12

AD A048348

TECHNICAL REPORT T-78-13

STATUS OF THE LASER AUTOMATED MISSILE POSITION AND ATTITUDE MEASUREMENT SYSTEM

U.S. ARMY MISSILE RESEARCH AND DEVELOPMENT COMMAND

Aeroballistics Directorate
Technology Laboratory

November 1977

Approved for public release; distribution unlimited.

AD NO.
DDC FILE COPY

Redstone Arsenal, Alabama 35809

D D C
RECEIVED
JAN 13 1978
D

DMI FORM 1000, 1 APR 77

DISCLAIMER NOTICE

THIS DOCUMENT IS BEST QUALITY PRACTICABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

DISPOSITION INSTRUCTIONS

DESTROY THIS REPORT WHEN IT IS NO LONGER NEEDED. DO NOT RETURN IT TO THE ORIGINATOR.

DISCLAIMER

THE FINDINGS IN THIS REPORT ARE NOT TO BE CONSTRUED AS AN OFFICIAL DEPARTMENT OF THE ARMY POSITION UNLESS SO DESIGNATED BY OTHER AUTHORIZED DOCUMENTS.

TRADE NAMES

USE OF TRADE NAMES OR MANUFACTURERS IN THIS REPORT DOES NOT CONSTITUTE AN OFFICIAL INDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL HARDWARE OR SOFTWARE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS
BEFORE COMPLETING FORM

1. REPORT NUMBER
T-78-13

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER
9

4. TITLE (and Subtitle)
(6) STATUS OF THE LASER AUTOMATED MISSILE POSITION AND ATTITUDE MEASUREMENT SYSTEM.

5. TYPE OF REPORT & PERIOD COVERED
Technical Report.

6. PERFORMING ORG. REPORT NUMBER
T-78-13

7. AUTHOR(s)
(10) K. Pell, A. Presson, R. Conard, and D. Brown

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Commander
US Army Missile Research and Development Command
Attn: DRDMI-TD
Redstone Arsenal, Alabama 35809

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
(16) DA 1L162303A214
AMCMS 612303.2140511.01

11. CONTROLLING OFFICE NAME AND ADDRESS
Commander
US Army Missile Research and Development Command
Attn: DRDMI-TI
Redstone Arsenal, Alabama 35809

12. REPORT DATE
(11) November 1977

13. NUMBER OF PAGES
24

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
(14) DRDMI-T-78-13

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

(12) 25p.

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

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

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ground-based tracking systems
Pulsed laser
Continuous wave laser
Retroreflecting arrays
Roof prisms
Earth-fixed cartesian system
Vehicle-based cartesian system

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Laser Automated Missile Position and Attitude Measurement system is a laser technique for automated, missile position, and attitude measurement on test ranges. During the past three years, the concept has been investigated and refined using experimental and analytical techniques. This report will describe the attitude measurement concept, present the results of laboratory and field tests, and summarize the status of hardware currently being fabricated by GTE Sylvania.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

CONTENTS

X

A

DDC

ACKNOWLEDGMENT

The authors wish to express their appreciation to Mr. James Starr and Mr. John Becker of GTE Sylvania for setting up and conducting the field tests of the attitude measurements.

I. INTRODUCTION

The Laser Automated Missile Position and Attitude Measurement System (LAMPAMS) is a laser technique for automated, missile position, and attitude measurement on test ranges. During the past three years, the concept has been investigated and refined using experimental and analytical techniques [1-5]. This report will describe the attitude measurement concept, present the results of laboratory and field tests, and summarize the status of hardware currently being fabricated by GTE Sylvania.

II. SYSTEM CONCEPT

The system includes two ground-based transmitter/detector tracking stations, each incorporating one pulsed and one continuous wave (CW) laser. On board the vehicle, two different types of retroreflecting arrays are required.

One type of array is composed of either conventional corner cubes, reflective tapes, and/or paints which have the property of retroreflecting a portion of the collimated incident beam back parallel to itself regardless of the orientation of the reflective surface. This array forms a retroreflecting band located on the perimeter of the vehicle body at one axial position. Illumination of and reflection by this retroreflecting band will then form the basis for a conventional laser radar tracking system.

Two roof prisms as shown in Figure 1 form a second array which is also mounted on the vehicle's surface. The roof prisms will be termed here, single plane corner reflectors. A plane which passes through the center of the reflecting surfaces of the roof prism and is also normal to these surfaces will be called the retroreflection plane. Collimated light incident on the single plane corner reflector and contained in its retroreflection plane is reflected back to the source. Two of these single plane corner reflectors are mounted on the surface of the vehicle in such a manner that their retroreflection planes are skewed relative to each other and the roll axis of the vehicle. The mathematical analysis to follow will consider the special case where the retroreflection plane of one of the arrays contains the roll axis. An illustration of an instrumented vehicle is presented in Figure 2.

As the vehicle flies downrange, it is tracked with the laser radar for determining the vehicle position as a function of time while also positioning the CW laser to provide continuous CW illumination of the vehicle. During each revolution of the spinning vehicle, two CW laser pulses are returned to each of the two tracking stations. The time interval between the pulses returned to two separate tracking stations and between the two pulses returned to each station provide sufficient data for determination of the vehicle attitude. A mathematical description of this system is presented in the next section.

III. MATHEMATICAL DESCRIPTION OF THE SYSTEM

In order to describe the system mathematically, two right-hand orthogonal coordinate systems are utilized: an earth-fixed cartesian system and a vehicle-based cartesian system. The earth-fixed system is defined with the origin located at the launch site, positive Z-axis pointing in the vertical upward direction from the center of earth, positive Y-axis in the downrange direction, and positive X-axis in the crossrange direction. The vehicle-based system is defined with the origin located at the vehicle center of gravity; ω-axis coinciding with the vehicle roll axis with the positive direction pointing toward the nose; η-axis oriented perpendicular to ω and parallel to the X-Y plane of the earth-fixed system; and ξ-axis oriented perpendicular to η and ω with its positive direction such that η, ω, and ξ form a right hand orthogonal system.

The components of the position vectors of the i^{th} ground station and the vehicle in the earth-fixed system are X_i, Y_i, Z_i and X_m, Y_m, Z_m, respectively. Using the well-known transformation

$$\left\{\begin{matrix} \eta_i \\ \omega_i \\ \xi_i \end{matrix}\right\} = \left\{\begin{matrix} \cos(\delta_2) & \sin(\delta_2) & 0 & X_i - X_m \\ \sin(\delta_1) & -\sin(\delta_2)\cos(\delta_1) & \cos(\delta_2)\cos(\delta_1) & Y_i - Y_m \\ \cos(\delta_1) & \sin(\delta_1)\sin(\delta_2) & -\sin(\delta_1)\cos(\delta_2) & Z_i - Z_m \end{matrix}\right\}$$

between the earth-fixed and vehicle-based systems, the following relationships are obtained for the coordinates of the ground stations in the vehicle-based coordinates:

$$\begin{aligned} \eta_i &= \cos(\delta_2)(X_i - X_m) - \sin(\delta_2)(Y_i - Y_m) \\ \omega_i &= \sin(\delta_2)\cos(\delta_1)(X_i - X_m) + \cos(\delta_2)\cos(\delta_1)(Y_i - Y_m) \\ &\quad + \sin(\delta_1)(Z_i - Z_m) \qquad (1) \\ \xi_i &= -\sin(\delta_2)\sin(\delta_1)(X_i - X_m) - \cos(\delta_2)\sin(\delta_1)(Y_i - Y_m) \\ &\quad + \cos(\delta_1)(Z_i - Z_m) \end{aligned}$$

where δ_1 and δ_2 represent pitch and yaw, respectively. Pitch is defined here to be the angle between the X-Y plane and the ω axis; yaw is defined to be the angle between the Y-Z plane and the projection of the ω axis into the X-Y plane as shown in Figure 3.

It can be shown [2-5] that the time interval between consecutive pulses (straight then skewed reflectors) at Ground Station 1 is given by

$$\Delta t_{11} = \frac{1}{\Omega} \left\{ \beta + \arcsin \left[\frac{\omega_1 \tan \gamma_2}{(\eta_1^{\,2} + \xi_1^{\,2})^{1/2}} \right] \right\} \quad . \tag{2}$$

The time interval between pulses from one reflector at the two different ground stations is

$$\Delta t_{21} = \frac{1}{\Omega} \left\{ \arctan \frac{\xi_1}{\eta_1} - \arctan \frac{\xi_2}{\eta_2} \right\} \quad . \tag{3}$$

Assuming that the missile position is known from the radar data and the roll rate is inferred from return pulse data at one station (every other pulse represents one revolution) substitution in Equations (2) and (3) of the relationships given in Equation (1) yields two equations in two unknowns (pitch, δ_1 and yaw, δ_2). These two equations can be solved simultaneously for the vehicle attitude.

IV. EXPERIMENTAL PROGRAM

A. Laboratory Experiments (University of Wyoming)

The objective of the laboratory experimental program was to verify the system concept, in particular the mathematical formulation developed in the previous sections. It might be expected that problem areas not identified in the mathematical studies and earlier concept studies could be uncovered and investigated using the experimental apparatus.

Two static laser ground stations were fabricated in addition to a model rocket equipped with two 90° roof prisms. The ground stations were located on a line x - 30 ft crossrange. The rocket was systematically positioned in various x and y coordinates along the line x - 0 in the earth-fixed system.

Each ground station incorporated a 3-mW helium-neon laser operating at 6328 Å,* a spatial filter, and a collimator. A mounting ring for the photodetectors was fixed to the collimator. Two holes were drilled through the ring and the photodetectors were inserted from the back and epoxied in place. No auxiliary optics were used in the detection system

---

*Metrologic Model 420 laser.

because it was found that an adequate signal was obtained without this complication. A simple amplifier for the signal from the photodetectors was housed in a small aluminum chassis box which was epoxied to the top of the laser.

The model rocket consisted of a short, heavy-walled, aluminum cylinder. At one axial position, two holes were bored through the wall of the cylinder. These holes were separated circumferentially by 90°. One hole accommodated a mount for a skewed reflector, allowing the angle γ for the reflector to be adjusted to a particular value prior to conducting the experiment.

A steel drive shaft was attached to the back of the cylinder along the axis of the cylinder. The shaft was supported in cantilever fashion, with two ball bearings which were mounted in bearing blocks which were in turn attached to a base plate. An electric gear motor (9.61 rpm) was attached to the base plate and coupled to the drive shaft through a flexible coupling.

Both lasers were mounted on heavy duty metal tripods to facilitate positioning and alignment. The model rocket was mounted on an L-bracket which was in turn attached to a rotary table. This arrangement provides a rather crude but rigid elevation over azimuth mount for the model.

In order to measure the various time intervals, two digital timers were used.* The output signals of the photodetectors were amplified in the amplifier located on top of each laser. The outputs of these amplifiers were used as inputs to the timers to initiate and terminate counting. A schematic representation of the detection/timing circuit is shown in Figure 4. The detection/timing circuit was used to make three different types of measurements. Roll rate was measured using a signal from one laser ground station. The time interval for one complete revolution of the rocket was measured by starting and stopping the counter with consecutive pulses from a single photodetector. This measurement was checked with a nearly instantaneous measurement of the roll rate which was obtained by starting the counter with a pulse from a photodetector located in the mounting ring on top of the collimator, and stopping the counter with a pulse from a detector located in the same mounting ring directly below the center of the collimator. The time interval between return pulses to the two laser stations from the straight reflector was measured by starting the counter with the pulse received at Station 1 and stopping the counter with the return pulse received at Station 2. Simultaneously, the time interval between pulse receptions from the straight and skewed reflectors at Station 1 was measured. The same pulse which initiated counting in the previous measurement initiated counting on the second counter. This count was stopped, however, by a return pulse form the skewed reflector received at Station 1.

---

*Universal Time Model 7370
Hewlett Packard Timer Model 5323DR

It is apparent that with only two counters available, all three intervals of interest could not be measured simultaneously. In view of the fact that the gear motor is synchronous, and therefore the roll rate would change only with the line frequency, the roll rate was measured separately and assumed to remain constant. Although this seems to be a reasonable assumption, it has been found that significant frequency fluctuations occur in the service provided by the University Power House. Therefore, the roll rate was measured before and after each attitude determination to check for constant roll rate.

B. Results of the Experimental Program

Setting the angle γ and measuring the various angles to a high degree of accuracy ultimately required the use of lasers and large optical levers. The entire system including ground stations, model, and retroreflectors was eventually aligned to an angular accuracy of 0.05°. Experiments were conducted with the model located at two different positions downrange and pitch and yaw attitudes varying from -20° to +20°.

The measured time intervals were used to determine the pitch and yaw attitudes. These tests indicate that, for the static system, the pitch and yaw can be determined to essentially the same accuracy as the experimental error associated with aligning the various components. Two demonstrations of this bench top system were conducted for Army personnel.

C. Field Experiments (GTE-Sylvania)

During fiscal year 1977 the US Army Missile Research and Development Command (MIRADCOM) contracted with GTE Sylvania to fabricate a single LAMPAMS station. The station is based on Sylvania's Product Assurance Tests (PAT) laser tracker. In addition to the standard tracker, a parallel CW Neodymium-YAG laser and detector are included on the mount. A series of static tests of attitude measurement have been conducted recently at the Sylvania plant using the CW laser and detector developed for the LAMPAMS stations.

The experiments conducted were similar to the laboratory tests. A replacement fuse for a 2.75-in. rocket was equipped with two roof prisms as shown in Figure 5. One of the prisms was located such that its plane of retroreflection was parallel to and contained the axis of symmetry of the replacement fuse. The second prism was rotated (β) 10° from the first prism and skewed 15°. A 0.25-in. drill rod shaft was located on the axis of the fuse and driven with a variable speed electric motor. The fuse shaft was mounted on bearings which were attached to a PIC mechanical experimenter's table which was in turn mounted on an elevation over azimuth mount. This target was located in a walled enclosure 750 ft downrange from the laser. The enclosure trapped the laser beam, effectively confining it to Sylvania property which is bounded by a commercial/agricultural/residential area. A heat exchanger, laser power supply, detector power supplies, and two counters for data measurement were housed in a small building adjacent to the laser/detector which was supported on a heavy duty tripod. The laser was operated at power levels estimated to be between 10 and 20 W. Neither the transmitted nor detected laser beam paths incorporate focusing optics. Four separate detector elements are used to provide an active surface area which is estimated to be approximately 5 in.^{2} in area. Figure 6 provides an overview of the experimental arrangement.

The experiment was conducted by using a conventional rifle scope mounted on a special fixture to orient the axis of the fuse at 90° to the laser beam. A theodolite mounted on the target table was then zeroed after which the laser was adjusted to provide a maximum return signal to the detector. Two counters were used to time both the interval between consecutive pulses and the interval between every other pulse. A simple flip-flop circuit was used to blank every other pulse to one counter providing a direct readout of the reciprocal of the roll rate. The other counter displayed the time interval between pulses which was used to determine yaw attitude. Because only one laser/detector station was used, only one angle was determined. In almost all runs, the pitch was fixed at zero and the yaw was systematically varied up to ±40° off normal.

Experiments were conducted for a variety of observers over a period of several days. The data obtained on the various days are presented in Table 1. Data reduction involved using the equation

$$\sigma = \arctan \left\{ \frac{\tan \gamma_2}{\sin\{2\pi\omega\Delta t - \beta\}} \right\} . \tag{4}$$

The two geometric constants were evaluated in the laboratory to be

$$\gamma_2 = 15.2°$$

$$\beta = 9.08° .$$

Experimental results [σ as determined from Equation (4)] are recorded in Column 5 of Table 1 with the difference between the theodolite reading and the calculated angle being recorded in Column 6.

It should be noted that very little effort was expended to set the pitch attitude to zero since the data did not seem to be sensitive to pitch. Other error sources include the fact that the detector was simply a threshold level detector rather than a beam center detector which will be incorporated in the attitude subsystem of LAMPAMS. The prisms are commercial items with 10-sec accuracy. No attempt was made to check the accuracy of the theodolite.

Ambient temperature during the field tests varied between 70° and 80°. The path of the beam was approximately 4 ft above the surface of the ground. The beam path crossed two black-topped road surfaces and a railroad track; however, the majority of the path was over bare earth, some of which was tilled. Scintillation caused apparent shifts of laser/detector of approximately 2 in. when viewed through the sighting scope or the theodolite.

V. HARDWARE STATUS

On 11 and 12 July, essentially all of the hardware subsystems of the LAMPAMS station were reviewed at the Sylvania plant. The GFE 266 Contraves mount had been equipped with 18-bit optical encoders and the instrumentation package support was partially dissassembled for modification. Considerable care had been taken to maintain the integrity of the machined in-place elevation bearing – instrumentation support assembly. The optical package for the pulsed tracking laser/detector was essentially complete with integration of a solenoid actuated shutter and detector electronics package currently underway. The pulsed laser was undergoing qualification tests. Hardware subsystems which were currently being worked on, tested, or ready for integration included the following:

a) Servo drive.

b) Computer interface unit.

c) TV camera and monitor.

d) Projectile initialization module.

e) Attitude subsystem.

f) Timing unit.

g) Laser power supply.

h) System control.

i) Range computer.

The attitude laser/detector and heat exchanger (for both lasers) which were used in the field experiments will be integrated into the final configuration. None of the computer-related equipment (mainframe, CRT, interfaces, or tape drive) was on hand. It should be noted that the software modification of the standard PATS operating system had not been initiated at this time.

VI. PROPOSED ADDITIONAL TESTING

Testing of the LAMPAMS system on Range No. 1 at Redstone Arsenal will be initiated in December. The first tests will be static, with the target utilizing the elevation over azimuth mount used in the field tests at the Sylvania plant. A rotating element driven with the variable speed drive and incorporating a single plane corner reflector will be used to confirm that the system meets specifications on roll rate determination. The replacement 2.75-in. rocket fuse used in the earlier tests at the Sylvania plant will also be used to test attitude measurement over a wide range of attitudes and ranges. A second series of tests will be dynamic, using a variety of vehicles as outlined in Table 2. These tests will primarily involve tracking and roll rate determination; however, six 2.75-in. rockets will be fitted with replacement fuses similar to the one used for the static tests so that a determination of the aspect angle (σ) can be made.

Follow-on tests are not well defined; however, they will include aspect angle determination for eighteen 2.75-in. rockets. These rockets will be fitted with replacement fuses incorporating bearing mounted elements housing skewed retroreflectors as shown in Figure 7. The bearing mounted sections will be prespun (prior to launch) to 9000 rpm. It is anticipated that a high data rate will be maintained throughout the duration of the flights.

VII. SUMMARY

Based on the analytical and experimental studies conducted, it appears that the LAMPAMS concept offers the potential of providing vehicle position to within ±1 ft and attitude (pitch and yaw) to within 0.1°. To date, no significant problems which could impact the performance of the system have been identified.

The state of the hardware is such that system integration and checkout at the GTE Sylvania plant should proceed on a timely basis to allow a December 1 delivery of the system to MIRADCOM at Redstone Arsenal assuming that the government funded equipment (GFE) is delivered to Sylvania in August.

TABLE 1. DATA COLLECTED DURING EXPERIMENTS

Date	Theodolite Reading (deg)	Δt_{11} (msec)	Δt Roll (msec)	σ (deg) Calculated	$\Delta\sigma$ (deg) Calculated
July 6	0.0	1.275	50.6	-0.03	-0.03
	0.17	1.283	50.6	0.18	+0.01
	1.33	1.329	50.6	1.39	+0.06
	4.67	1.451	50.6	4.59	-0.07
	10.83	1.696	50.6	10.92	+0.09
	19.93	2.072	50.65	20.01	+0.18
	0.0	1.279	50.65	0.04	+0.04
	-0.17	1.272	50.65	-0.15	+0.02
	-1.17	1.227	50.65	-1.33	-0.16
	-4.67	1.100	50.65	-4.66	+0.01
	-10.83	0.860	50.65	-10.85	-0.02
	-19.83	0.490	50.65	-19.85	-0.02
	0.0	1.227	50.65	-0.01	-0.01
July 7	0.0	1.277	50.6	0.02	+0.02
	4.67	1.452	50.6	4.62	-0.05
	7.5	1.566	50.6	7.58	+0.08
	10.83	1.694	50.6	10.87	+0.04
	13.33	1.789	50.6	13.25	-0.07
	15.17	1.859	50.6	14.98	-0.19
	16.83	1.934	50.6	16.81	-0.02
	19.83	2.060	50.6	19.78	-0.05
	22.00	2.159	50.6	22.05	+0.05
	24.50	2.272	50.6	24.54	+0.04
	0.0	1.279	50.7	0.01	+0.01

TABLE 1. (Continued)

Date	Theodolite Reading (deg)	$\Delta\tau_{11}$ (msec)	$\Delta\tau$ Roll (msec)	σ (deg) Calculated	$\Delta\sigma$ (deg) Calculated
July 8	0.0	1.314	52.2	0.07	+0.07
	4.67	1.495	52.2	4.55	-0.12
	10.83	1.740	52.2	10.68	-0.21
	15.17	1.919	52.1	15.10	-0.07
	19.83	2.119	52.1	19.74	-0.09
	24.50	2.330	52.1	24.34	-0.16
	15.17	1.915	52.1	15.05	-0.12
	0.0	1.310	52.1	-0.11	-0.11
	-24.00	0.310	52.06	-24.09	-0.09
July 12	0.0	1.265	50.27	Used to Verify β	
		1.262	50.00		
		1.263	50.05		
	5.0	1.451	50.05	5.01	+0.01
		1.455	50.15	5.04	+0.04
		1.453	50.17	4.97	-0.03
		1.450	50.11	4.94	-0.06
	10.0	1.640	50.20	9.82	-0.18
		1.636	50.10	9.80	-0.20
		1.641	50.12	9.92	-0.08
		1.640	50.10	9.91	-0.09
	15.0	1.840	50.15	14.92	-0.08
		1.842	50.15	14.97	-0.03

TABLE 1. (Concluded)

Date	Theodolite Reading (deg)	$\Delta\tau_{11}$ (msec)	$\Delta\tau$ Roll (msec)	σ (deg) Calculated	$\Delta\sigma$ (deg) Calculated
July 12	20.0	2.050	50.13	20.00	0.00
		2.049	50.15	19.96	-0.04
		2.051	50.25	19.91	-0.09
	23.33	2.200	50.30	23.25	-0.08
		2.201	50.25	23.32	-0.01
		2.204	50.25	23.39	+0.06
	30.17	2.542	50.25	30.08	-0.09
		2.516	50.30	29.88	-0.29
		2.524	50.30	30.03	-0.14
	40.0	3.080	50.15	39.85	-0.15
		3.078	50.18	39.79	-0.21
		3.075	50.23	39.70	-0.30
		3.075	50.19	39.74	-0.26
	-10.0	0.885	50.20	-10.01	-0.01
		0.884	50.10	- 9.99	+0.01
		0.883	50.18	-10.05	-0.05
	-21.67	0.404	50.07	-21.71	-0.04
		0.405	50.08	-21.69	-0.02
		0.406	50.07	-21.67	0.00
	-35.0	-0.257	50.18	35.05	+0.05
		-0.258	50.14	25.07	+0.07
		-0.259	50.11	35.09	+0.09

TABLE 2. DYNAMIC TESTS

Target	No. of Rounds	Muzzle Velocity (fps)	In-Flight Acceleration (g's)	Spin Rate (rps)	Launch QE	Range Meter	Type Launcher	Auto Track	Position	Data Required Roll	Aspect Angle
105 mm	2	750*	0	123	54°	4450	Tube	X	X	X (to 3000 ft)	
	2	950*	0	152	7 1/2°	1970	Tube	X	X	X (to 3000 ft)	
	2	950*	0	152	15°	3775	Tube	X		X (to 3000 ft)	
	2	1200*	0	212	7 1/2°	3200	Tube	X		X (to 3000 ft)	
	2	1200*	0	212	12°	4700	Tube	X	X	X (to 3000 ft)	
2.75-in.	4	0	60	0	3°	500	Sled	X	X		
Rocket	2	185	60	2-20	5°	3000	Tube	X	X	X (to 2250 ft)**	X (to 2250 ft)**
	2	185	60	2-20	8°	3500	Tube	X	X	X (to 2250 ft)**	X (to 2250 ft)**
	2	185	60	2-20	10°	4000	Tube	X	X	X (to 2250 ft)**	X (to 2250 ft)**
TOW Missile	2	200	30	0	0°	3000	Tube	X	X		
Helicopter	1	hr flight		0		1000 to 16,500 ft		X	X		

*± 50 fps

**Data anticipated to loss of spin (~ 1000 ft)

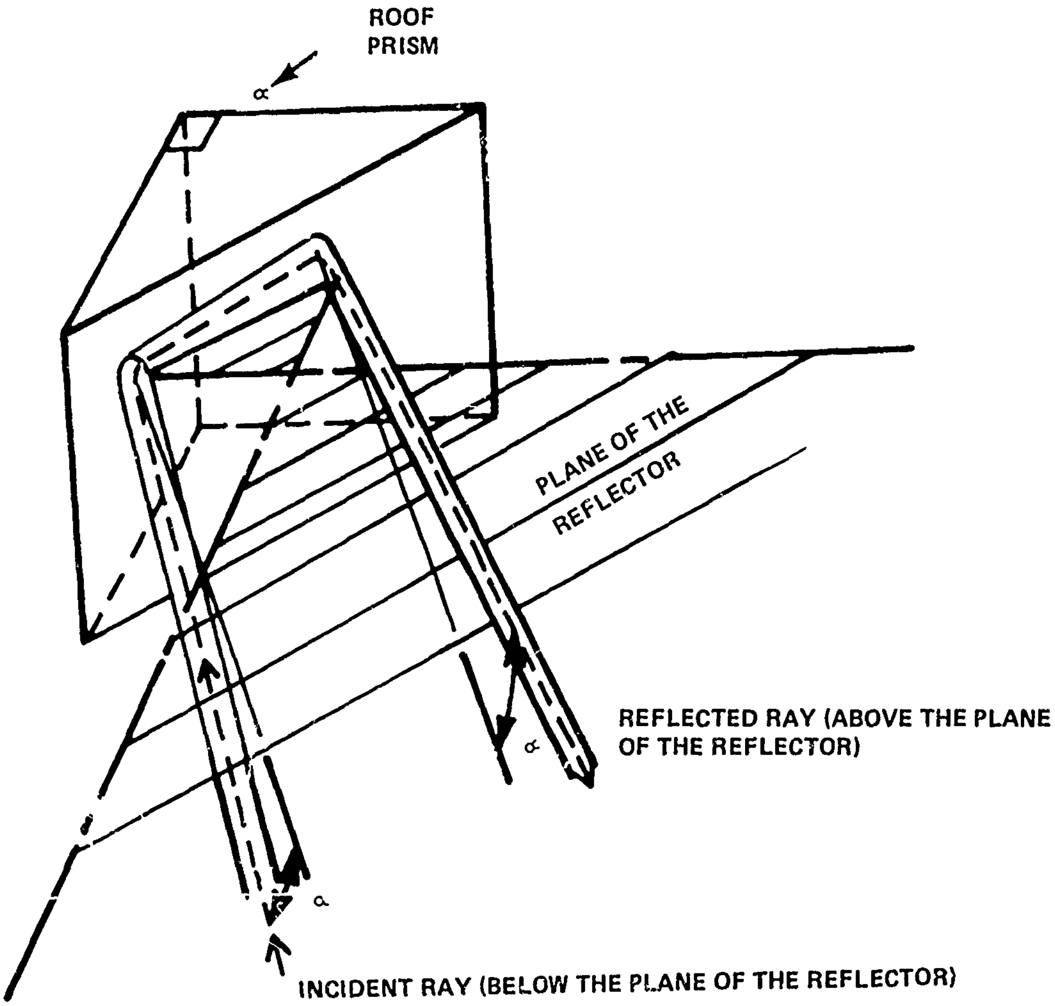

Figure 1. Geometric optics of a single plane corner reflector (roof prism).

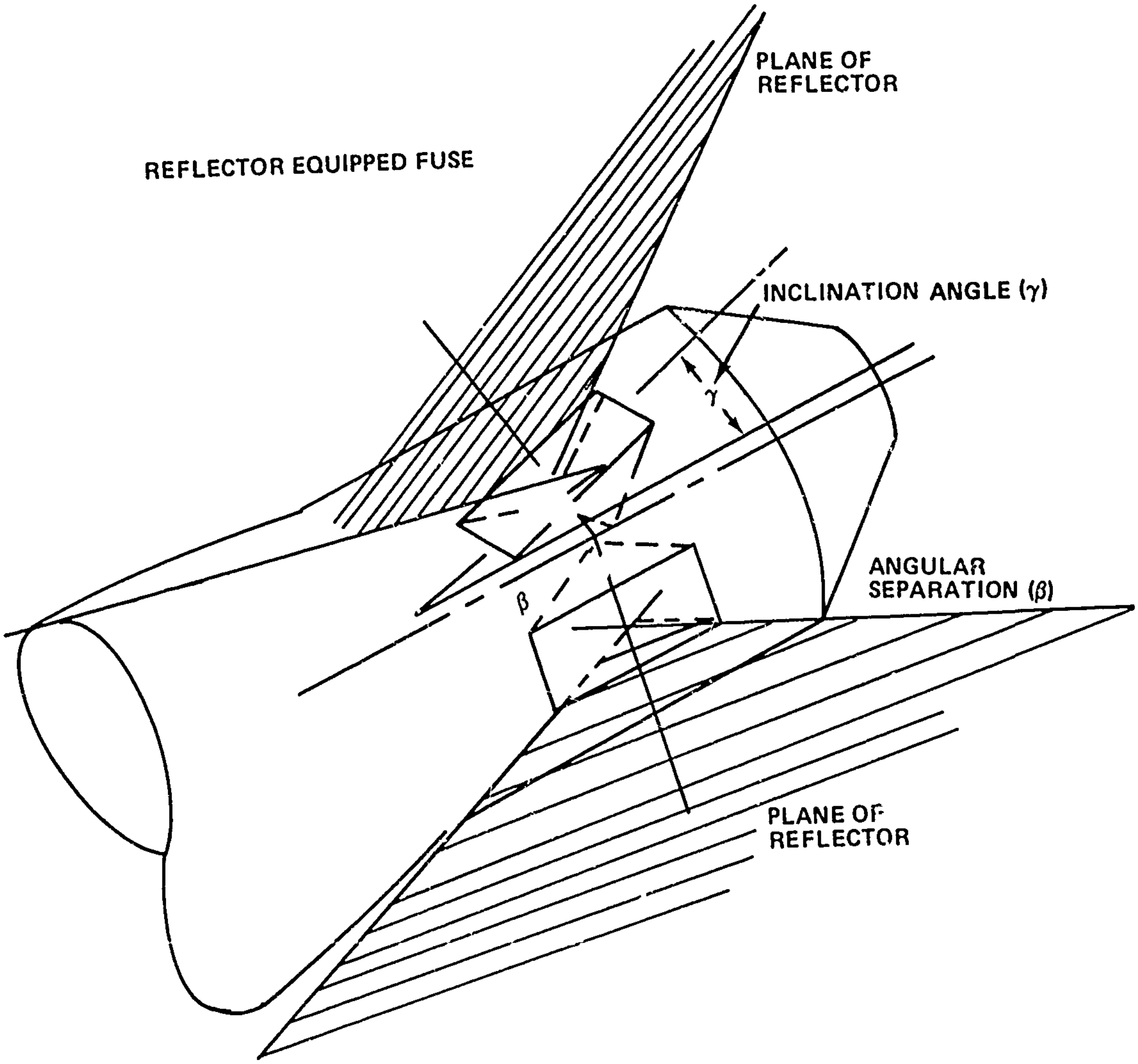

Figure 2. Reflector equipped rocket.

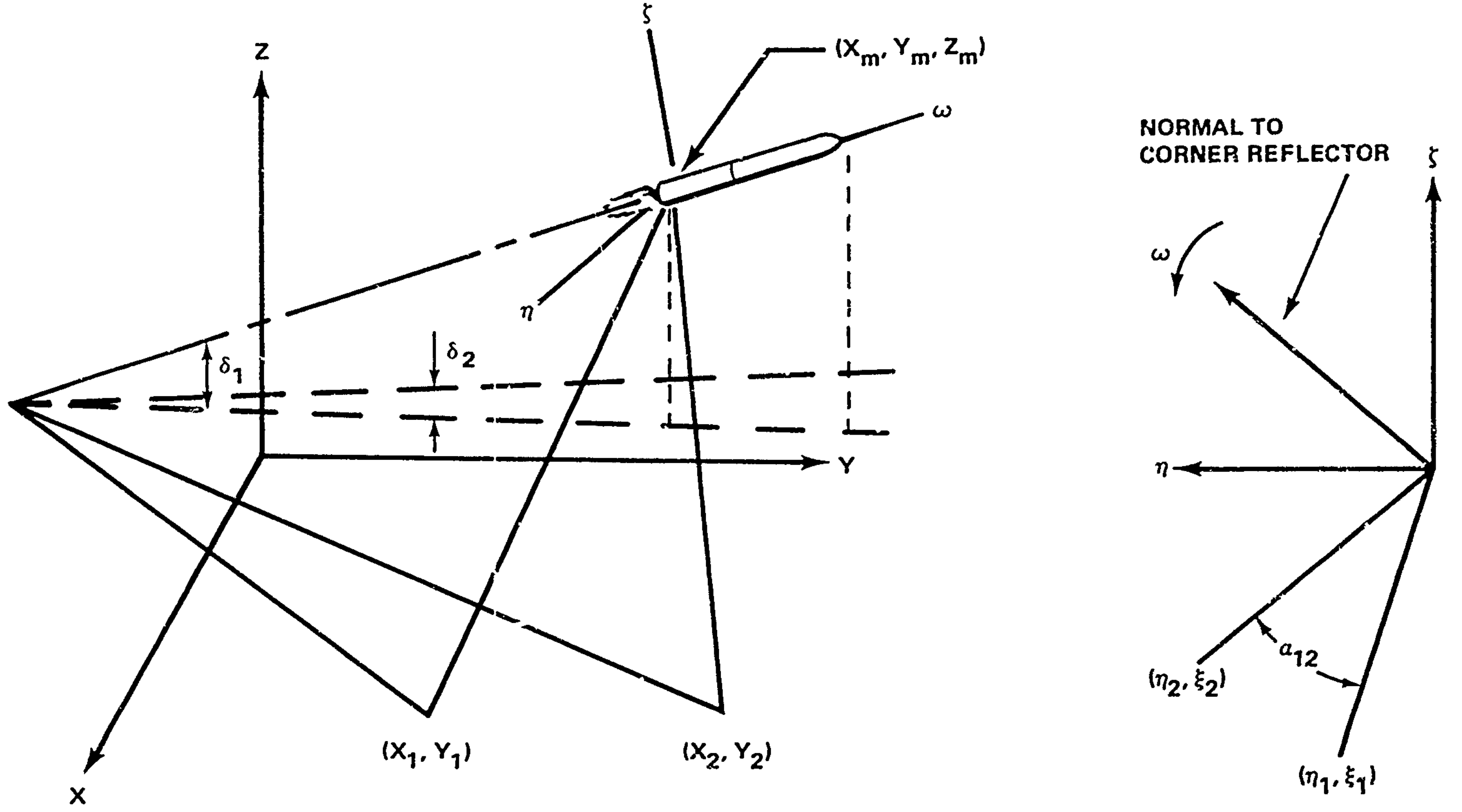

Figure 3. Geometry and notation.

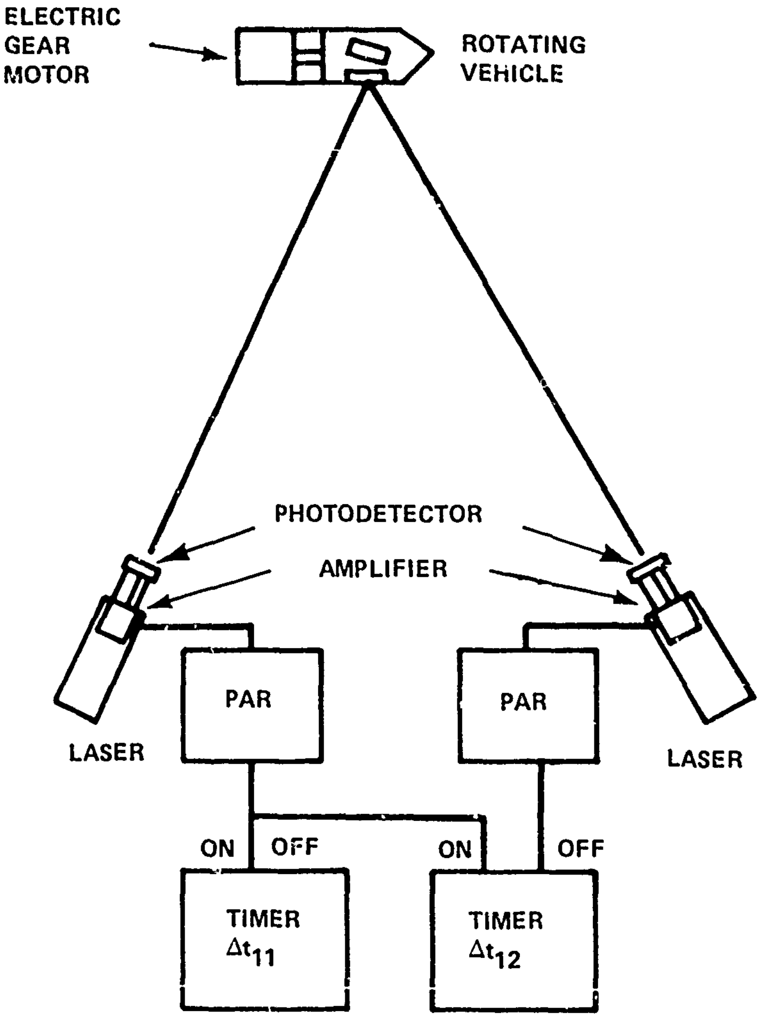

Figure 4. Laboratory experimental model.

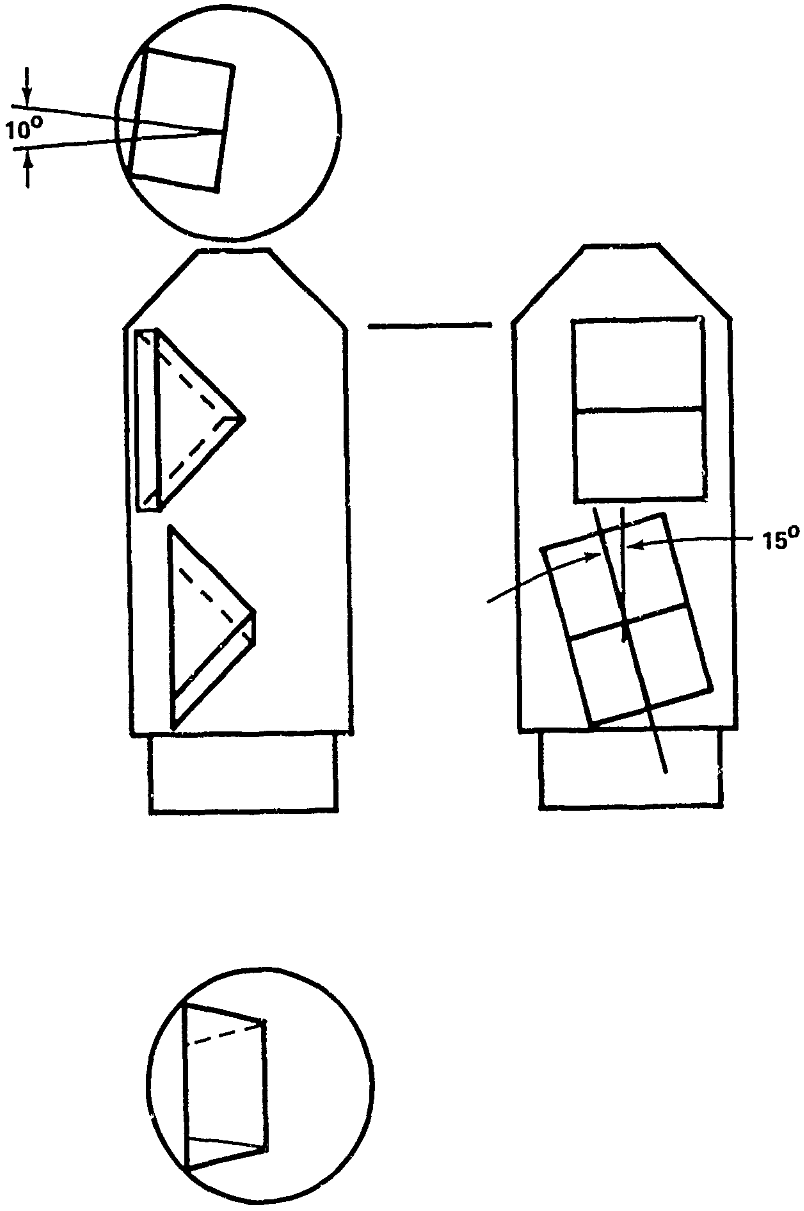

Figure 5. Fuse replacement (2.75-in. rocket).

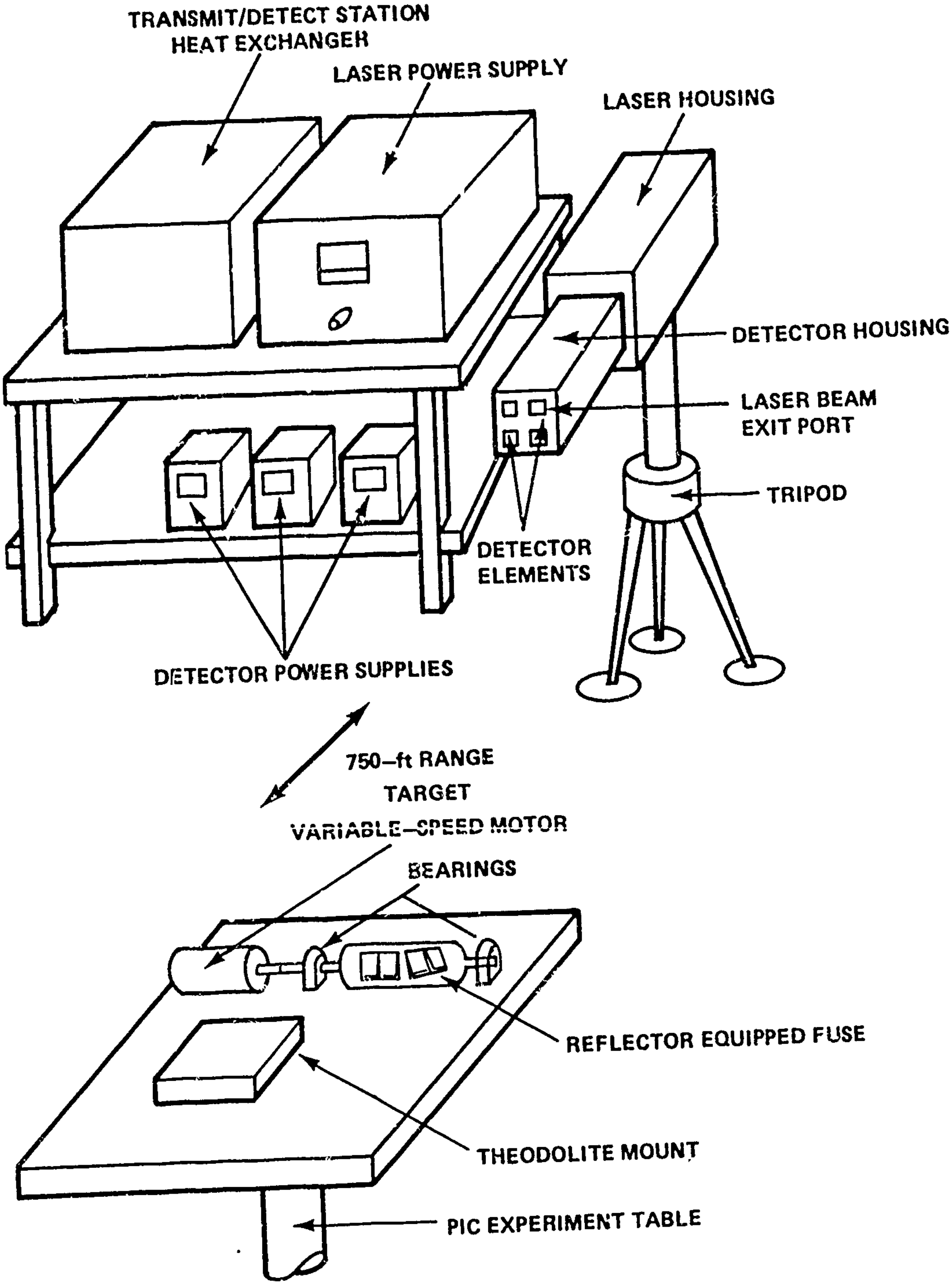

Figure 6. Field experiments.

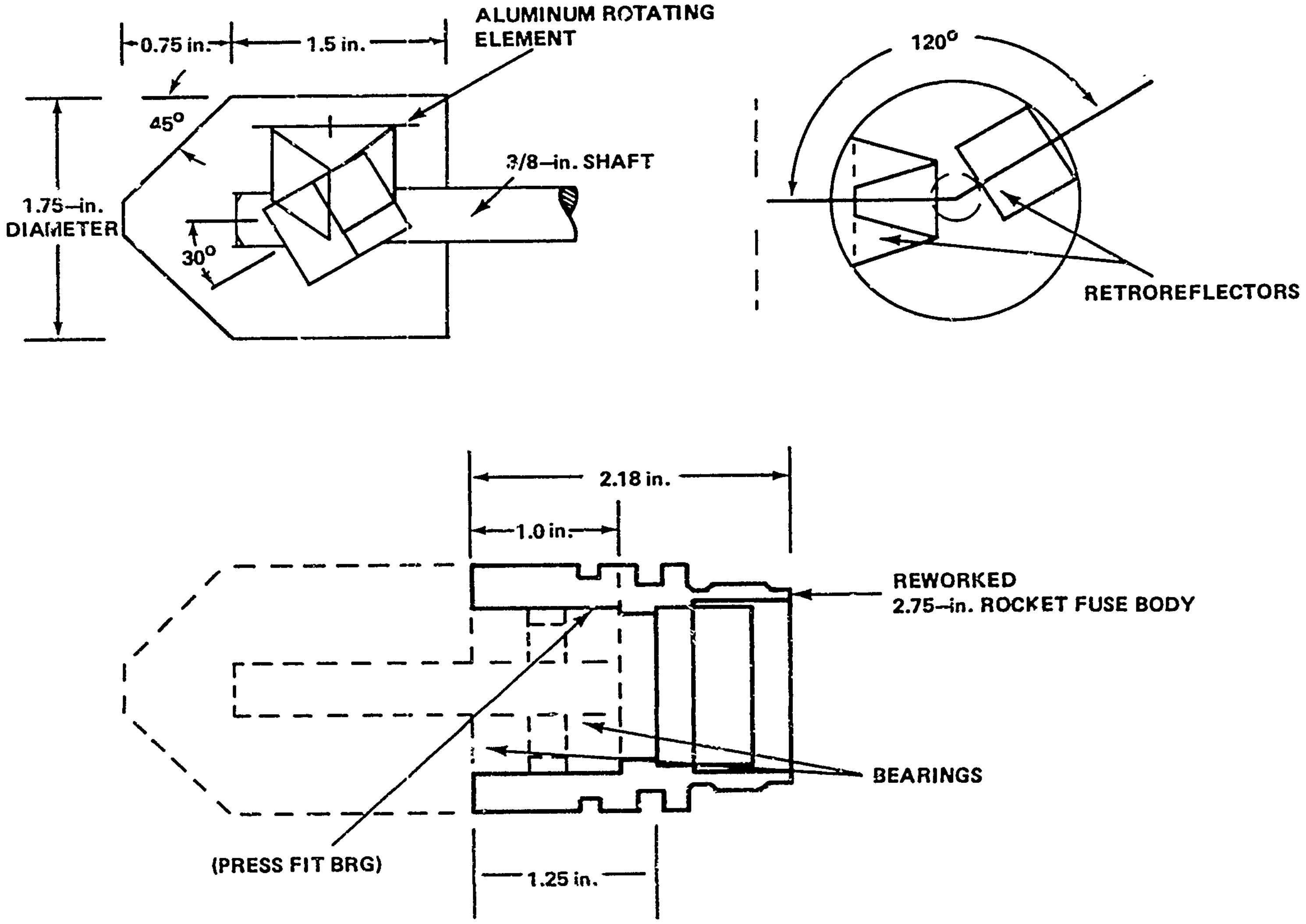

Figure 7. Prespun fuse.

LIST OF SYMBOLS

X_i – Crossrange coordinate of i^{th} ground station

Y_i – Downrange coordinate of i^{th} ground station

Z_i – Vertical coordinate of i^{th} ground station

X_m – Crossrange coordinate of vehicle

Y_m – Downrange coordinate of vehicle

Z_m – Vertical coordinate of vehicle

ω_i – Body centered coordinate coinciding with roll axis

ξ_i – Body centered coordinated perpendicular to ω and η

η_i – Body centered coordinate parallel to X-Y plane

δ_1 – Geometric pitch

δ_2 – Geometric yaw

Ω – Vehicle roll rate

β – Separation angle (between reflectors)

γ_2 – Skew angle (second reflector)

REFERENCES

1. Conard, R. G., Brown, D. B., Pell, K. M., and Nydahl, J. E., Techniques for Remote Sensing of Missile Position and Attitude, US Army Missile Command, Redstone Arsenal, Alabama, October 1975, Report No. RD-76-11.

2. Conard, R. G., Pell, K. M., and Nydahl, J. E., Measurement of Missile Position and Attitude by Lasers, US Army Missile Command, Redstone Arsenal, Alabama, July 1975, Report No. TR-76-7.

3. Lain, K., "Rocket Attitude Determination Using Two Ground Based Laser Trackers," (MS Thesis) 1975, University of Wyoming, Laramie, Wyoming.

4. Inagaki, N., "Experimental Investigation of a Laser System for Measurement of Rocket Attitude," MS Thesis, 1975, University of Wyoming, Laramie, Wyoming.

5. Nydahl, J. E. and Pell, K. M., A Laser System for Determination of Rocket Attitude Using Two Ground Stations, US Army Missile Command, Redstone Arsenal, Alabama, December 1976, Final Report Grant No. DAAG29-76-G-0073.

DISTRIBUTION

	No. of Copies
Defense Documentation Center Cameron Station Alexandria, Virginia 22314	12
Commander US Army Materiel Development and Readiness Command	
Attn: DRCRD	1
DRCDL 5001 Eisenhower Avenue Alexandria, Virginia 22333	1
University of Wyoming Department of Mechanical Engineering Attn: Dr. Kynric M. Pell Laramie, Wyoming 82070	1
Superior Technical Services, Inc. Attn: T. Ward 4308 Governors Drive Huntsville, Alabama 35805	1
DRSMI-LP, Mr. Voigt	1
DRDMI-	
-T, Dr. Kobler	1
-RS, Mr. Seggel	1
-TF, Mr. Thomas	
-TD, Dr. McCorkle	1
-TDF	12
-ET	3
-ET, Mr. Storey	1
Mr. Presson	1
-TBD	3
-TI (Record Set)	1
(Reference Copy)	1