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# REPORT OF THE

# ARMY SCIENTIFIC ADVISORY PANEL

# AD HOC GROUP

# ON HOSTILE ARTILLERY LOCATING SYSTEMS (U)

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## I. INTRODUCTION.

The ASAP Ad Hoc Group on Hostile Artillery Locating Systems was established "to determine which techniques offer the most promise of satisfying the Army's requirement to accurately and responsively locate the firing position of hostile artillery."

The Army has counterbattery and countermortar radar development programs aimed at satisfying this requirement. The emphasis in the committee's assignment was on non-radar techniques, with the object of identifying promising non-radar approaches which could be pursued at an increased level of effort in parallel to the radar development.

This report presents the Group's conclusions and recommendations, and some of the supporting studies leading to these findings.

Membership of the Group and the Group's charter are attached as Appendices I-1 and I-2.

## II. OVERVIEW OF THE PROBLEM.

### A. Objectives.

Hostile artillery location is only one step in obtaining artillery superiority on the battlefield. The Group's principal attention was directed to hostile artillery location, but it is clear that location must be considered in the context of a complete Artillery Superiority Program (ASP) which integrates the functions:

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ARTILLERY SUPERIORITY PROGRAM

OBJECTIVE: { Detect / Locate / Identify / Engage / Neutralize/Destroy } ENEMY ARTILLERY

B. <u>ASP Implications</u>.

Current Army requirements for hostile artillery location are phased in the terms of the "classical" situation of location using sensors emplaced behind a FEBA. This situation limits the set of admissable concepts, both for target location and destruction. There is at least as much unexploited potential in ASP systems operating or employing elements deployed forward of a FEBA (when one exists) as in rearward emplaced systems.

C. <u>Potential for System Improvement</u>.

Potential avenues for overall system improvement includes:

1. Exploitation of new sensors

2. Improvement of existing location systems

3. Exploitation of new system operational concepts, including forward sensors and platforms, and hunter-killer vehicles.

4. Exploitation of improved and different terminal effects for hostile artillery neutralization/destruction.

D. Signature Considerations.

The critical function of an ASP system is the detection and processing of characteristic signatures associated with the enemy weapon, weapon firing, projectile flight and impact. Figure 1 sketches some of the candidate signatures reviewed by the Group.

Signature data is most conspicuously absent for those signatures which might serve as the basis for new location schemes. These include unintentional electromagnetic radiation, laser cross section of the effluent gases and dust cloud associated with firing, and, surprisingly, the detectability of the projectile in flight by infrared. Undoubtedly, a substantial amount of relevant signature data exists at various agencies. A comprehensive summary of available data does not appear to exist.

In addition to signature/sensor data, development and assessment of candidate location system options requires information on the effect of the transmitting medium on signal propagation, and on the characteristics of background noise. This data is also deficient in the case of many sensors of interest.

For example, the effective range of acoustic systems depends as much on meteorological conditions as it does on system design characteristics. It is remarkable that there does not seem to be an objective analysis of the performance limits of an "ideal" acoustic location system as a function of meteorological parameters and their frequency of occurrence. Determination of these limits should end much of the uncertainty regarding the unexploited potential of acoustic systems.

E. Operational Considerations.

The ability to acquire and utilize a signature depends on the relative location of sensor to source. Operational constraints may be considered as dividing potential systems into two classes: systems in which the sensors must be located behind a well defined FEBA; and systems which involve forward placement of sensors. Within these categories, suboptions are listed below:

1. Operations from behind FEBA.

   a. Ground Stations
   b. Airborne Platforms

2. Forward Stations.

   a. Ground Sensors
   b. Drones, Remotely Piloted Vehicles (RPV's)
   c. Ballistic Vehicles (e.g. I-SPY projectile)
   d. Manned Platforms
   e. Satellites

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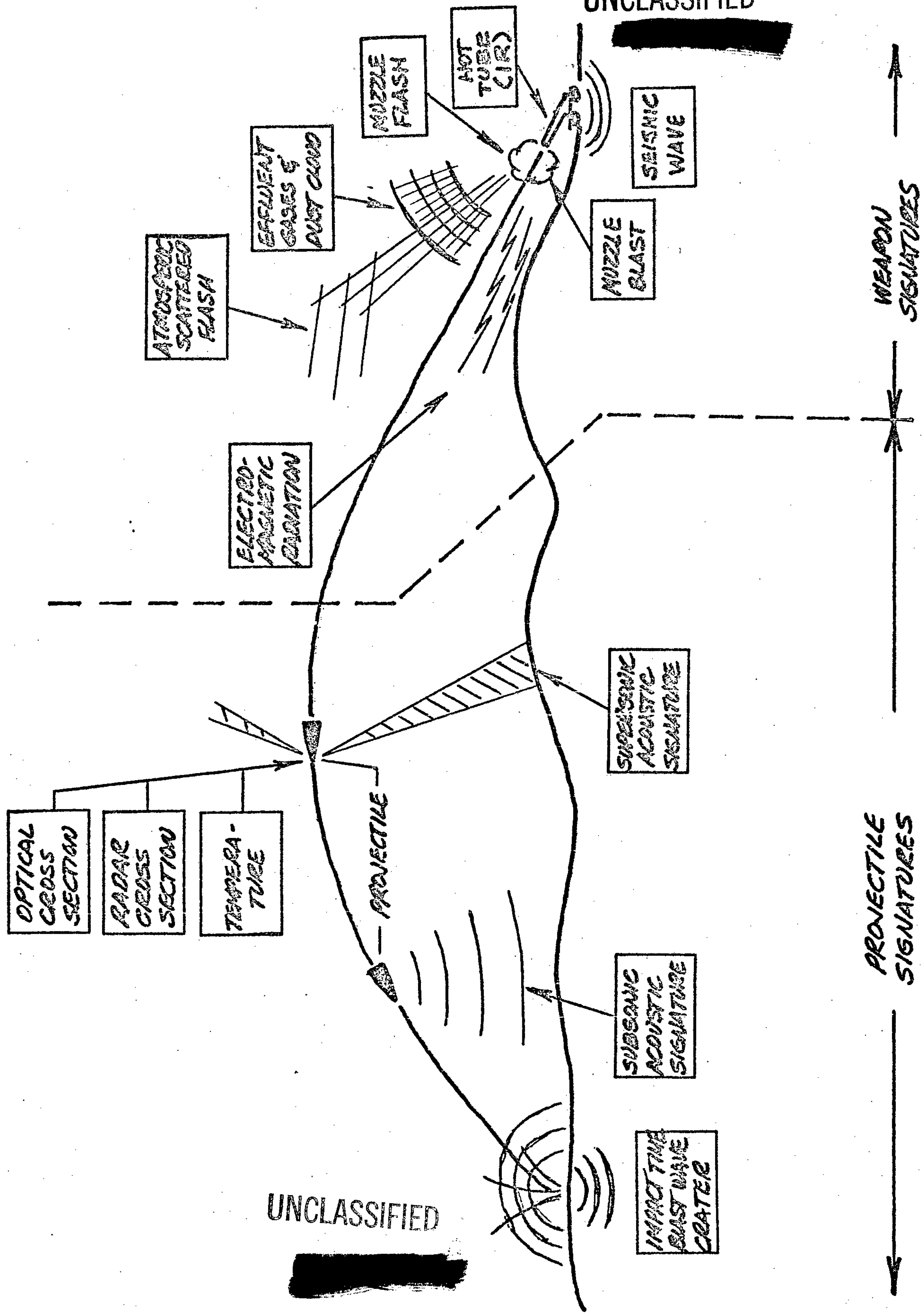


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FIGURE # 1

F. System Considerations.

Ground stations must either depend on projectile tracking and extrapolation of the trajectory back to its source for sensors requiring an unobstructed line of sight, or are subject to limitations caused by signal attentuation and deviation for non-line-of-sight phenomena such as sound. Airborne platforms, unfortunately, currently involve expensive coordinate reference systems.

In spite of these difficulties, radar sensors are capable of providing the required solution, and other sensors may have an attainable gap filler capability to handle short range traffic at acceptable cost. Development of a relatively low cost coordinate reference system would greatly enhance the attractiveness of airborne platforms.

The use of forward stations allows additional options for solution. Forward emplaced acoustic sensors have been demonstrated to have effective operational potential, and location relatively close to enemy weapon sites substantially reduces the problems in sound path variability. Meteorological sensors exist which can be air delivered and allow real time information to be obtained in advance of the FEBA for artillery firing, and for calibration of conventional acoustic systems.

Jurisdictional problems with the Air Force are involved in possible use of manned or unmanned air supported platforms forward of the FEBA. An advantage of overflights of possible enemy positions is that short-range sensors such as METRA and infrared detection of hot gun barrels become usable. How much effort to devote to this type of system depends on the user's judgement as to the frequency of tactical situations in which it could be exploited. However, given airborne penetrating platforms, the following options may be considered:

1. Detect, locate, and report position of enemy weapon.

2. Detect, locate, and designate for remotely fired homing projectile.

3. Detect, locate, and attack with on-board weapons.

Even when operated by the Air Force, design of these platforms should be responsive to Army requirements and provide system interfaces designed for optimum overall system effectiveness, considering both Army and Air Force functions.

Ballistic vehicles have the unique advantage of penetrating enemy airspace without requiring jurisdictional problems to be resolved. The I-SPY reconnaissance projectile is particularly attractive for this reason, in addition to its demonstrated feasibility. Although its limited coverage per shot may not qualify it as a primary artillery location means, the attainable resolution and coverage seen adequate for precise location of an enemy weapon, based on an initial rough fix obtained from some system or source. Given an I-SPY pictorial readout of an enemy weapon against terrain background, an unexplored possibility is attack on the weapon with an artillery missile using terrain correlation homing. The suggested possibility of using I-SPY to refine an initial rough location obtained by some other means, followed by an attack using I-SPY data, emphasizes the necessity for evaluating component solution options to the overall Artillery Superiority Problem on a complete systems basis.

Similar comments apply to the possible use of satellite information. A satellite does not by any means qualify as a primary means for enemy artillery location; however, information obtained by satellite may be of value in artillery operations. Both the potential utility of such information and development of information channels for its prompt transmittal need to be assessed.

III. CONCLUSIONS.

A. General.

Hostile artillery location is only one step in obtaining artillery superiority on the battlefield. All efforts supporting the overall objective should be coordinated in an Artillery Superiority Program.

B. Signature Data.

Artillery location systems exploiting signatures not previously utilized are possible. However, acquisition of experimental data is necessary to assess their feasibility.

C. Systems for Operation from Behind the FEBA.

1. Although no immediately available technique superior to counter-battery radar has been identified for operation from behind a FEBA, alternate techniques to radar are essential as backup to radar in case of radar jamming or neutralization, and as lower cost complementary solutions in the event that the radar unit cost prevents procurement of a sufficient number of units to completely satisfy the Army's requirements.

2. Conventional sound ranging has a demonstrated, but limited, capability which can be improved by better meteorological data (nowcasts) and data processing. An unexplored potential for additional improvement exists in the use of additional information and constraints on the solution, including impact sensing, use of enemy firing table data, and sensings of the projectile acoustic signature.

3. There is a wide divergence of opinion on the capability of existing sound ranging systems. What seems to be lacking is a set of engineering tests in which the performance limits imposed by specific equipment capabilities are separated from the performance limits imposed by meteorological conditions. If well determined, the latter would help to establish the maximum capability attainable by any specified sound system.

4. The major shortcoming of current airborne flash ranging systems is considered to be the cost of the subsystem for determining the location and orientation of the observing platform at the instant of target location.

5. Other systems for operation behind the FEBA include polystation doppler radar and infrared projectile tracking. The former was not considered far enough along in development to allow an evaluation of its ultimate capability. The single infrared projectile tracking concept reviewed was considered to have operational limitations (weather and multistation operation) which were unfavorable when compared against its probable cost. Experimental data on projectile signature and background noise do not appear to be currently available, and their lack limits the degree to which low cost concepts can be usefully explored.

D. Systems Employing Stations or Sensors Forward of the FEBA

1. Forward emplaced acoustic sensors and associated data processing appear to have demonstrated state-of-the-art feasibility of providing weapon location data, of desired accuracy, subject to operational problems in emplacement.

2. Seismic sensors are considered inferior to acoustic sensors because of the difficulty of calibrating them against local signature propagation characteristics.

3. If manned, drone, or RPV aerial platform operation forward of the FEBA is considered tactically feasible, system concepts of wider scope than those constrained by current requirement documents on hostile artillery location become candidates for evaluation. These include both weapon directing platforms and hunter-killer vehicles. In addition, relatively short range sensors such as METRA become candidates for evaluation.

4. Ballistic vehicles, such as I-SPY, in addition to a demonstrated reconnaissance capability, have the advantage of avoiding jurisdictional problems of penetration of enemy airspace.

5. Concepts employing forward platforms should be explored in the context of the complete Artillery Superiority Program, including tactical, vulnerability and cost considerations as well as target acquisition potential.

## IV. RECOMMENDED PROGRAMS.

The recommended programs are grouped in four categories.

Acquisition of signature data

Location systems for operation from behind the FEBA

Location systems using stations forward of the FEBA

Management of integrated Artillery Superiority Program (ASP)

### A. Acquisition of Signature Data.

The feasibility of using sensors not previously exploited for hostile artillery location requires signature and background data and propagation characteristics for evaluation. Table 1 lists signature types, estimated status of existing signature data, and recommended priorities for new data acquisition. Emphasis is on remote sensor operation, as opposed to signatures requiring overflights for detection. Recommendations with regard to specific signatures are:

1. Weapon Signatures.

a. Unintentional radiation

(1) Search for electromagnetic radiation from artillery and rocket firings over the frequency range from DC to 2,000 MHz, with particular emphasis on frequencies below 5 MHz where propagation beyond line of sight is feasible. Radiation above 5 MHz may also be useful in the development of airborne sensors.

(2) If useful signals are discovered, determine feasibility of countermeasures, i.e., suppression at the source by relatively simple means, both to eliminate this signature in the case of our own weapons, and to estimate the viability of this means of detecting enemy weapons considering possible enemy use of suppression means.

b. Effluent sensing.

Measure laser cross section and persistence of gases and dust cloud vs. laser wavelength for both artillery and rocket firings.

c. Scattered radiation from muzzle flash.

Extend existing measurements of detectability of muzzle blast of weapons in defilade via atmospheric scattering of IR radiation of flash.

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TABLE 1

SIGNATURE STATUS AND RECOMMENDED ACTION

| | Signature | Data Status * | Recommended Action ** |
|---|---|---|---|
| Weapon | Unintentional Radiation | C | A |
| | Laser Cross Section of Effluent Gases and Dust Cloud | C | A |
| | Atmospheric Scattering of Muzzle Flash | B | A |
| | Hot Tube Signature | B | B |
| | Metra | B | B |
| | Muzzle Flash | A | C |
| | Muzzle Blast | A | C |
| | Seismic Signature | A | C |
| Projectile | Temperature in Flight | C | A |
| | Subsonic Acoustic Signature | C | B |
| | Supersonic Acoustic Signature | A | C |
| | Radar Cross Section | A | C |
| | Impact Signature | A | C |
| Data Bank | (all signatures) | C | A |

*Data Status: A-Good to Excellent
B-Limited
C-Fragmentary or non-existent

**Recommended Action: A-Expedite Data Acquisition
B-Additional data desirable, but lower priority
C-Existing data probably adequate for concept evaluation

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d. Hot Tube Signature.

Extend existing measurements of range of detection with advanced IR sensors, emphasizing remote detection without overflight of gun position.

2. Projectile Signatures.

a. Infrared sensings of projectile in flight.

(1) Conduct program of measurement of projectile temperatures in flight.

(2) Measure power spectral density of background radiant emittance as seen by "staring" narrow field IR sensors in 8-14 micron range, under variety of meteorological conditions.

b. Subsonic acoustic signature.

Conduct limited program to determine detectability of subsonic acoustic signature of artillery projectiles. (This data may already exist.)

3. Data bank.

Establish central data bank of data on signatures, propagation characteristics, and background noise to bring together the large amount of information now available at widely separated and incompletely identified sources.

B. Location Systems for Operation from Behind the FEBA.

These systems are classical responses to the Army's requirements. Recommended actions are summarized in Table 2. Signature recommendations appropriate to this system class are repeated from Table 1, since each signature represents a potential new system. Recommendations with regard to specific systems are:

1. Counterbattery radar.

Expedite current development program. At present state-of-the-art the counterbattery radar is considered to have the highest probability of satisfying the established requirement.

2. Sound ranging.

a. Expedite the current effort to provide radio data link, automatic data processing, and improved meteorological data.

b. Evaluate the Johnsrud proposal to improve the solution by introducing sensings of projectile impact time and location and a priori knowledge of enemy firing table data.

c. Evaluate the possibility of obtaining additional solution improvement by introducing constraints based on acoustic sensing of the projectile, and determine feasibility of obtaining and integrating these sensings in system data processing.

d. Conduct comparative tests of US and foreign equipment instrumented in sufficient detail to identify sources of error, i.e., equipment or meteorological.

e. Conduct analysis to establish maximum attainable performance of "ideal" sound ranging equipment as a function of meteorological parameters.

f. Evaluate possible improvement in solution by employing forward emplaced meteorological sensors.

3. Location from airborne platform.

Emphasis in this section is on location from platforms operating behind the FEBA.

a. Continue component development of flash location system.

b. Develop reduced cost airborne coordinate reference systems.

c. Investigate feasibility of combining sensors with helicopter-borne MTI radar (ALARM) display.

d. Determine extended range detectability of muzzle flash of weapons in defilade via atmospheric scattering of IR radiation of flash.

[redacted]

TABLE 2

PROGRAM RECOMMENDATIONS

ARTILLERY LOCATION SYSTEMS FOR OPERATION BEHIND FEBA

| SYSTEM | RECOMMENDED ACTION |
|---|---|
| Counterbattery Radar | Expedite Development |
| Acoustic (Sound Ranging) | Expedite Improvements |
| Airborne Flash Ranging | Continue Component Development, Reduce Platform Costs |
| Polystation Doppler Radar | Monitor Current Program |
| SENSORS | |
| Infrared Projectile Tracking | Expedite Signature Measurements and Sensor Evaluation (System development potential contingent on signature measurement results) |
| Unintentional Radiation | |
| Laser Effluent/Dust Detection | |
| Atmospheric Scattering of Flash | |
| Hot Tube Detection | |




[redacted]

e. Determine extended range detectability of hot-tubes with advanced IR sensors.

4. Polystation doppler projectile tracking.

The polystation doppler technique is not considered far enough along at the present time to warrant expansion of the current effort. No action beyond monitoring of the current program is recommended.

C. Location Systems Using Stations Forward of the FEBA.

Location systems using stations forward of the FEBA involve judgements as to operational as well as technical feasibility. In general, they do not fit established requirements. They offer the unique potential of bringing the sensor close to its target. Since many of the system options involve considerations considerably beyond those of artillery location, recommendations include the assessment of system concepts on an overall basis, additional to the limited function of target location. Recommended actions are summarized in Table 3. Recommendations with regard to specific primary and supporting systems are:

1. Primary location systems.

a. Ground emplaced acoustic sensors.

Expedite development of a generic "Annie Oakley" type of system.

Operational feasibility and acceptable accuracy are considered to have been demonstrated.

b. Airborne platforms.

(1) Develop operational concepts consistent with probable tactical situations for employment of manned, drone, or RPV vehicles forward of the FEBA.

(2) Evaluate concepts for weapons location, including short-range as well as long-range sensors.

(3) Evaluate concepts for use of platforms for target location and designation for remotely fired homing weapons.

(4) Evaluate concepts for platforms operating in hunter-killer mode.

(5) For all concepts involving forward operations of airborne platforms, assess cost, vulnerability and possible jurisdictional problems as well as data acquisition, processing and transmittal.

2. Supporting systems.

a. Ballistic platforms.

(1) Expedite development of I-SPY type of system as means of pinpointing approximate weapon location derived from other means.

(2) Evaluate technical feasibility and cost of development of artillery projectile for obtaining meteorological data in flight.

## TABLE 3

## PROGRAM RECOMMENDATIONS

### SYSTEMS EMPLOYING STATIONS FORWARD OF THE FEBA

| SYSTEMS | | PRIORITY |
|---|---|---|
| Ground Emplaced Sensors Acoustic | Expedite Development | A |
| Airborne Manned Platform, Drone or RPV Weapon Location | Evaluate in conjunction with short-range as well as long-range sensors | B |
| Weapon Location and Designation for Remotely Fired Homing Weapons | Evaluate Concept | B |
| Hunter-Killer | Evaluate Concept | B |
| SUPPORTING SUBSYSTEMS | | |
| Ground Emplaced Sensors Meteorological Stations | Evaluate cost vs value | A |
| Ballistic Platform | | |
| I-SPY | Expedite | A |
| Meteorological Projectile | Evaluate | B |
| Satellite | Insure prompt availability of information of value to artillery | A |

b. Ground emplaced sensors.

Evaluate cost-effectiveness of forward emplaced meteorological sensors to support improved data processing of acoustic sensings as well as general improvement in artillery accuracy.

c. Satellites.

Determine information obtained by satellites of value in artillery operations, establish artillery need, and negotiate and establish information channels for prompt transmission information to artillery.

D. <u>Management of Integrated Artillery Superiority Program (ASP)</u>.

Hostile artillery location is only one element of the primary objective of securing artillery superiority on the battlefield. To maximize the attainment of the overall objective, it is recommended that all activities supporting the attainment of artillery superiority be coordinated in an integrated program. This program should include the functions of hostile artillery detection, location, identification, and destruction.

## V. Discussion of Requirements.

Artillery is expected to have a maximum range of up to 30 km and the Soviet unguided Frog rockets are credited with a range of up to 50 km (Frog-4). However, the heavy artillery and longest range rockets are placed closer to the FEBA than their maximum range in order to secure a wide lateral coverage. Figure 2 shows typical distributions of the artillery locations.

"Conventional" artillery location devices would normally also be located somewhat to the rear of the FEBA for protection against direct enemy attack and so the required location range would be comparable to that of the weapon being located.

"Counterbattery" targets are typically considered to cover an area of about 100 x 100 yards. Presumably this includes not only the gun or launcher, but ammunition stacks as well.

The usual objective in counterbattery fire is to obtain 30% personnel casualties among the artillery crew. This requires many artillery rounds to be dropped on the target simultaneously in a pattern. Round to round dispersion from a gun is sufficiently small, as shown in Figure 3, so that the principal errors causing reduction in fire effectiveness are those in target location and other errors, (e.g., incomplete meteorological corrections). The number of rounds required to obtain a specified casualty level increases roughly as the square of the probable error when this is larger than the target radius.

The objectives for accuracy of weapon location shown in Table 4, therefore appears reasonable for counterbattery fire with fragmenting weapons.

The Group observes that an unexploited method of economically neutralizing an enemy weapon for long periods of time is to cover its position with artillery delivered "scatterable" mines (such as the tripwire mine). Since the coverage need not be obtained in a single salvo, and the coverage persists until the mines are cleared, a large area can be covered with few guns and few rounds.

OPERATIONAL PROBLEM:

## PROBABLE LOCATION OF ENEMY ARTILLERY

DENSITY AS FUNCTION OF RANGE FROM RADAR (Tars - 75 Scenario)

| | KOREA | EUROPE |
|---|---|---|
| 50% of all weapons are located within | 12.2 km | 16.0 km |
| 90% of all weapons are located within | 16.0 km | 24.0 km |

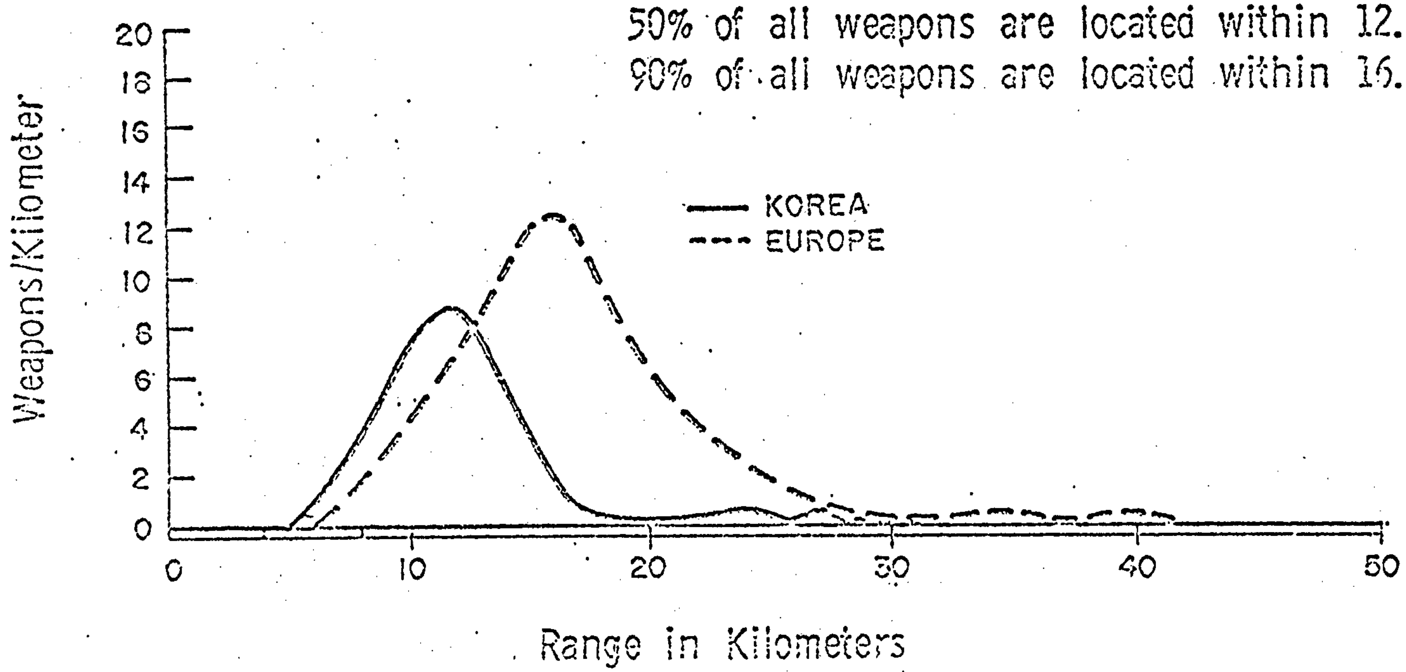




FIGURE # 2

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FIGURE 3

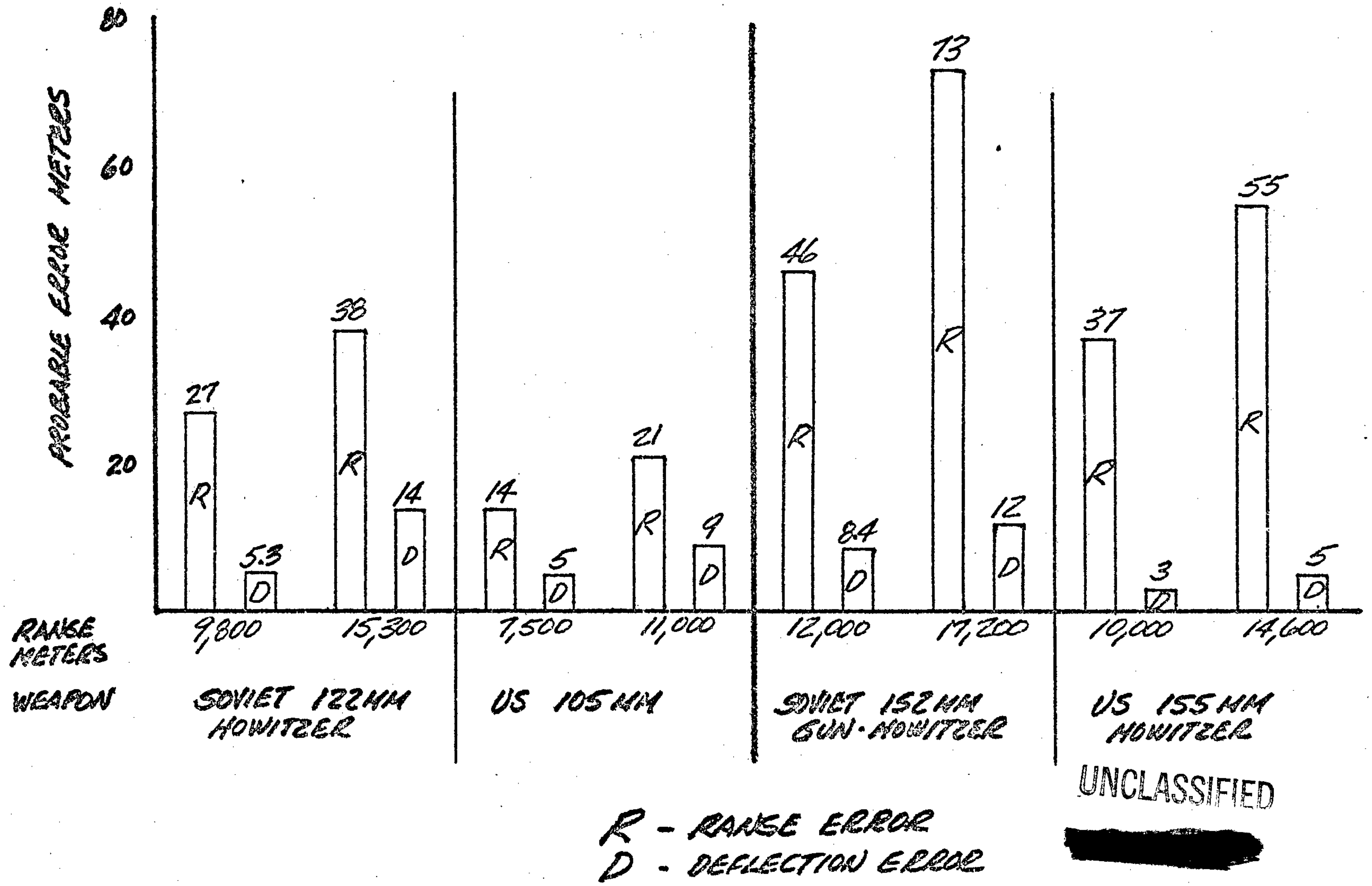


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FIGURE # 3

TABLE # 4

GENERAL DEVELOPMENT OBJECTIVES

| | |
|---|---|
| RANGE | |
| ARTILLERY .............................. | 35KM |
| MISSILES ................................ | 50KM |
| ACCURACY ................................ | 0.35% OF RANGE |
| AZIMUTH COVERAGE ........................ | AS GREAT AS POSSIBLE |
| AUTOMATIC OPERATION ..................... | FOR SPEED & ACCURACY |
| MULTIPLE TARGET CAPABILITY .............. | UP TO 10 TARGETS SIMULTANEOUSLY |
| FRIENDLY FIRE REGISTRATION .............. | DESIRED |
| SINGLE OBSERVING STATION ................ | DESIRED |

Since the mines can remain activated for any preselected period and large numbers can be delivered over the area, the joint effect of the casualties they produce and the time to clear them may have a cumulative suppressive effect many times that of conventional fire.

The number of pieces of artillery and rocket launchers covering a given length of the FEBA varies widely with the caliber. The number of shorter range weapons is very large compared with the number of weapons of great range. Hence most of the fire will originate at ranges much shorter than the 30-50 km maxima.

This suggests that a system meeting all other requirements except range, and with significantly lower cost than radar, can be used in combination with radar to obtain greater overall effectiveness for given total cost.

The required traffic handling capacity indicated in the requirement may be underestimated. It is noted that in World War II, the Russians averaged 140 artillery gun tubes for each 1000 yards of front in offensive operations, and in some cases this number was as high as 310 tubes per 1000 yards.

## VI. Direct Techniques for Hostile Artillery Weapon Location.

A checklist of methods of locating enemy artillery and rocket launchers developed by the Group is attached as Appendix I-3. The present section discusses those methods considered in detail by the Group. Methods for locating the artillery piece or rocket launcher are discussed first, then methods for sensing the projectile and deriving the launch position are discussed. None of the latter category was considered sufficiently competitive to conventional radar at this time to justify system development.

### SOUND RANGING TECHNIQUES

Historically, sound ranging techniques have proven to be a reasonably effective means of locating hostile artillery. The position of the field gun is usually calculated from the time differences between the arrival of the sound at three or more acoustic sensors located at known positions. Alternatively, the source position may be determined by triangulation from measured directions of arrival of the sound at two or more widely separated sensor arrays.

Three factors significantly affect the accuracy of this relatively inexpensive position locating device, namely:

- Variations in the speed and deviation in the direction of propagation of acoustic waves.
- Timing errors.
- The geometry of the deployed sensors, and associated data reduction procedures.

The most serious errors are propagation variations caused by meteorological and orthographic conditions, which also affect the range at which sound can be detected from its source.

In addition, temperature and velocity gradients in the atmosphere may deflect the acoustic waves upward so that they are undetected by a ground observer. A decreasing temperature with altitude refracts initially horizontal rays upwards. A head wind tends to refract acoustic waves upwards; a tail wind tends to refract them back toward the horizontal.

Limited Range

Under ideal conditions, atmospheric attenuation and divergence are the basic factors limiting the range at which the sound of a discharging weapon can be heard.

Atmospheric attenuation varies with the wavelength of the sound, approximately doubling at each octave band (0.525 dB/Km at 75 - 150 Hz; 1.08 dB/Km at 150 - 300 Hz). Acoustic frequencies associated with explosions and sound ranging have reported infrasonic ($\leq$ 25 Hz) components; examination of the 1969 Fort Sill microphone data indicate that the recorded sonic frequencies are in the order of 30 - 100 Hz. This is supported by the Meppin test data in which microphones in the 0 - 80 Hz range were used to record artillery discharges, which had an average frequency of 35 Hz.

On the basis of the impulsive duration of firearm discharges (approximately 5 M sec. for a 155 mm howitzer), a pessimistically high frequency of 1 KHz might be assumed for the highest propagation acoustic frequency, for which the atmospheric attenuation is in the order of 04.9 dB per Km. If we also assume a peak sound pressure level of 190 dB at a reference level of 0.0002 dynes/cm$^2$ for an artillery piece, at a unit distance of 1 m. from the muzzle, the effective detection range could then be calculated:

$$P_t = P_s - 20 \log(R) - 4.9R\,(10^{-3})$$

in which

$P_t$ - is the detectable signal (dB).

$P_s$ - is the source signal (dB).

R - is the range in meters.

When $P_t$ = 25 dB, the maximum detection range would be 16 Km under these assumptions. Assuming a statistical fluctuation of $\pm$ 10 dB of background noise, the probability of a 25 dB signal being a part of background noise, is 0.13. At a lower acoustic frequency of 500 Hz, the 25 dB limit is approached at 30 Km. Since sound ranging techniques utilize significantly lower acoustic frequencies, a realistic maximum detection for (155 mm) artillery pieces under ideal conditions might be over 25 Km.

The effects of terrain/vegetative attenuation are also dependent upon the acoustic frequency. In a European/American environment, it is expected that the battlefield would be perhaps 5% dense forest and 95% agricultural land. In tropical zones, one would expect something in the order of 30% cultivated or savanna land, 40% light forest and 30% dense rain forest. At source frequencies of 75 - 150 Hz, a weighted average terrain attenuation of approximately 41 dB/Km. is expected for flat tropical landscapes and 10 dB/Km. for an European theater.

Under such unfavorable conditions, attenuation drastically reduces the effective range (see Table 1).

Although terrain attenuation may radically limit the effective range of acoustic systems, direct ray paths between source and sensor and curved paths over undulating terrain are not appreciably influenced by terrain attenuation. Assuming that under average battlefield conditions, approximately 10% of the ray path is affected by terrain attenuation (5% at each terminal of the paths), 500 Hz sound propagation in the European theater would attain the 25 dB threshold at approximately 17 Km.

Wind conditions seriously degrade the effective range; an irregular wind of 6 - 12 M/Sec. attenuates sound, in the 200 - 1,000 Hz frequency band, by approximately 50 dB/Km. Presuming that irregular wind conditions affect 10% of the ray path, the 500 Hz sound propagation would reach a 25 dB threshold at approximately 10 Km.

The significance of atmospheric conditions on sound ranging cannot be over-emphasized. Even light winds and anomalous temperatures, if ignored, readily destroy validity of acoustically determined positions.

TABLE # 1

| Range (Km.) | SPL (dB) (1) | *SPL (2) (dB) | | | SPL (3) (dB) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Tropical | | European | |
| | | 1 KHz | 500 Hz | 100 Hz | 500 Hz | 100 Hz | 500 Hz | 100 Hz |
| 0.3 | 142 | 141 | 141 | 142 | 115 | 131 | 136 | 140 |
| 0.5 | 136 | 133 | 134 | 135 | 91 | 115 | 119 | 130 |
| 1.0 | 130 | 125 | 127 | 129 | 40 | 88 | 98 | 119 |
| 2.0 | 124 | 115 | 119 | 123 | | 41 | 61 | 103 |
| 4.1 | 118 | 98 | 109 | 116 | | | | 76 |
| 8.2 | 112 | 72 | 92 | 108 | | | | 28 |
| 16.4 | 106 | 26 | 66 | 98 | | | | |
| 25.0 | 103 | | 42 | 90 | | | | |
| 32.7 | 100 | | | 83 | | | | |

* - Sound pressure level (SPL) is referred to 190 dB above 0.0002 dynes/cm$^2$ at 1 M.

(1) Divergence effects only.

(2) Atmospheric and divergence effects.

(3) Atmospheric divergence and terrain effects.

## Meteorological Data Requirements

Experimental data collected at the Meppin Proving Ground were analyzed to estimate the required frequency and types of meteorological data needed to support acoustic systems for precise source locations. When using averaged meteorological data collected one hour before the event, the actual propagation velocity varied from that predicted by 1M/Sec. Averaged data, up to two hours old, gave corresponding errors of 2 M/Sec.

With a relative system timing accuracy of 0.03 seconds, 1 M/Sec. propagation errors lead to a 27 meters location error at 10 Km. under otherwise ideal conditions.

The referenced analysis concluded that meteorological data should be acquired every 30 minutes, if accuracies in the order of 0.5% of range are to be consistently obtained by acoustic ranging. In addition to temperature and humidity profiles, measurements of wind strengths and directions should be obtained and used in the range computation.

To satisfy these data requirements, and the associated computational difficulties, it would be necessary that all data be transmitted and processed at a central field computing center.

The problem of obtaining frequently updated meteorological data over hostile territory for artillery fire is a continuing one. It is particularly important to obtain the variations in the wind vector along the acoustic paths from the enemy weapon to the sensors.

Several concepts in support of this objective were discussed by the Group, as follows:

(1) Development of an artillery round that telemeters back meteorological data useful to the artillery and to acoustic artillery locators. The data might include side acceleration and excess drag acceleration due to wind, static air pressure, and temperature.

(2) Complete meteorological data might be obtained through the employment of forward emplaced existing USAF air-droppable transmitting meteorological sensors.

(3) The I-Spy projectile might serve as an indirect means of obtaining meteorological data, as the system resolution and associated data reduction procedures are improved, using trajectory deviations to assess wind velocities over the flight path. If the projectile were also equipped with an impact fuze and HE charge, the impact detonation and trajectory information might be used to calibrate sound ranging sensors.

The Group has no recommendation for expedited action with regard to the development of new meteorological sensors, but emphasizes that the value of acoustic location systems is a sensitive function of the quality and currentness of available meteorological data.

Geometric and Computational Aspects

The accuracy of sound locating systems depends on the precise survey of the sensor positions and their deployment in a configuration which leads to a strong geometric solution.

Base line system deployment, in which the sensors are located parallel to and along FEBA, is frequently the only possible configuration. The number of sensors, their mutual separation and distance from the artillery, contribute to the expected positional accuracy that can be obtained.

For example: Consider a base line system comprised of two sensors, separated by 10 Km and at distances of $S_1$ = 14 Km. and $S_2$ = 10 Km. from the gun. Let the range errors $dS_1$ and $dS_2$ be 0.5% of $S_1$, $S_2$. The standard circular error $M_p$ in locating the gun by trilateration may be calculated from:

$$M_p = \left[(dS_1 \cos \theta)^2 + (S_1 \sin \theta \, d\theta)^2\right]^{1/2}$$

since the azimuth angle $\theta = 45^\circ$. $\theta$ is the aximuth of the line S, with respect to the base line, and $d\theta$ is its expected error, computed from $dS_1$ and $dS_2$. Substituting numerical values leads to a position error of $M_p$ = 228 meters. However, if the two sensors were both 14 Km from the gun, and separated by 20 Km, a circular error in the order of 110 meters is expected.

Distributed or clustered sensor arrays, which furnish some directional information, provide added constraints to the position calculations, and should be more precise. Furthermore, improved resolution of ambiguities should result from this configuration.

The deployment of sensors for optimum location accuracy, when gun locations are approximately known, may be assessed through a rigorous error analysis. Recent experimental tests performed at Fort Sill to evaluate seven different sound ranging systems did not furnish results suitable for either a geometric analysis or a comparative system error analysis. Although this may be attributed to poor experimental design or data reduction techniques, a re-examination of these data should be made in order to determine the causes of the poor results. In this regard, additional constraints imposed in the range/position computations and improved computational techniques, if capable of being effected rapidly, may be of significant value in accurizing sound ranging systems.

## Additional Constraints on Solution

A particularly ingenious procedure for employing additional information in the solution of the sound ranging problem has been suggested by A.E. Johnsrud. The concept is to combine with the sensing of the muzzle blast, the time and location of projectile impact, and a priori information on the enemy firing tables. Assuming that the weapon type can be identified and that a set of time of flight vs. range functions is available for each of the discrete weapon charges, Johnsrud has shown in a preliminary analysis how to combine the sensing to determine (1) the most probable charge used, and (2) the most probable weapon position. He also indicates that a significant improvement in accuracy of estimation of the range to the enemy weapon may be achieved by the imposition of the additional information and constraints on the solution.

The associated data processing is moderate, and the potential of the method should be carefully evaluated.

## Forward Emplaced Sensors

The most straightforward way of minimizing the adverse effects of meteorogical degradation of sound ranging accuracy is to emplace the sensors as close as possible to potential or suspected enemy artillery positions. The associated operational problems of placing the sensors in hostile territory, locating them, and transmitting data back to a data processing station on friendly soil have been worked out, and the most recent analyses of generic Annie Oakley data and field demonstration of this type of system exhibit excellent performance, both with regard to accuracy of weapon determination and suppression of false solutions.

Given the ability to emplace forward sensors, the Annie Oakley type of system appears to have the highest potential of all sound ranging systems of providing accurate location data against remotely emplaced enemy weapons.

For those situations where forward sensors are not available, conventional sound ranging systems are considered to have a cost effective supplemental role which can be enhanced by simplified design and operational characteristics, the provision for using more frequently updated meteorological data and centralized data processing.

A completely unexplored potential for improvement of the solution obtained from conventional sound ranging is the use of information on the point and time of shell impact in conjunction with a prior knowledge of enemy weapon ballistic data as suggested by Johnsrud.

## Conclusions

There is a wide difference of opinion on the capability for artillery location which can be achieved by sound ranging. Some of the references cited indicate the potential of good range and accuracy; user tests with seven sound ranging systems at Fort Sill generated very poor results. These differences should be resolved. The components of a sound ranging system have such a low cost, compared with altnerate methods of location, that it is highly desirable to conduct engineering experiments to identify the various error sources and the contribution of each to overall location error. This would include meteorological sources of error, the determination of which error components could be reduced by better meteorological data and the random residue as related to meteorological conditions. In particular, the frequencies with which unfavorable meteorological conditions might be encountered in various theaters of observation should be determined.

Emphasis in the final system design configuration should be on a reasonable balance between the complexity of the data processing and the marginal improvement from added equipment.

The objective should be to develop a sound ranging system which is a reasonable compromise between the accuracy attained and the cost of achieving that accuracy, and which achieves the basic characteristics of ease of deployment and reliability and operation and relatively unskilled personnel.

## AIRBORNE FLASH RANGING AND ASSOCIATED DETECTION MEANS

Flash ranging systems are somewhat weather limited, and if ground based can be severely line of sight limited. Airborne systems can obtain a line of sight to much greater ranges. The weather limitation is considerably mitigated by the intensity of the source. It has been estimated by ECOM, in ECOM-3386, that with a 2.0 to 25 micron sensor a large caliber gun can be detected at 30 Km when the visual meteorological range is only 10 Km.

Component development has been carried to the demonstration of feasibility. The principal disadvantage of the present concept is the cost of the airborne equipment for determining the aircraft position and orientation at the moment of flash sensing with sufficient accuracy to meet the location accuracy requirements of the detected flash. Although this cost may be amortized over other target location functions of the aircraft it would hinder the acquisition in quantity of airborne flash ranging units. Nevertheless, the demonstrated capability of this approach is sufficient to justify further component development, emphasizing cost reduction.

An alternate method of locating the gun position, discussed by the Group is to superimpose the flash sensing on the display of a side-looking or a helicopter-borne MTI ("ALARM") radar. The gun position might then be referenced to identifiable terrain features. Acronymically, this Flash Integrated Representation Equipment might be designated FIRE ALARM.

The possibility of detecting enemy artillery by infrared detection of the hot barrel after firing was considered. Some experimental data taken with the AN/AAS-18A Infrared Reconnaissance System indicates an existing capability to detect and identify exposed 8" and 175 mm hot tubes over an hour after firing in an overflight at an altitude of 1500 feet; 105 mm tubes were detected and identified from 750 feet. Camouflage, consisting of overhead canvas, effectively prevented detection of the tubes. Detection capability fell off rapidly with increased altitude and non-vertical viewing. The Group did not attempt to estimate how much detection range might be increased with improved sensors of increased thermal and spacial resolution, but additional investigation is considered desirable.

It is also possible that scattered radiation from the gun flash will permit detection at useful ranges, even though a direct line of sight to the weapon from the sensor is not available. A report of higher classification contains experimental data. For long range detection of enemy weapons from behind the FEBA, however, neither of these phenomena appear useful, based on current data, although they might be exploited at relatively short ranges or from overflights.

## LOCATION BY DETECTION OF UNINTENTIONAL ELECTROMAGNETIC RADIATION

There is very little experimental evidence related to the possibility of detecting or locating artillery via unintentional electromagnetic radiation produced by muzzle blast or related effects. However, recent experiments have shown that 30-calibre small-arms fire can be detected up to 1 mile away using wide-band receivers tuned to center frequencies in the range of 100 to 2,000 megahertz. One brief set of observations at these frequencies was made of large caliber weapons, with some successes. Nonetheless, it seems reasonable that the E-M energy thus radiated should be proportional to the size of the propellant charge, suggesting that artillery location might be feasible.

The following factors seem relevant as background for future planning:

1) E-M observations to date have concentrated in the frequency range from 50-to-2000 MHz; there seems to be no available information on possible radiation below this range.

2) In the range where measurements have been made, it is noted that the E-M radiation occurs as a very short pulse, typically lasting from 0.2 to 10 nanoseconds. Because the pulses are so short (at least in the frequency range where measurements have been made), the spectrum of the radiated energy is coherent over a very wide bandwidth, and the signal-to-noise ratios are hence improved as the receiver bandwidth is increased. This requirement for wide bandwidth suggests that large center frequencies are called for.

3) In detecting small-arms fire, there is not much difference between the results seen at 100 MHz and those at 1,500 MHz.

4) There is no available information concerning low-frequency radiation from large field pieces. However, it is at these low frequencies that one might expect to find substantial emissions from the massive plasma discharges from the barrels of large artillery pieces when they are fired. It is signals at low frequencies (HF, LF, VLF, and ELF) that can propagate

beyond the horizon, be received by ground-based observers, and afford reasonably good precision of source location using direction finding techniques.

5) No record has been found of measurements of electromagnetic radiation associated with the launch of rockets.

RECOMMENDATIONS:

1) Data should be obtained, in various frequency bands from DC up to at least 1,000 MHz, on the possibility of using E-M radiation to detect the firing of artillery pieces and rockets. No new receiver development is believed necessary for preliminary experiments; readily available commercial units might be adapted.

2) Not only should the radiation be measured; it should also be determined whether the radiation can be completely suppressed by simple means. This step is a precaution against developing a sensing system that might be easily countered by the enemy; it would also provide protection of friendly equipment against similar enemy sensings.

3) Available information and experience in this area, such as resides with the Navy Weapons Lab at Dahlgren and Lockheed Aircraft Company in Sunnyvale, should be exploited.

4) If preliminary results are encouraging, a more detailed study of the nature of the unintentional radiation, including its causes, its spectral content, and its duration, would provide the necessary information to determine the feasibility of using unintentional E-M radiation for artillery location.

## LIDAR (LASER)

LIDAR means "light detection and ranging" - that is, optical radar. It is line-of-sight limited. However, the particulate matter emitted from a gun barrel or kicked up on firing rises above the gun, and may attain sufficient height to be visible above terrain that masks the gun from an observer. This cloud can be detected by LIDAR.

Stanford Research Institute made experimental observations using a neodymium laser radar operating at 1.06 microns, having a 50 megawatt peak power, a pulse of 12 nanoseconds width, and a maximum p.r.f. of 1/5 per second. A six-inch diameter aperture was used in the receiver. Modal detection ranges projected from experimental data were 5 km for mortars and 9 km for 155 mm howitzers. Note that the average transmitter power at max. p.r.f. was 0.12 watts. In order to be a useful artillery detection device, a LIDAR should emit one pulse per beamwidth (0.2 milliradians), and perform a 45$^\circ$ horizon scan (just above the terrain mask) in, say 20 seconds, the time it takes a dust cloud to rise above the mask, and before the cloud has a chance to disperse. This suggests a p.r.f. of roughly 200 per second, for a minimum required average power of 120 watts, assuming 0.6 joule per pulse. A further increase of a factor of 10 may be necessary to increase detection range and overcome field degradation. So we are suggesting laser transmitters of average power between 120 and 1200 watts. This is conceivably within the current state of the art, either with a single laser or with a multiplicity of lasers. Recently this same phenomenon of detecting particulate matter ejected by guns with lasers at kilometer distances has also been demonstrated with the 10.6 micron $CO_2$ laser which can easily achieve the power levels stated previously; therefore, it would appear that this technique deserves further investigation.

Medium power lasers have a potential for detecting emissions from guns which have been fired. The following calculations are based on the $CO_2$ contained in the burning propellant, but other gaseous components and indeed even those present during ammunition storage, etc., might be detectable also. This is clearly quite an unexplored field, and one that deserves review both because it may offer a solution to the present problem, but it also may have significant long-term applications to other problems such as locating a concentration of internal combution engines, campfires, etc. One would envision the system operating by sending out an intense pulse of 10.6 micron laser radiation which would propagate through the atmosphere and be scattered by the hot $CO_2$ discharged from the gun barrel. This mode of operation may have one distinct advantage in that the gases issuing from the gun barrel would tend to move at or above the speed of sound and propagate upward very rapidly, whereas the shell burst from counterbattery fire should not give such a violent upward blast of gases, and therefore a much smaller signal, and may provide a means of discrimination between gun firings and our counterbattery fire. As a typical example,consider the following scenario.

Consider a light base situation in which the visibility is several kilometers. The gas ejected from the gun firing is assumed to be a column 1 meter diameter and contains 50% $CO_2$ at 500°C. The laser transmitter is scanned at a single elevation near the horizon over a 90 degree field of view in one second. This method of employing the laser beam differs fundamentally from a microwave radar artillery locating device in that the target which is to be located is assumed to be detectable for at least 1 second, which is not the case with a fast moving artillery shell. Further, since it is assumed that the cloud of hot $CO_2$ will remain in the near vicinity of the gun, say, a few tens of meters for this one-second time interval, calculation involving back plotting the trajectory is not required. Therefore, a standard PPI scope-type presentation with the field of view swept every second not only reduces the data rate requirements of the entire system because of the slow sweep speed, but makes the problem of multiple target handling almost trivial since if several guns are fired at once this would simply show up on the scope as several discrete returns which are then located. The range information is, of course, obtained in the normal radar time-of-return mode. The laser transmitter aperture is 50 centimeters, and the receiver aperture is also 50 centimeters. The laser transmitter is pulsed at a 30 kilohertz repetition rate. The receiver is assumed to be a heterodyne-type receiver with a heterodyne efficiency of 30%, and the bandwidth is assumed to be 1 megacycle. With the optics described above, the spot at a range of 5 kilometers will be 24 centimeters in diameter. This diameter assures that several pulses will be incident upon the $CO_2$ cloud which is only 1 meter in diameter.

Lacking concrete data, it would be best to take the most pessimistic case for the reradiation of 10.6 micron radiation from this hot $CO_2$ cloud, and this was calculated by considering the loss of 10.6 micron radiation due to collisions predominately with nitrogen and $H_2O$ in the atmosphere and assuming that the radiation was isotropically emitted. Also, the branching ratio between 10.6 micron and 4.3 micron radiation to the ground state was included. 4.3 micron return radiation was not considered as it is strongly absorbed by the $CO_2$ in the atmosphere.

Using the best available numbers, it is calculated that for every photon absorbed in the $CO_2$ cloud, approximately $10^{-7}$ photons will be reradiated from the cloud. We will further assume a false alarm probability of $10^{-6}$ and also require that the possibility of detecting a single return pulse be 99%. The above requirements give a required signal-to-noise ratio of 16 db. One can then calculate the required power as a function of range. Two points were chosen and at a range of 3 kilometers only 7.6 kilowatts of average laser power is required, and at 5 kilometers 82 kilowatts of laser power would be required. It should be noted that the required power is going up more rapidly than the range squared due to the attenuation of the 10.6 micron radiation under the haze conditions assumed.

It should be emphasized that the amount of scattering that has been assumed in this exercise has been purposely made extremely conservative, and therefore it is possible that a stronger signal may result. In addition, it should be pointed out that this whole field of laser beam probing to determine atmospheric constituents has seen quite a bit of activity in the area of atmospheric pollution studies and is expanding at a very rapid rate. It is recommended that a modest experimental program using the 10.6 micron laser radar described, interacting with $CO_2$, be carried out, as well as the use of other laser systems which show promise of giving signals from gun firings.

The most useful information to determine feasibility would be a complete measurement of "laser cross section" of the effluents associated with artillery and rocket firings, as a function of illuminating frequency. This could be used to determine what laser wavelength might give unique signature detection and identification. It has been suggested that a better match of illuminator to target might be achieved if, instead of $CO_2$ for example, the illuminator were able to lase a mixture of the predominant constituents of the propellant gases which it is attempting to detect. For example, one might expect to find water vapor which is undoubtedly present in the burning propellant to have a serious detrimental effect on the laser output, whereas other species such as CO, $CH_4$, $NH_3$, NO, etc., might be quite compatible with laser operation. This, of course, would be a matter for further research and development.

## PASSIVE SPECTROMETRIC SENSORS

The use of airborne and ground based spectrometers to detect gas traces in the atmosphere suggests that spectrometers could be employed for detecting effluents from artillery pieces. Discussions with representatives of Barringer Research indicate that a clear weather system could probably be developed.

Currently Barringer's Airtrace TM is used to detect gas traces having an absorption in the 2.5 micrometer band. It has been successfully used to detect carbon monoxide, carbon dioxide, methane, propane and water vapor, and should be applicable to the detection of any hydrocarbons. The sensitivity of the system is reported to be in the order of $10^{-13}$ gm/litre.

A brass board telescopic model, having a 2 degree field of view, and weighing 100 lbs., is being used by Barringer for experimental purposes. A narrow angle telescope system, with a field of view less than 0.25 degrees, man portable, and having an effective range to the horizon is considered feasible.

From spectral data on artillery firings collected and reported by Frankin Institute in AMC 706-255 and the reported Airtrace TM Parameters computations done within the group indicate a possible effective range against a 155 mm gun of about 11 km with a $1^o$ field of view, based on $CO_2$ sensing.

It should be possible to develop a unit with scanning optics and an encoder, enabling azimuths to be recorded. Two or more such units could then be used to triangulate the position of emitted gases. The possible disadvantages of such a system, if developed, would be:

1. Its probable limitation to one specific absorption band.

2. Response time between signature detection and target location (computational lag).

3. Inaccuracy, estimated at 300m. at 15 kilometers.

4. Atmospheric scattering/attenuation and weather limitations.

5. Line of sight requirement.

Advantages would appear to be:

1. Insensitive to saturation.

2. Portability.

The disadvantages are considered to outweigh the advantages of this method.

## METRA

The Group considered the potential of the METRA phenomenon as a means for locating enemy artillery. Since it appeared that the limited detection range currently obtainable by this means could be overcome only by an overflight of the weapon position, and the focus of the Group's attention was on systems capable of artillery location from positions behind the FEBA, METRA was not considered to be useful within this limitation. However this conclusion should not be considered prejudicial to the possible use of METRA in aircraft overflying enemy terrain.

## SEISMIC SENSORS

The possible use of forward emplaced seismic sensors was considered by the Group. Although some interesting findings on the possibility of weapon identification as well as location by seismic sensings were reviewed by the Group, it was concluded that the difficulty of calibrating local terrain seismic signal propagating characteristics, as well as the relatively limited range of the sensors, make the choice of forward emplaced acoutic sensors preferable.

VII. Supporting Systems.

The following systems may provide information of value in artillery location, but are not considered to qualify as primary systems.

## I-SPY PROJECTILE

The I-Spy projectile is a device employing a conventional spinning artillery projectile containing a point detector. Images are generated by the spinning action and the forward motion. By proper matching of the aperture to the spin rate, and transmission of the signal back to a ground station, a ground picture can be reconstructed without additional processing for a limited segment of projectile trajectory about the apogee. Additional ground data processing is required for image reconstruction from the ascending or descending portions of the trajectory.

Analysis by Dr. Paul Kruse (ASAP) of a day system, and demonstration of a day system using a silicon detector by the Naval Ordnance Laboratory, indicate the feasibility of the system. The Naval Ordnance Laboratory has proposed a day-night IR system using an indium antimonide detector operating in the 3-5 micron range. The sensing element is designed to fit a projectile by replacing the conventional fuze.

Dr. Kruse's analysis indicates ground resolution of 2-4 feet from a 5000 meter apogee. This is a "worst case" analysis. Better resolution at lower altitudes from the far trajectory leg should be obtained if the data is rectified by processing. Lower and flatter trajectories would also provide superior resolution over longer trajectory segments. However, 2-4 feet resolution should be sufficient to identify artillery.

The system does not qualify as a primary means for artillery location because of its limited lateral search capability. It might, however, be used to locate artillery against recognizable terrain configurations given an initial approximate fix obtained by some system of lower accuracy.

In fact the I-Spy system is considered to be a highly attractive concept since it places under the immediate control of the artillery battery commander a means of conducting prompt, if limited, reconnaissance over his area of responsibility. Targets, when identified, can be referenced to surrounding terrain features and then located on artillery maps for counterbattery fire. The effects of counterbattery fire may be assessed by follow-up rounds.

The I-Spy is conceptually competitive with reconnaissance drones. The drones may, however, require more expensive on-board equipment for scanning, whereas the more costly components of the I-Spy system remain on the ground.

Dr. Kruse indicates that there would be a significant cost difference between a day and a night system, with a cost of about \$10 for a silicon detector and a cost of about \$700 for an InSb detector. No estimates are available on the cost of ground equipment.

It is concluded that I-Spy constitutes a new capability of high potential value in supporting the hostile artillery mission and that exploratory development should continue. Without prejudicing the findings of a future comprehensive cost-effectiveness analysis, it is suggested that a reasonable cost objective for acceptability might be that the ground equipment cost no more than one self-propelled heavy artillery piece, \$150,000, and that the cost of one round of I-Spy not exceed that of two rounds of Improved Conventional Ammunition, \$600.

## USE OF SATELLITE INFORMATION

Space-borne targeting and mapping systems have been actively deployed and effectively used during the past decade for intelligence purposes. Although the U.S. satellites are believed to be deployed for strategic purposes, it is well within the state of the art to fabricate and deploy a contingency satellite which can be maneuvered into an appropriate orbit on command, to furnish high resolution intelligence data of a selected hostile area.

The conventional reconnaissance satellite, operating at an altitude of 125 - 300 km., provides complete coverage of the earth's surface with usual sensors every 14 days. The probability of detecting an artillery piece at the instant of discharge with such a system is extremely small, however, for pre-survey of target areas, such a system would be valuable. If tactically useful intelligence data, believed to be currently gathered by satellite systems, were made available to battalion commanders, targeting problems might be greatly reduced.

Tactical reconnaissance systems in a nominally polar orbit could be furnished with a significantly improved orbit-adjust capability and real-time readout when within range of tracking stations. However, orbit adjustment usually requires a minimum of three revolutions for completion. This implies a delay of about five hours after command that the satellite would be on site for tactical reconnaissance.

It would be more appropriate to employ a specially-designed orbiting system, which had both a quick-response, orbit-adjust capability and ultra-high resolution, electro-optical sensors which could be pointed at pre-assigned/commanded target areas. It is noted that the space-hardened, optical-bar panoramic camera, carried on the recent Apollo missions, has a dynamic resolution of over 125 l/mm. At an altitude of 125 km., the radial ground resolution is 1.6 m. Relative mapping accuracies in the order of $\pm$ 20 m are obtained from this system. Consequently, we must assume that current reconnaissance systems have at least this capability.

Data transmission to intelligence headquarters could be via military communication satellite(s), thereby decreasing the lag between data capture and evaluation. Recently published information in the open literature imply that such tactical satellite systems are actively deployed by USSR.

It is recommended that:

1. If information obtained from satellites is capable of being used to locate hostile weapons (before, during, or after firing), this information should be made available to tactical units in a form and within a time frame useful to the tactical units to locate and counter the hostile weapon.

2. That DA actively participate in proposed or existing studies relating to contingency or pointing satellite systems, in order that the Army's requirements can be accommodated during final design stages.

## AIRBORNE PLATFORMS

The utility of airborne line-of-sight artillery locators is critically dependent on the existence of cheap and accurate means for determining the location and orientation of the airborne platforms in real-time at the instant the target is located.

Therefore little effort should be devoted to airborne locator systems until the platform location and orientation problem is resolved. Conversely, techniques for determining aircraft position and orientation should be intensively investigated, and the development of appropriate techniques should be encouraged.

VIII. Projectile Tracking Techniques.

COUNTERBATTERY RADAR

The Ad Hoc Group on Hostile Artillery was briefed on the Army's plans for development of counterbattery radars and concurs completely with the report of the ASAP Ad Hoc Group for Artillery Locating Radar, which stated:

"While methods other than radar can be used for the location of enemy artillery (flash locators, seismic locators, optical sights, infrared sensors, sonic locators) none but radar have the demonstrated capability to deliver precise locations beyond the optical horizon. Radar accomplishes this by tracking incoming projectiles, determing their trajectories, and extrapolating back to their origins. Thus there is a need for the unique artillery locating capability that radar can provide" ...

"A number of things have happened in the fifteen years since the AN/MPQ-32 development was begun that favor successful development of a new counterbattery radar system at this time; and seem to mitigate against the possibility of the kind of technical and financial catastrophe that befell the AN/MPQ-32" ...

"The Ad Hoc Committee indorses the expedited development of the counterbattery radar" ...

POLYSTATION DOPPLER

This is a multiplicity of wide-beam C.W. transmitters and receivers operating "polystatically" to derive doppler histories of target returns and compute trajectories therefrom. The scheme requires at least five and probably eight fixed and carefully surveyed tower emplacement of the transmitters and receivers, an approach that seems inconsistent with the need for force mobility. The system's ability to properly associate the multiple doppler returns and produce proper trajectories when multiple targets are in view has not been demonstrated. The computational problems are enormous and as yet unsolved; near real-time simultaneous tracking of many doppler histories is necessary and the compution of a single target position from its doppler histories requires the inversions of a matrix of about 20X20.

The system could possibly be improved by using coded-pulse transmitters and pulse compression at the receivers to permit range determination and range resolution of target returns, and thus mitigate the track-association and trajectory computation problem.

Army support of developmental or experimental effort on the polystation doppler system should not be undertaken without a very specific preliminary system design that comes close to meeting Army artillery location objectives. Some support to a concept study intended to lead to such a preliminary design is, however, justifiable.

## COMPARISON OF RADAR, INFRARED, AND ACOUSTIC PROJECTILE TRACKING TECHNIQUES

The Group considered several alternative methods of locating hostile artillery by observing projectiles inflight, deriving sequential position estimates, and computing weapon location by extrapolating the estimated trajectory back to its source.

On the basis of obtainable signal to noise ratio, relative immunity to adverse weather conditions, single station operability, and cost, none of the alternative methods appear competitive with radar. The ability of radar to track projectiles at extended ranges, during the initial trajectory segment, minimizes errors of trajectory extrapolation and this can be done under almost all weather conditions.

The other two alternatives considered were infrared and acoustic projectile sensing. These are discussed below.

### Infrared Sensing of the Projectile.

The ability of infrared sensors to detect projectiles in both the near and far infrared regions has been demonstrated experimentally to a limited degree.

In the near infrared region detection has been accomplished by sensing the passage of the projectile across a narrow field of view, with the possibility of either positive or negative signals relative to background; the former when the projectile reflects solar radiation, the latter when it contributes no signal, but obscures a small portion of the background within the field of view. In the latter case, sensings have been obtained of projectiles obscuring less than $10^{-3}$ of the field of view.

In the far infrared region (8-14 microns) artillery projectiles have been observed in flight with FLIR from positions near the artillery piece. However, no successful sensings were reported to the Group which were obtained by scanning type far infrared sensors viewing the trajectory from down range. As discussed below, the Night Vision Laboratories have proposed a non-scanning system, which their computations indicate will successfully detect a projectile from a down range position in favorable weather. The only infrared system presented to the Group for weapon location based on projectile sensing was this preliminary concept proposed by the Night Vision Laboratories.

The Night Vision Laboratories concept proposes to accomplish trajectory extrapolation based on sensings from spaced arrays of infrared sensors, operating in the 8-14 micron region. Each array is proposed to consist of several thousand sensor elements, each with about a 1/2 milliradian field of view. Arrays, at least two of which are required to obtain a solution, might be spaced several kilometers apart. The system is non-scanning and the number of sensor elements results from the desired accuracy for trajectory reconstruction and the desired maximum range. For the preliminary concept, a maximum range objective of over 30 Km was assumed.

In estimating the ability of an individual sensor element to detect the passage of an projectile through its field of view, a principal uncertainty results from lack of information on the temperature of the projectile relative to its background. A second unknown is the rate at which the radiant emittance of the background, as seen by a single sensor element, may change with time.

The change in irradiance at each sensor caused by the intrusion of a projectile will normally be very small. Differences in the radiant emittance of the background as seen by individual sensors may be significantly greater than the change caused by the projectile and in addition relatively large, slow changes in background level will be caused by passage of clouds. Night Vision Laboratory proposes to "bias out" the background level, presumably by use of a filter which will not pass signals from zero to a few Hz.

Such a filter will also exclude projectile signatures when the projectile passes very slowly through the field of view, as on almost directly incoming paths. However, the intent is to orient the array to view the airspace at a low elevation angle. This reduces the probability of sensing being interrupted by cloud cover, allows detections when possible to be made at the trajectory segment near the gun, and insures a relatively high crossing angular velocity of the projectile through the field of view. Problems associated with possible screening of the sensor by battlefield smoke have not been assessed.

Some elementary computations were done within the Group, which generally confirm the Night Vision Laboratory estimates of detectability, given Night Vision Laboratory estimates of projectile temperature. The range of detection can be shown approximately in parametric form using the following expression:

$$r^2 \tau_a^{-1} \cong \left[ |\Delta T/T| \; / (S/N) \right] \frac{A_p \; D_o \; D^*}{\omega (f/no)(\Delta f)^{1/2}} (R \, \tau_o)$$

where

$r$ = range at which a specified signal to noise ratio is obtained.

$S/N$ = signal to noise ratio

$A_p$ = projectile area

$D_o$ = diameter of the collector optics

$D^*$ = detectivity of the sensor element

$\Delta f$ = signal processing bandwidth

$\tau_o$ = transmissivity of the optical system

R = radiant emittance of background within the effective sensor wavelength band

T = equivalent balckbody temperature of background ($K^o$) ($300^oK$ for this example)

$\Delta T$ = difference between background and projectile temperature

$\omega$ = angular view of the sensor (milliradians)

$\tau_a$ = transmissivity of the atmosphere

The relation is only valid for small $|\Delta T/T|$ with T in the neighborhood of $300^oK$. (See Appendix I-6).

For different emissivities $\epsilon$ of background and target, replace $|\Delta T/T|$ by -

$$/\Delta T/T \;-\; 0.25\,\Delta\epsilon/\epsilon\,/$$

Figure 3 sketches the relationship of detection range to temperature difference and signal/noise ratio for several values of $\alpha$, where

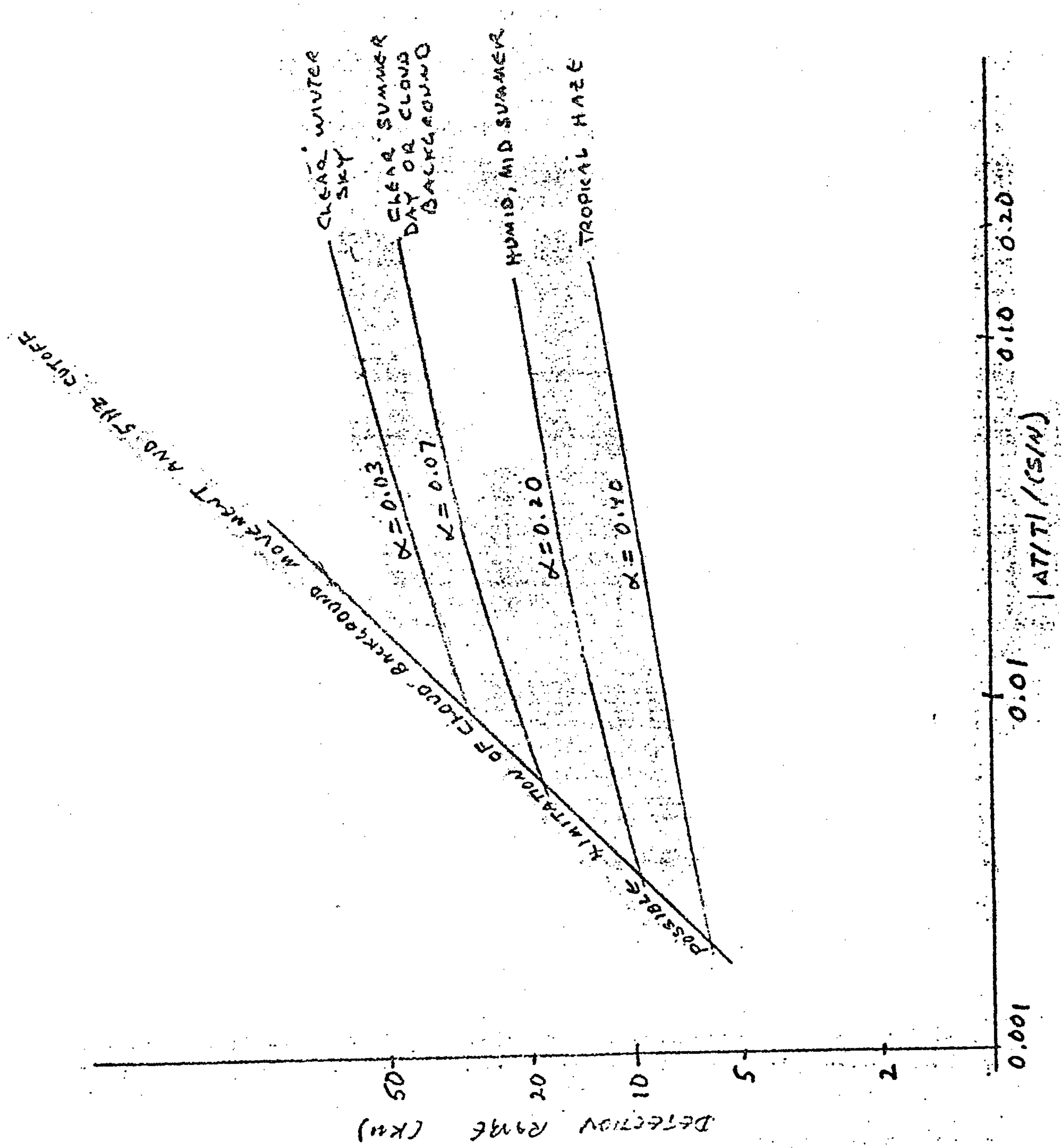
$$\tau_a = e^{-\alpha r\,(km)};\ \alpha \text{ is in units of } km^{-1}$$

and for the design point parameters initially suggested by Night Vision Laboratory. The effect of changing some of these parameters such as $\omega$, $D_o$, projectile caliber, R, etc can immediately be inferred by reference to the Equation above and the Figure.

Separate computations are in agreement with NVL's statement that the system performance is limited by detector noise as given by the expression above, rather than by photon noise from the background.

UNCLASSIFIED

[redacted]




[redacted] 52 FIGURE # 3

UNCLASSIFIED

With a temperature difference between projectile and background of about 10% it appears that with the system parameters chosen by NVL, a signal/noise ratio of 6.0 might be anticipated on a 155mm projectile at between 15-20 kilometers, in clear weather, the lower value corresponding to conditions of high humidity.

This is an attractive performance expectation, but it must be viewed against the likelihood of adverse weather, the ten thousand or so sensor elements in each array, the fact that multiple observing stations are required, and the possibility that the cost of a pair of stations might be of the order of a million dollars. Weather limitations can be assessed from the data in Appendix I-5.

On the other hand, this is a preliminary concept, and NVL has suggested that substantial cost reduction might be achieved by reducing the stringent range and accuracy objectives set for the initial analysis. This seems to be a reasonable expectation. It is felt, however, that additional paper studies along these lines would lack plausibility in the absence of experimental data on projectile temperature.

Another source of uncertainty in performance estimation is the width of the spectrum about DC that must be suppressed to remove background changes caused by atmospheric movements, such as cloud motion. Some rough computations based on very limited information on the Wiener spectrum of a partly cloudy sky suggest that blanking out the frequency range 0-5Hz should eliminate this source of difficulty. The limit imposed on the system with a 5Hz cutoff against clouds moving at 3 m/s traversely to the line of sight and behind, but close to the projectile, is sketched in Figure 3. This is a very unreliable estimate and better background data, preferably taken with a fixed, narrow view sensor, are required for a valid computation. If the suppressed low frequencies extend beyond a few Hz the effect on detection of the signal itself must be evaluated, since the frequency spectrum of a pulse has its maximum value at zero Hz.

Although the Group does not favor the NVL system as originally proposed, on the grounds of probable high cost and vulnerability to weather, it does not wish to categorically exclude infrared systems for projectile tracking as a possible future means of supplementing radar systems, if a very low cost concept of operational simplicity can be devised. To provide a better experimental basis on which to assess the feasibility of modifications of the NVL concept, or new concepts, it is therefore recommended that a limited experimental program be carried out to determine:

(1) Temperature of projectiles in flight.

(2) Power spectral densities of changes in background radiant emittance with time as seen by a "staring" sensor with very narrow field of view.

Acoustic Sensing of the Projectile.

As noted in the discussion of weapon location by acoustic sensing of the muzzle blast, the maximum range at which the weapon can be accurately located, or even sensed, by direct acoustic means is limited by the vagaries of sound propagation through the atmosphere. On the other hand, the muzzle blast is not the only acoustic signal available as a potential data source for information which may be used to solve the weapon location problem. The proposal of A.E. Johnsrud, cited in Section VI, to use projectile impact sensing in conjunction with muzzle blast sensing and enemy firing tables as an additional constraint on the solution suggests that one might reasonably consider whether acoustic sensing of the projectile in flight could provide additional information leading to further improvement in the accuracy of weapon location.

Only limited data is on hand at the time of writing on the acoustic signatures of artillery projectiles. Assuming the projectile crosses the FEBA the signal intensity required for detection by a sensor array behind the FEBA will be substantially less than that required to detect the muzzle blast of the gun. More important, since the projectile to sensor range is relatively small, meterological distortion of the acoustic path and attenuation of the signal will be relatively small.

The following considerations are related to the acoustic signature generated by a projectile:

a. The rate of energy loss of a projectile due to aerodynamic drag can be of the order of several horsepower (155 mm projectile at about 800 meters/sec), however the efficiency with which acoustic power is developed is extremely low in subsonic flight.

b. At supersonic velocities there is good acoustic coupling via wave drag, with an associated shock wave, as is well known from experience with sonic booms produced by aircraft. For an unaccelerated, non-lifting supersonic projectile, sonic "bang" theory indicates that the pressure rise observed by a sensor at a given distance from the source will be proportional to $C^{3/4} M^{1/4}$, where C= caliber, M=Mach number. The acoustic intensity (power) will then be proportional to $C^{3/2} M^{1/2}$. Theory also indicates that the variation of intensity with increasing range to the sensor is only as $r^{-3/2}$ rather than as $r^{-2}$.

c. These relations suggest that the acoustic power generated by a projectile will not vary widely with Mach number, as long as the projectile remains supersonic, and also that the variation across calibers will be only slightly greater than direct proportionality. These inferences are in general agreement with ground sensings of the shock wave (designated "ballistic wave") of large caliber projectiles at Fort Sill.

d. When the projectile is subsonic, it is conjectured that the principal source of acoustic power is that developed in the turbulent wake. Limited information indicates that the efficiency of conversion of power from aerodynamic turbulence to acoustic power is roughly about $10^{-4} M^5$. A subsonic projectile loses energy at a rate proportional to $C^2 M^3$, but there is no basis on hand for estimating the absolute intensity of the acoustic signal of a subsonic projectile.

Limited experimental data and comments from experience indicate that:

a. The peak intensity of the ballistic wave developed by a 155mm projectile fired from a howitzer at Charge 8 has been recorded at Fort Sill by ground sensors down range from the weapon. Near the weapon (about 1 km down range and 0.5 km from the trajectory), the acoustic intensity of the ballistic wave was about 100 dB (referenced to 0.0002 dynes/cm$^2$). The ballistic wave was still detectable by sensors 16 km down range from the weapon, within a few km of the ground track.

b. Apparently no sensing were obtained at Fort Sill on subsonic projectiles. The well defined signature of the ballistic wave vanishes as the projectile drops below sonic velocity.

c. On the other hand, military personnel who have been exposed to enemy artillery fire report that they could hear subsonic projectiles approaching their area, and that with some experience they could judge whether the impact would be close to their position. They also remark that supersonic signatures are much more intense.

d. At the low end of the caliber spectrum, experience at Fort Ord with acoustic sensors for sensing of near misses with rifle bullets indicates that no useful signal could be obtained with acoustic sensors from subsonic near-misses, although the equipment worked well against supersonic near-misses.

In the absence of experimental data on the acoustic signature of subsonic projectiles, it is therefore estimated that it will be difficult to obtain subsonic sensings at ranges of a kilometer or so. On the other hand, the ballistic waves from supersonic projectiles should be relatively easy to sense.

The ballistic wave signature of a large caliber projectile has a duration of 5-10 ms from Fort Sill records, and analysis indicates that it is possible to distinguish between the ballistic wave signature and the signature of the weapon muzzle blast. Multiple sensings of the ballistic wave combined with the coordinates and relative time of projectile impact might allow a reconstruction of the projectile ground track, even in the absence of muzzle blast detection. Lack of time has prevented exploration of possible algorithms.

However, together with muzzle blast sensing, and the Johnsrud proposal to include a priori information on enemy firing table data, ballistic wave sensing might provide another constraint on the determination of probable enemy weapon location that could significantly improve its accuracy.

No consideration has yet been given to the data processing problems, or the problem of sorting out multiple sensings on multiple rounds. The purpose at this time is to suggest that it may be possible to improve the accuracy of weapon location by sound ranging by taking advantage of information and sensings additional to those of the weapon muzzle blast.

APPENDIX

## APPENDIX I-1

## ASAP AD HOC GROUP

## ON

## HOSTILE ARTILLERY TARGET LOCATING SYSTEMS

MR. HERBERT K. WEISS, CHAIRMAN

MR. HOWARD GATES, JR., MEMBER

PROFESSOR JAMES B. ANGELL, MEMBER

PROFESSOR ENOCH J. DURBIN, MEMBER

DR. RUSSELL G. MEYERAND, MEMBER

DR. FELIPE J. MONTERO, MEMBER

MR. CHARLES MOORE, SPECIAL CONSULTANT, USAECOM

LTC ROBERT S. BORER, MILITARY STAFF ASSISTANT

### MEETING DATES

9-10 December 1971, Pentagon

13-14 January 1972, Pentagon

28-29 February 1972, Fort Ord, California

4-5 May 1972, Litton Industries, Van Nuys, Calif

6 June 1972, Pentagon (Mr. Weiss & Mr. Gates)

4 October 1972, Pentagon (Mr. Weiss)

AGENDAS AND/OR BACKGROUND INFORMATION FOR GROUP MEETINGS ARE INCLOSED.

DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20310

15 November 1971

Dear Sir:

Enclosed is a schedule of subjects to be discussed during the first two-day meeting of the Ad Hoc Group of the ASAP on Hostile Artillery Target Locating Systems. Subsequent meeting schedules and subjects will be arranged as desired by the Ad Hoc Group.

This initial meeting will be held in the Pentagon. The room number is 3E-389. If I can be of any assistance to you please contact me.

Sincerely,

Robert S Borer

ROBERT S. BORER
LTC, GS
STANO DIVISION, OCRD
(OX59452/74639)

1 Incl
As Stated

MEETING OF THE AD HOC COMMITTEE

GROUP OF THE ARMY SCIENTIFIC ADVISORY PANEL

TO STUDY HOSTILE ARTILLERY TARGET LOCATING SYSTEMS

DATE: 9 December 1971

PENTAGON - ROOM 3E-389

| SUBJECT: | TIME: |
|---|---|
| INTRODUCTION | 0915 |
| BACKGROUND | 0930 |
| ARMY REQUIREMENT | 1000 |
| APPLICATION OF INFRARED TO COUNTERBATTERY | 1015 |

DATE: 10 December 1971

PENTAGON - ROOM 3E-389

| SUBJECT: | TIME: |
|---|---|
| FLASH RANGING | 0830 |
| SEISMIC DETECTION | 1030 |
| L U N C H | |
| SOUND RANGING | 1330 |
| UNINTENTIONAL RADIATION | 1530 |

| JOINT MESSAGEFORM | SECURITY CLASSIFICATION UNCLAS EFTO |
|---|---|

| PAGE | DRAFTER OR RELEASER TIME | PRECEDENCE ACT | PRECEDENCE INFO | LMF | CLASS | CIC | FOR MESSAGE CENTER/COMMUNICATIONS CENTER ONLY | DATE – TIME | MONTH | YR |
|---|---|---|---|---|---|---|---|---|---|---|
| 01 OF 03 | | RR | RR | | EEEE | | | | | |

BOOK NO

MESSAGE HANDLING INSTRUCTIONS

FROM: DA (DARD-DD)

TO: CGUSACDC

CGUSACONARC

INFO: CGUSAMC

CGUSAECOM FT MONMOUTH NJ

CGUSAFAS FT SILL OK

COUSACDCFAA FT SILL OK

CGUSACDCCOMSG FT LEAVENWORTH KN

UNCLAS E F T O

DARD-DDS-S

USACDC FOR CDCCS-DS-O; USACONARC FOR ATIT-RD-MD; USAMC FOR AMCRD-OS; AND USAECOM FOR AMSEL-CT-HD.

SUBJ: MEETING OF AD HOC COMMITTEE OF ARMY SCIENTIFIC ADVISORY PANEL(ASAP)TO STUDY HOSTILE ARTILLERY TARGET LOCATING SYSTEMS(HATLS).

1. AN AD HOC COMMITTEE OF THE ASAP HAS BEEN FORMED TO STUDY THE VARIOUS NON-RADAR TECHNIQUES APPLICABLE TO THE PROBLEM OF LOCATING HOSTILE ARTILLERY WEAPONS.

2. THE AD HOC COMMITTEE MET ON 9 & 10 DECEMBER 1971 AND

DISTR:

DARD-DDS-S & DAFD

DRAFTER TYPED NAME, TITLE, OFFICE SYMBOL AND PHONE
R.S. BORER, LTC, DARD-DDS/59452/

RELEASER TYPED NAME, TITLE, OFFICE SYMBOL AND PHONE
Colonel, GS
Deputy Director of Developments

SIGNATURE
W E Menzen

SPECIAL INSTRUCTIONS

SECURITY CLASSIFICATION UNCLAS EFTO

61

DD FORM 1 JUL 68 173 REPLACES DD FORM 173, 1 NOV 63 AND DD FORM 173-1, 1 NOV 63, WHICH ARE OBSOLETE.

| JOINT MESSAGEFORM | SECURITY CLASSIFICATION |
| --- | --- |

| PAGE | DRAFTER OR RELEASER TIME | PRECEDENCE ACT | PRECEDENCE INFO | LMF | CLASS | CIC | FOR MESSAGE CENTER/COMMUNICATIONS CENTER ONLY DATE – TIME | MONTH | YR |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 02 OF 03 | | RR | RR | | EEEE | | | | |

BOOK 10

MESSAGE HANDLING INSTRUCTIONS

WAS BRIEFED ON SOUND RANGING, SEISMIC DETECTION, FLASH RANGING, INFRARED COUNTERBATTERY APPLICATIONS, THE EXPECTED PERFORMANCE CHARACTERISTICS OF THE COUNTERBATTERY RADAR, AND THE ARMY REQUIREMENTS.

3. THE AD HOC COMMITTEE WILL MEET AGAIN ON 13 & 14 JAN 72, IN RM 3E-389, PENTAGON, WASH DC. ADDITIONAL SUBJECTS FOR BRIEFINGS AND DISCUSSION HAVE BEEN REQUESTED BY THE AD HOC COMMITTEE FOR THIS JANUARY MEETING.

4. THE COMMITTEE DESIRES TO GAIN A BETTER INSIGHT INTO ARMY ARTILLERY DOCTRINE AND PRESENT COUNTERFIRE CAPABILITY. THEY REQUESTED ARTILLERY REPRESENTATION FOR INFORMAL DISCUSSIONS IN THE FOLLOWING AREAS: TECHNIQUES OF CONDUCTING COUNTERFIRE, TO INCLUDE A TYPICAL SCENERIO; PRESENT CAPABILITY FOR LOCATING HOSTILE ARTILLERY; PRESENT AND ANTICIPATED COUNTERFIRE WEAPON CAPABILITY.

5. REQUEST USACDC AND USACONARC TAKE ACTION TO PROVIDE APPROPRIATE REPRESENTATION AT THE AD HOC COMMITTEE MEETING OF 13 & 14 JAN 72 TO DISCUSS THE AREAS IDENTIFIED IN PARA 4, ABOVE. DIRECT COORDINATION BETWEEN CDC AND CONARC IS

DISTR:

DRAFTER TYPED NAME, TITLE, OFFICE SYMBOL AND PHONE

SPECIAL INSTRUCTIONS

RELEASER TYPED NAME, TITLE, OFFICE SYMBOL AND PHONE

SIGNATURE



SECURITY CLASSIFICATION

GPO : 1969—643—16—80375-1 335-393

DD FORM 1 JUL 68 173 REPLACES DD FORM 173, 1 NOV 63 AND DD FORM 173-1, 1 NOV 63, WHICH ARE OBSOLETE.

| JOINT MESSAGEFORM | SECURITY CLASSIFICATION |
|---|---|

| PAGE | DRAFTER OR RELEASER TIME | PRECEDENCE ACT | PRECEDENCE INFO | LMF | CLASS | CIC | FOR MESSAGE CENTER/COMMUNICATIONS CENTER ONLY DATE – TIME | MONTH | YR |
|---|---|---|---|---|---|---|---|---|---|
| 03 OF 03 | | RR | RR | | EEEE | | | | |

BOOK NO

MESSAGE HANDLING INSTRUCTIONS

AUTHORIZED. FURTHER REQUEST CDC AND CONARC AUTHORIZE DIRECT COORDINATION BETWEEN APPROPRIATE SUBORDINATE AGENCIES AND DA POINT OF CONTACT. DA POINT OF CONTRACT IS LTC BORER, DARD-DDS-S, 0X59452/74639.

6. THIS ACTION HAS BEEN PROCESSED IN ACCORDANCE WITH PROCEDURES FOR DIRECTING USACDC TO ACCOMPLISH SPECIALIZED TASKS IN SUPPORT OF ARMY STAFF REQUIREMENTS.

DISTR:

DRAFTER TYPED NAMED, TITLE, OFFICE SYMBOL AND PHONE

SPECIAL INSTRUCTIONS

RELEASER

TYPED NAME, TITLE, OFFICE SYMBOL AND PHONE

SIGNATURE

63

SECURITY CLASSIFICATION

DD FORM 1 JUL 68 173 REPLACES DD FORM 173, 1 NOV 63 AND DD FORM 173-1, 1 NOV 63, WHICH ARE OBSOLETE.

DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20310

2 February 1972

Dear Sir:

The Ad Hoc Group on Hostile Artillery Locating Systems will meet on 28 & 29 February 1972 at Fort Ord (Monterey) California. Arrangements have been made with Fort Ord to provide a conference room work area during this period.

Since the purpose of the meeting is to begin preparation of the Ad Hoc Group report, no agenda has been arranged. However, at 0900 hours, 28 February, representatives of Fort Ord will present a customary briefing on the missions and roles of Fort Ord and USACDEC. This will last approximately one hour.

Realizing that the members of the Ad Hoc Group will be arriving in the Monterey area at varying times and will be staying at different motels according to preference, it seems appropriate to meet initially at the building on Fort Ord where the Conference Room is located. This will be Building Number 2917. Your names have been provided to the military contact at Fort Ord so that the gate guards will be notified.

These guards can assist in guiding you to Building 2917. Security clearances are being sent to Fort Ord by the ASAP Office here in the Pentagon.

I suggest we meet at Building 2917 at 0845 hours on 28 February. This will allow time for any preliminaries required by Ord - followed by the courtesy briefing. I have mailed classified information to each of you and will either mail, or bring to the meeting, any additional information I receive. If I can be of any assistance please call.

Sincerely,

ROBERT S. BORER
LTC, GS
STANO DIVISION, OCRD
(OX59452/74639)

Copies TO:
Mr. Weiss
Professor Angell
Mr. Gates
Professor Durbin
Dr. Meyerand
Dr. Montero
Mr. Moore

DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20310

6 April 1972

Dear Sir:

The Ad Hoc Group on Hostile Artillery Locating Systems will meet on 4 and 5 May 1972 at Litton Industries, Van Nuys, California. A map will be provided by separate mail to assist you in locating the meeting site. Security clearances are being sent to Litton by the ASAP Officer here in the Pentagon.

Mr. Weiss has asked that each member of the Group prepare their comments in written form so he can begin consolidation of the Group report.

I suggest we plan on meeting at 0900 hours on 4 May. If I can be of assistance please call.

Sincerely,

ROBERT S. BORER
LTC, GS
STANO DIVISION, OCRD
(OX74639/59452)

Copies Furnished To:
Mr. Weiss
Professor Angell
Mr. Gates
Professor Durbin
Dr. Meyerand
Dr. Montero
Mr. Moore

## APPENDIX I-2

## ASAP STUDY PROPOSAL

1. Proposed Name: ASAP Ad Hoc Group on Hostile Artillery Target Locating Systems.

2. Statement of the Problem: To determine which techniques offer the most promise of satisfying the Army's requirement to accurately and responsively locate the firing position of hostile artillery.

3. Considerations:

a. There are many techniques and concepts which might meet the Army's requirement to accurately locate the position of hostile artillery. Radar, polystation doppler, infrared, flash ranging, sound ranging, seismic detection, and unintentional radiation detection are some of the methods envisioned to solve the problem.

b. Artillery Locating Radar has been indorsed as technically feasible and attainable within the present state-of-the-art. The Army now has a development program to fabricate and test a Counterbattery Radar. This radar is being developed against a current requirement for such a system and testing of advanced development models is expected in FY 75. The Army is also developing a Countermortar Radar system which will locate the firing positions of high angle fire at shorter ranges. This radar will start engineering tests in FY 75. The polystation doppler approach is currently under investigation by the Marine Corps.

c. Although none of the non-radar techniques offer a strong possibility of satisfying the hostile artillery locating problem at this time, there is a possibility that some possible techniques have been overlooked. Non-radar approaches have not received the concentrated developmental effort that radar has toward meeting this requirement. In the interest of studying a broad base of techniques, and of providing diversification of capability, the Army is interested in applying developmental effort toward promising non-radar methods.

d. To economize both money and time, an analysis by experts within the disciplines represented by the non-radar approaches is essential. The techniques showing the most promise can thus be identified and pursued at a greater level as parallel efforts to the radar development.

4. Proposed Terms of Reference: In its study of the problem the Ad Hoc Group should:

a. Review the Army requirements as expressed in the Combat Development Objectives Guide.

b. Examine the non-radar techniques applicable to hostile artillery locating.

c. Identify promising techiques, if any.

d. Make recommendations concerning future Army development programs for non-radar techniques to meet the hostile artillery locating requirement.

# APPENDIX I-3

## OPTIONS CONSIDERED

1. Location Beyond Line of Sight of Weapon.

    a. 1.1 Sound Emission.

    (1) Direction of Arrival Triangulation.

    (2) Time of Arrival Triangulation.

    b. 1.2 Seismic Disturbances.

    c. 1.3 Laser Detection of Emitted Effluents.

    (1) Reflection/Scattering of Illuminating Beam.

    (2) Detection of Stimulated Emissions.

    d. 1.4 Unintentional Radiation (ELF/VLF/LF).

2. Location/Detection within Line of Sight of Weapon.

    a. 2.1 Harmonic Radar Detection of Metals (METRA).

    b. 2.2 Photographic, Visual, LLLTV, IR Recon, Shape Recognition, Laser Line Scan.

    c. 2.3 Detection of "Unintentional Radiation" at LOS Frequencies.

    d. 2.4 Doppler Radar Detection.

    (1) Gun Recoil.

    (2) Effluent.

    e. 2.5 Remote Spectroscopy.

    f. 2.6 "Sniffers".

    g. 2.7 Radiometry.

3. Projectile Detection, Tracking and Back Extrapolation.

a. 3.1 Radar.

(1) Pulse Doppler.

(2) Polystation Doppler.

b. 3.2 IR.

c. 3.3 Acoustic.

d. 3.4 Crater Analysis.

e. 3.5 Laser Radar.

(1) Projectile Tracking.

(2) Trail Tracking.

f. 3.6 Unintentional Radiation from RAP.

4. Platforms (Methods of getting acceptable ranges from LOS - Limited Systems).

a. 5.1 Fixed Wing Aircraft of Helicopters.

(1) Manned.

(2) Unmanned.

b. 5.2 Satellites.

c. 5.3 Artillery Shell.

d. 5.4 Artillery or Air-Implanted Sensors.

e. 5.5 Balloons.

f. 5.6 Towers.

5. Location Methods.

a. 6.1 Locate the Target in Recognizable Terrain Background.

b. 6.2 Locate Target in Sensor Coordinates.

c. 6.3 Locate Target in Platform Coordinates.

Location of Platform Relative to Grid.

(1) Radio Navigation.

(2) Inertial Navigation.

(3) Radar.

d. 6.4 Locate Target Directly in Friendly Artillery Coordinates.

## APPENDIX I-4

## GEOMETRIC LINE OF SIGHT PROBABILITY

1. For those sensors requiring an unobstructed geometric line of sight to the target, the frequency with which this condition can be obtained as a function of range, terrain, and height of the observing station is of interest. The following data provide this information.

2. Terrain is defined in terms of a "Mask Angle". Figure 4 shows, for three types of terrain, the probability that a point on the ground can be seen from a remote observing point, if the line of sight is inclined from the horizontal at an angle specified as the "Mask Angle". For example, the curve indicates that over moderately rough terrain, the probability of seeing a point on the ground along a line of sight inclined at $5^{o}$ is 0.6; with a complementary probability of 0.4 that the line of sight will be interrupted by some intervening terrain feature.

3. Using this type of Mask Angle data, the altitude required to observe specified percentages of terrain can be computed, and Table II relates the height required in the instance of a single observing point vs a two-point observation case to secure a constant percentage field-of-view on the ground. Both of the observation points are randomly selected relative to each other and to the ground except that the two points are separated at least $30^{o}$ from points in the field to be observed. The use of a larger number of observing points, as for example, an airborne platform cruising along FEBA, or the selection of points to coincide with best fields-of-view for the particular terrain to be observed, could be expected to decrease the required altitude of observation somewhat for any given desired percentage field-of-view.

PAGE 72 NOT USED

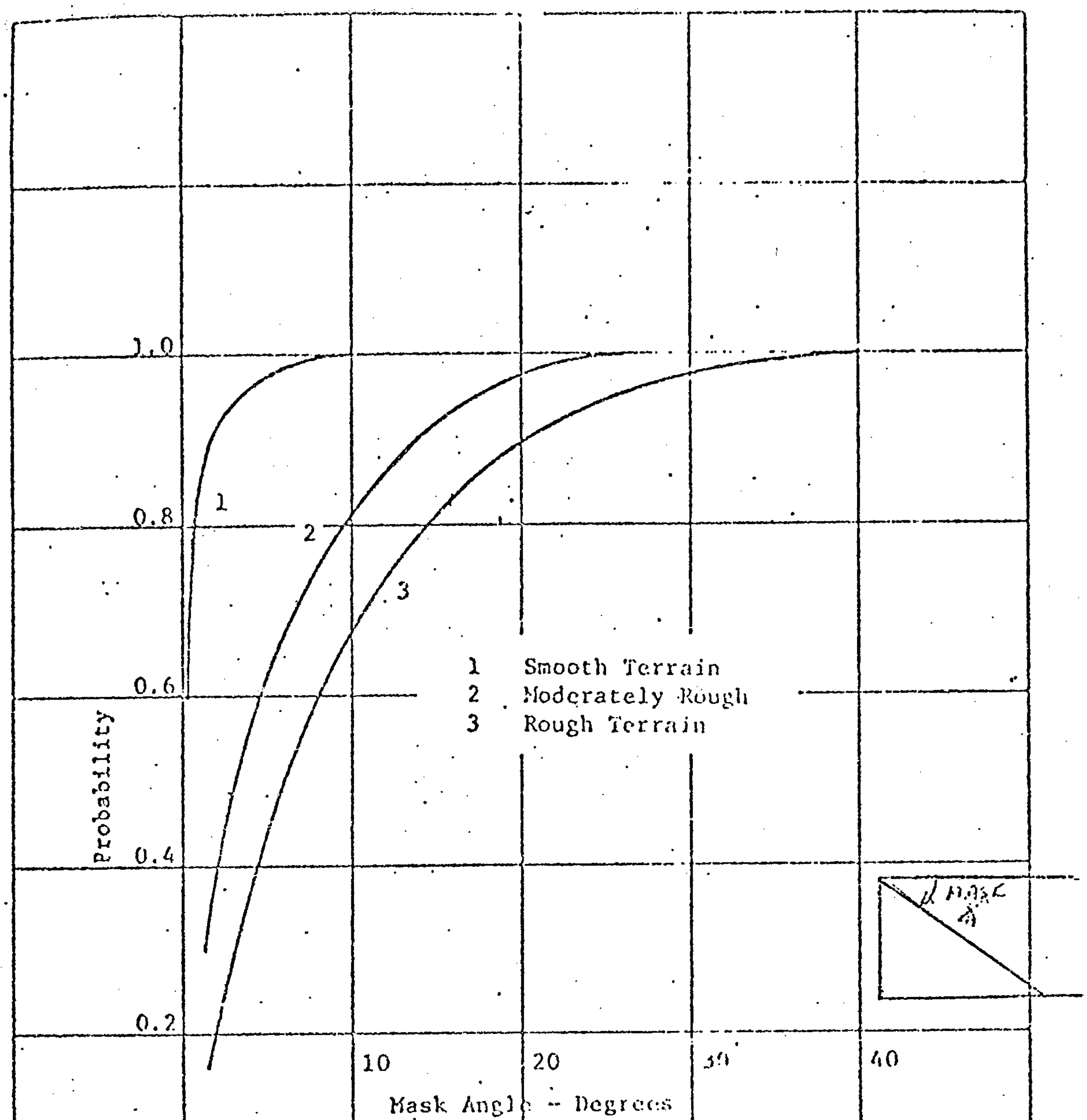



Figure 4. (U) Mask Angle Probability



FIGURE #4

TABLE II

REQUIRED ALTITUDE
TO OBSERVE 50% OF TERRAIN
TO 20 KM

| TERRAIN TYPE | ALTITUDE/FEET | |
|---|---|---|
| | ONE-POINT OBSERVATION | TWO-POINT OBSERVATION |
| PLAINS | 2229 | 1188 |
| LOW HILLS | 3630 | 1935 |
| HIGH HILLS | 4578 | 2442 |
| LOW MOUNTAINS | 7380 | 3930 |
| HIGH MOUNTAINS | 9198 | 4905 |

| TERRAIN TYPE | MAXIMUM HEIGHT DIFFERENCE |
|---|---|
| PLAINS | 500 FEET |
| LOW HILLS | 500-1000 FEET |
| HIGH HILLS | 1000-2000 FEET |
| LOW MOUNTAINS | 2000-3000 FEET |
| HIGH MOUNTAINS | 3000-4500 FEET |

## APPENDIX I-5

### WEATHER AND THE PROBABILITY OF A PENETRABLE OPTICAL PATH

1. In the case of visual and infrared sensors the probability of being able to detect a target depends not only on the existence of a geometric line of sight, but also on the atmospheric transmission as a function of weather.

2. Table III provides a summary of a large volume of data bearing on the probability of penetrable optical paths to points on the ground from an airborne observation platform as a function of altitude of the platform and ground range between platform and point under observation. The data is also interpretable to find the probability of detecting a target in the sky from a ground point as a function of range and altitude of the target. While the data is for optical paths, meaningful extrapolations can be made to the IR case. The data was compiled from a statistical analysis of cloud height and density actually observed at a very large number of locations throughout the world. The raw data comes from daily observations at each location, compiled in many cases over a period of years. The report averages the data for each location and for each of the four seasons of the year. The data does not consider possible terrain masking and assumes line-of-sight in this respect. Table III is a very quick "eye-ball" averaging of the total information. The spread of percentages results from the seasonal variation in cloud height and density and variations of weather over large countries. It seems that if the observation point is below 1500-2000 feet, the probability of an optical path to 10 KM is acceptable. Furthermore, the data would indicate that if the path is clear to 10 KM, it is also clear, so far as weather is concerned, to the energy/sensitivity limits of the observing sensor.

3. Meteorological data selected for three areas of interest are summarized in Tables IV, V, and VI, which also provide frequencies of wind velocity. Note that wind velocity is less than 6 knots more than 50% of the time for all three areas.

## *TABLE III*

PROBABILITY OF IR PATH TO 10 KM
AS CONSEQUENCE OF WEATHER
(POSSIBLE TERRAIN MASKING NOT INCLUDED)

| COUNTRY | ALTITUDE AIRBORNE OBSERVATION POINT | |
|---|---|---|
| | 1 KM | ½ KM |
| Norway | 40-60% | 60-90% |
| Sweden | 40-50% | 60-80% |
| Finland | 30-50% | 60-80% |
| England | 50-70% | 60-70% |
| Ireland | 30-50% | 40-60% |
| Denmark | 40-60% | 50-70% |
| Netherlands | 20-60% | 40-60% |
| Belgium | 20-60% | 40-70% |
| France | 40-70% | 60-80% |
| Spain | 60-90% | 70-90% |
| Germany | 40-70% | 60-80% |
| Austria | 40-80% | 60-80% |
| Czechoslovakia | 40-80% | 60-80% |
| Poland | 20-60% | 40-70% |
| Hungary | 60-90% | 80-90% |
| Yugoslavia | 60-90% | 80-90% |
| Rumania | 40-80% | 60-90% |
| Bulgaria | 40-90% | 70-90% |
| Italy | 60-90% | 80-90% |
| Greece | 70-90% | 80-90% |
| Turkey | 70-90% | 80-90% |

TABLE III (CONT.)

| Country | Altitude Airborne Observation Point 1 KM | ½ KM |
|---|---|---|
| USSR N of 50° L | 30-70% | 50-80% |
| USSR 50° L to 60° L | 70-90% | 80-90% |
| Syria | 60-80% | 70-90% |
| Lebanon | 70-90% | 80-90% |
| Israel | 80-90% | 90% |
| Jordan | 80-90% | 90% |
| Arabia | 90% | > 90% |
| Iraq | 80-95% | 90-95% |
| Iran | 90% | > 90% |
| Pakistan | 70-90% | 80-95% |
| India | 80-95% | > 90% |
| Kashmir | 80% | 90% |
| Mongolia | 70-90% | 90% |
| Taiwan | 50% | 70-80% |
| South Korea | 70-90% | 80-90% |
| Japan | 60-90% | 80-90% |
| Burma | 60-90% | 80-90% |
| Thailand | 50-80% | 80-90% |
| Malaysia | 60-70% | 80-90% |
| South Vietnam | 40-60% | 60-80% |
| Laos | 50-60% | 70-90% |
| Cambodia | 60-70% | 80-90% |
| China | 70-90% | 80-90% |

# TABLE IV

STATION: Jerusalem, Israel

POR Mar 49–Jun 67 with many missing periods in between

Temperature

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ann |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean Max | 54.6 | 57.0 | 60.0 | 69.1 | 76.7 | 81.3 | 83.1 | 85.3 | 81.6 | 77.8 | 67.1 | 58.2 | 71.0 |
| Mean Min | 43.5 | 44.5 | 46.6 | 53.2 | 58.9 | 63.0 | 65.1 | 66.7 | 63.7 | 61.5 | 54.2 | 46.8 | 55.6 |
| Extreme Max | 79 | 81 | 88 | 95 | 95 | 99 | 100 | 102 | 100 | 97 | 82 | 79 | 102 |
| Extreme Min | 30 | 28 | 28 | 37 | 46 | 52 | 55 | 59 | 57 | 48 | 34 | 32 | 28 |

Annual % freq. of Precip 4.3%
Annual % freq. wind speed Calm 16.1%
Annual % freq. wind speed < 6 Kts 54.9%
Annual % freq. wind speed > 16 Kts 6.3%
% freq ceiling less than 1000 ft 11.0%
% freq ceiling less than 3000 ft 17.4%
% freq visibility less than ½ mi 1.5%
% freq visibility less than 5 mi 12.3%

## TABLE V

STATION: Tan Son Nhut Airport, S. Vietnam

POR Jan 57–Feb 67
(Extremes POR 62–65)

Temperature

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ann |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean Max | 88.1 | 91.7 | 92.8 | 94.4 | 92.6 | 91.2 | 90.1 | 89.1 | 88.5 | 89.0 | 88.4 | 87.8 | 90.3 |
| Mean Min | 68.7 | 71.2 | 73.9 | 77.4 | 77.2 | 76.3 | 76.2 | 75.7 | 75.8 | 75.2 | 73.6 | 71.1 | 74.5 |
| Extreme Max | (94) | (97) | (99) | (100) | (97) | (95) | (98) | (93) | (95) | (92) | (93) | (88) | (100) |
| Extreme Min | (60) | (64) | (63) | (73) | (74) | (73) | (72) | (72) | (72) | (72) | (65) | (63) | (63) |

Annual % freq. of Precip 5.8%
Annual % freq. of wind speed Calm 19.8%
Annual % freq. of wind speed < 3 Kts 24.2%
Annual % freq. of wind speed < 6 Kts 73.9%
Annual % freq. of wind speed > 16 Kts 0.2%
% freq ceiling less than 1000 ft 1.0%
% freq ceiling less than 3000 ft 10.8%
% freq visibility less than ½ mi 0.2%
% freq visibility less than 5 mi 7.6%

Note: Extremes temp statistics are based on a maximum of four years of data and, therefore, probably do not reflect actual extremes expected in a 10-yr period of record.

# TABLE VI

STATION: Wiesbaden Germany — POR Mar 46-Oct 65

Temperature (°F)

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ann |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean Max | 37.2 | 39.5 | 49.7 | 59.6 | 66.6 | 72.3 | 75.5 | 73.8 | 68.6 | 56.9 | 45.9 | 38.8 | 57.4 |
| Mean Min | 29.0 | 29.1 | 35.1 | 42.4 | 48.7 | 54.1 | 57.0 | 56.2 | 51.6 | 43.1 | 37.1 | 31.2 | 43.1 |
| Extreme Max | 57 | 63 | 71 | 86 | 89 | 96 | 99 | 95 | 93 | 79 | 62 | 60 | 99 |
| Extreme Min | 3 | -3 | 9 | 28 | 33 | 38 | 41 | 42 | 35 | 24 | 15 | 7 | -3 |

Annual % freq. of Precip 12.0%
Annual % freq. wind speed Calm 19.7%
Annual % freq. wind speed < 3 Kts 36.0%
Annual % freq. wind speed < 6 Kts 62.0%
Annual % freq. wind speed > 16 Kts 2.0%
Annual % freq. ceiling less than 1000 ft 5.9%
Annual % freq ceiling less than 3000 ft 23.5%
Annual % freq visibility less than ½ mi 3.4%
Annual % freq visibility less than 5 mi 34.2%

## APPENDIX I-6

## SIMPLE APPROXIMATIONS TO BLACKBODY RADIATION WITHIN LIMITED SPECTRAL WINDOW

The spectral distribution of the radiant emittance of a blackbody is given by Planck's Law as -

$$R_\lambda = (c_1/\lambda^5)(e^{c_2/\lambda T} - 1)^{-1} \qquad (1)$$

where $c_1$, $c_2$ are constants, $\lambda$ = wavelength, and T = temperature

The total radiant emittance is the integral over all $\lambda$

$$R = \sigma T^4 \qquad (2)$$

where $\sigma$ = the Stefan-Boltzmann constant.

For approximate computations, we assume that we have a sensor which views the band $\lambda_1$ to $\lambda_2$, and has zero sensitivity outside that band. We would like a simple analytic expression which will allow us to determine how the radiant emittance in that band changes for small changes in the blackbody temperature T. It is clear that we cannot simply differentiate (4), because of the complex form of (1). Normally one would obtain the variation from tables or a radiation slide rule.

However, in the course of the present review, it was observed that for rough initial computation, the integral

$$f = \int_0^\lambda (R_\lambda / R)\, d\lambda \qquad (3)$$

can be closely approximated by -

$$f = 0.64 \operatorname{Log}_e (\lambda T/1900) \qquad (4)$$

$$0.2 < f < 0.8; \quad 2500 < \lambda T < 6500$$

and

$$f = 0.013 \left[(\lambda T)/1500\right]^6 \qquad (5)$$

$$0.004 < f < 0.15; \quad 1200 < \lambda T < 2400$$

Assuming that the radiant emittance to which the sensor is exposed can be represented by blackbody radiation multiplied by an emissivity $\epsilon$, and that $\epsilon$ is constant over the window and with small changes in T, and that the differential variations considered remain within the window, Egs. (4) or (5) as appropriate, may be differentiated to obtain the desired simple expression.

For the 8-14 micron window considered in the system examined in the body of this report, and T=300°K, Eq. (4) applies. The radiant emittance to which the sensor is exposed is -

$$R_s = \sigma\epsilon\ T^4 \left[ f(\lambda_2) - f(\lambda_1) \right]$$

$$= \sigma\epsilon\ T^4 \quad 0.64\ \text{Log}_e(\lambda_2/\lambda_1) \qquad (6)$$

hence $\Delta R_s/R_s = 4\,\Delta T/T$ (7)

and this is exactly the result that would have been obtained by differentiating Eq. (2).

For windows at lower wavelengths one could not use this approximation. Dr. Paul Kruse cites a criticism in the literature of a paper by Wilson, in which E.W. Bivans comments on R.A. Wilson's use of (7) for a window from 4 to 5.5 $\mu$ at 300° K. For Wilson's case however, one may use Eq. (5) and obtain

$$R_s = \sigma\epsilon\ T^{10}(.013) \left[ (\lambda_2/1500)^6 - (\lambda_1/1500)^6 \right.$$

hence $\Delta R_s/R_s = 10\Delta T/T$

$= 4\Delta T/T\ (2.5)$

For this case by numerical methods, Bivans obtained

$$\Delta R_s/R_s \doteq 4\Delta T/T(2.51)$$

Since these simple approximations are apparently not generally known, they are recorded here as a matter of interest.

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