The Radiation Laboratory
Department of Electrical Engineering
The University of Michigan

07988-1-F

Cross Sections of Mortar Projectiles

Final Report
P.O. 95001
May, 1966

7988-1-F = RL-2172

Prepared by

E. F. Knott

Contract With
Sylvania Electronics Systems
100 First Avenue
Waltham, Massachusetts

TABLE OF CONTENTS

I

INTRODUCTION

This report describes the measurements performed for Sylvania Electronic Systems Co. of Waltham, Massachusetts. The measurements were of three mortar projectiles supplied by Sylvania, each a different size. The objects are: 60 mm projectile, marked 2276, 82 mm projectile, marked 3122, and 120 mm projectile, marked 3122. The radar cross section of each was measured for a variety of pitch angles with vertical polarization at a frequency of 9.722 GHz. Some limited data were obtained for horizontal polarization.

In the report we discuss the models, the experimental facility and the experimental procedures used in obtaining the data. The data are presented, we discuss the sources of error, and we estimate their magnitudes.

II

THE MODELS

The three test objects were received in good condition on 14 April 1966. After receipt and examination, we made several modifications on the targets either because such changes seemed prudent or because they were requested by Mr. K. Duncan of Sylvania. The modifications were mainly that of concealing small holes in the objects and are summarized in Figures 1 through 3. The conducting tape used to do this was thin, adhesive-backed aluminum.

The 60 mm projectile has a pair of small wire clips within the fin assembly extending aft from a support band about the narrow part of the model. The clips were movable and it was first thought that some changes in position (of the clips) were the cause of poor repeatability. After the clips were immobilized with masking tape the repeatability (as discerned from two separate and distinct measurement sequences) improved somewhat but, as we will show later, they were apparently not the major source of the trouble.

The propellant port of the 120 mm projectile was open (while those of the 60 mm and 82 mm projectiles were not) and some data were obtained with and without this port concealed with conducting tape. This comparison showed that for aspects beyond $\pm 35^{o}$ of tail-on there is negligible effect. At precisely tail-on the change is less than 0.5 db and the average levels for the tail-on region are substantially unchanged.

60 mm

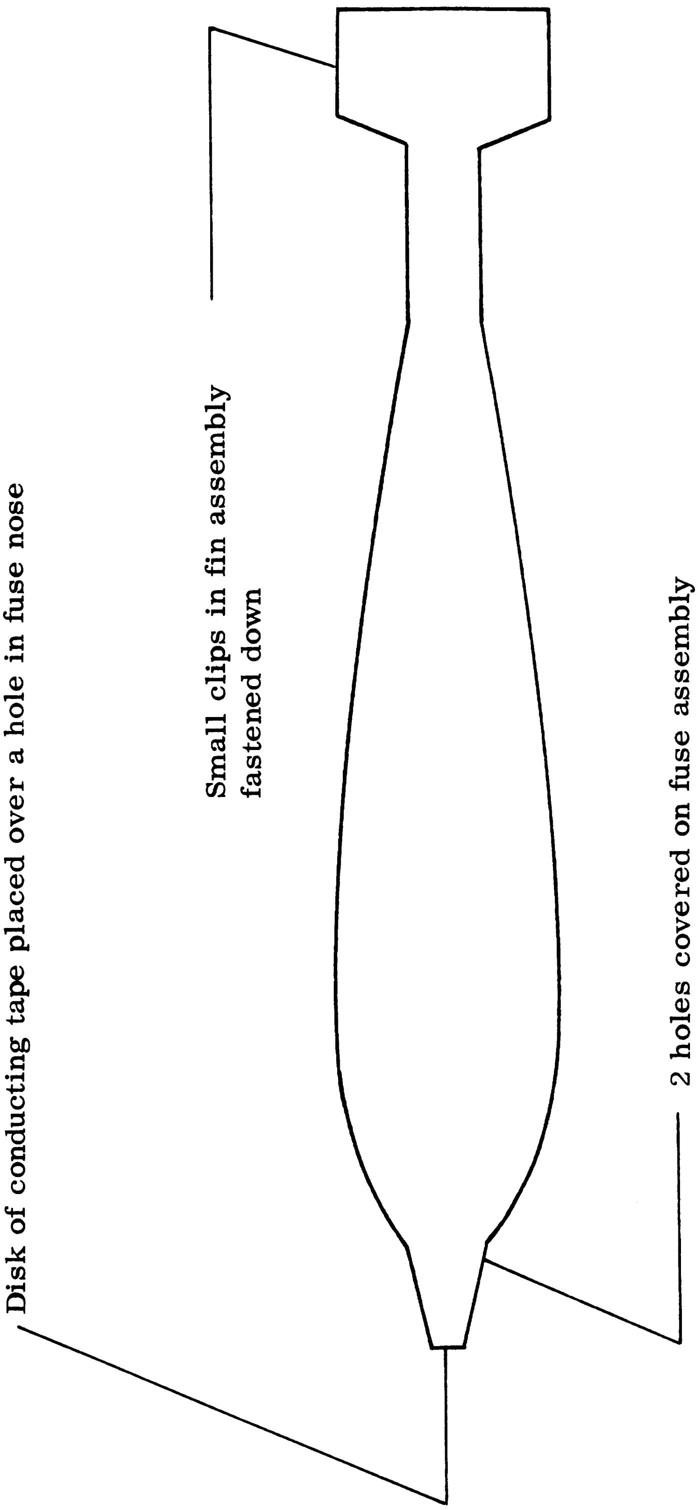


Figure 1: Modifications Made on 60 mm Projectile

82 mm

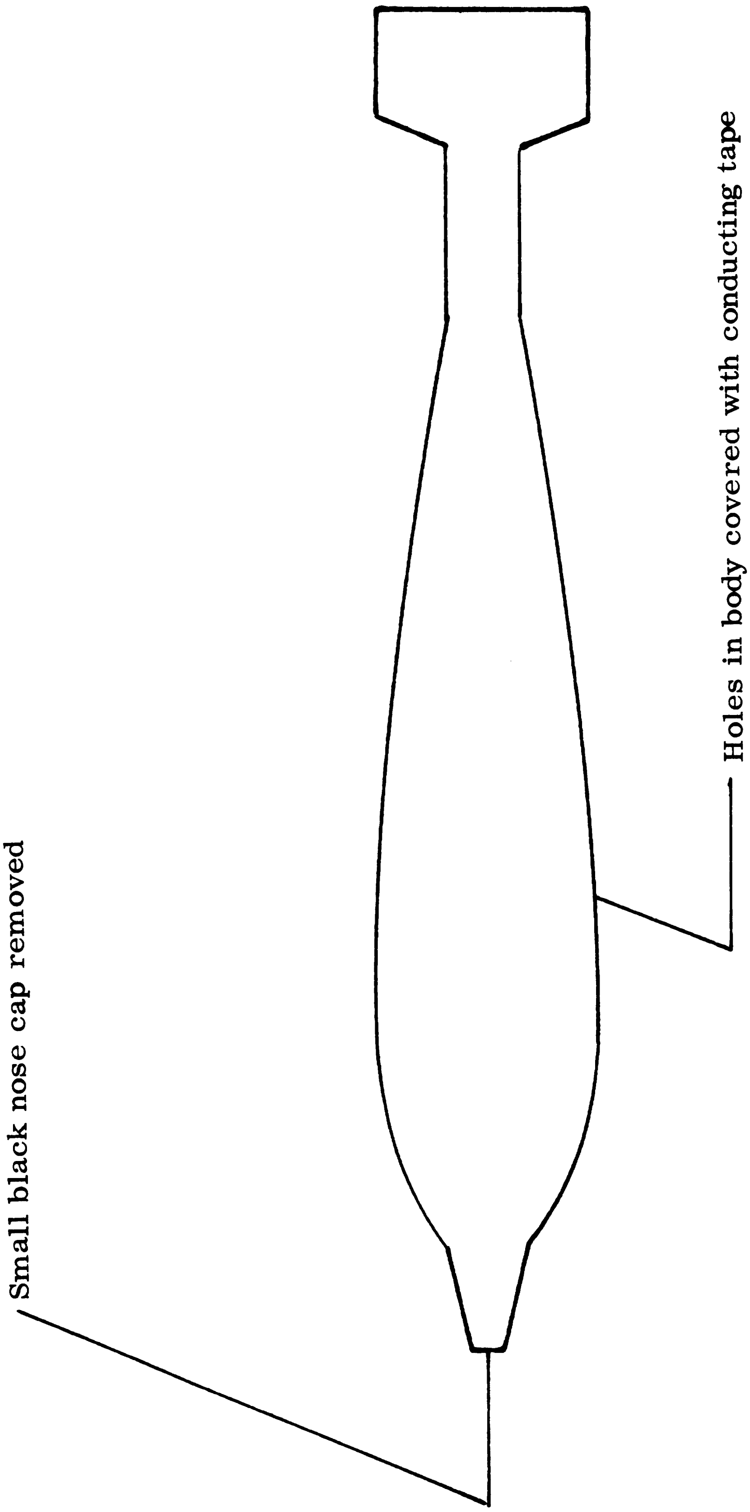


Figure 2: Modifications Made on 82 mm Projectile

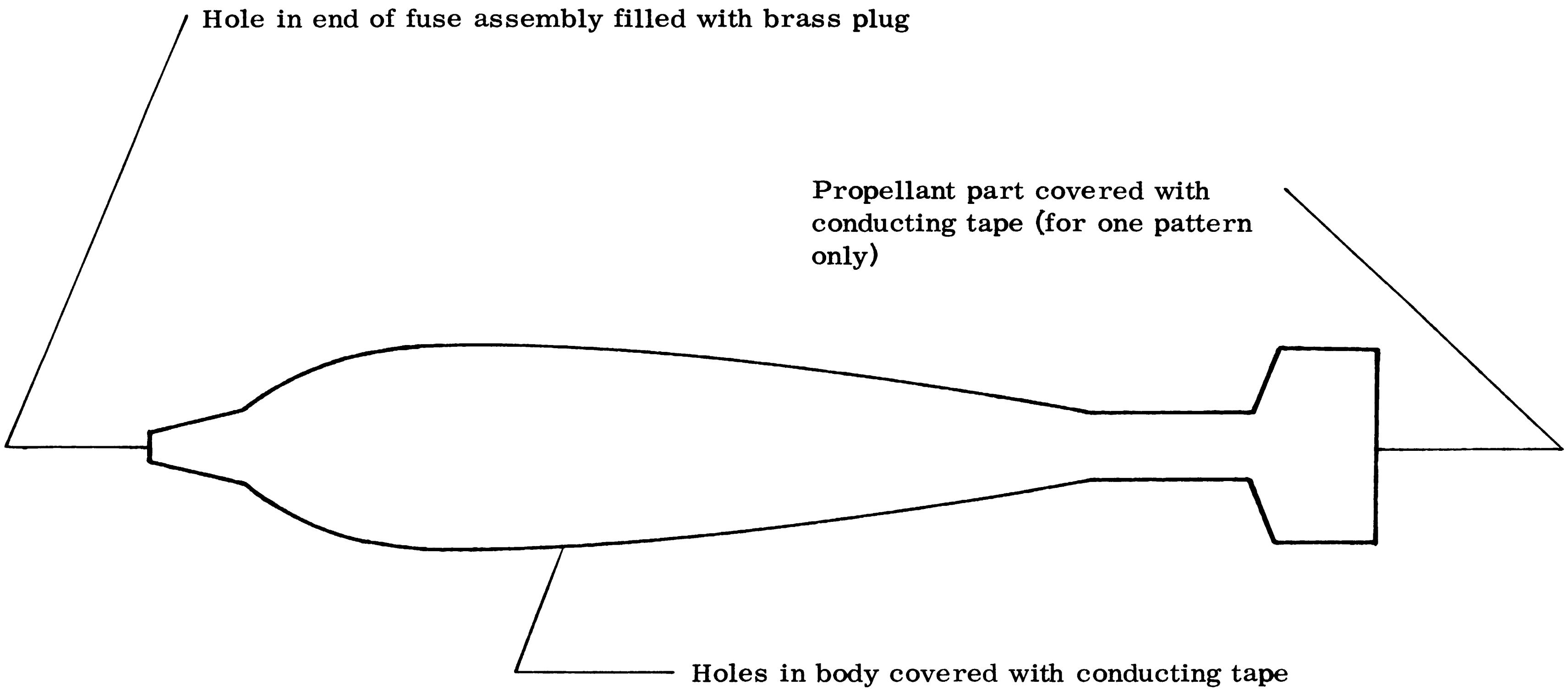


Figure 3: Modifications Made on 120 mm Projectile

120 mm

III

EXPERIMENTAL FACILITY

A photograph of the anechoic chamber and allied equipment used for the measurements appears in Figure 4. A movable partition ordinarily separates the equipment and personnel from the interior of the chamber, but this has been removed to show the chamber details. The room is 105 feet long, 28 feet wide, and 14 feet high. High performance absorber is used on the rear wall and lower grade material covers the remaining walls.

The RF system, Figure 5, is a conventional CW bridge radar which requires the use of a stable signal source. The stability is obtained by the use of a synchronizer which phase-locks the klystron to a stable quartz-crystal oscillator. The klystron output is fed to a hybrid tee which separates the received from transmitted signals, delivering each to its destination. A balancing network is used to cancel unavoidable reflections due to the imperfect match of the antenna as well as the residual reflections from the empty chamber itself. The balancing is performed in the absence of the target and the residual leak-through is more the 95 db below the transmitted signal.

When the target is installed upon its support pedestal the balanced condition is upset and the reflected energy from the object is fed to the receiver by the action of the hybrid tee (actually a "magic tee" under balanced conditions). This signal is directly proportional to the radar cross section of the target, hence the receiver indication is a measure of the cross section; the receiver output is fed to a pattern recorder for display. The proportionality constant is in effect determined by the substitution of a scatterer of known cross section in the place of the target. For the data presented below, a perfectly conducting sphere and a perfectly conducting cylinder were used as calibration standards.

MISSING
PAGE

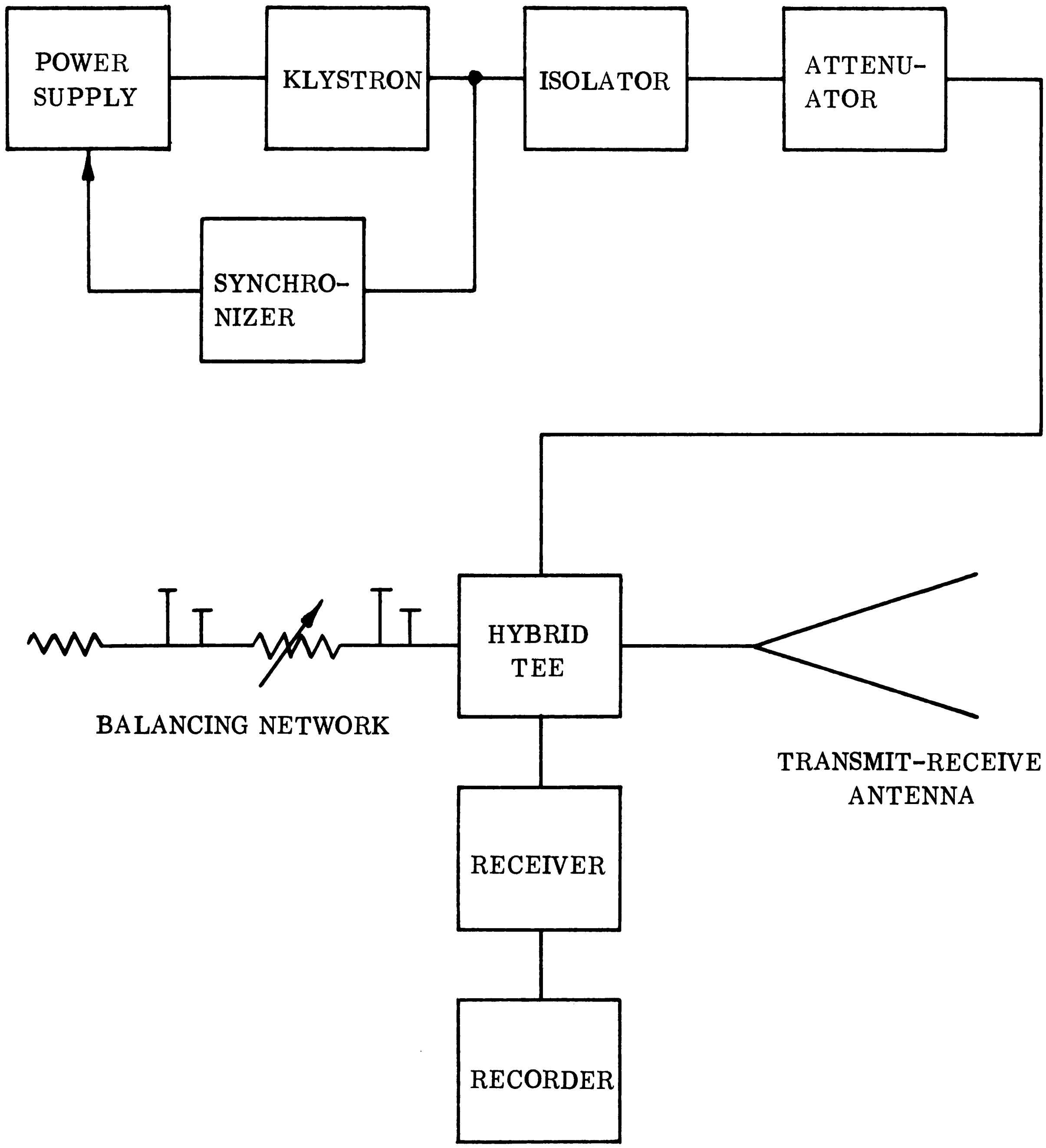


FIG. 5: CW Backscatter Radar

IV

EXPERIMENTAL PROCEDURE

The study of radar cross section as a function of pitch angle required a large time investment to produce the foam support saddles for the targets. In general each pitch angle required a different supporting mount but for the 60 mm projectile measurements small modifications were made on three basic foam caps to obtain the desired result. For the 120 mm projectile five separate foam supports were used and were carefully made because of the size and weight of the object.

The required pitch angles were obtained by canting the nose of each projectile downward. Canting downward instead of upward was decided the better way because the center of gravity of the 120 mm target lies forward of its midpoint. Canting downward thus lowers the center of gravity and increases the physical stability of the object in its test position. This consideration is not so critical for the smaller projectiles, but for the sake of consistency in recording data, they, too, were canted downward to obtain the required pitch angles.

Prior to the measurements of the test objects, the returns of two spheres 3.935 and 3.735 inch diameter, and a cylinder, 3 inches in diameter and 14 1/8 inches long, were compared. The theoretical cross sections of the three objects are -21.0 dbM^2, -22.5 dbM^2, and 0.0 dbM^2 respectively and the experimental comparison was within 0.5 db of these values. A cross section pattern of the cylinder as a function of azimuth was also recorded to establish that asymmetrical target patterns were due to the targets themselves and not to the measuring equipment.

A typical measurement run begins with the balancing process in the absence of the target as discussed above. After balancing has been performed, the test object is installed on its support column. The pitch angle alignment is checked with a spirit level and the model is aligned nose-on to the transmitter by eye. The pattern is recorded, after which the model is removed. The receiver indication is checked in the absence of the target to verify that the system is still balanced. The calibrating object is then installed and its level recorded. The entire sequence is repeated under the same target conditions to obtain a second pattern which may be compared with the first to assess repeatability.

V

ERRORS

Sources of error in the system are multiple and statements of their magnitudes are often estimates. Receiver and recorder response are linear over a 40 db range within 0.5 db. The linearity is better than this over a smaller dynamic range. In general, support column diffraction is a possible source of error and although it is often difficult to assess, we believe it is negligible for the measurements performed.

Another source of error is the shadowing effect of the target upon the rear wall. Even if the wall return were perfectly balanced out, the installation of the target on the pedestal changes the field distribution over the rear wall, hence the wall reflections are different from those which were cancelled. Therefore, the very presence of the test object changes the balance condition. Moreover, since the target forward scatter responsible for the change is a function of target aspect, the error changes with viewing angle.

The error due to shadowing effect is fortunately easy to estimate if the test object can be moved in range. The motion causes the phase of the target return to shift while that of the rear wall is fixed; the combined signal therefore goes through alternate peaks and nulls and the peak-to-peak signal excursion is the range of error that may be expected. This evaluation must be performed at discrete aspects representing typical levels of return; usually the errors are different for different levels.

The errors in cross section due to rear wall shadowing by the targets have been estimated by the target motion technique discussed above. These errors depend upon the level of cross section, as summarized in Table I.

Target	Cross Section Level, M^2	Estimated Error, db
60 mm projectile	0.1	0.2
	0.01	1.5
	0.001	4.0
82 mm projectile	0.1	0.1
	0.01	1.0
	0.001	3.0
120 mm projectile	1.0	0.2
	0.1	1.0
	0.01	3.0

Table I. Estimated Errors Due to Room Shadowing

A detailed study of the errors in the recorded data because of possible pitch angle misalignment has not been performed. For each model, pitch angle, and roll angle, however, at least two patterns were recorded and for a few selected conditions, several patterns were obtained which give us an estimate of the effect of misalignment. For small pitch angles, the error is of the order of one db and may be as large as 4 to 6 db for the steeper angles. This is because the scattering lobes in the plane of pitch are very sharp and alignment must be held within limits which cannot possibly be attained in the short duration of this contract. The error can cause a change in fine structure of the pattern, occasionally shifting the position of the peaks and nulls or it can enhance some lobes while suppressing others. The change in average cross section over, say, a given 30-degree range of aspect, seems to be affected very little by the pitch misalignment. Thus in spite of alignment errors, we feel the average cross section levels are substantially unaffected.

VI

DATA

The data are analog plots of radar cross-section in db as a function of azimuth. On each pattern is a heavy horizontal line derived from the level of return from the standard scatterer. The azimuth 0 degrees corresponds to viewing the object when the nose is pointed toward the transmitter, independent of pitch angle; note that this definition is meaningless when the pitch is 90 degrees.

Each object was measured with vertical polarization at 9.722 GHz. The pitch angles used were 0, 20, 30, 40, 50, 60, 80, 90 degrees with an accuracy of $\pm$ 0.5 degree. For the intermediate pitch angles (20, 40, 60, 80), two roll angles were examined, as outlined in Table II, and the 30 and 50 degree angles were used only for the two larger projectiles. A reference fin on each object was selected and marked and the 0 degree roll was always obtained by having that fin pointed directly upward. The other roll angles were obtained by pointing the reference fin the required angle away from the vertical. In addition to the vertical polarization patterns, a single horizontal polarization cut was made on each object for a level flight condition. The reference fin was rolled 90 degrees to the side for these data so that the azimuth angle for the horizontal patterns corresponds to the pitch angle for the vertical patterns. The pitch angles are marked on these for reference.

Object	Polar	Pitch	Roll	Pattern No.
60 mm	H	0	90	3672
	V	0	0	3717
		20	0	3720
		20	22 1/2	3721
		40	0	3724
		40	22 1/2	3726
		60	0	3727
		60	22 1/2	3730
		60	22 1/2	3736 *
		80	0	3732
		80	22 1/2	3733
		90	----	3735
82 mm	H	0	90	3761
	V	0	0	3737
		20	0	3740
		20	45	3741
		30	0	3801
		40	0	3744
		40	45	3749
		50	0	3803
		60	0	3752
		60	45	3753
		60	45	3754 *
		80	0	3755
		80	45	3757
		90	----	3759
120 mm	H	0	90	3765
	V	0	0	3775
		20	0	3777
		20	0	3772 *
		20	45	3780
		30	0	3797
		40	0	3781
		40	45	3784
		50	0	3799
		60	0	3786
		60	45	3787
		80	0	3790
		80	45	3792
		90	----	3793

Table II. List of Cross Section Patterns

* Check of Repeatability

In each case, two patterns were recorded to obtain a measure of the repeatability. The entire measurement sequence (balancing, installing and removing target, installing reference scatterer, etc) was performed for each pattern. Of the two patterns, one was selected as representative and copies thereof were made for this report.

The repeatability was not as good as we usually require and the horizontal patterns show why. It can be seen that the pitch angle has a strong effect since there are many narrow lobes in the plane of pitch. For some pitch angles, an error of only 1/4 degree can cause the level to change by 6 db or more. Moreover, some of the required pitches lie on the steep sides of a lobe, instead of at the peak value. The repeatability is therefore no better than our capability to reproduce the pitch and roll conditions, run-to-run. Although the repeatability is only fair, the average levels of return are relatively unaffected.

The test conditions for each run are labelled in the corner of each pattern. The 60 mm and 82 mm data were obtained at a range of 24 feet, while that of the 120 mm were obtained at 44 feet. Note that $\frac{2D^2}{\lambda}$ is 10.7, 22.8, and 92 feet respectively for the 60mm, 82mm, and 120mm projectiles. We feel that although the data for the last object were obtained in the "near field", the phase error (which the criterion seeks to minimize) is negligible.

THE UNIVERSITY OF MICHIGAN

07988
23 September 1966

MEMO TO E. F. Knott

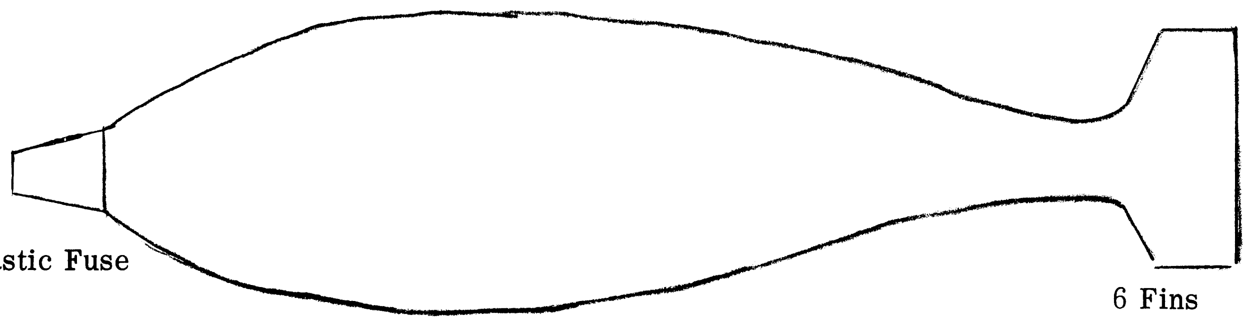
FROM T. E. Hon

SUBJECT Second Set of Sylvania Projectile Measurements

During your absence in July a second set of backscatter measurements for Ken Duncan of Sylvania were conducted. Since the experimental technique was explained in detail in the final report P. O. 95001, May, 1966 Prof. Hiatt felt it not necessary to repeat, but for our information I will describe briefly the two new models and include a chart to describe what measurements were performed.

On the evening of July 7, Mr. Ken Duncan of Sylvania arrived at the Huron Motor Inn where I met him and took possession of the two new models. He informed me that the first set of models were actual mortars used by the Viet Cong. The two new models are mortars presently used by the US Army. The following morning we embarked upon a measurement program similar to that of the first set and we used a frequency of 9.73 GHz and, for the most part, vertical polarization. When Mr. Duncan arrived we uncrated the models and discovered an 81 mm mortar very similar to the 82 mm used by the Viet Cong and a mortar we called SP-24 for lack of its proper designation. The SP-24 stands for silver printed and 24 for its length in inches (the model was made of wood). I can recall two major differences in the 81 and 82 mm projectiles; 1) the 81 mm had 6 tail fins and I believe the 82 had only four, 2) one of the two had a plastic fuse on the nose and I believe it to be the US 81 mm. I do remember that Mr. Duncan was surprised when the nose-on cross section was larger for the plastic fused mortar than that of the all metal nosed mortar.

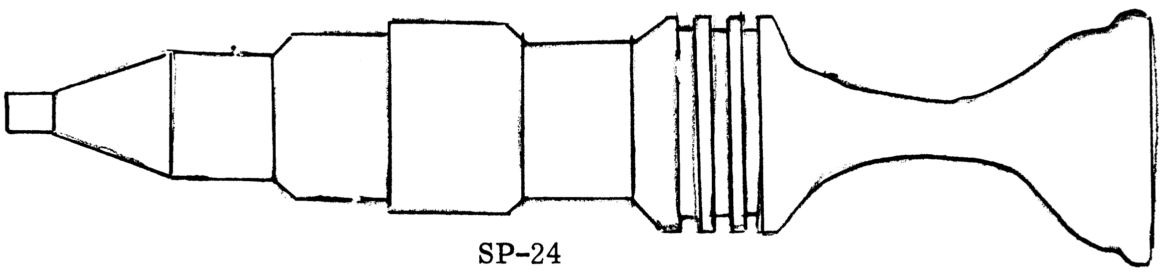
We were fortunate to have saved the Styrofoam supports after the first set of measurements, which allowed us to save much time in preparing suitable supports. To the best of my knowledge the measurements ran smoothly although at the end of



Plastic Fuse

6 Fins

81 mm



SP-24

12 Fins

the first day when Duncan was preparing to leave we had only completed those measurements for the 81 mm projectile. We ran, I believe, two or three ozalid copies for him with the agreement that the copies for SP-24 would follow as soon as they were ready by air express. The models themselves would then be shipped to Duncan by railway express. His visit to us was on a Friday and we noted that no weekend work would be necessary; the work would be resumed the following Monday. On the following Tuesday the SP-24 model measurements were completed, ozalid copies made of the data, and I delivered them to Claire White. She prepared a letter to Ken Duncan to be sent with the copies. We postponed shipping the models for a few days to make sure there would be no further measurements required. Listed on the following page in chart form are the conditions with which the measurements were made.

Model	Polar	Pitch (degrees)	Roll (degrees)	Pattern No.	
	Horiz.	0	0	4051	
	Horiz.	0	30	4050	
	Vert.	0	0	4020	
	Vert.	0	30	4022	
81 mm	Vert.	20	0	4024	
	Vert.	20	30	4026	
(Measured	Vert.	30	0	4046	
at 24'	Vert.	30	30	4048	
range)	Vert.	40	0	4028	
	Vert.	40	30	4030	
	Vert.	50	0	4042	
	Vert.	50	30	4044	
	Vert.	60	0	4038	
	Vert.	60	30	4040	
	Vert.	80	0	4032	
	Vert.	80	30	4034	
	Vert.	90	-	4036	
	Vert.	90	-	4049	← with fin holes covered
	Horiz.	0	0	4053	
	Horiz.	0	15	4055	
	Vert.	0	0	4059	
	Vert.	0	15	4057	
SP-24	Vert.	20	0	4061	
	Vert.	20	15	4063	
(Measured	Vert.	30	0	4067	
at 40'	Vert.	30	15	4065	
range)	Vert.	40	0	4071	
	Vert.	40	15	4069	
	Vert.	50	0	4073	
	Vert.	50	15	4075	
	Vert.	60	0	4077	
	Vert.	60	15	4079	
	Vert.	80	0	4081	
	Vert.	80	15	4083	
	Vert.	90	-	4084	