciting currents on conducting surfaces and measuring the resulting radiated fields at various locations on the gorund. This source-on-missile with measurements-on-ground experiment can be compared to the threat condition of an incident EMP inducing missile currents and voltages by the use of reciprocity concepts. One could use pulse techniques, but a stepped CW source would probably give better sensitivity. Existing narrow-band ground antennas might then be used to monitor various frequency regions.

This source-on-missile, receiver-on-ground approach has several conceptual advantages. First of all, the need for sensitive missile instrumentation and telemetry links is eliminated. Secondly, one may be able to use existing large

TABLE 1. EXPERIMENT CONCEPTS

SENSOR LOCATION / SOURCE LOCATION	MISSILE	GROU
MISSILE	EXCITE CURRENTS ON THE MISSILE MEASURE RESPONSES ON THE MISSILE USE TELEMETRY OR RECOVERABLE DATA PACKAGE	EXCITE CURR MISSILE MEASURE "AN ON THE GR
GROUND	RADAR EXCITATION MEASURE RESPONSES ON THE MISSILE USE TELEMETRY OR RECOVERABLE DATA PACKAGE	RADAR CROSS MEASUREME

ground antennas for measuring the radiated signal. The approach also has several disadvantages, however. These include the problems of how to drive a large enough current on the missile for the radiated signal to be measured on the ground, and how to interpret these measured signals in a manner that tells us something about the EM features of the in-flight missile.

Consider first the second problem of how to interpret measured ground data. The radiated signal will depend not only on the missile details, but also on the rocket exhaust plume. The conductivity profiles of such plumes are not well established, although several calculational plume models have been considered over the past few years. Deducing plume electrical parameters solely from ground measured data is expected to be very difficult, if not impossible (e.g., different combinations of plume parameters may result in almost identical radiated waveforms). It would thus appear that the best one might do is to compare the measured data with that predicted, using various plume models. If the results agree with predictions, one has more confidence in the models, but there is no guarantee that the assumed plume parameters are the actual ones. (In other words, the measured output of this experiment may not be very sensitive to plume details.)

Another potential problem is the source level needed for measurable signals. Crude estimates of required signal levels can be obtained by modeling the missile and plume as a simple center-fed dipole antenna. An expression for the radiated power, P_r, far from an electrically short dipole antenna is

$$P_r = \frac{\eta k^2 I_o^2 h^2 \sin^2\Theta}{32\pi^2 r^2} \quad \frac{\text{watts}}{\text{m}^2}$$

where $\eta = \sqrt{\mu/\varepsilon} \simeq 120\pi$ ohms

$k = \omega/c$ = wave number

h = total dipole length

I_o = peak current on dipole

r = distance to observer

Θ = polar angle with respect to the dipole axis

and it is assumed that $kh << 1$.

Note that the angular dependence of the radiated power (the $\sin^2\Theta$ term) indicates that we need to know the angle between the missile axis and the ground antenna fairly accurately. Also, the peak current, I_0, will depend upon plume conductivity while the antenna length, h, is a function of plume length.

As an example, let $I_0 = 1$ amp, $kh = 0.1$, and $r = 20$ km. For $\Theta = 90^0$, the radiated power is calculated to be 3×10^{-11} watts/m^2. This corresponds to a radiated electric field of only about 10^{-4} v/m, using

$$P_r \approx \frac{E^2}{\eta}$$

One would thus need a current of 10^4 amps to get an incident field on the ground of 1 v/m.

The situation is slightly better at higher frequencies. For a half-wave dipole, where $\lambda = h/2$ (h being the total dipole length), the radiated power is

$$P_r = \frac{15 I_o^2}{\pi r^2} \left\{ \frac{\cos[(\frac{\pi}{2})\cos\Theta]}{\sin\Theta} \right\}^2 \quad \frac{\text{watts}}{\text{m}^2}$$

For $r = 20$ km, $I_o = 1$ amp, and $\Theta = 90^0$, one gets $P_r \approx 1.2 \times 10^{-8}$ watts/m^2. This corresponds to a field of 2.1×10^{-3} v/m for each amp of current on the dipole.

In either of the above cases, power levels at the ground are quite small unless very large currents are induced on the in-flight missile.

It should be noted that there may be a number of problems involved in trying to drive large skin currents on an in-flight missile. First of all, there are practical safety and EMI considerations that depend upon the specific missile being used for any test. More general considerations, however, include the problem of how to excite skin currents without degrading missile flight performance.

From an electromagnetic point-of-view, the most desirable way to drive the missile would be to create a gap in its conducting surface and attach a voltage source across the gap (see Figure 1A). This involves a basic change in missile design, however, since no conductors can traverse the gap. In general, then, this approach is not feasible since it would require a complete

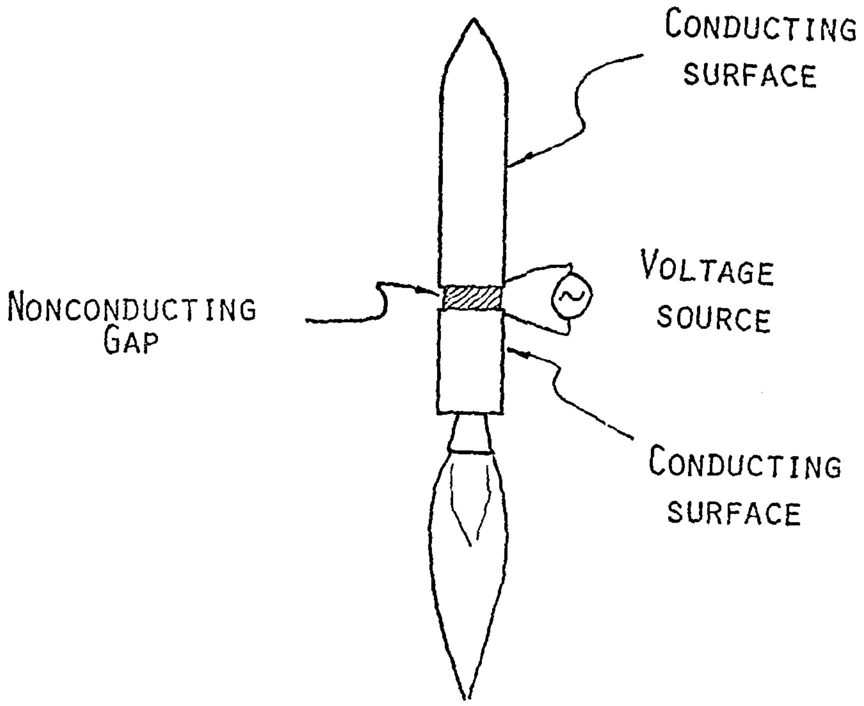

Figure 1A. Voltage Gap Drive

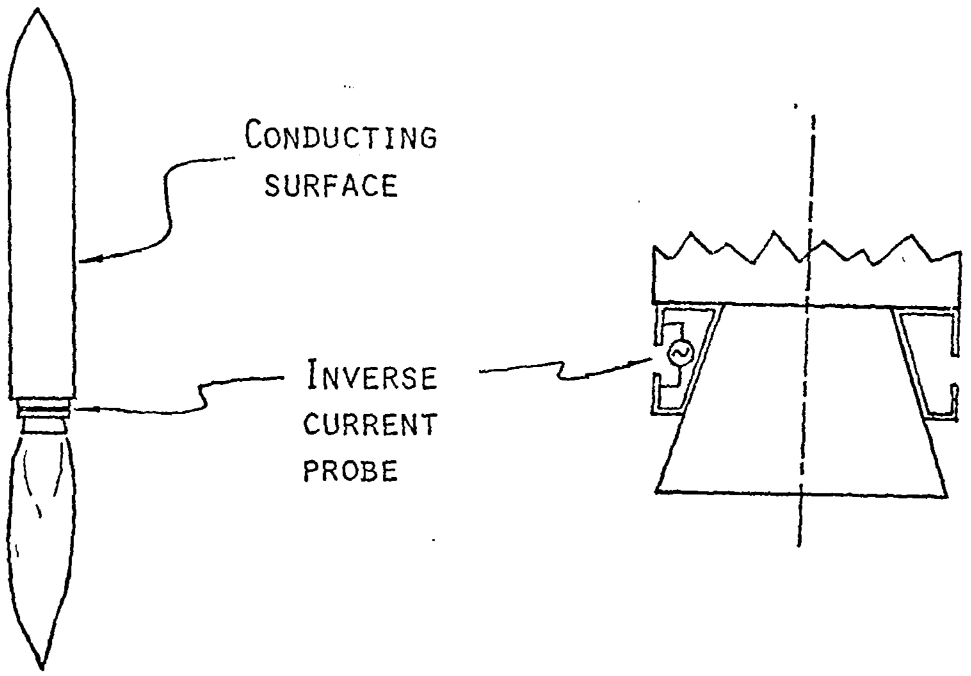

Figure 1B. Inverse current probe drive

change in the missile design (i.e., missile electronics on each side of the gap would be required to operate without a conducting link). It could probably only be carried out with a missile specifically designed for such a test.

Another concept, which would have less impact on missile design and operation, is to drive skin currents with an inverse current probe. This idea is illustrated in Figure 1B, where the inverse current probe is placed near the base of the missile (surrounding the nozzle) and recessed to minimize aerodynamic interference. With this drive, a voltage is impressed across the gap of the annular probe, and missile conductors run through the center aperture. Similar probes have been designed, built, and used for measuring the EMP response of missiles in simulators.

The problem with using such a current probe in an inverse fashion is that it is a very inefficient coupler. Any voltage source connected across the gap will have to supply very large currents (because the interior conductors tend to short out the gap). The ultimate result of this drive inefficiency is that large power sources will be required to excite large missile currents. The problem can be alleviated somewhat, of course, by specially designed couplers, but details still need to be resolved.

C. Source on Ground/Sensors on Missile

This approach is the inverse of the one just discussed. It has the conceptual advantage that it resembles the high-altitude EMP excitation where the EM driver is created far from the missile. One also does not have the need to carry a large power source on the missile, while large ground-based transmitters are certainly feasible as are existing radar antennas.

In this case, the missile and its plume become the receiving antenna. Sensitive receiving equipment must thus be installed on the missile and measured responses must either be recorded (and recovered) or sent back to ground via telemetry. As in the previous case, missile location and orientation with respect to the ground-based source must be accurately known in order to interpret results. Atmospheric attenuations or dispersion (e.g., by the ionosphere for high-altitude missiles) may also cause data interpretation problems.

D. Source on Missile/Sensors on Missile

In this configuration, both the EM source and the response sensors are mounted on the in-flight missile. One thus has the previously discussed problem of driving large currents on the missile, but the need for very large currents is now lessened as response measurements can be made quite near the source. Problems of knowing the missile orientation and location are thus eliminated, but the amount of on-board instrumentation is larger than for the other experimental options.

Measurements to be made for this test configuration are also different than previously discussed. For other source/sensor locations, one measures such parameters as the radar cross-section and the radiated or received power. In this case, one can measure the current or charge distribution resulting from a given excitation point, or one could measure the resulting current for a given voltage driver. (This last configuration could give a direct measurement of plume impedance that might be used to guide ground-based EMP tests.) One could also place sensors both inside and outside any EM shields on the missile to get some indication of in-flight shielding effectiveness. Note that one could conceptually make all these same measurements with the source on the ground, but signal levels on the missile would probably be quite small and difficult to accurately measure (especially for measurements inside shields).

2. TYPES OF FLIGHT VEHICLES

Another means of characterizing in-flight EM experiments is in terms of the type of flight vehicle to be used. For example, one might consider a relatively simple add-on to existing research flight tests. Examples might include the Scout missile which is periodically launched by NASA for research purposes or DNA missile launches used primarily for studying upper atmospheric air chemistry.

More complex experiments could be carried out with a missile especially purchased for and fully dedicated to an in-flight electromagnetic coupling test. The problem, of course, is that such a fully dedicated missile test would be fairly expensive, even if a readily available sounding rocket and telemetry package were used. (Rocket and telemetry costs alone would probably be in the $200-$300K range).

Finally, one could consider making measurements during operational flight development tests of a military missile of interest, such as the MX. Such tests would be of great potential interest, since they might provide information directly applicable to the EM survivability of a military system; however, the amount of instrumentation that might be added to such an operational missile test may be quite limited due to its impact on missile performance.

IV. BACKGROUND INFORMATION

1. PERSONS CONTACTED

A number of persons at various agencies were contacted in the attempt to collect information on plume phenomenology, on missile availability for add-on experiments, and on the general problems of in-flight experimentation. A partial list of contact is shown in Table 2.

2. PREVIOUS STUDIES OF INTEREST

As mentioned previously, radar cross-sections of missiles and their associated plumes have been measured in the past for a number of in-flight missiles. SRI International has been involved in such radar cross-section measurements since 1959. Appendix A contains a brief description of SRI's experience over the years and a list of associated references. A future effort might examine the details of this past work to see if it might be useful for helping to understand plume effects on EMP coupling.

3. ON-GOING WORK

Although no directly applicable on-going missile EM coupling experimental studies were discovered, it was determined that plume effects in general are of great interest to numerous other government agencies and organizations. In particular, a Joint Army-Navy-NASA-Air Force (JANNAF) Exhaust Plume Technology Subcommittee exists for coordinating research on various aspects of plume effects. An annual report which describes this committee and its work is attached in Appendix B.

As indicated in Appendix B, plume studies are going on in a variety of places. Personnel at the Jet Propulsion Laboratories were quite helpful in describing various efforts. Their research is primarily involved with plume contamination effects, and they have several space shuttle experiments planned to study such phenomena.

TABLE 2. IN-FLIGHT MISSILE COUPLING EXPERIMENT CONTACTS (JULY - DECEMBER

Place	Name	Phone
AEDC	Herman Scott	(615) 455-2611 x 7834
AFGL	McIntyre	(617) 861-3637
Aeronautical Research Associates of Princeton	H.S. Pergament	--
China Lake	Andy Victor	(714) 939-3134
Edwards (RPL)	Al Kawasaki	--
Edwards (RPL)	Dan Stuart	(805) 277-5623
Edwards (RPL)	David Mann	(805) 277-5240
Johns Hopkins Univ. (Applied Physics Lab)	Ted Gilleland	--
JPL	Frank Bouquet	(213) 354-4321 x 4031
JPL	Carl Maag	(213) 354-4321 x 6453
JPL	Lou Molanary	(213) 354-4321 x 4515

TABLE 2. (CONCLUDED)

Place	Name	Phone
NASA/Marshall	Terry Greenwood	--
SAMSO/LA	Major Sumondi	(213) 643-0093
White Sands	John Morgan	(505) 678-3348
White Sands	Maj. Jim Parks	(505) 678-1251
White Sands	Bill Hansen	(505) 678-1245
White Sands	Frank McKenna	(505) 678-1156

V. RECOMMENDATIONS AND CONCLUSIONS

After considering the various options, it appears that an in-flight missile EM coupling experiment with both the source and the sensors on the missile would be the most desirable of the tests considered. This type of experiment has the advantage that several objectives can be simultaneously pursued. For example, one can measure plume impedance, external current/ charge distributions, and shielding effectiveness, in addition to checking various coupling models.

Such tests would probably be most meaningful if they could be done as part of the MX missile flight program. In order to gain experience, however, it is recommended that any in-flight tests first be attempted as add-on experiments to research rocket launches where the impact of added instrumentation is not great. Once experimental experience is gained, tests on operational missiles can be designed with higher confidence that missile operation will not be greatly perturbed.

Note that in-flight test data would be useful and interesting, but obtaining such data is expected to be neither easy nor inexpensive. The need for such tests must therefore be carefully evaluated and compared to other research programs of interest since both time and money are always limited.

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JANNAF plume program, October 1979.

Technical discussions with Capt. McKechney of DNA regarding the DNA missile flight test program, 24 October 1979.

APPENDIX A

SRI RADAR CROSS-SECTION MEASUREMENTS

(THIS INFORMATION WAS PROVIDED BY SRI INTERNATIONAL
PER LETTER DATED 18 JULY 1979)

II EXPERIENCE AND BACKGROUND

In 1959 SRI designed and conducted an experimental program to measure the radar cross sections of missiles and their associated plumes as a function of frequency and aspect angle.[2-19] These early measurements on the Eastern Test Range were extremely successful in identifying frequency and aspect-angle sensitivity of missile plumes. In several ways the technical problems were more complex than those envisioned for the experiments now being planned by the Air Force. For example, the previous measurement program took place at the Eastern Test Range (ETR) so that all the missile trajectories were directed over water immediately after liftoff. In order to obtain a wide range of viewing aspect angles and at the same time full coverage of the altitude range of interest (sea level to 600 kft), SRI fully instrumented and operated a ship with multifrequency radar equipment. A wide variety of missiles were observed--everything from the solid-fueled Polaris and Minutemen to the liquid-fueled Titans and Atlases--so that from one launch to the next, one had to contend with greatly different flight parameters and trajectories. This required careful experimental planning in order to maximize the information obtained on each launch. The frequencies used in those tests were lower (10 to 370 MHz) than the frequencies specified for the presently planned experiment (1 to 10 GHz). The calibration of radars at the lower frequencies--especially 10 to 50 MHz--is difficult. Antenna patterns cannot be measured on antenna calibration ranges but mustinsteadbe "flown" by aircraft towing radio beacons. Sphere-drop calibration tests that are quite routine in the

GHz range are difficult in the MHz range due to the much larger spheres needed in the latter case. Additional complexities resulted from the variation of the plume radar cross section at high altitudes (over 300 kft) as a function of the time of day and the state of the ionosphere. These difficulties were successfully overcome by the suitable design of the experimental program.

In 1964-65 SRI designed what was known as the ETR Missile Phenomenology Program,[23-25] and aided DARPA (formerly ARPA) in its coordination, and collated the data from the experiment. The objectives of the program were to test the validity of several different electrical and scattering models of missile plumes and to provide information for the design of operational military systems. The ETR program involved simultaneous measurements of missiles and their plumes by a number of different contractors and government agencies. The equipment included both pulse and CW at a variety of frequencies (10 to 64 MHz). The measurements were made using both monostatic (transmitter and receiver collocated) and bistatic (transmitter and receiver separated) geometries from a number of different sites. The objectives of the program were successfully accomplished.

Plasma diagnostic techniques have been used at SRI for over 15 years. Radar-beam electron density measurements in rocket exhaust gases were developed for the Air Force Western Development Division. Measurements have been made in rocket exhausts for the Polaris, Atlas, and Minuteman missiles.

Since 1965 SRI, under Project RONDO, has designed and directed several experiments related to testing the validity of models of radar scattering from reentry wakes.[28] Although differences exist between radar scattering from missile plumes and reentry wakes, the theory of scattering from a turbulent plasma is applicable to both.

As part of the RONDO program SRI has been actively engaged in laboratory studies of electromagnetic scattering from turbulent jets. This work has been largely successful in the development of a model and computer codes for calculating the scatter from turbulent plasmas.[29-32] The laboratory-developed scattering model has been applied with considerable success to reentry-wake scattering.

The RONDO program involved the measurement of reentry wakes using a polystatic geometry (two receiving sites each widely separated from the transmitter) at 1.3 and 5.1 GHz. The equipment was specified by SRI and a test plan was written that was followed by field-site personnel under the employ of another contractor. All of the digital data tapes recorded in the field were reduced and analyzed by SRI personnel in Menlo Park, California. The entire RONDO program was under the scientific direction of SRI.

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APPENDIX B

JANNAF EXHAUST PLUME TECHNOLOGY SUBCOMMITTEE
ANNUAL REPORT - SEPTEMBER 1979

JANNAF EXHAUST PLUME TECHNOLOGY SUBCOMMITTEE
ANNUAL REPORT - SEPTEMBER 1979

I. SCOPE

The technical areas of concern to this subcommittee involve phenomena associated with the exhausts from rocket and ramjet missile and space propulsion systems and gun systems. These phenomena can be divided into three technical areas; plume flow fields, plume radiation, and a broad area incorporating other plume effects.

The plume flow field area encompasses the physical phenomenology required to describe the thermodynamic, gas dynamic, chemical and physical state of the plume.

Plume radiation addresses the physical processes associated with the emission, scattering, absorption and reflectance of electromagnetic radiation from exhaust plumes covering the spectrum from the ultraviolet and visible through the infrared and microwave regions.

Plume effects include the interaction of plumes with external structures which lead to the imposition of thermal, chemical and mechanical stresses, and the electromagnetic interference effects which degrade guidance and sensor systems.

II. GENERAL TECHNICAL OBJECTIVES

A. Identify and actively pursue cooperative plume technology programs which provide a cost effective technology base and avoid duplication of effort.

B. Identify ad hoc panels in specialized technical areas and sponsor workshops to promote the exchange of technical information for the purpose of solving plume problems.

C. Standardize, update and maintain computer programs for common use by government and industry in order to describe plumes amd their interaction effects in a cost effective manner.

D. Define nomenclature, definitions, measurement techniques and analytical methods in order to promote the adoption of standard practices.

E. Promote technical information exchange through meetings, program plans and reviews, and special publications.

F. Disseminate information to the user community by means of plume handbooks, workshops and technical meetings.

III. ORGANIZATION

The organizational structure of the Subcommittee consists of the Technical Steering Group (TSG) and Ad Hoc Technical Panels. These Ad Hoc Panels are called into existance by the TSG to deal with particular problems or situations. They are disbanded when the problem no longer exists. Within this philosophy a one-day workshop may be viewed as a Panel. At the present time two Panels have been formalized for extended existance by the TSG; these are the Visual Signature Panel and the Tactical Missile IR/UV Signature Panel. The organizational structure is shown in the attached organizational chart.

The names and affiliations of members of the TSG and the panel chairmen are listed below. A list of the members and information exchange participants is attached to this report.

A. Technical Steering Group

Mr. A. C. Victor, NWC, China Lake, CA (Chairman FY 1979)
Dr. D. M. Mann, AFRPL, Edwards AFB, CA (Chairman FY 1980)
Mr. S. H. Breil, NWC, China Lake, CA
Mr. J. R. Fultz, AFAPL, Wright-Patterson AFB, OH
Dr. T. F. Greenwood, NASA/MSFC, AL
Dr. T. D. McCay, AFRPL, Edward AFB, CA
Mr. B. B. Roberts, NASA/JSC, Houston, TX
Dr. H. E. Scott, AEDC, Arnold AFS, TN
Dr. B. J. Walker, MICOM, Redstone Arsenal, AL

B. Panel Chairmen

Tactical Missile IR/UV Signature Panel, Dr. H. E. Scott, AEDC
Visual Signature Panel, Lt. E. G. Lund, AFRPL

IV. ACCOMPLISHMENTS

A. The TSG has defined a number of tasks for the purpose of achieving the general technical objectives of the Subcommittee. With the exception of administrative functions which can be performed by the members of the TSG, these tasks all fall into two domains. That is, they appear as part of the technical programs of individual agencies and/or agency organizations and also as part of the Subcommittee plan. Funding for the performance of these tasks is provided by the individual agencies which have interest in their accomplishment. The tasks were summarized in a paper at the 11th Plume Technology Meeting (8-10 May 1979) (See Attachment 1).

1. JANNAF Plume Technology Handbook, CPIA Publication 263

The purpose of this handbook is to document in a single source the basic principles and solution techniques required to solve plume effects problems. Solution techniques are divided into three categories of increasing complexity; hand calculations, desk calculation solutions and detailed SOTA computer programs. It is intended as an introduction for the novice, a reference source for the plume phenomenologist and a practical handbook to solve plume-related problems for the system user. This task is managed by the TSG. Management of individual chapters is assigned to the agency with the greatest interest in the particular technology area covered. Although most work on the handbook has been performed on contract, some is done in-house by government laboratories. During the past year work has continued on Chapter 3 (Rocket Exhaust Plume Radiation) and Chapter 5 (Base Heating and Base Flow).

2. Tri-Service Smoke Visibility Plan

The objective of this plan is to provide the framework leading to standardized smoke definition and measurement techniques. This is to be accomplished through coordination of existing service programs and tri-service support for new programs. The plan was prepared in response to the

Executive Committee's direction. The current version of the plan, incorporating some changes suggested by members of the Executive Committee, is attached to this report (Attachment 2). This task is to be managed by the Visual Signature Panel.

3. Tri-Service Tactical Missile IR/UV Signature Plan

The principle objective of this plan is to fulfill the common needs of the three services for plume IR and UV data and modeling capabilities. The basis for this plan was established during the TSG meeting in September 1977. Since then a major tri-service program has been assembled and coordinated. During this past year a draft of the plan was prepared (see Attachment 3). This task is managed by the Tactical Missile IR/UV Signature Panel.

B. Meetings and Workshops

1. JANNAF Plume Technology Meeting (frequency: 18 months)

The 11th JANNAF Plume Technology Meeting was held at Redstone Arsenal, Alabama during 8-10 May 1979. Over 100 people attended the meeting at which 37 papers were presented and two workshops were held.

2. Technical Review Workshops

The following two workshops were held in conjuction with the 11th JANNAF Plume Technology Meeting:

a.	Plume Radiation (50 attendees)	8 May 1979
b.	Plume Flow Fields (60 attendees)	9 May 1979

3. Task Review Workshops

Task reviews are held periodically to review the progress of tri-service sponsored contracts. At the present time these contracts involve two modeling efforts: (1) Standardized Plume Flow Field (SPF) Program and (2) Standardized Infrared Radiation Model (SIRRM) Program.

a. SPF Quarterly Reviews:

7 November 1978, Redstone Arsenal, AL
7 February 1979, AFRPL, Edwards, CA
7 May 1979, Redstone Arsenal, AL

b. SIRRM Review

25 January 1979, Photon Res., La Jolla, CA.

4. Technical Steering Group Meetings

The TSG met at Redstone Arsenal, AL on 10 May 1979, and at Cal Tech, Pasadena, CA on 24 August 1979. In addition a majority of the TSG attended the SPF Quarterly reviews and were able to conduct small amounts of business at these meetings.

5. Panel Meetings

Major planning meetings associated with the tasks of the Tactical Missile IR/UV Signature Panel were necessary:

a. 8-9 November 1979, Redstone Arsenal, AL

b. 11 May 1979, Redstone Arsenal, AL

In addition most members and participants of the Tactical Missile IR/UV Signature Panel participated in Flight Simulation Test Program at AEDC during the last two weeks of March 1979.

6. Signature Studies Specialist Session, (30) attendees was held on 8 March 1979 in Anaheim, CA as part of the 1979 JANNAF Propulsion Meeting.

C. Publications

1. Chemical Propulsion Information Agency, "JANNAF 11th Plume Technology Meeting-Unclassified Papers." CPIA Publication 306, 2 Volumes.

V. CURRENT TASK AREAS:

A. Standardized Plume Codes.

There are two basic areas of plume technology as shown in Figure 1 where it has become imperative to make model standarizations. These are (1) Plume Flow Field, (2) Plume Radiation. This has become necessary because of a wide proliferation of analytical models, many of which are not validated, poorly documented, or both. Since these two areas underlie all the plume technology programs, this is the highest priority current task. The goal of this standardization is to establish a standard set of codes to allow the predictions to start at the chamber of the rocket and utilize the JANNAF SPP, ODK, and/or TDK to predict the rocket nozzle properties. The Standardized Plume Flowfield (SPF) code is utilized to go from the nozzle exit plane to the end of the plume by calculating the flow field structure. Utilizing the flow field structure, the Standardized Plume Infrared Radiation (SIRRM) Code is utilized to predict source radiation from the plume as well as transmission through the atmosphere if plume/atmospheric correlation is important. For the case when correlation is not important, the transmission to the sensor is made by utilizing the standardized atmospheric attenuation codes developed by USAFGL (HI-TRAN, LOW-TRAN).

With the development of these two standardized codes it becomes possible to solve plume technology application problems utilizing a JANNAF accepted model in each of the technology areas. Hence, whether the technology application be plume signature, or plume interference, standardized prediction codes will be available to predict these effects.

The standardization of these two basic areas has begun and is described in what follows.

Standardized Plume Flow Field (SPF) Program

This program will describe the plume flow field from tactical and strategic missiles in flight at altitudes from sea level to 70 KM. It will cover the Mach number range from 0-10. It will focus on exhaust plumes which contain particles while also being able to handle purely gaseous plumes. It will contain various mixing models including eddy viscosity and turbulent kinetic energy. It will have non-equilibrium chemistry capabilities. It will consider axial and lateral pressure gradients. Non-optimum expansion and shock waves will be taken into account. The capability to add a base flow region will be included. Multiple nozzle and three-dimensional flow effects will not be considered. The code will be modular in form in order to facilitate future changes in technology. This program will be compatible with the JANNAF Improved Solid and Liquid Propellant Performance Program by utilizing their output directly as input to this program. Additionally, the output of SPF will be compatible with the input of the Standardized Infrared Radiation Model (SIRRM) Program. This program is being managed by MIRADCOM and developed by ARAP (Aeronautical Research Associates of Princeton).

This program will be applicable to all phases of the plume technology program since the flow field is an integral part of all applications.

This program is a three (3) year program which began in April 1978. During the first year the model was formulated. During the second year the model will be coded. During the following nine (9) months, the code will be validated against experimental data and demonstrated on each government participant's computer system. During the remaining three (3) months, the code will be extensively documented.

Standardized Infrared Radiation Model (SIRRM) Program

This model, and its standardized computer code, will be capable of predicting the infrared radiation of tactical and strategic missiles below 70 km altitude over the full spectral range from 1 to 25μm. Both liquid propulsion (gas only exhaust) and solid propulsion (gas/particle exhaust) system will be treated, and varying levels of approximations for treatment of the complex gas/particle radiative transfer processes will be included, commensurate with the level of engineering approximation required to solve a given problem. Variable viewing geometries and lines of sight will be included, as well as the capability to handle missile obscuration. In general, a band-model approach is used for gases in order to minimize computer run times while retaining adequate accuracies. A line by line spectral capability will be included in order to handle those diatomic gases not amenable to band-model solutions. The code will be modularly structured so that component parts can be easily maintained and upgraded as needed. In the case where plume/atmospheric correlation is important, the code will be capable of treating the coupled radiation transfer. It will be user-oriented with various options to allow for solutions ranging from quick and approximate to more detailed time-consuming and to accommodate both experienced (plume phenomenologist) and unexperienced (system designer or analyst) users. The code input will be compatible with the output from the Standardized Plume Flowfield (SPF) code, and its output will be compatible with the industry standard AF Geophysics Lab's Low-Tran/Hi-Tran Atmospheric Transmission codes.

This program which began in September 1978 will be a 30 month effort by Photon Research Inc. and Grumman. Technical proposal evaluations were conducted during June-July by a Tri-Service evaluation team. The program is being managed by the Air Force Rocket Propulsion Laboratory and is divided into two phases. During Phase I the contractor will formulate and demonstrate the overall methodology, with particular emphasis on the treatment of gas/particle radiative techniques. During Phase II the model will be coded, validated against experimental data, demonstrated on the various government participant's computer systems and documented. A techni workshop will be held near the completion of the effort to demonstrate the code's capabilities and to deliver copies to the user community.

B. Exhaust Plume Technology Handbooks:

This is an on-going task of this subcommittee and is being developed on a chapter by chapter basis proceeding from Plume Flow Fields to Experimental Measurements. The status of the handbook chapters is:

Chapter 1. Introduction, to be done
Chapter 2. Gas Dynamic Flow Models, May 1975
Chapter 3. Plume Radiation, in final review
Chapter 4. Plume-Electromagnetic Interactions, April 1977
Chapter 5. Base Flow, in progress
Chapter 6. Plume Impingement and Contamination, to be done
Chapter 7. Plume Measurement Techniques, to be done

The handbook is a loose leaf style publication which is a primary method of technology transfer to government-industry personnel who utilize this technology in their businesses. Typical applications include the effects of plume impingement on rocket launchers and spacecraft surface design of an IR sensor, etc. This is a problem solving handbook which contains three levels of complexity going from hand calculations to comple computer code solutions. This handbook is written to stand alone with a minimum of references being required for its use. Effort to be expended on the handbook during the next year will consist of the completion of the writing on Chapter 5 and the final review and publication on Chapter 3.

The completion of Chapter 3 has lagged the planned schedule. In order to comply with revisions requested by TSG reviewers, small contracts were awarded to Aerodyne Research, Inc. and REMTECH, Inc. in FY 1979. These contracts are scheduled to be completed in late September 1979.

The improved technology resulting from the two standardized plume codes (see Section V.A) will require that additions be made to Chapters 2 and 3 sometime after the beginning of FY 1981.

C. Tri-Service IR/UV, Tactical Missile Program Plan.

This jointly funded, Tri-Service program will continue through the next year. Periodic meetings will be held under the auspices of the Tactical Missile IR/UV Signature Panel and in conjunction with other Tri-Service Working Groups involved with the application of this technology base to sensor designs. Emphasis is currently being placed on technical reviews of ongoing, jointly sponsored programs and program definition of new starts. The plan is presented in attachment 3.

D. Tri-Service Smoke Visibility Program Plan.

This plan, presented in attachment 2, was prepared in response to the Executive Committee's direction. The Visible Signature Panel has been formed to coordinate the individual service activities and Tri-Service sponsored efforts cited in the plan as contributing to the overall goal of developing standard definitions and measurement techniques for missile exhaust smoke.

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