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NATIONAL BUREAU OF STANDARDS REPORT

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FORCE AND MOMENT CHARACTERISTICS OF FULL SCALE MODELS OF THE CHEMICAL CORPS CLUSTER MISSILE E12R1 AND THE FIRE ROCKET E12

by R. H. Heald and G. H. Adams

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FORCE AND MOMENT CHARACTERISTICS OF FULL SCALE MODELS OF THE CHEMICAL CORPS CLUSTER MISSILE E42R1 AND THE FIRE ROCKET E42

by R. H. Heald and G. H. Adams

Fluid Mechanics Section
Mechanics Division

To

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FORCE AND MOMENT CHARACTERISTICS OF FULL SCALE MODELS OF THE CHEMICAL CORPS CLUSTER MISSILE E42R1 AND THE FIRE ROCKET E42

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1. INTRODUCTION

In accordance with a request from the Army Chemical Center, Maryland, wind tunnel measurements have been made at the National Bureau of Standards to determine static stability, lift, and drag characteristics at various yaw presentations of twenty-one experimental configurations of the A.C.C. Cluster Missile E42R1 and the Fire Rocket E42. Full scale models, consisting of thick cardboard body sections, (cylindrical in shape) with attached support spindle, interchangeable wooden nose sections and metal tail sections were supplied for the tests by the Army Chemical Center. The maximum model diameter was 8.75 inches and the overall length approximately 60 inches. Two sets of measurements were made, at separate times, and the results were supplied in preliminary form to a representative of A.C.C. at the completion of each series of tests. The models were fitted with a round nose in all tests except one in which an ogive nose was used (table 2). The present report is a formal summary of the experiments. The work was conducted in the NBS 6-foot wind tunnel at an airspeed of 200 feet per second. All measurements were made with plane of one pair of opposite fins oriented 90 degrees to the plane of yaw.

2. PROCEDURE

The model under test was supported, by means of its attached side spindle, in the chuck of the flexure-plate aerodynamic balance. This balance is capable of indicating forces in the range of 0-100 pounds and moments in the 0-100 foot-pound range. An indexing head permits setting yaw angles in the horizontal plane.

In the first set of measurements various combinations of nose, body and tail units, both with and without the afterbody fairing were used. These configurations were designated the E4R1 assemblies. One of the E4R1 assemblies, description and data for which are contained in table 11, is shown mounted for testing in the photograph of figure 1. In the second series of measurements a single nose and body combination was used and the principal modifications consisted of changes in fin length. The assemblies comprising this group were designated the E4 configurations. In all cases lift, drag and torque (restoring moment) measurements were made at 2 degree intervals for both positive and negative angles of yaw and the values given in the tables are the means of observed values at corresponding yaw angles. The measurements were made for yaw angles ranging from 0 to the neighborhood of ±20 degrees in the cases of the E4R1 configurations. The test range for the E4 configurations was 0 to ±12 degrees. For all the experiments on the E4R1 configurations the spindle was kept at its original point of attachment to the body. Likewise, the spindle location on the body of the E4 was not changed during the measurements on the latter configurations. The values of torque (restoring moment) and center of pressure position are given in the tables with regard to these two fixed spindle positions.

3. RESULTS

The results of the measurements on the various configurations of the E4R1 model are given in tables 1-14. The data obtained for the E4 assemblies are given in tables 15-21.

Comparison of the data of tables 1-14 shows that the largest center of pressure values, throughout the 2-20 degree test range of yaw angles of the E4R1 model, occurred when the model was equipped with the fins which were not cut out and the 26-inch fairing. As will be seen in table 14 center of pressure distances for this

configuration ranged from 1.17 feet aft of the support spindle at 2 degrees yaw to 1.62 feet aft of the spindle at 20 degrees yaw with a mean of 1.42 feet for the test range. The accompanying values of restoring moment (torque) about the spindle ranged from 3.4 pounds feet at 2 degrees yaw to 68.9 pounds feet at 20 degrees yaw. The drag values for this configuration ranged from 5.3 pounds at 0 degrees to 17.2 pounds at 20 degrees yaw.

The second largest set of center of pressure values for the test range of the E42R1 assemblies occurred in the case of the configuration of table 10. This configuration which was equipped with attached fins and 12-inch boat tail fairing gave center of pressure distances ranging between 1.07 feet at 4 degrees to 1.55 feet at 20 degrees yaw. The values of righting moment for the assembly varied between 3.4 pounds feet at 2 degrees and 65.0 pounds feet at 20 degrees yaw and drag values ranged between 5.5 pounds at 0 degrees and 16.6 pounds at 20 degrees. Other arrangements of the E42R1 group which exhibited relatively large values of center of pressure distance and restoring moment are those of tables 1, 6 (in the 2-10 degree yaw range), 11, 12 and 13.

The results of the measurements on the various arrangements of the Fire Rocket E42 are given in tables 15-21. In general, these arrangements show increasing center of pressure distance with increase of yaw angle in the test range of 2-12 degrees. Based on mean values in this range the largest center of pressure distance of the E42 series occurred when fin unit F and tail 3 (table 20) were used on the model. This arrangement gave rise to center of pressure distances ranging from 0.45 feet at 2 degrees to 0.75 feet at 12 degrees yaw and values of restoring moment ranging from 1.4 to 18.2 pounds feet. Drag values varied between 4.3 pounds at 0 degrees and 8.6 pounds at 12 degrees yaw.

Equipped with fin unit G and tail 4 (table 21) the E42 model exhibited center of pressure distances almost as large as those obtained using the fin F and tail 3 combination. Fitted with fin G and tail 4 the model showed center of pressure distances ranging between 0.45 feet at 2 degrees and 0.72 feet at 12 degrees yaw with corresponding values of restoring moment of 1.4 and 18.2 pounds feet. Drag at 0 degrees for this arrangement amounted to 4.3 pounds; drag at 12 degrees was 9.3 pounds. Other arrangements of the E41 giving relatively large values of center of pressure distance and restoring moment were those of tables 15 and 17.

In conclusion reference is made to NBS Confidential Report 6A237 to the Army Chemical Center in which attention is called to the possibility of large-angle oscillations of certain finned missiles known, on the basis of wind tunnel tests using models, to possess good static stability.

Table 1

ACC Missile E42R1 (Cardboard Model)

Equipped with Round Nose and Tail Assembly Consisting of Unfinned Boattail 5 Inches Long and Cut Out Fins of 10 7/8-Inch Chord and 13 3/8-Inch Span

One Pair of Fins 90° to Plane of Yaw
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal* Force lb	Torque about Spindle lb-ft	Center of Pressure** Distance (Aft of Spindle) ft
0	-	4.2	-	-	-
2	2.9	4.5	3.1	+2.6	0.85
4	6.4	4.9	6.7	5.9	.88
6	5.3	5.8	9.9	10.1	1.02
8	14.3	7.3	15.2	16.7	1.10
10	19.6	9.3	20.9	25.8	1.23
12	24.6	11.4	26.4	34.5	1.31
14	29.5	13.7	31.9	42.5	1.33
16	34.4	15.3	37.3	50.5	1.35
18	39.2	19.4	43.3	58.7	1.35
20	44.1	22.2	49.1	66.8	1.36

* Computed from: Lift x $\cos\alpha$ + Drag x $\sin\alpha$ = Normal Force.

** Computed from: $\frac{\text{Torque}}{\text{Normal Force}}$

Table 2

ACC Zl2Rl Missile

Equipped with Ogive Nose and 26-Inch Narrow Fins*

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	6.5	-	-	-
2	3.6	6.9	3.8	0.3	0.08
4	7.5	7.4	8.0	0.8	.10
6	11.4	8.3	12.2	2.1	.17
8	17.0	9.5	18.1	4.4	.24
10	23.0	11.1	24.6	7.9	.32
12	29.1	13.2	31.2	11.8	.38
14	35.6	15.7	38.3	16.7	.44
16	42.7	18.7	46.2	22.6	.49
18	50.6	22.6	55.1	29.7	.54
20	58.0	26.5	63.6	37.0	0.58

* Fins mounted on body, extending forward from base.

Table 3

ACC E42R1 Missile

Equipped with Round Nose and 26-Inch Narrow Fins*

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	6.6	-	-	-
2	3.6	6.9	3.8	0.6	0.16
4	7.4	7.4	7.9	1.1	.14
6	11.8	8.2	12.6	2.6	.21
8	16.7	9.4	17.8	4.9	.28
10	22.3	11.0	23.9	8.0	.33
12	28.5	13.3	30.6	12.5	.41
14	35.1	15.9	37.9	17.2	.45
16	42.2	18.8	45.8	23.2	.51
18	49.4	22.3	53.9	29.8	.55
20	57.3	26.5	63.0	37.0	0.59

* Fins mounted on body, extending forward from base.

Table 4

ACC E42R1 Missile

Equipped with Round Nose and 10-Inch Narrow Fins*

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	6.1	-	-	-
2	2.9	6.4	3.1	1.1	0.35
4	5.8	7.0	6.3	1.4	.22
6	9.0	7.6	9.8	2.7	.28
8	12.6	8.5	13.6	4.8	.36
10	17.3	9.6	18.8	7.3	.39
12	20.0	10.9	21.8	10.0	.46
14	23.6	12.1	25.8	12.7	.49
16	28.1	14.0	30.9	16.5	.53
18	32.3	16.3	35.7	20.0	.56
20	36.8	18.8	41.1	24.0	0.58

* Fins mounted on body, extending forward from base.

Table 5

ACC E42R1 Missile

Equipped with 10-Inch Narrow Fins and Finned Boattail*

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	4.6	-	-	-
2	2.2	4.7	2.3	0.4	0.17
4	5.5	5.0	5.9	1.1	.19
6	8.9	5.4	9.4	3.1	.33
8	12.8	6.4	13.5	6.2	..46
10	17.8	7.9	18.9	11.6	.61
12	22.7	9.4	24.2	17.9	.74
14	28.1	11.5	30.0	24.5	.82
16	33.8	14.0	36.4	32.6	.89
18	38.8	16.4	42.0	39.6	.94
20	44.3	19.4	48.3	47.3	0.98

* Fins mounted on body, extending forward from base.

[redacted]

Table 6

ACC E42R1 Missile

Equipped with Extension Fins at Rear of Unfinned Boattail

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	5.1	-	-	-
2	3.7	5.1	3.8	4.5	1.18
4	7.1	5.6	7.5	9.0	1.20
6	10.9	6.3	11.5	13.6	1.18
8	14.3	7.0	15.1	17.3	1.15
10	17.0	8.3	18.2	19.7	1.08
12	19.7	10.0	21.3	20.5	0.96
14	21.5	11.5	23.6	19.0	.81
16	23.3	13.5	26.1	16.7	.64
18	25.4	15.3	28.9	15.6	.54
20	27.3	17.2	31.6	13.5	0.43

[redacted]

Table 7

ACC E42R1 Missile

Equipped with Extension Fins Ahead of Unfinned Boattail

Fins 90°

Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	5.3	-	-	-
2	4.3	5.6	4.5	1.2	0.27
4	8.6	6.2	9.0	5.8	.64
6	13.1	6.9	13.8	11.3	.82
8	16.9	8.1	17.8	14.4	.81
10	19.9	9.7	21.3	15.3	.72
12	22.1	11.2	23.9	17.6	.74
14	24.5	12.9	26.8	16.1	.60
16	27.0	14.8	30.1	15.7	.52
18	29.8	16.9	34.1	16.3	.48
20	33.0	19.2	37.6	18.1	0.48

Table 8

ACC M42R1 Missile

Equipped with Sub-Caliber Fins and 18-Inch Fairing

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	3.8	-	-	-
2	1.5	3.8	1.6	0.2	0.13
4	3.5	4.1	3.8	0.2	.05
6	5.9	4.6	6.4	1.1	.17
8	8.7	5.2	9.3	1.1	.12
10	11.7	6.0	12.6	6.2	.49
12	15.2	7.3	16.4	9.6	.59
14	18.9	8.6	20.4	13.7	.67
16	22.7	10.3	24.7	18.2	.74
18	26.6	12.1	29.0	23.0	.79
20	30.4	14.1	33.4	27.8	0.83

[redacted]

Table 9

ACC E42R1 Missile

Equipped with Sub-Caliber Fins, Shroud and 18-Inch Fairing

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	5.3	-	-	-
2	1.0	5.4	1.2	0.6	0.50
4	2.8	5.6	3.2	.4	.13
6	5.0	6.1	5.6	0.5	.09
8	7.6	6.6	8.4	1.1	.13
10	10.5	7.6	11.7	3.7	.32
12	13.5	8.6	15.0	6.7	.45
14	16.8	9.9	18.7	10.3	.55
16	20.5	11.4	22.9	15.0	.66
18	24.2	13.1	27.0	18.9	.70
20	27.9	15.0	31.4	23.6	0.75

[redacted]

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Table 10

ACC E12R1 Missile

Equipped with Boom-Attached Cut Out Fins and 12-Inch Fairing

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	5.5	-	-	-
2	3.7	5.7	2.9	3.4	1.17
4	5.6	6.2	6.1	6.5	1.07
6	9.0	6.8	9.7	12.0	1.24
8	12.5	7.6	13.4	17.4	1.30
10	16.3	8.6	17.6	23.8	1.35
12	20.6	9.8	22.2	31.2	1.41
14	24.9	11.3	26.8	38.9	1.45
16	29.4	13.1	31.9	47.4	1.49
18	33.8	15.1	36.8	55.9	1.52
20	38.5	16.6	41.9	65.0	1.55

[redacted]

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Table 11

ACC E42R1 Missile

With Attached Fins and 18-Inch Fairing

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	5.4	-	-	-
2	3.1	5.6	3.3	2.8	0.85
4	6.4	6.0	6.8	7.6	1.12
6	9.8	6.8	10.5	12.7	1.21
8	13.6	7.7	14.5	18.7	1.29
10	17.4	8.6	18.6	25.5	1.37
12	20.9	9.8	22.5	31.3	1.39
14	23.4	10.6	25.3	36.2	1.43
16	25.5	11.7	27.7	41.3	1.49
18	29.5	12.9	32.0	47.1	1.47

[redacted]

Table 12

ACC E42R1 Missile

Equipped with Boom-Attached Cut Out Fins and 18-Inch Fairing

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	5.3	-	-	-
2	2.5	5.4	2.7	2.9	1.07
4	5.5	5.8	5.9	6.6	1.12
6	8.8	6.6	9.5	11.5	1.21
8	12.2	7.4	13.1	16.9	1.29
10	16.5	8.5	17.8	23.9	1.34
12	20.7	9.8	22.3	31.0	1.39
14	24.9	11.2	26.8	38.1	1.42
16	29.4	12.7	31.8	45.7	1.44
18	32.9	14.5	35.8	53.2	1.49
20	37.0	16.6	40.5	61.4	1.52

Table 13

ACC E42R1 Missile

Equipped with Cut Out Fins and 25-Inch Fairing

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	5.1	-	-	-
2	2.7	5.2	2.8	2.8	1.00
4	5.7	5.7	6.1	6.4	1.05
6	9.3	6.3	9.9	10.9	1.10
8	12.8	7.2	13.6	16.2	1.19
10	16.8	8.3	18.0	22.5	1.25
12	21.3	9.5	22.8	29.5	1.29
14	25.6	11.1	27.5	37.2	1.35
16	30.2	13.0	32.6	45.2	1.39
18	34.9	15.1	37.8	53.9	1.43
20	40.1	17.6	43.8	62.3	1.42

Table 14

ACC E42R1 Missile

Equipped with Fins Not Cut Out and 25-Inch Fairing

Fins 90°

Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	5.3	-	-	-
2	2.7	5.4	2.9	3.4	1.17
4	5.6	5.8	6.0	7.4	1.23
6	9.0	6.4	9.6	12.3	1.28
8	12.4	7.3	13.3	17.8	1.34
10	16.3	8.3	17.5	24.4	1.39
12	19.4	9.6	21.0	32.0	1.52
14	24.8	11.4	26.6	39.9	1.50
16	29.5	13.0	32.0	49.5	1.55
18	34.3	14.9	37.2	59.1	1.59
20	39.0	17.2	42.6	68.9	1.62

Table 15

ACC Fire Rocket E 42

Equipped with Fin A, Tail No. 1 (Length of Outboard Edges 9 1/2 Inches)

One Pair of Fin Blades 90° to Plane of Yaw

Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	4.3	-	-	-
2	2.5	4.4	2.7	0.5	0.19
4	5.8	4.8	6.1	1.9	.31
6	9.6	5.4	10.1	4.2	.42
8	13.7	6.3	14.4	8.1	.56
10	18.6	7.8	19.7	14.9	.76
12	24.0	9.6	25.5	22.4	0.88

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Table 16

ACC Fire Rocket E 42

Equipped with Fin B, Tail No. 1 (Length of Outboard Edges Reduced to 8 1/2 Inches by Removing Strips One Inch Wide from Trailing Edges of the Fins of Table 15)

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	4.3	-	-	-
2	2.9	4.5	3.0	0.5	0.17
4	6.2	4.8	6.6	2.0	.30
6	9.2	5.4	9.7	3.3	.34
8	13.7	6.4	14.4	7.5	.52
10	18.3	7.7	19.4	13.6	.70
12	23.1	9.4	24.6	20.4	0.83

Table 17

ACC Fire Rocket E 42

Equipped with Fin C, Tail No. 1 (Length of Outboard Edges Reduced to 7 1/2 Inches by Removing Strips One Inch Wide from Trailing Edges of Fins of Table 16)

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	4.2	-	-	-
2	2.7	4.4	2.8	0.9	0.32
4	5.9	4.7	6.3	2.1	.33
6	9.2	5.2	9.7	4.0	.41
8	13.1	6.2	13.8	6.8	.49
10	17.3	7.5	18.4	12.4	.67
12	22.6	9.8	24.0	19.0	0.79

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[redacted]

Table 18

ACC Fire Rocket E 42

Equipped with Fin D, Tail No. 1 (Length of Outboard Edges Reduced to 6 1/2 Inches by Removing Strips One Inch Wide from Trailing Edges of the Fins of Table 17)

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	4.2	-	-	-
2	2.7	4.4	2.8	0.6	1.21
4	5.9	4.7	6.3	1.5	.24
6	9.0	5.2	9.5	2.7	.28
8	12.7	6.0	13.5	5.8	.43
10	17.1	7.3	18.2	11.3	.62
12	22.2	9.0	23.6	17.5	0.74

Table 19

ACC Fire Rocket E 42

Equipped with Fin E, Tail No. 2 (Length of Outboard Edges 7 1/8 Inches)

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	4.6	-	-	-
2	2.9	4.7	3.0	0.5	0.17
4	6.0	5.0	6.4	2.0	.31
6	9.4	5.6	10.0	3.9	.39
8	13.2	6.5	13.9	6.6	.47
10	17.4	7.6	18.5	10.3	.56
12	21.8	9.0	23.2	15.9	0.69

[redacted]

[redacted]

Table 20

ACC Fire Rocket E 42

Equipped with Fin F, Tail No. 3 (Length of Outboard Edges 8 1/8 Inches)

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	4.3	-	-	-
2	3.0	4.5	3.1	1.4	0.45
4	6.4	4.8	6.8	3.1	.46
6	9.7	5.3	10.2	5.1	.50
8	13.5	6.3	14.2	7.5	.53
10	17.6	7.5	18.8	11.7	.62
12	22.9	8.6	24.2	18.2	0.75

Table 21

ACC Fire Rocket E 42

Equipped with Fin G, Tail No. 4 (Length of Outboard Edges 9 1/8 Inches)

Fins 90°
Airspeed 200 fps

Angle of Yaw deg	Lift lb	Drag lb	Normal Force lb	Torque about Spindle lb-ft	Center of Pressure Distance (Aft of Spindle) ft
0	-	4.3	-	-	-
2	3.0	4.5	3.1	1.4	0.45
4	6.3	4.8	6.8	3.0	.44
6	10.0	5.8	10.5	5.1	.49
8	14.0	6.3	14.7	7.6	.52
10	18.5	7.6	19.6	12.0	.61
12	23.8	9.3	25.2	18.2	0.72

[redacted]

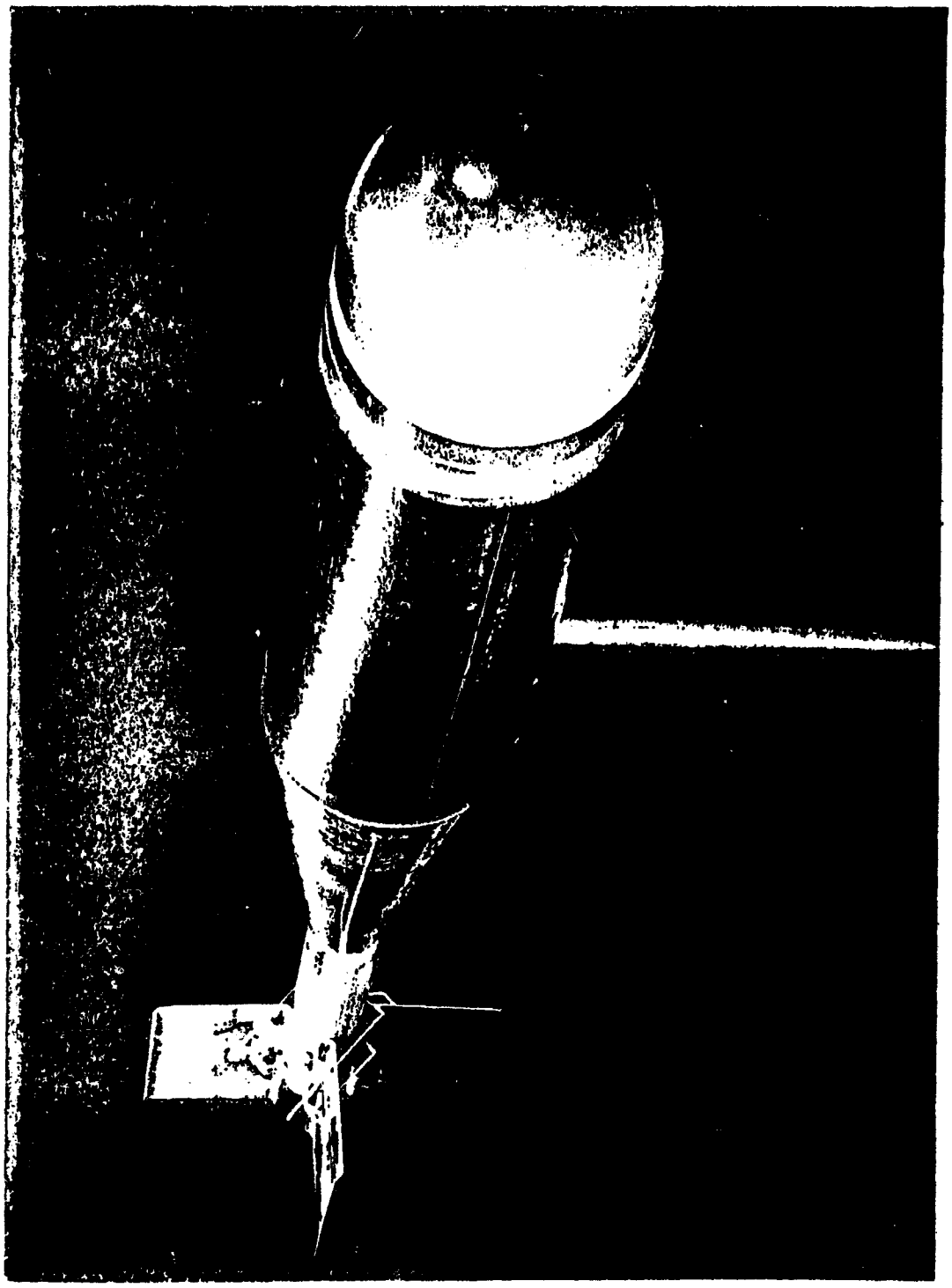

FIG. 1

[redacted]

U.S. DEPARTMENT OF COMMERCE
Frederick H. Mueller, Secretary

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

Electricity and Electronics. Resistance and Reactance. Electron Devices. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Photographic Technology. Length. Engineering Metrology.

Heat. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Molecular Kinetics. Free Radicals Research.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Radiation Theory. Radioactivity. X-rays. High Energy Radiation. Nucleonic Instrumentation. Radiological Equipment.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer. Concreting Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Application Engineering.

• Office of Basic Instrumentation.

• Office of Weights and Measures.

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships. VHF Research. Radio Warning Services. Airglow and Aurora. Radio Astronomy and Arctic Propagation.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Research. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation Obstacles Engineering. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Electronic Calibration Center. Microwave Physics. Microwave Circuit Standards.

Radio Communication and Systems. Low Frequency and Very Low Frequency Research. High Frequency and Very High Frequency Research. Ultra High Frequency and Super High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Systems Analysis. Field Operations.