298

No

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

INTERNAL NOTE MSC EG - 69 - 7

PROJECT APOLLO

RANGEFINDER TESTS FOR THE D MISSION RENDEZVOUS

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

February 26, 1969

INTERNAL NOTE MSC-EG-69-7

PROJECT APOLLO

RANGEFINDER TESTS FOR THE D MISSION RENDEZVOUS

Prepared by

Indulis Saulietis

Approved by

Paul E. Ebersole, Chief
Guidance Development Branch

Robert G. Chilton
Deputy Chief
Guidance and Control Division

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

Houston, Texas

February 26, 1969

SUMMARY

Three passive optical rangefinding devices were evaluated on an optical range, using the LM ascent stage as the target. Ranges of 4.0 to 0.6 n.mi were evaluated. A training procedure was developed to attain the required 5% absolute accuracy goal. The D Mission prime and backup Command Module pilots were trained in the use of the flight-type rangefinder. Test results are tabulated and evaluated.

INTRODUCTION

The availability of accurate relative range data during the terminal phase of the CSM-LM rendezvous provides several operational advantages such as single crew-member workload compatibility, improved performance in certain backup mode situations, and as a confidence factor. Terminal phase here is defined as relative ranges between 0.5 and 4.0 n.mi. Furthermore, the CSM rescue operation requires that the relative range data be available to the single CM crew-member at the commander's station. Since the VHF ranging capability in the CM was not implemented until CM-106 and CM-104 was programed for the D Mission, a method for satisfying the D Mission requirement was formulated. The method selected utilizes a passive optical rangefinder. This note discusses the results of an evaluation of two optical ranging devices, the development of a training procedure for D Mission ranging, and the laboratory training results for Apollo 9 CM pilots, Lt. Col. David R. Scott and Cmdr. Richard F. Gordon.

OPTICAL RANGEFINDER EVALUATION

Because of time constraints, an evaluation of existing optical devices suitable for ranging was initiated. These devices were a production model T-2 Handheld Space Sextant, Part No. EG-25102, borrowed from Ames Research Center and manufactured by Kollsman Instrument Corporation (KIC), and an engineering model Diastimeter, manufactured by KIC and modified by MSC. Both of these devices had already been extensively evaluated in earlier studies (Ref. 2,3) and the purpose of the re-evaluation was to determine their usefulness with a LM ascent stage target. A short discussion of each instrument follows:

<u>T-2 Handheld Space Sextant</u>.- This device (Fig. 1) has a fixed and a movable line of sight, employing a trunnion mirror. The angle between the two lines of sight is measured mechanically with a drum-type readout scaled to the nearest 0.001 degrees. The Sextant employs optics with an 8x magnification and an 8 degree real field of view. Ranging with this device is accomplished by bringing the two images of the target into tangency (Fig. 5) and reading out the target's angular subtense on the drum-scale. If the target's baseline dimension is known, the range can be easily calculated or determined from a single line conversion chart.

Kollsman Prototype Diastimeter.- This device also has two lines of sight, one of which is movable. Line of sight motion is accomplished by means of two counter-rotating optical wedges (Fig. 2,3) rather than with a trunnion mirror as in the T-2 Sextant. The Diastimeter has a maximum line of sight excursion of about 1 degree as compared with 90 degrees for the T-2. The wedge rotation is indicated on a drum-scale which is calibrated directly in target range (for fixed target dimensions), and ranging is performed by image tangency (Fig. 5(a),(b), the same as with the T-2.

Optical Range Simulator.- Because of the many problems associated with full scale ranging simulations, an optical simulator was built for the ranging tests. Figure 4 shows this simulator. A 1/40 scale LM ascent stage model is illuminated by a small Xenon arc-lamp light source. A lens of approximately 12" focal length forms a real image of the model in the focal plane of a 25" focal length collimating lens. A 10:1 ratio zoom lens focused at infinity looks into this collimated beam and forms a second real image in the focal plane of a 12" diameter parabolic mirror of 94" focal length. This mirror forms a virtual image of the model at infinity, and the apparent angular size of the image can be varied by changing the focal length of the zoom lens. The apparent angular subtense of the target was measured at several zoom lens settings, using a Questar telescope mounted on a rotary index table. This angular subtense could be reliably measured to one arc second, which gave a maximum calibration error of less than one percent. The angular sizes were reduced to apparent range (knowing the target's dimensions) and a calibration graph was prepared giving true range vs zoom lens setting. Ranges other than calibration points are obtained by interpolation.

TEST PROCEDURES

Before meaningful range data could be obtained, a baseline dimension for the LM ascent stage had to be determined. This determination involves several constraints as follows:

a. Continuous visibility during the terminal phase.

b. Maximum practicable length for best accuracy.

c. Constant aspect to rangefinder (vehicle attitude constraints)

d. Easy observer recognition

The D Mission rendezvous geometry is as follows: The two vehicles roll axes are nominally pointed at each other, and the sun is located underneath, and behind the LM. It was found that the only practicable baseline is that shown in Fig. 5 and corresponds to the distance between the outboard ends of the ascent stage propellant tanks. Its length is nominally 173.11 inches and this dimension was assumed for all range calculations. This baseline meets constraints b, c, and d, above at all times, but is marginally visible at the longer ranges. The outboard running lights were also considered, but because of their location, it is unlikely that both will be seen simultaneously, without a 90 degree pitchdown maneuver, and their useful range is limited to an estimated 1.0 n.mi.

TEST DATA

T-2 Space Sextant.- Two untrained observers took range data with this instrument. Bias errors were established by superposing the two images five times and recording the deviation from zero on the degree counter. The range was then set a minimum distance and each observer took several readings. This was repeated at several ranges and the data converted to range based on a 173.11 inch baseline dimension. Table I presents the data and errors obtained with the T-2. As can be seen, the errors are large and highly random. This is attributed to one or more of the following causes:

a. Observer unfamiliarity with task

b. Quantization of T-2 readout

c. Four arc seconds offset in the two lines of sight, making tangency estimates at long ranges difficult

d. Sensitivity of angular motion: The T-2 can measure angles to 90°, but all ranging is done at angles of less than 0.5°, thus the total excursion of the angle readout dial was extremely small over the range of distances to be measured.

Prototype Diastimeter.- The Diastimeter was first used with a six power miniature telescope. This telescope did not have provision for focus adjustment and therefore the test data is degraded for those observers who noted that the target image was slightly defocused. The same ranging procedure was used as with the T-2 Sextant and the data is shown on Table II. No significant improvement over the T-2 was noted at this time, but since limitations b, c, and d noted for the T-2 were absent, it was decided to change the test procedure to allow for observer training. A focusable 7x telescope was also installed.

TRAINING PROCEDURE DEVELOPMENT

It was noted that most of the large errors recorded were absolute errors, and that the repeatability for each observer was good. This could result only from the observer's lack of knowledge of what the target appearance should be when correctly set at different ranges. Correspondingly, the observers were allowed prior knowledge of the true range and were allowed to set the true range on the Diastimeter and observe the target. Following this, the observers were allowed practice shots at ranges known to them. Once they were able to achieve good accuracy and repeatability at such known range, a series of unknown ranges were set up and data taken. A significant improvement in performance was immediately noted, as can be seen in the data on Table III. Follow-on data runs were taken on subsequent days to test the observer's memory (de-learning) of the task, and a slight degradation was noted. Based on this data, it was concluded that 5% absolute ranging was possible for the D Mission rendezvous situation, provided that the crew was trained as described above, and that a refresher training session was also given.

Astronauts Dave Scott and Dick Gordon were trained using the prototype Diastimeter and the procedure outlined earlier. Their data after training is presented in Table IV, and their comments on the procedure were favorable.

In the follow-on session, the training unit Apollo rangefinder, Part No. 2013250-011, manufactured by Kollsman Instrument Corporation, was used. This rangefinder is optically the same as the prototype (Fig. 6,7) except that the telescope portion of the instrument is identical with the T-2 Sextant. The data obtained is shown on Table V, and since no significant degradation was observed, it was concluded that the training was completed.

TASK SUMMARY

All objectives of the D Mission rangefinder task were completed as follows:

a. The available rangefinding devices were evaluated.

b. The LM baseline was established at 173.11 inches.

c. A training procedure was developed to attain the 5% accuracy goal for the instrument.

d. Apollo 9 CM pilots were trained successfully.

TABLE I

T-2 SPACE SEXTANT DATA

Observer: D. A. Peterson

True Range, Ft.	Observer % Error				Average Error %
33534	-12.2	+24.0	+17.1	+24.0	+13.2
27685	+ 4.2	+ 6.4	+ 2.1	+11.0	+ 5.9
20830	+ 2.8	+13.1	+19.0	+19.0	+13.5
14225	+16.9	+15.5	+16.9	+16.9	+16.6
10742	+12.5	+15.4	+13.4	+14.4	+13.9
6289	+11.3	+11.3	+ 9.6	+ 7.5	+ 9.9
4975	+ 4.8	+ 2.6	+ 3.3	+ 2.2	+ 3.2
3876	+ 0.7	- 0.0	+ 1.6	+ 0.7	+ 0.7

Observer: I. Saulietis

33534	-15.7	-12.2	-15.7	+10.9	- 8.2
27685	-10.4	-10.4	-20.2	+ 2.1	- 9.7
20830	- 7.1	-15.2	+ 2.8	-10.7	- 7.6
14225	- 1.6	- 4.5	- 4.5	- 6.3	- 4.2
10742	+ 3.6	- 1.8	- 1.8	+ 7.0	+ 1.8
6289	+ 0.3	+ 6.5	+ 5.0	+ 6.0	+ 4.4
4975	- 1.7	+ 7.2	+ 5.2	+ 5.2	+ 4.0
3876	+ 4.8	+ 6.3	+ 1.6	+ 5.1	+ 4.4

TABLE II

DIASTIMETER DATA BEFORE TRAINING

Observer: D. A. Peterson (First Run)

True Range, Ft.	Readout Error %				Average Error %
3953	+ 6.6	+ 4.9	+ 3.1	+ 3.1	+ 4.4
5056	+ 1.6	+ 1.0	- 4.3	+ 4.6	+ 1.1
8992	-14.4	-13.1	-15.1	- 6.4	-12.2
15315	-30.9	025.4	027.0	-35.6	-29.7
22018	-44.3	-40.5	045.4	-49.8	-45.0
35153	-45.3	-52.8	-47.0	-45.6	-47.7

Observer: C. M. Cottle (First Run)

3953	+ 2.6	+ 3.4	+ 3.4	+ 4.2	+ 3.4
5056	+16.5	+14.1	+ 8.8	+ 21.3	+15.2
8992	+13.6	+16.3	+ 7.0	+20.3	+14.3
15315	+ 2.0	-12.1	-13.7	+ 2.0	- 6.3
22018	+11.9	+ 6.5	+ 9.2	+11.9	+ 9.9
35153	+ 2.6	+ 3.3	+ 6.0	+ 4.3	+ 4.1

Observer: I. Saulietis (First Run)

3953	- 3.4	- 1.2	+ 1.9	+ 0.4	- 0.6
5056	+11.7	+ 2.2	+12.9	+12.9	+ 9.9
8992	+ 3.6	+13.6	+15.0	+ 7.0	+ 9.8
15315	+13.8	+ 3.6	+24.8	+13.8	+14.0
22018	+25.6	+20.1	+20.1	+36.5	+25.6
35153	+12.9	+19.7	+ 9.4	+16.3	+14.6

Observer: D. A. Peterson (Second Run)

3953	+ 9.5	+11.0	+ 8.7	- 1.2	+ 7.0
5056	+ 1.6	- 3.7	+ 8.2	+ 4.6	+ 2.7
8992	+ 0.3	+ 7.0	+13.6	+ 7.0	+ 7.0
15315	+ 2.0	+17.0	+16.2	+12.3	+11.2
22018	+12.0	+17.4	+20.1	+14.7	+16.5
35153	- 0.8	-16.2	-16.2	-11.1	-11.1

Observer: C. M. Cottle (Second Run)

3953	+10.2	+ 8.0	- 2.7	+ 9.5	+ 6.2
5056	+ 3.4	+14.1	- 0.1	+ 7.0	+ 6.1
8992	-25.1	-26.5	-17.1	-31.8	-25.1
15315	-31.7	-26.2	-29.4	-28.6	-29.0
22018	- 9.9	-12.6	-12.6	-29.0	-16.0
35153	-12.8	+ 4.3	+ 9.4	-11.1	- 2.6

TABLE II (continued)

Observer: I. Saulietis (Second Run)

3953	+ 1.9	+ 1.1	+ 4.0	+ 1.1	+ 2.0
5056	+ 4.1	+ 4.6	+ 4.6	+ 4.6	+ 4.5
8992	+ 7.0	+ 7.0	+12.3	+ 7.0	+ 8.3
15315	-12.1	- 5.8	+ 6.0	- 6.6	- 4.6
22018	-12.6	+ 9.2	+14.7	-17.0	- 1.4
35153	- 0.8	- 0.8	- 0.8	-11.1	- 3.4

TABLE III

DIASTIMETER DATA AFTER TRAINING

Observer: E. M. Jones (During Training)

True Range	Readout Range					Average Error, %
3836	3872	3944	3728	3848	3872	+0.42
6309	6277	6301	6493	6433	6253	+0.67
10858	10462	10822	11063	10702	10822	+1.07
21882	22246	20442	21044	20442	21645	-3.29
23364	23088	23448	24050	24050	25252	+2.63

Observer: D. A. Peterson (During Training)

3836	3872	3848	3848	3848	3836	+0.36
6309	6313	6313	6253	6133	6373	-0.51
10858	10823	10943	10823	10823	10823	-0.08
21882	20443	21645	20443	22847	22847	-1.08
23364	21645	21645	24050	24050	24050	-1.18

Observer: I. Saulietis (During Training)

3836	3848	3848	3848	3824	3848	+0.18
6309	6253	6313	6313	6373	6301	+0.03
10858	11063	10702	10702	10942	11063	+0.33
21882	21645	21645	21645	21645	21645	-1.08
23364	22847	23449	22847	23449	24050	-0.15

Random Ranges, One Shot Each Range, Range Decreasing

D. A. Peterson

True Rng. Ft.	Readout	% Error
19650	21044	+7.09
15260	15031	-1.82
8210	8117	-1.13
5450	5531	+1.49

I. Saulietis (1st Run)

True Rng. Ft.	Readout	% Error
21920	21645	-1.25
15260	15632	+2.44
12960	12030	-7.17
10360	10221	-1.34
6800	6854	+0.79
4930	4990	+1.22

I. Saulietis (Run 2)

True Rng. Ft.	Readout	% Error
19650	19000	-3.31
15260	15632	+2.99
11400	11304	-0.84
8210	8177	-0.40

TABLE IV

ASTRONAUT TRAINING DATA

Single Shot Each Range, Range Decreasing, First Run After Training With P-2 Diastimeter.

Astronaut: D. Scott

True Range, Ft.	Readout	Error, %
21,900	20,683	-5.56
19,700	18,157	-7.83
15,300	15,151	-0.97
11,400	10,942	-4.02
8,200	7,696	-6.15
5,430	5,050	-7.00

Astronaut: R. Gordon

True Range, Ft.	Readout	Error, %
21,900	19,240	-12.15
19,700	18,037	- 8.44
15,300	15,632	+ 2.18
11,400	11,544	+ 1.26
8,200	8,177	- 2.80
5,430	5,592	+ 2.98

Astronaut: D. Scott (2nd Run)

True Range, N.mi.	Readout, N.Mi.	Error, %
3.80	3.60	-5.26
3.35	3.30	-1.49
3.30	3.10	-6.06
2.71	2.60	-4.06
2.35	2.30	-2.13
1.48	1.50	+1.35
1.09	1.10	+0.92
0.77	0.80	+3.90

All this data with training unit rangefinder include instrument error.

TABLE IV (continued)

Follow-on session, single shot each range, range decreasing

Flight Training Unit was used

Astronaut: D. Scott (1st Run)

True Range, N.Mi.	Readout, N.Mi.	Error, %
3.65	3.70	+1.37
3.39	3.50	+3.24
3.22	3.10	-3.73
2.45	2.60	+6.12
2.10	2.10	0.00
1.70	1.70	0.00
1.15	1.20	+4.35
0.89	0.90	+1.12
0.70	0.70	0.00

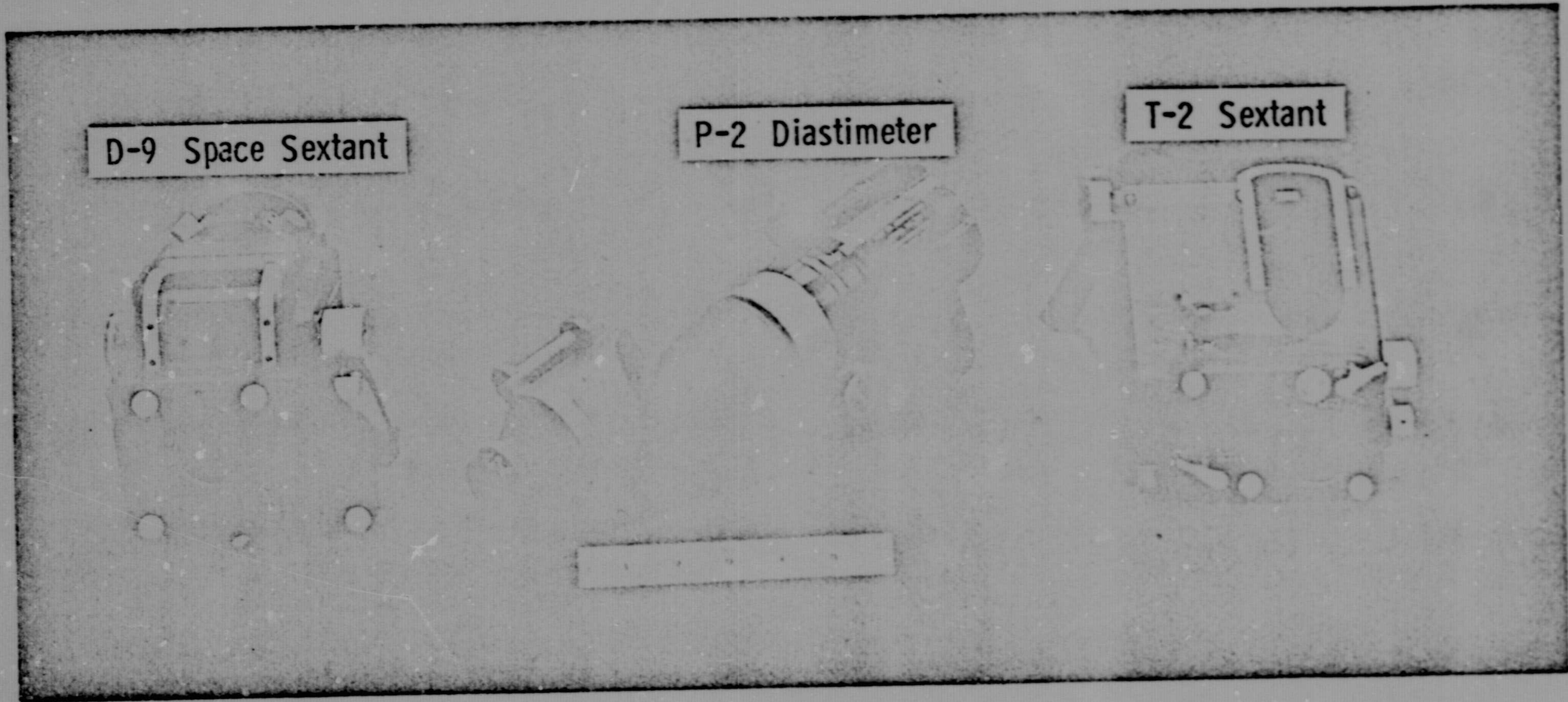
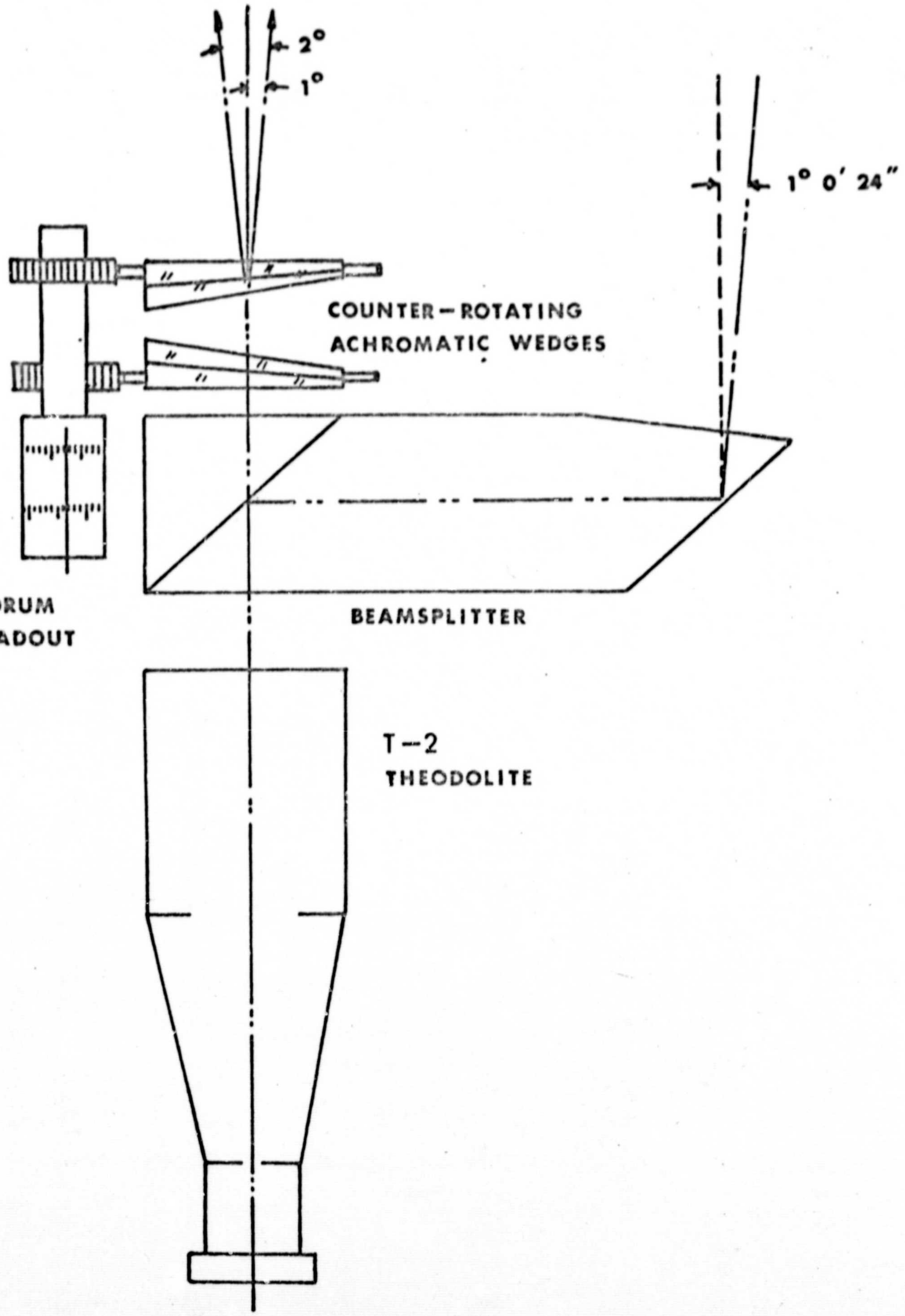
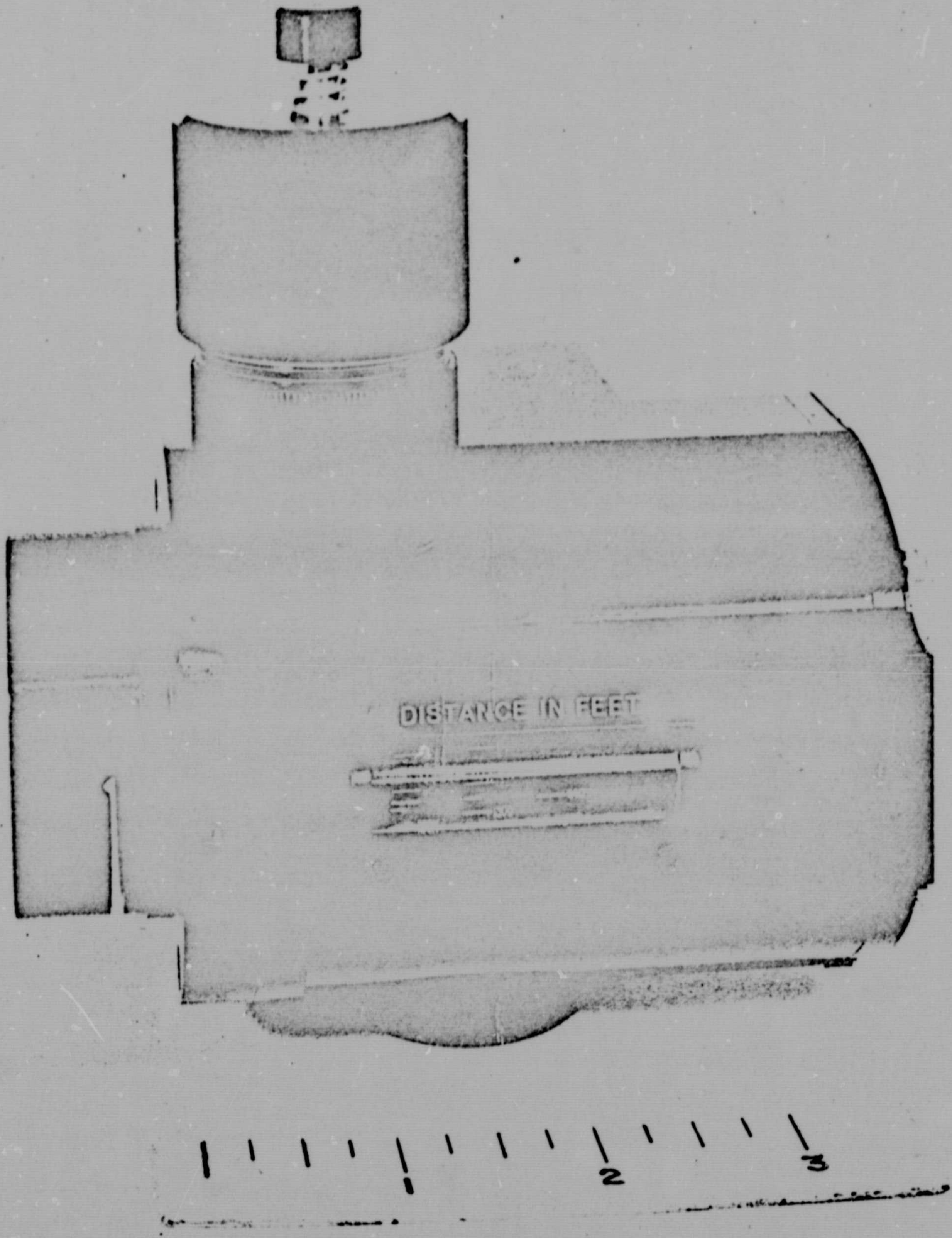


Figure I.- Range finding devices



DIASTIMETER OPTICAL SCHEMATIC

FIG. 2



KOLLSMAN DIASTIMETER
FIG. 3

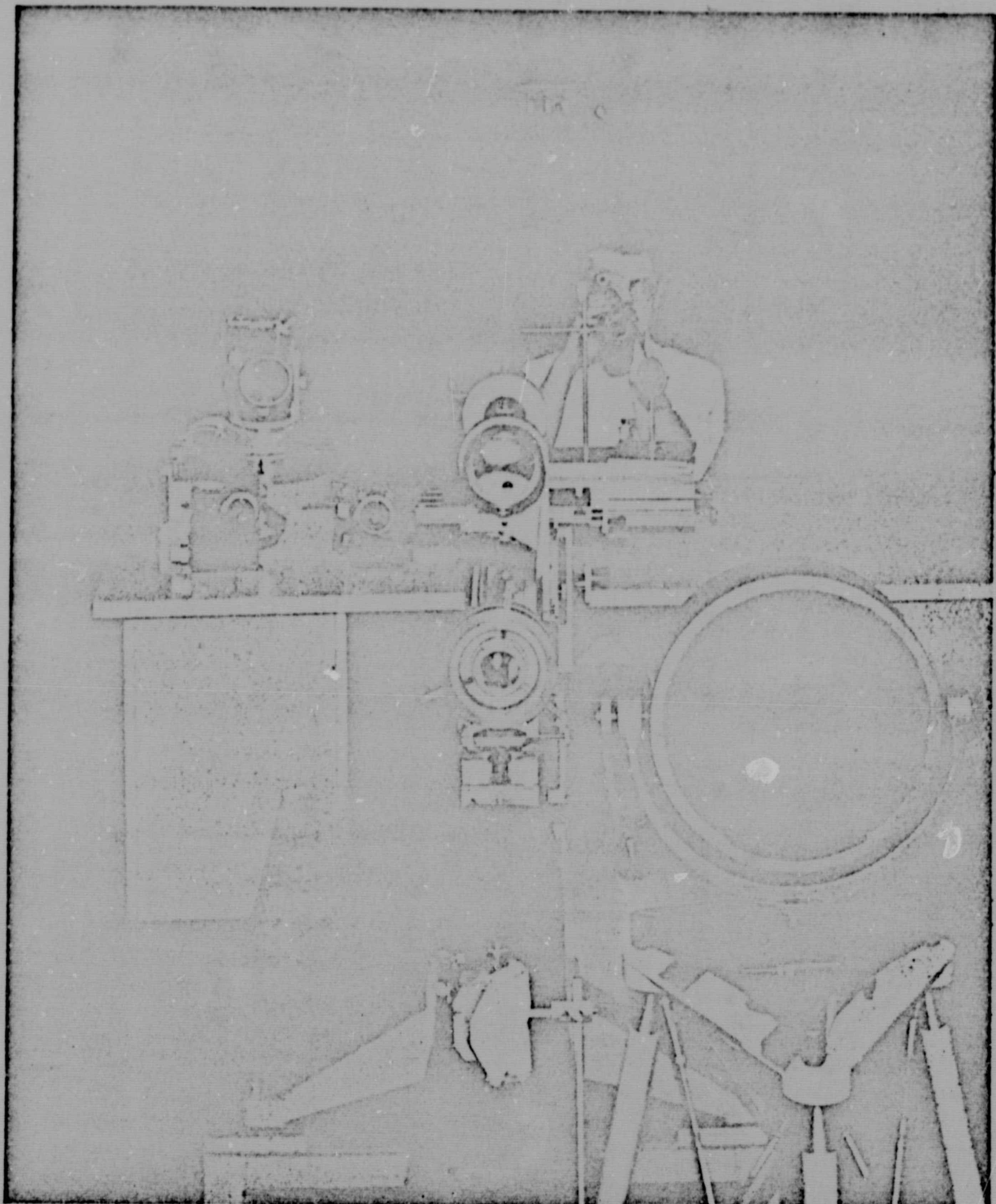


Figure 4. - Optical range simulation

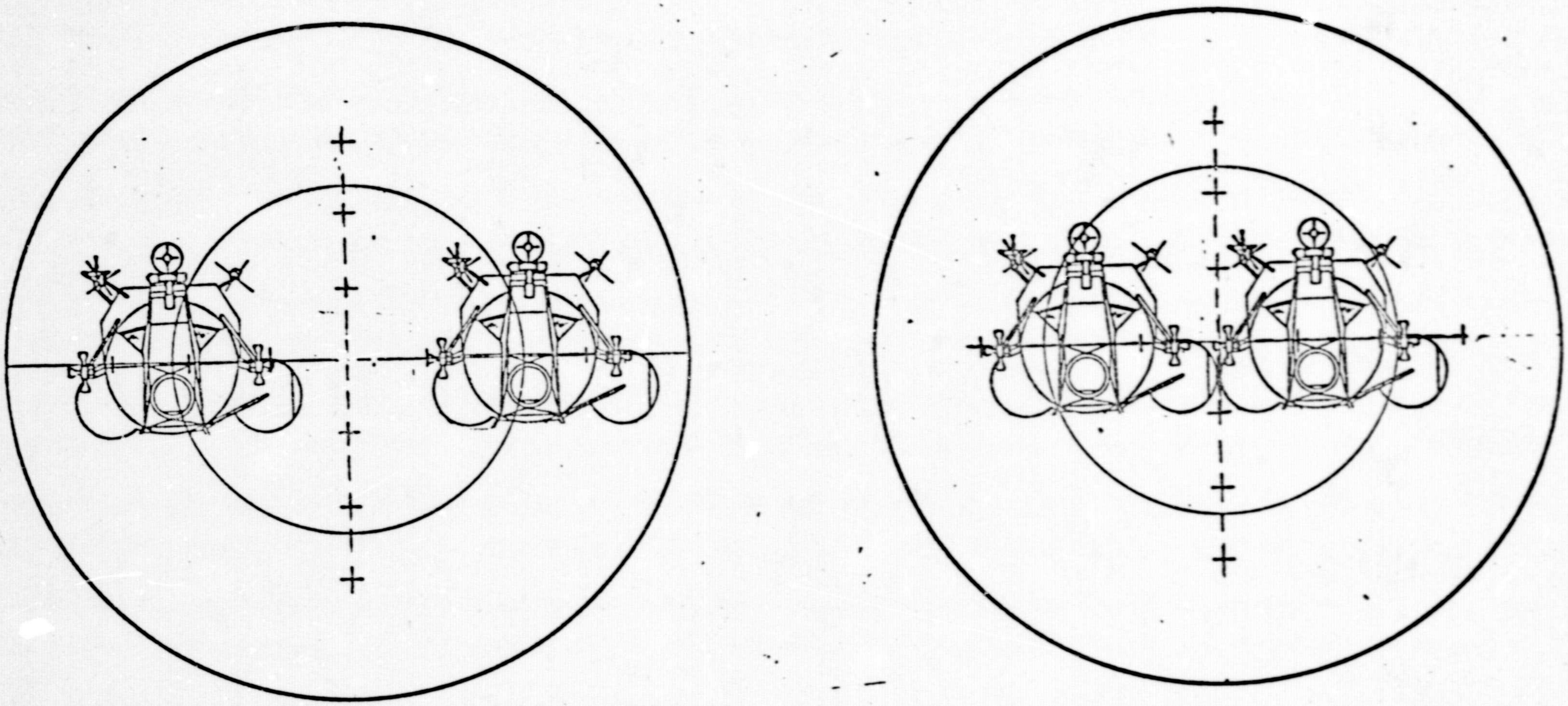


FIG. 5 TANGENCY RANGING

a) Acquisition of Vehicle Target Images in Field-of-View

b) Image Tangency Position and Measurement

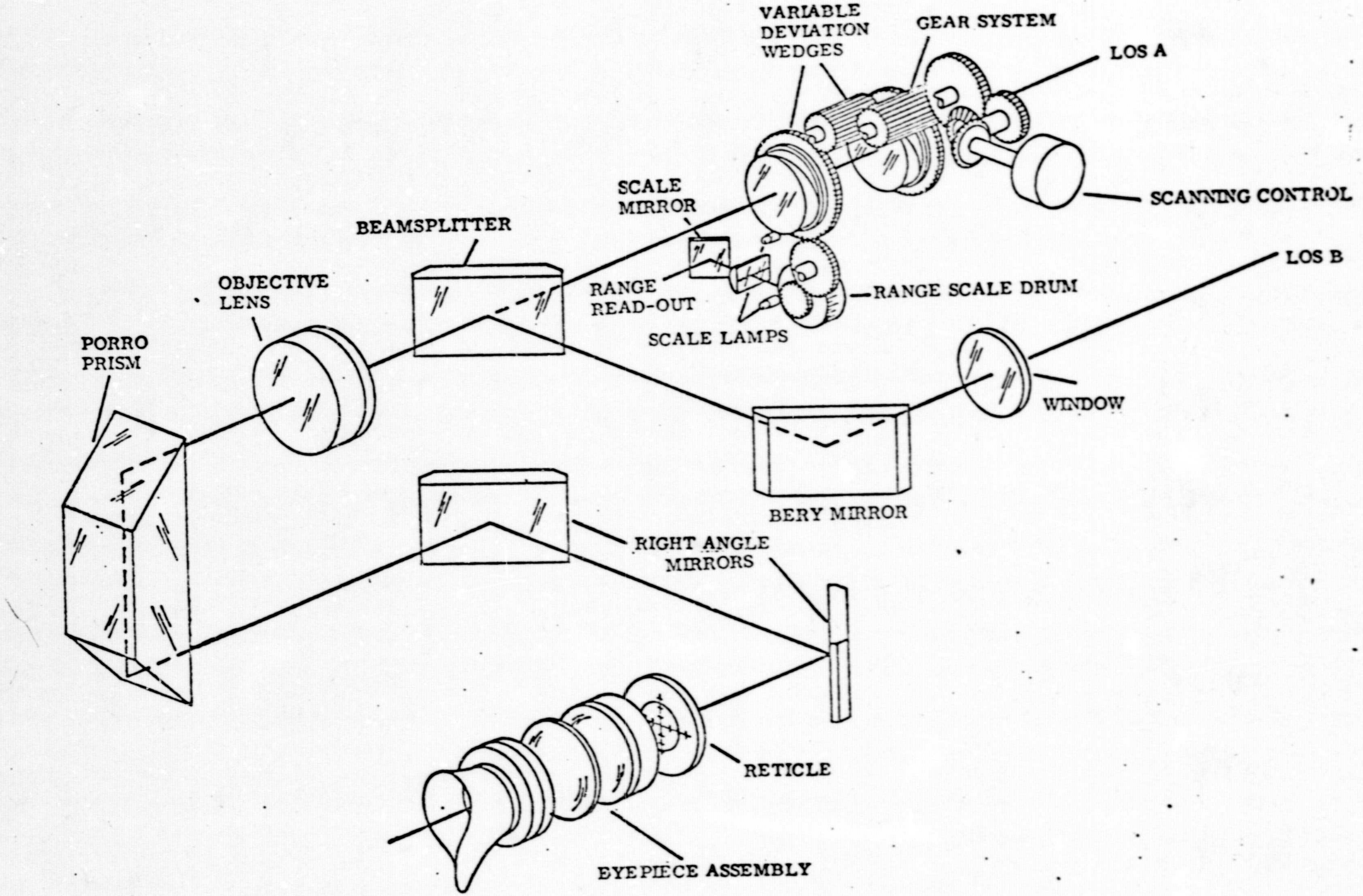


FIG.6 APOLLO RANGEFINDER SCHEMATIC

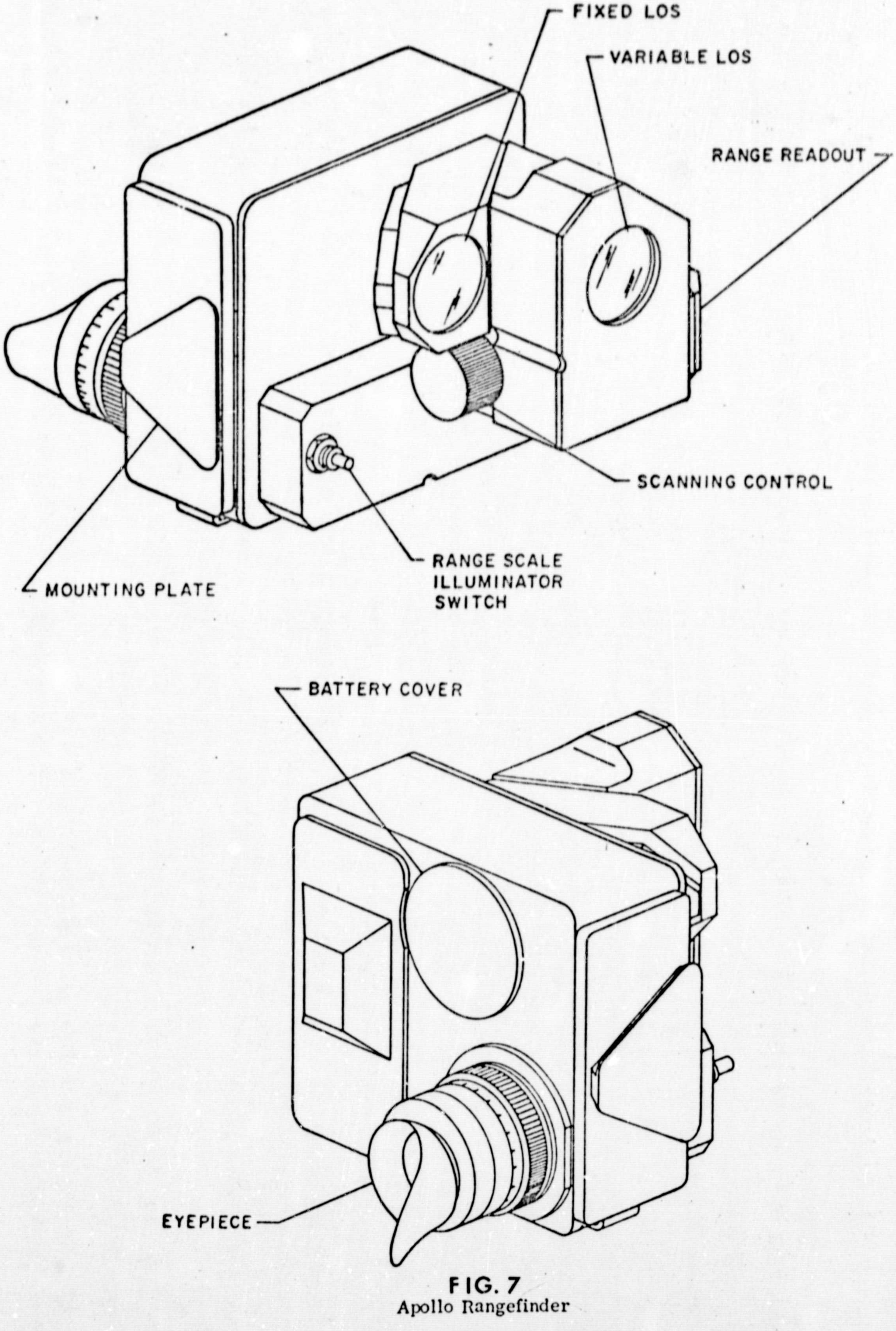


FIG. 7
Apollo Rangefinder

REFERENCES

1. MSC Internal Note - 67-EG-7, "Evaluation of Prototype Rangefinder for LM/CSM Lunar Rendezvous", I. Saulietis

2. MSC Internal Note - 66-EG-21, "Handheld LEM Optical Rangefinders for LEM/CSM Lunar Rendezvous", G. Roland and I. Saulietis

3. Memorandum, "Report on Rangefinder Studies for Apollo Mission AS-258" EG26-67-39, February 15, 1967, I. Sauliets, P. Ebersole