N R L REPORT NO. R-3209

COPY NO.

S-BAND PROPAGATION WITH ACID-ANILINE FLAME BARRIERS

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H. M. Bryant, and F. E. Boyd

Approved by:

Dr. R. M. Page, Superintendent, Radio Division III

Problem No. 36R25-03 December 5, 1947

NAVAL RESEARCH LABORATORY
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The facilities afforded by the Naval Ammunition Depot in combination with Reaction Motors, Incorporated are acknowledged to be especially adaptable for much work of the type reported herein. The proximity of these facilities to the Naval Research Laboratory enables the efficient use of manpower on this relatively expensive type of research activity.

The excellent cooperation of Captain Gearing, Commanding Officer (Naval Ammunition Depot) and Reaction Motors, Incorporated is herewith acknowledged. The display of teamwork and technical competence of the individual members of the field party deserves special comment. Particular mention is made of the efforts of Messrs. Fye, Wilkins, and Klein in collecting and packing the necessary equipment in the truck-trailer unit; the work of Messrs. Peck, Boyd, Morehouse, and Parker for r-f equipment; the work of Messrs. Boyd and Keith in obtaining suitable antenna equipment; the efforts of Messrs. Headrick, Grimm, Wyman, Bryant, and Zettle on general instrumentation, incidental modulation, and magnetic detecting equipment; the work of Mr. Bryant for photography and data analysis; and the efforts of Mr. J. L. Smith for the excellent condition of the truck-trailer and auxiliary power equipment.

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CONTENTS

ABSTRACT

Flames of the 400-pound-thrust and 220-pound-thrust "Lark" missile reaction motors operating in static thrust were subjected to horizontally polarized S-band radiation for quasi-optical propagation effects. Results, presented in the form of deviations from the normal field pattern, indicate that these flames are nearly transparent to horizontally polarized S-band radiation. Propagation anomalies due to the flame are substantially secondary when compared with artificial barriers such as a hollow plastic tube (lucite), a length of 2 x 4 inch wood, "Harp" tubing, and a 2-inch copper pipe.

PROBLEM STATUS

This is an interim report on this problem: work is continuing.

S-BAND PROPAGATION WITH ACID-ANILINE FLAME BARRIERS

INTRODUCTION

Naval Research Laboratory Report No. R-3197* includes a general discussion of NRL activity on Problem 36R25-03, "Propagation through Propellant Gases." It also serves as an over-all introduction to a series of reports emanating from Radio Division III covering various phases of activity in this field.

This report is first in this series and is concerned with an S-band propagation study with horizontally polarized radiation. Other reports, covering further experimental work with the "Lark" missile flame are in preparation. These will cover such phases as vertically polarized S-band propagation studies, incidental modulation studies, photo-analysis studies, and the effects on flames of electrostatic and electromagnetic fields.

A Naval Research Laboratory field party conducted the subject investigation with the "Lark" motors operating in a static thrust stand situated in one of the test cells of Reaction Motors, Incorporated, at the Naval Ammunition Depot, Lake Denmark (Dover), New Jersey. The following text encompasses the facilities available, the preliminary planning, and the instrumentation for the subject measurements as well as presenting experimental data and conclusions associated with these investigations.

EXPERIMENTAL FACILITIES

Reaction Motor Specifications

The reaction motors employed in the subject tests were the 622D2 design (400- and 220-pound-thrust units), manufactured by Reaction Motors, Incorporated. The motors were mounted on a horizontal thrust stand, the small motor above the large one, (Figure 1) with the large motor throat approximately 27 inches from the ground. For all the tests, the motors were fueled with mixed acid and aniline. The mixed acid was a Calco product (88% nitric, 12% sulphuric) and the aniline (crude) was supplied Reaction Motors, Incorporated by the Fuels and Lubrication Section, Bureau of Aeronautics.

Operating Facilities

The motor operating facilities of Reaction Motors, Incorporated were more than adequate for the purposes of the subject studies. Test cell No. 6 (Figure 2) was employed for

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* Gager, F. M., "Propagation of Electromagnetic Waves Through Propellant Gases," NRL Report No. R-3197, November 1947

Fig. 1 - Two Motors in Horizontal Thrust Stand

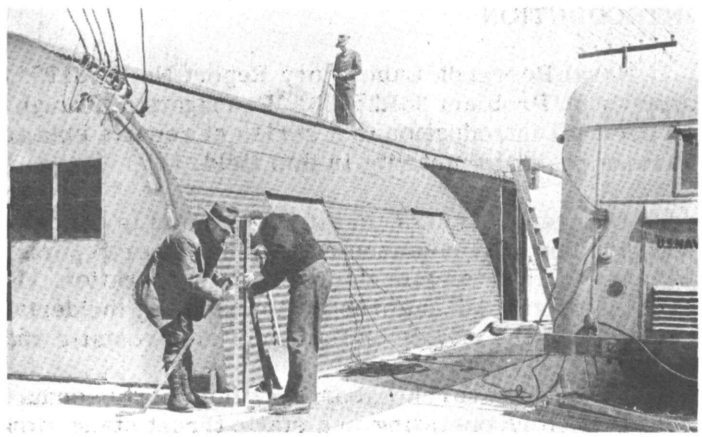


Fig. 2 - Test Cell No. 6 and Trailer, Reaction Motors, Inc., Lake Denmark (Dover), New Jersey

all investigations. At one end of this cell was located the motor control room (Figure 3) which contains the necessary fuel and valve control mechanisms along with motor performance chart recorders. The motor test stand (Figure 1) was located at the opposite end of Test Cell No. 6. Behind the motor stand, at the rear of the blast wall, separate subcells house individual 250-gallon fuel tanks for the acid and aniline (Figure 4). Pressurization of these tanks was controlled from the test cell control room by nitrogen cylinders (2000 pound pressure) located a considerable distance away.

The above-mentioned motor operating facilities, handled throughout by Reaction Motors, Incorporated personnel, provided sustained firing of both motors, either motor by itself, or to simulate the "Lark" missile conditions, the small motor continuously and the large motor pulsing. Motor performance charts were taken by Reaction Motors' personnel simultaneously with the data recorded by the Naval Research Laboratory field unit and were made available to the Naval Research Laboratory for correlation purposes.

Flame Characteristics

The apparent dimensions and shape of the flame emitted by a reaction motor depends upon the means of detection. Figures 5 and 6 show, respectively, the 400-pound "Lark" flame, and the 400- and 220-pound "Lark" flames together. Both of these figures constitute what the camera and film saw at a fixed distance with a given aperture, exposure time, etc. It should be pointed out, however, that the 400-pound flame (Figure 5) appears to the eye, at night, to end at a distance of seven feet from the motor throat. That which is pictured by Figures 5 and 6 constitutes the inner part of what the eye sees as the entire flame. One must not forget that altitude can materially change flame dimensions and flame charge density as well as prolong the time in which free charge can be present in a region. Thus, flame and flame-trail dimensions become a variable rather than a fixed entity. Both Figure 5 and 6 show flame bending not in accordance with the small angular displacement between the motors, but explainable by the principle of Bernoulli.

Preliminary Planning for Field Party Measurements

It was determined that exploratory measurements applicable to the "Lark" program* as well as the general problem† should include as parameters vertical and horizontal polarization, selected radiant energy incident angles and points of incidence upon the flame, and various conditions of single- and two-motor operation. Incidental amplitude-modulation studies were included in the plan, as well as some exploratory electric and magnetic measurements which it was believed would serve as initial probing on the nature and extent of charge distribution in a flame.

Fig. 3 - Control Panel in Motor Control Room of Test Cell No. 6

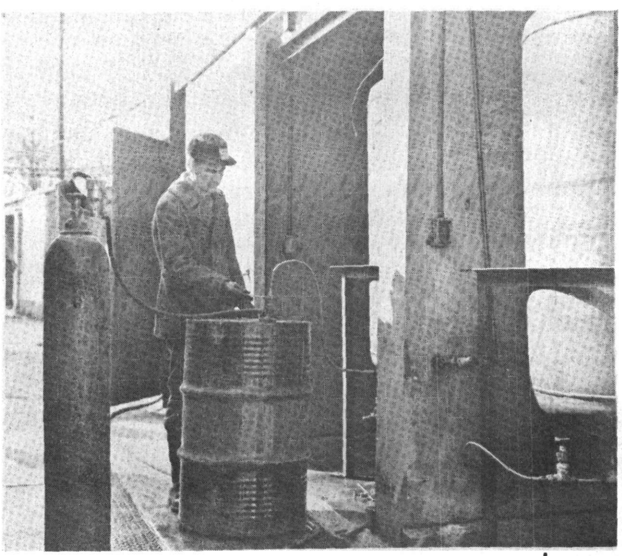


Fig. 4 - 250-gallon Acid and Aniline Fuel Tanks between Blast Walls

From the standpoint of propagation and incidental modulation studies, the use of a single transmission path was ruled out on the basis that any change in such a path could hardly be reconciled with physical facts - unless it was assumed (quite incorrectly) that attenuation would be the sole phenomenon to be experienced. To further establish the extent of quasi-optical phenomena, it was believed than an arc of dipole pickups should be employed to respond to any changes in the distribution of transmitted

* BuAer ltr to Director NRL Aer-E-3152-FWS, 7 April 1945, Assignment of Problem A-156R-S, "Lark Missile Control - Development of, and Modification of SP Radar for Beacon, Control of"

† BuAer ltr to Director NRL Aer-E-3144-HMM, 23 January 1945, Assignment of Problem A-140 R-S, "Radio Wave Propagation Through Propellant Gases"

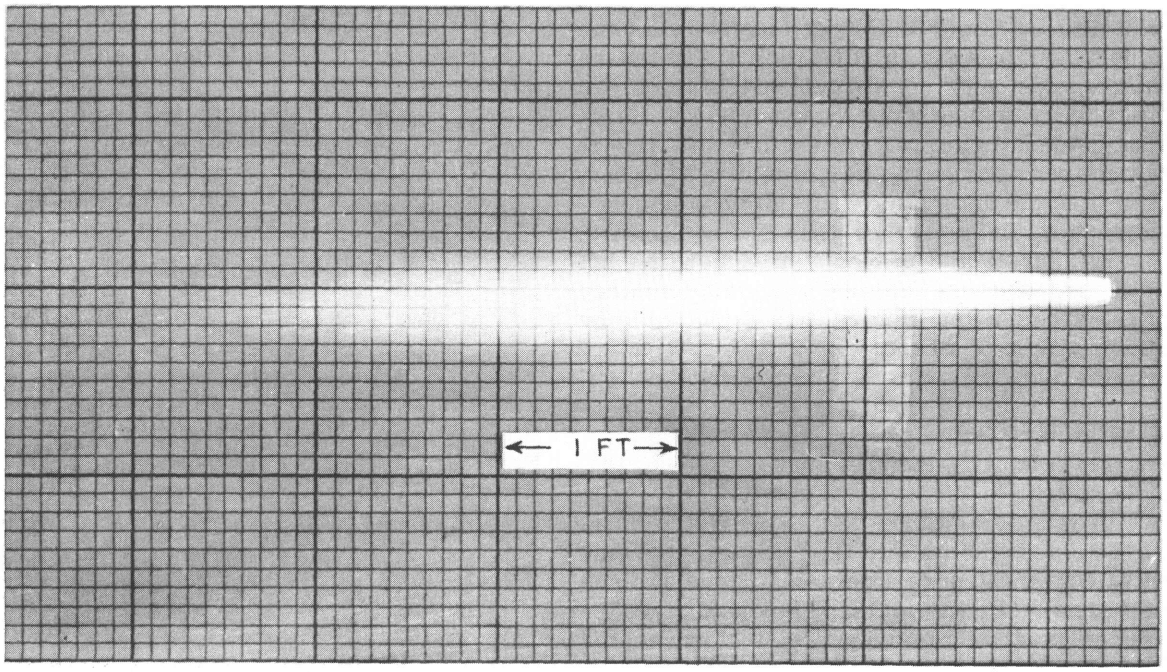


Fig. 5 - Flame of 400-lb-thrust Lark Motor Burning Mixed Acid and Aniline (Triple-S Pan Cut Film)

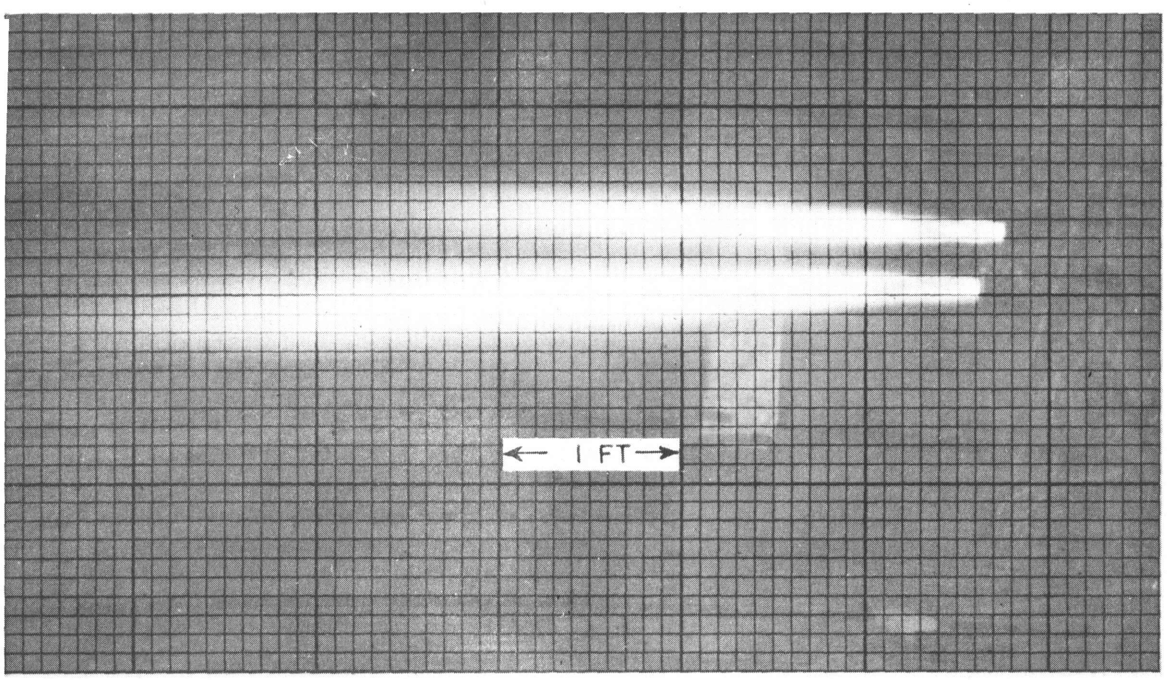


Fig. 6 - Flames of 220-lb and 400-lb-thrust Lark Motors Burning Mixed Acid and Aniline (Triple-S Pan Cut Film)

energy. This technique would provide for the interposition of the flames in the multiple transmission paths situated between the transmitting antenna and the pick-up antennas and in this manner propagation phenomena could be determined at least in one plane. Also, dipole pick-up antennas for the study of incidental modulation could be selected from those already in the arc, or special ones placed along the arc in addition to those employed primarily for propagation, because it was believed that the character of any observable incidental modulation could differ when observed along a reflection, refraction, or line-of-sight path.

It was further reasoned that electronic equipment should be removed from the vicinity of the motor for many reasons. A study of incidental modulation is complex enough without masking the desired data with microphonics and spurious vibrations caused by the intense accoustical pressures normally encountered in the vicinity of a flame. This undesirable feature would be reduced by the selection of a relatively powerful c-w S-band source. The use of such a source would also permit mounting of crystal rectifiers (without amplifiers) immediately behind the dipole pick-up antennas. In addition, a suitable magnitude of rectified r-f current would be available at a remote point for recording purposes. The choice of the relatively high-power c-w source would provide an additional advantage in that the cable leading from the remotely located transmitter to the transmitting antenna would serve as a variable attenuator by selecting a suitable length of cable for a particular data run. The use of attenuation in this manner would provide stable frequency operation of the magnetron source. At this juncture it might well be stressed that any system where detuning of the antennas can take place, due to the close proximity of a semiconducting flame, allows for mutual reaction upon both the transmitter and receiver equipment. This reaction can result in a change of radiated power from the transmitter as well as a material change in the sensitivity of the receiver. Data obtained under such conditions is of little value unless suitable power-flow monitoring is provided at the transmitter antenna. For the receiver, monitoring corrections under such circumstances would be extremely difficult, since the design of many receivers is such that sensitivity at any frequency is materially dependent upon the antenna equivalent generator impedance.

EXPERIMENTAL ARRANGEMENT

The block diagram of Figure 7 shows the instrumentation arrangement used for all propagation measurements. An outline plan, drawn to scale, is shown in Figure 8. The truck and the trailer carrying the transmitter and the receiving-recording equipment, respectively, are shown in Figures 9 and 10. For transverse-flame work, the remotely located transmitter and recording equipment were used with but two (sometimes one) pick-up antennas, as shown in Figures 7 and 11. The multiple pick-up antennas arranged along an arc in the radiation field of the transmitting antenna are shown in Figure 12.

Typical pick-up antennas and stand assemblies are shown in Figure 13. Each antenna was provided with a special choke-type crystal holder mounted immediately behind the one-foot-square antenna back plate. The design of the antenna crystal assembly was found to be electrically, and for the most part mechanically, satisfactory. For example, no temperature drift of the crystals was observed, even on transverse-flame measurements, because the antenna back plate provided heat shielding. Scotch tape was placed over the slot between the dipole segments of each antenna to prevent raw fuel and combustion products from entering the antenna coaxial line and cable fitting. The tripod-type antenna stands were designed and fabricated of angle iron for use on uneven terrain by providing adjustment of the foot angle. Additional features allowed vertical adjustment of each antenna, polarization change of the dipole, and backward tilt of the antenna assembly to minimize partially any ground effect. The foot members of each stand were turned

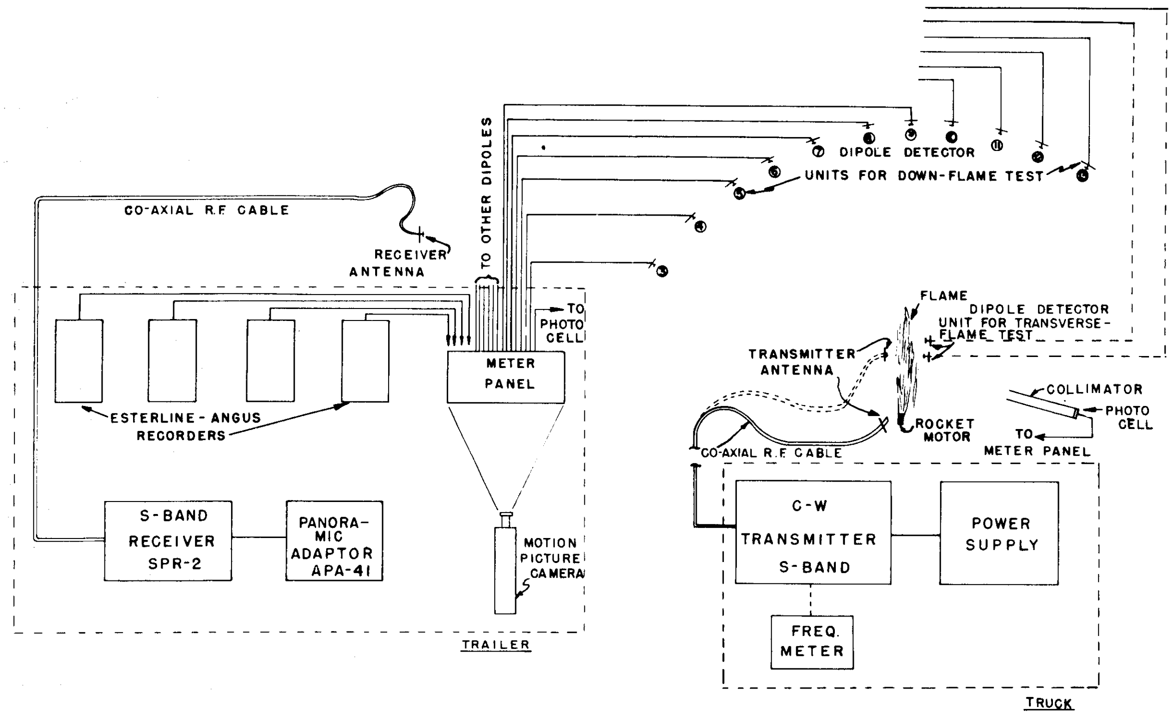


Fig. 7 - Block Diagram of NRL Instrumentation

horizontally, making them adaptable for use even on frozen ground. The mechanical stability of the entire assembly was materially assisted by sand-bagging the stand feet (Figure 12), and further, the inherent design caused flame thrust to drive the support members more firmly against the ground.

The direct-current component and incidental modulation products produced at each crystal pick-up unit were carried to the trailer by shielded cable (Figure 7). Data provided by these facilities were recorded as a function of time.

The c-w transmitter, an adaptation of the transmitter unit in the AN/APQ-20 system, provided operation of any one of the series of magnetrons QK-59, 60, 61, and 62. The QK-59 was used exclusively, however, in the measurements reported herein. The transmitter was first designed with r-f and power supply as a single unit. Subsequent modulation measurements made at the Naval Research Laboratory indicated that a separation of the transmitter into two units (Figure 7) provided a slight reduction in the power supply modulation figure. The transmitter was capable of a nominal 60-watt output. This output was padded down by selected lengths of cable (RG-9/U) connected between it and the transmitter antenna (Figure 7). This feature provided stable operation of the magnetron, minimized reaction of the antenna-flame combination upon the magnetron's power and allowed suitable output from the transmitter antenna to provide the desired pick-up antenna crystal currents. The magnetron frequency was measured with a Sperry type MK S22 frequency meter. In addition, an AN/SPR-2 receiver provided with a panoramic adaptor (AN/APA-41) was actuated by a special pick-up antenna arranged on the arc of pick-ups so as to intercept mostly the through-flame radiation. This facility allowed for a visual indication of the magnetron frequency stability, including magnetron moding, if such should happen due to improper load or gradual tube failure.

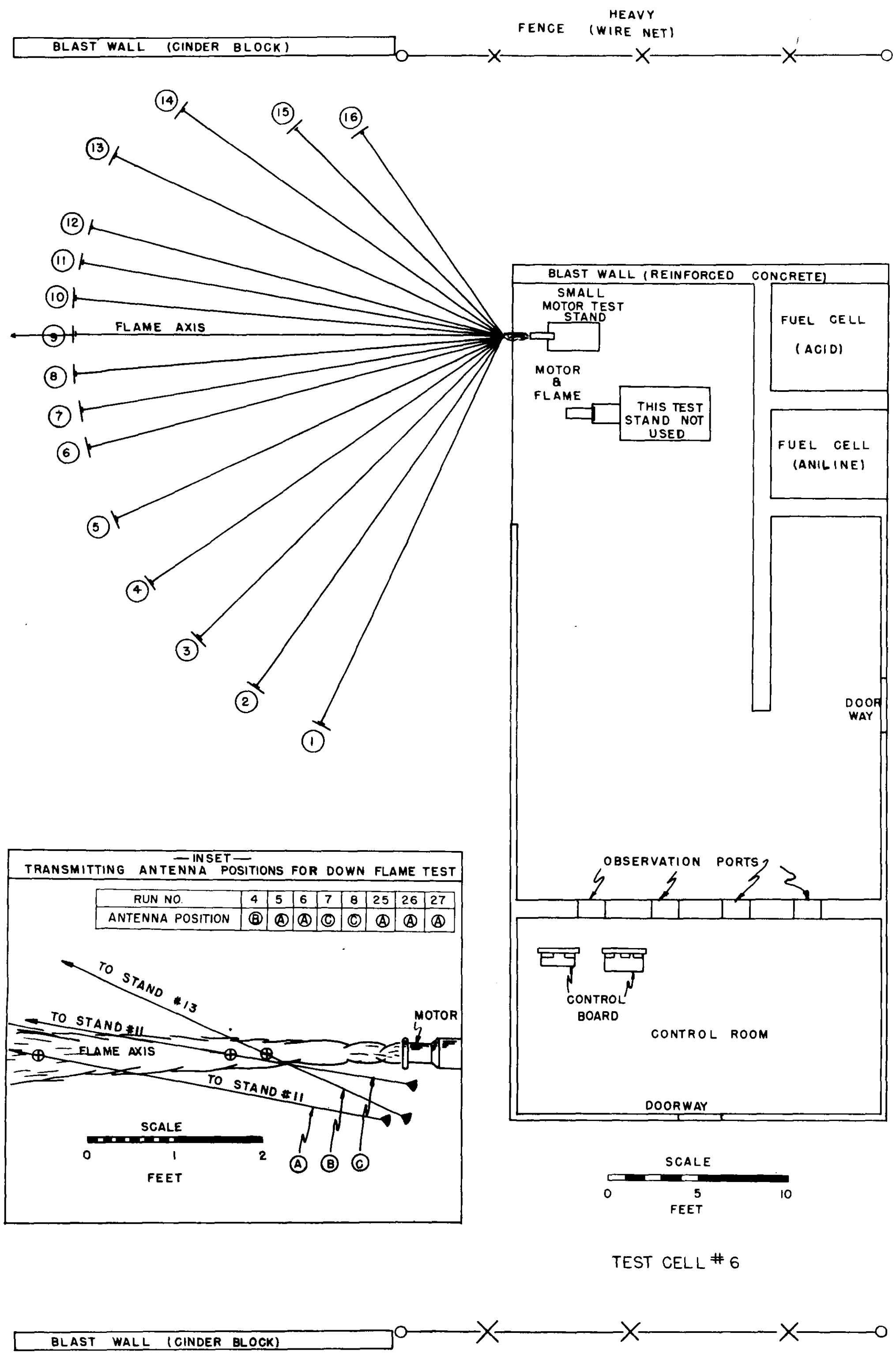


Fig. 8 - Plan View of Test Cell No. 6

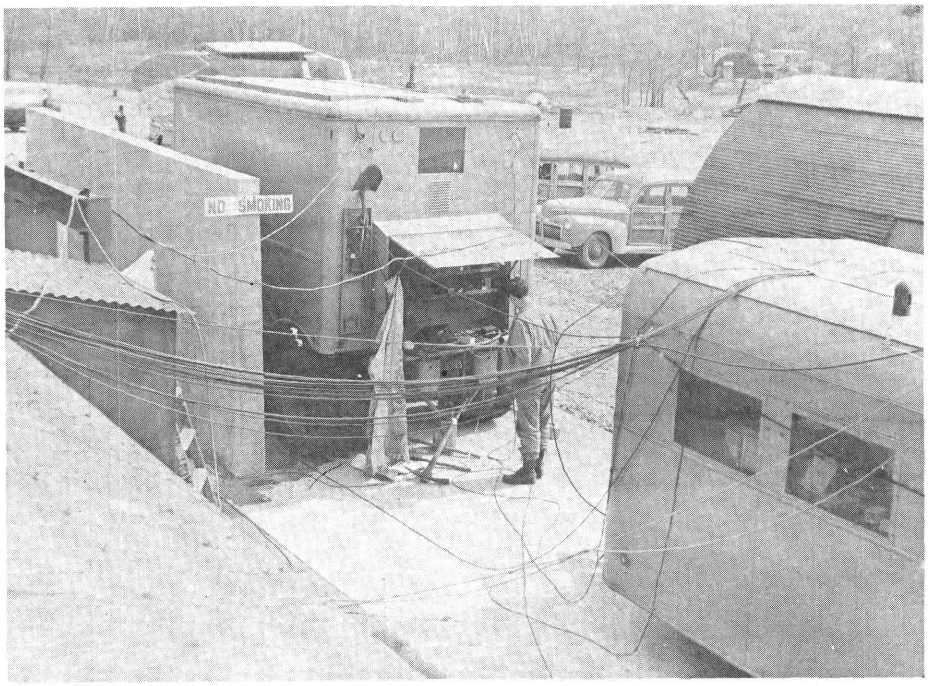


Fig. 9 - Truck-Trailer Laboratories from Roof of Test Cell No. 6

Fig. 10 - Truck-Trailer Laboratories and Protective Blast Wall

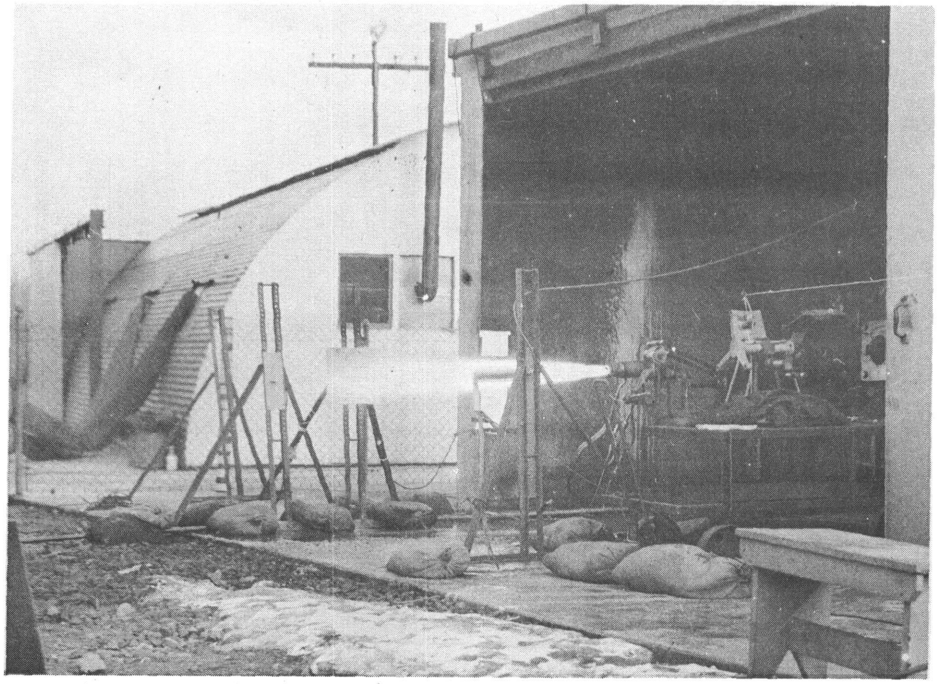


Fig. 11 - 400-lb Motor Operating for Transverse-Flame Study

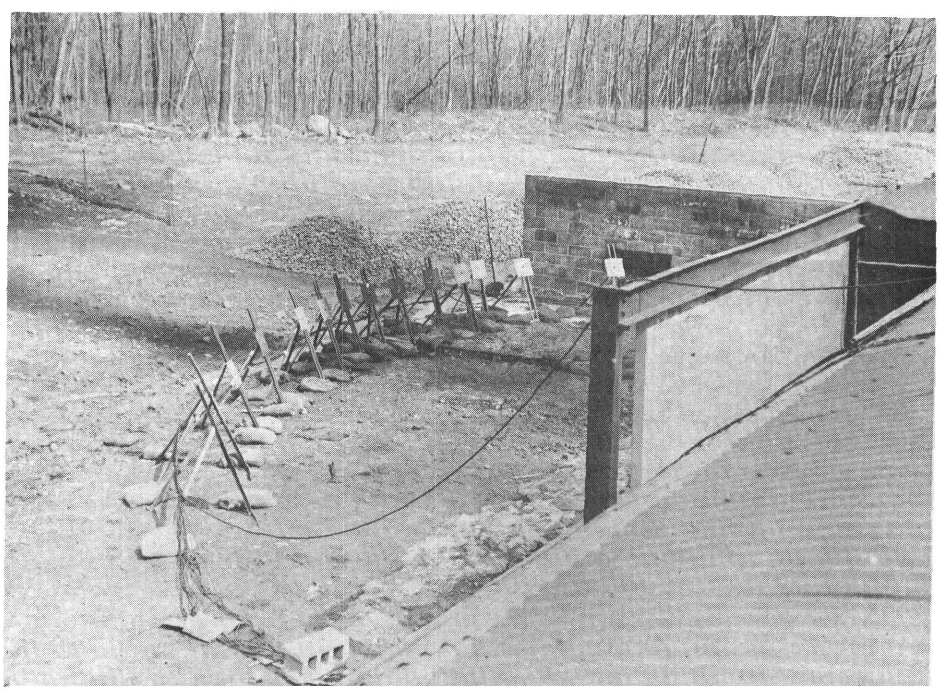
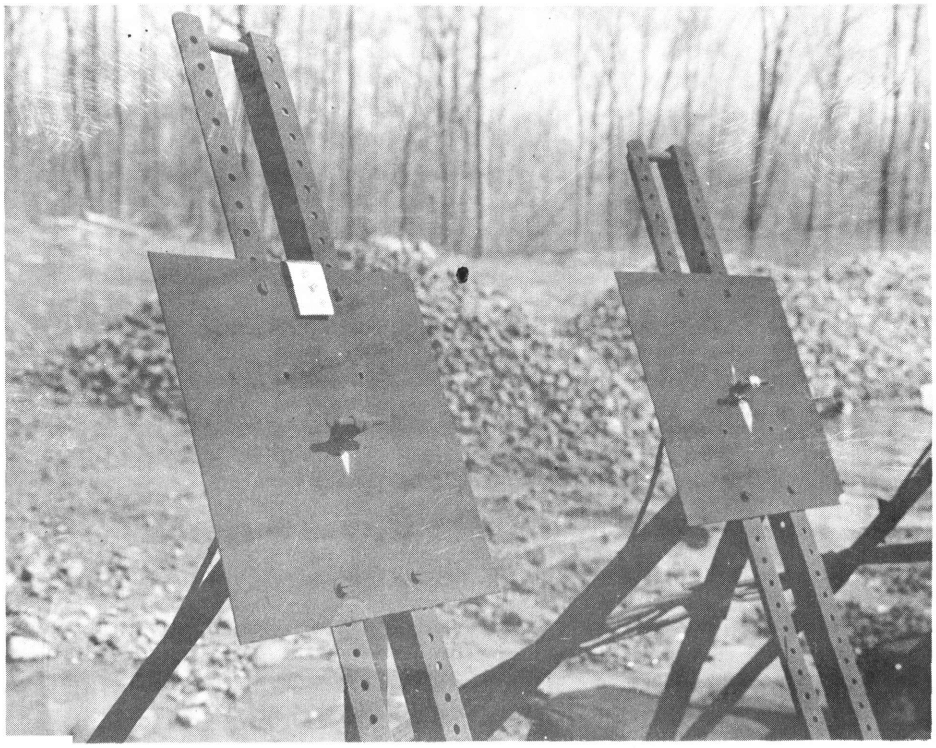


Fig. 12 - Dipole Probe Antennas Arranged in an Arc



;. 13 - Dipole Probe Antennas and Antenna Stand Showing "Split" Dipole Covered with Scotch Tape and the Carbon Deposit on Dipoles and Back Plates Due to Flame Trail

Transmitter antennas of two types were employed. A dipole (identical to the pick-up antennas, Figure 13) was used for broad-pattern radiation and an 18-element end-fire array (Figures 11 and 14) provided a concentrated field. The dipole antenna exhibited the usual field pattern for such a radiator; the end-fire array had a main lobe approximately 23 degrees wide at the half-power points. Both of these antennas, in conjunction with the RG-9/U cable padding from the transmitter, provided crystal currents capable of operating the 0-100 microammeters or the Esterline-Angus recorders without operating the crystals at an excessive average current or experiencing any serious drifting due to current heating.

The 0-100 microammeters which indicated the direct-current component from each antenna pick-up were mounted on an approximately square panel (Figure 15), with suitable photoflood lamp illumination provided for photographic purposes. Each meter was connected with an adjustable shunt for the purpose of equalizing the pick-up antenna indications to the degree thought necessary for the transmitter antenna pattern in use and the physical position of the pick-ups in the radiation field. A 16MM and a 35MM moving picture camera were situated so as to photograph the meter panel before, during, and after a propagation run. Also, an aircraft-type split-second stop-clock was centered on the meter panel for accurate timing. In addition a remote-operated pilot light on the panel could be operated manually as a frame marker or be motor switched to provide markers for synchronizing the film records of the two cameras. These features allowed for a positive flame-on, flame-off condition and were particularly valuable in the analysis of the data on a frame-by-frame basis.

DATA AND ANALYSIS

Observed Data

Extensive horizontal polarization measurements were made in an attempt to determine the degree of quasi-optical phenomena which might exist for both transverse-flame and down-flame propagation under the following selected conditions: (1) operating the 400-pound-thrust motor by itself, (2) the 400-pound motor and the 220-pound motor in continuous thrust, and (3) the 220-pound motor in continuous operation with the 400-pound motor pulsing. The latter was an attempt to simulate "Lark" missile power-plant performance. Data was also taken under a number of conditions for the interposition of known types of barriers (all physically smaller than the 400-pound motor flame) in an attempt to characterize the flame in a qualitative sense. For the most part, the degree of radiant energy vector redistribution caused by the flame on both down-flame and transverse-flame measurements was secondary when compared with the redistribution caused by a copper pipe, a hollow lucite tube, dry pine wood (2 x 4 inches), and "Harp" tubing barriers. The secondary nature of the observed redistribution of radiant energy was sufficiently in evidence, but required that the down-flame data be treated on a satistical basis. The transverse-flame redistribution was even less in evidence than the down-flame data. The presentation of down-flame results is indicative of quasi-optical propagation performance of both the flame and a good portion of the flame trail; the transverse-flame data generally indicates the degree of shadow effect which might be encountered by a receiving antenna located near the flame on a missile air-frame member.

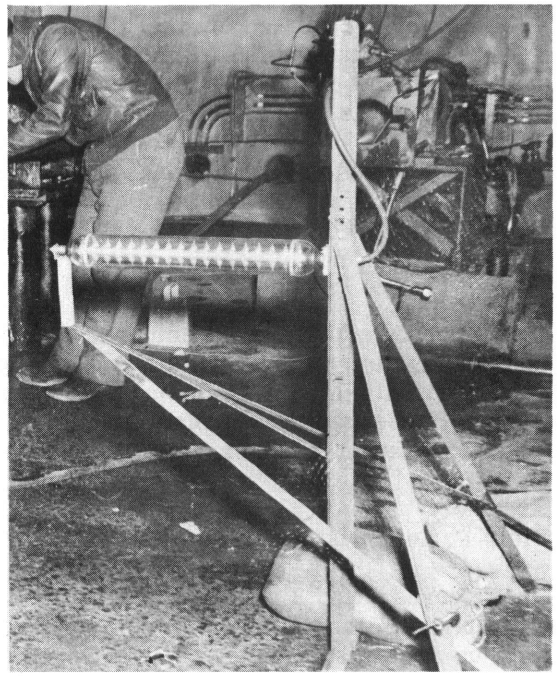


Fig. 14 - 18-Element End-Fire Antenna Array

Transverse-flame measurements were made with both the dipole and the 18-element end-fire transmitter antenna in conjunction with two (sometimes one) dipole pick-up antennas as radiation field probes. The pick-up antennas and flame were located beyond the Fresnel zone of the transmitter antennas at all times. Transverse propagation was observed, with distance from the motor throat and distance of the pick-up antennas from the flame as variables, in an attempt to locate any umbra-like or penumbra-like shadow effects caused by the interposition of the flame.

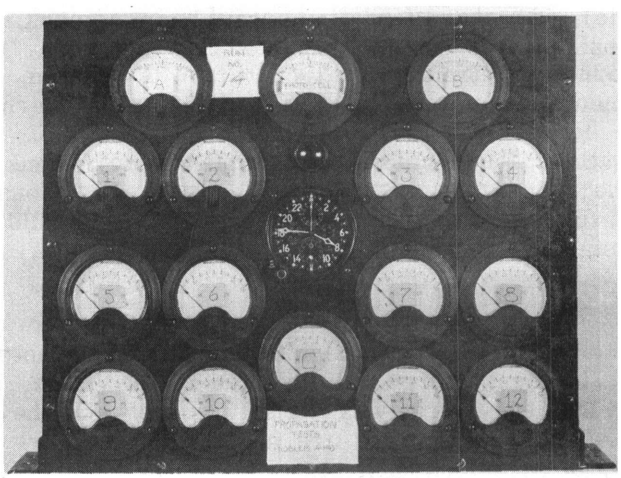


Fig. 15 - Meter Panel

It should be pointed out that the pick-up dipoles in some instances were located within five inches of the nominal flame edge. This minimum distance did not scorch the scotch tape seal at the center of the dipole, but in one instance combusting drops of the fuel mixture burned holes in the tape. The sound level at the distances probed by the pick-up antennas in these measurements was much greater than plus 120 decibels. These severe sound intensities revealed some faulty crystals and provided a degree of random drift with satisfactory crystals which sets a level on the results below which it is difficult to determine the nature or the existence of quasi-optical effects. Fortunately this level of uncertainty is low in magnitude.

It can be stated that attempts to locate "shadows" produced a negative result. The most likely source, the larger flame (400 pounds thrust), appeared quite transparent to 2700- and 2810-Mc transmission. Pick-up amplitude changes greater than ±2.5 percent were not observed to take place, and much if not most of this ±2.5 percent was due to severe vibration of the crystals.

Field Pattern Distortion Due to the Flame

Figures 7 and 8 show the arrangement of the propagation equipment and flame and indicate the meaning of the terms "transverse" and "down-flame". It is noted that some pick-up antennas, those on the right hand side of the arc, are foreshortened with respect to the true arc. This procedure was necessary because of the close proximity of the blast wall shown. "Harp" destructive interference material particularly adaptable for S-band use was secured to the blast wall to minimize reflections from the wall which might supply energy to some pick-up antennas along an undesired path.

The polar plots, Figures 16 and 17, indicate the deviation from the "normal value" field pick-up pattern due to down-flame propagation, where "normal value" is the field pattern undisturbed by a flame. These polar plots also serve to compare results obtained under different conditions.

Figure 16, depicting a horizontal polarization study of the 400-pound motor shows plots of data taken both from a broad (dipole) and a sharp (end-fire array) beam antenna. If attenuation were the only factor to be considered, it would be expected that the sharp and broad beam measurements would produce the same general character of pattern. However, with other quasi-optical phenomena present, the character of the two patterns should be different. Thus, the difference between the two curves of Figure 16 is further evidence that the optical laws are active. Furthermore, the amplitude deviations from normal are so small as to be in the range of expected change of path variations caused by reflection, refraction, and diffraction, and not too much significance should be placed upon the loss of amplitude at stand No. 10 being attributable solely to attenuation.

Figure 17 compares the 400-pound motor alone with both the 400- and 220-pound motors in operation together. In the former case incident energy was directed at the flame, in the latter case the major portion of the incident energy was transmitted between the flames, in both cases towards station No. 11. These curves are not readily comparable partly because two-motor operation indicated less consistency on repeating data due to flame whipping (change of antenna aiming) and more intense sound vibration. In general, these plots show diminution through the flame and trail, and reflection and multiple path effects elsewhere.

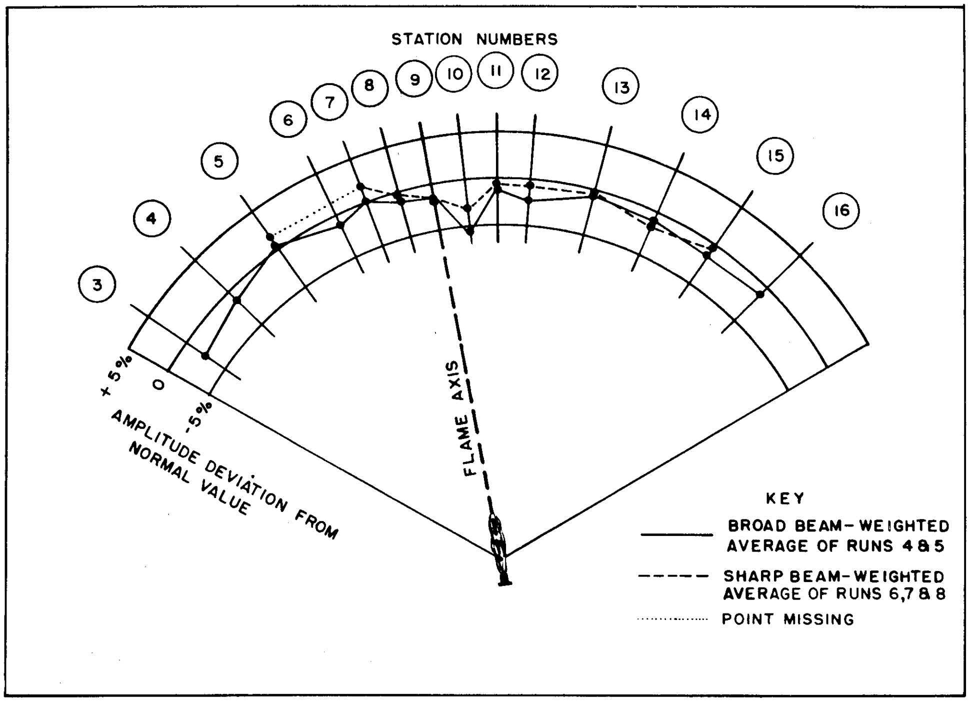


Fig. 16 - Field Pattern Distortion Due to 400-lb Motor; Polar Plot of Broad vs Narrow Beam Conditions

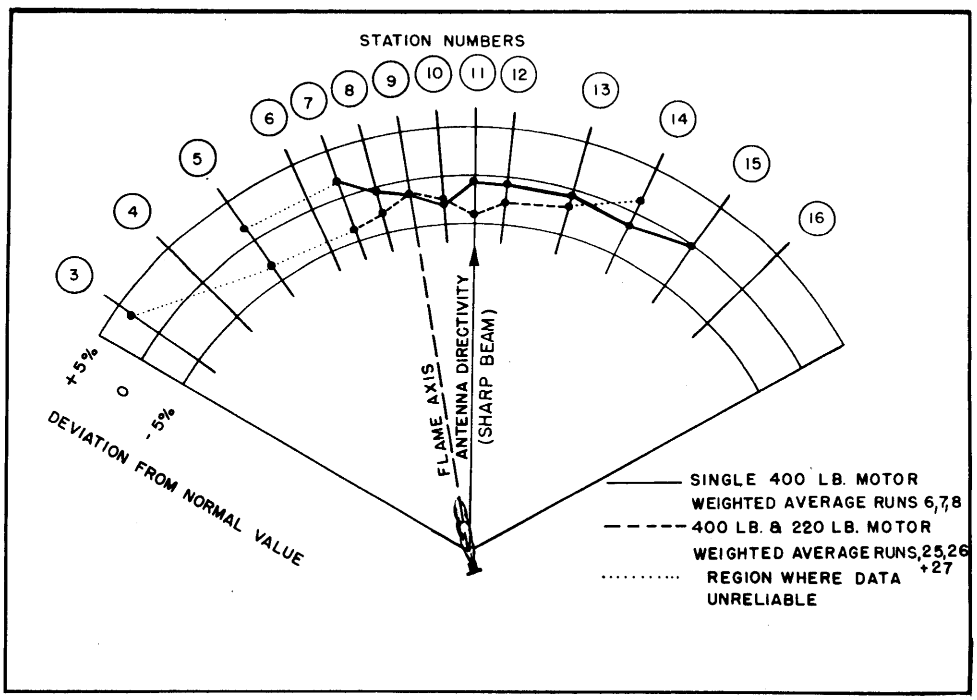


Fig. 17 - Field Pattern Distortion; Polar Plot Single- vs Two-Motor Conditions

Flame vs Barriers

It was mentioned previously that barriers, all physically smaller than the 400-pound flame, were substituted for the flame and placed in the flame position to determine the relative effect each one might have upon propagation in the down-flame direction as compared with the flame itself. Figure 18 represents a horizontal polarization study where radiant energy was directed down and across the flame and flame trail towards station No. 11. This plot represents the percent amplitude deviation from the normal value of the field pattern plotted against angular deviation from the axis of the flame. The zero ordinate axis represents the "normal value" field pick-up pattern obtained without the flame or special barrier objects interposed in the radiation field. The curves show the degree of redistribution of energy caused by the interposition of the flame and the designated barriers. For comparison, particular mention should be made of the solid line, that caused by the interposition of the 400-pound flame above. This curve shows a redistribution of energy representative of the weighted average of two propagation runs. Weighting was done on the basis of drift in the crystal current, the assumption being made that crystals showing the least drift after each run would have given the most reliable data. It is noted that the 400-pound flame caused a redistribution of the radiant energy vectors which is secondary in magnitude in comparison with the other barriers shown.

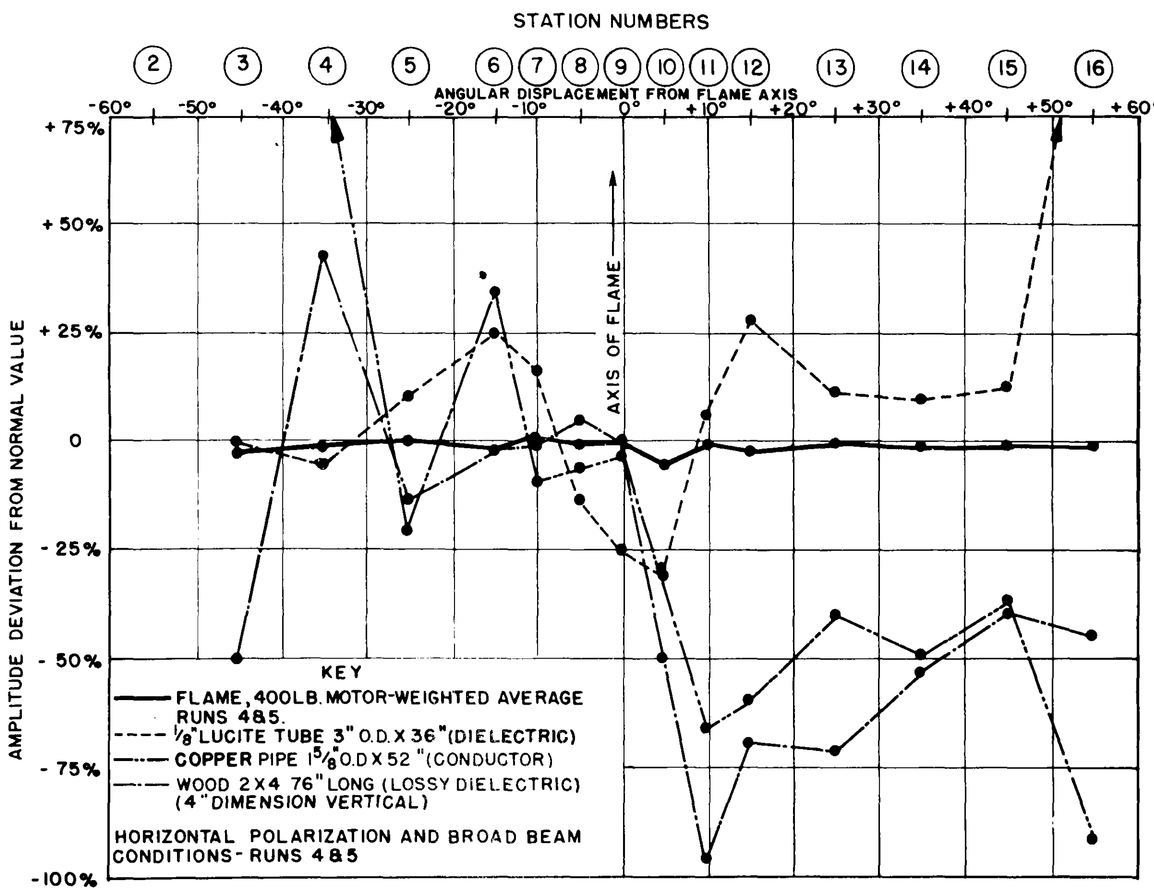


Fig. 18 - Field Pattern Distortion Due to Different Barriers

Flame Temperature Measurements

Coincident with the field measurements made at Reaction Motors, Incorporated by members of the Components Section (now Special Research Section), Radio Division III, two members of the Optics Division, Naval Research Laboratory, made optical radiation measurements on the acid-aniline (Lark) flame. It was determined that the spectral distribution curve of the flame was not unlike that of tungsten at 2760° K. The emissivity of the flame, however, was found to be 0.006. The apparent radiation temperature computed from these data was in agreement with that obtained (approximately 800° K) from direct measurement of total radiation. (The foregoing optical data was obtained from a small portion of the flame in comparison with the flame diameter at forty inches from the throat of the 400-pound-thrust motor.) The details of these particular optical radiation measurements are the subject matter of Naval Research Laboratory Report No. N-3097*.

CONCLUSIONS

Several general conclusions can be drawn with respect to the propagation of S-band energy impinging upon the flame and trail of the "Lark" motors. These are as follows:

(1) The pattern displayed by the propagation data, observed under the conditions of down-flame incidence of the major portion of the radiant energy is a small redistribution of the radiant energy due to slight optical effects caused by the flames. It is more correct to state that what was observed was more of a redistribution of energy than an attenuation effect.

(2) The pattern displayed by the transverse-flame data is one where umbra-like and penumbra-like shadow effects were substantially absent. Above a random variation of the signal amplitude of ±2.5 percent, the aforementioned shadow zones were not observed.

(3) The effective flame transparency indicated by conclusions (1) and (2) above is, to a degree, substantially perfect at 2700 to 2800 Mc as compared with copper, wood and lucite.

(4) It is apparent from the physics of a flame and the data at hand that it would be misleading to ascribe uniformity to said flame and draw attenuation data therefrom for presentation on a db-per-meter basis.

(5) Flame enlargement would be produced by an increase in altitude. However, the "Lark" missile ceiling is not so high as to produce extensive enlargement.

(6) The absolute temperature of the "Lark" flame (400 pound) was found to be substantially 2760° K.

(7) The subject data is not without ground effect. The frequency sensitivity of the "normal value" of the field pattern has been observed and will be subject to treatment in a future report on vertical polarization studies. It is believed that the ground effect will not materially change the above list of conclusions.

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* J. A. Curcio and C. P. Butler, "Optical Radiation from Acid-Aniline Jet Flames," NRL Report No. N-3097, Confidential, July 1947

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