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COMPARISON OF BUDD AND REVERE 4.5" ROCKETS

by

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Abstract

Two types of 4.5" rocket have been fired statically and in flight to determine the differences in performance due to differences in design and methods of manufacture of the rocket motors. The following conclusions can be drawn from the data obtained:

1. When fired at high temperatures the Budd motor is slightly less likely to fail than the Revere motor. The critical temperature range for both rockets with 4.8 lbs. propellant is from 110° to 120°F.

2. The low temperature limit for satisfactory operation is 25°F lower for the Budd than for the Revere.

3. The Budd outranges the Revere by 24%.

4. When fired from a 20 ft. launching tube the lateral dispersion of the Budd is about 40% less than that of the Revere. From a 10 ft. tube the dispersions of the two rockets are not significantly different.

An extended series of tests has been made to compare the behavior of two types of 4.5" rockets. These tests were planned and executed by the Ballistic Research Laboratory with the cooperation of members of Division 3 of the National Defense Research Committee. This report presents and discusses the complete data of the static tests and gives a summary of the flight test results. The flight test data are given in detail in Intra-office Memoranda E-46-6,7,8, and 9 of the Photographic Measurement Section, Exterior Ballistic Branch.

Characteristics of the Rockets.

The significant features of the two types of 4.5" rockets are illustrated in Figure 1. The fins are not shown in this diagram but can be seen in Figure 2.

The rockets are manufactured respectively by the Revere Copper and Brass Co. and by the Budd Wheel Co. and the Budd Induction Heating Co. Their important differences lie in the construction of the motors and are listed below.

1. Method of manufacture. The Budd Motor is made from 1035 steel seamless tubing which has been hardened by induction heating. It is machined to size, and the threaded end is left considerably thicker than the rest of the wall of the motor.

The Revere motor is made from welded 1025 steel tubing, formed and strengthened by cold drawing. There is no extra thickness at the threads.

In each type of motor there is cut a safety groove slightly back of the threads. The purpose of this is to cause a clean break separating the motor from the HE head if excess pressures are developed in the chamber. Without such a groove the motor is in danger of shattering. The Budd safety groove is set to break at about 6000 lbs/sq.in., although it can safely be set at 6500 as the ungrooved Budd motor will hold pressures up to 8,000.

2. Throat diameter. On the Revere motor the diameter of the throat of the venturi varies from 1.820 to 1.835 inches. Under normal conditions (4.8 lbs. powder, 70°F) this gives a peak pressure of about 2500 lbs/sq.in. (see Table II). To take advantage of the greater strength of the Budd rocket the throat diameter was set at 1.750 inches. The corresponding peak pressure is about 3400 lb/in^2. This higher operating pressure gives shorter burning time and consequent lower dispersion in flight. Also, the higher pressure obtained in the Budd gives satisfactory powder burning at a temperature well below that at which the Revere ceases to function properly (Tables V and VI.)

3. Fin assembly. The fin assemblies of the two rockets are shown in Figure 2. The Revere assembly is somewhat more rugged than the Budd, but it exerts a large drag on the rocket in flight. The 800 yard shorter range of the Revere rockets (see Table VII) can presumably be accounted for mainly by the different fin assemblies.

Description of Tests.

Throughout these tests the loading of the rockets was kept as constant as possible. Each rocket was loaded with 4.80 lbs. of Radford Ordnance Works Lot 10015. This is one of the lots which is loaded into standard rounds, and it is assumed, for lack of any information to the contrary, that it is typical JPT powder. Its properties are given in Table I.

The Revere rockets used in the flight tests were standard rounds, the igniter consisting of two 20 gm. bags of grade A-1 black powder and a plastic cup containing 45 gm. of the same powder. All Budd rockets and all Revere rockets tested statically were ignited by a single bag containing 35 gms of this same powder.

For the high temperature tests the rockets were left in an oven for from 36 to 44 hours. The oven had no forced air circulation, but at the times the rockets were removed there was a difference of at most 4°F between the top and the bottom of the oven. The rockets were carried from the oven to the firing position in individual insulated boxes. No more than four minutes elapsed between removal of a round from the oven and firing, and about three minutes of this time were spent in the insulated box. A test round fitted with a thermometer in contact with the powder showed a drop of 2°F under this treatment. The two types of motors were distributed evenly on the shelves of the oven, except in the case of the eight Budds at 140°F, and were fired alternately. During the time of firing of 8 rounds (the capacity of the oven), the temperature at the top of the oven fell about 4°F and that at the bottom rose between 4° and 14°F, this rise being due to the activation of the heating element. In each round, maximum pressure was measured by two ball crusher gages firmly fastened inside the motor.

In the low temperature tests the rounds were left in a refrigerator for from 18 to 24 hours. Since the refrigerator was quite near the firing position no insulated boxes were used. From 1 to 4 minutes elapsed between removal from the refrigerator and firing, the longer period being due to the delay involved in connecting pressure strain gages.

The rockets used in the flight tests were stored together overnight, transported together to the firing position, and kept, throughout the firing, as much as possible under the same conditions. All the Budds were inert-loaded to 38.5 lbs. with a mixture of parafin and red lead and a dummy fuze. The Reveres were H. E. loaded. Those used on 27 April had a dummy fuze and were brought up to 38.5 lbs. with sand and metal slugs. The rest of the Reveres were standard M8 rounds, their weights varying between 38.0 and 39.0 lbs. Before firing, the safety pin was not withdrawn, but was cut off flush with the outside of the head.

Survey of the Data.

1. High temperature tests. The results obtained from tests at high temperatures are given in Tables III and IV. By taking rough averages we obtain the following table of pressures and behaviors.

	110°F	120°F
Budd	5000 p.s.i; 8 held out of 8	5800 p.s.i; 4 held out of 8
Revere	4200 p.s.i; 7 held out of 8	4600 p.s.i; 1 held out of 7

It seems that the step from 110° to 120°F is rather critical for both types of rockets. The superior strength of the Budd is evident, as its maximum safe pressure is about 1000 p.s.i. higher than that of the Revere. Moreover, as has been pointed out earlier, the safety groove in the Budd can safely be set to 6500 p.s.i. instead of 6000, and at this setting a temperature of 120°F should be relatively safe. (If one accepts the pressure records on the individual rounds, two of the Budds would have failed at 120° even with the safety groove set at 6500 p.s.i. On the same basis, only two of the eight should have failed in the actual test. Since neither the pressure readings nor the setting of the safety grooves are particularly accurate such discrepancies are to be expected).

In addition to the difference in strength of the motors shown by these data there is a significant difference in the types of failure. All the Budds broke off cleanly at the safety groove, the motors being otherwise intact. In all but two of the Reveres, however, the safety groove did not break at all. The motors merely spread apart at the threads and slipped off the heads. The difference in behavior is undoubtedly due mainly to the different thickness of the two types of motors at the threads. The behavior of the Reveres makes it impossible to strengthen them by changing the depth of the safety groove.

2. Low temperature tests. The behavior of the rockets at low temperatures is shown in Tables V and VI. The significant point to be noted here is that the critical temperature dividing continuous from interrupted burning ("chuffing") is around -15°F for the Budd rockets and 10°F for the Reveres. Since interrupted burning is a relatively useless, and at times a dangerous, performance, the useful lower temperature limit for the Budd is about 25°F lower than for the Revere.

It should be noted that even with continuous burning at low temperatures the performance of the rocket will not be particularly good. The long burning times which are obtained at these temperatures will lead to a very large dispersion in the flight of the rocket, with a consequent lowering of its efficiency as a weapon.

3. Flight tests. The flight data have been tabulated and exhaustively analyzed in a separate report. (Intra-office Memoranda E 46-9). Hence we give here only a summary of the more important data (Table VII). The following conclusions can be drawn from these figures:

a. The burnt velocity of the Budd rocket averages 27 ft./sec., or about 3% higher than that of the Revere. This is presumably due to the higher working pressure in the Budd, which gives a higher gas velocity and hence greater efficiency of the motor.

b. The Budd outranges the Revere by 775 yds. (24%). The difference in velocities can account for at most 6% out of the 24%, the remaining difference is obviously due to the different fin assemblies. The flange which supports the Revere fins clearly causes a considerable drag on the rocket in flight.*

c. The burning distance of the Budd rocket is considerably less (about 20 ft.) than that of the Revere. (Since very short burning distances did not record on the films the statistic given for this quantity is the mode rather than the mean. Even the mode could not be determined for the extremely short burning distances of the Budd on the second day's firing.) This is another effect of the higher pressure in the Budd.

d. The lateral dispersions of the two types of rockets, as measured by the standard deviations of their lateral deflections from the assumed line of fire, are very nearly the same for the firings from the 10 ft. launching tube, about 15 mils. From the 20 ft. tube, however, their values, 9.0 mils for the Budd and 15.2 mils for the Revere, are considerably different. The reason for this behavior becomes apparent if we consider the burning distances outside the tubes. For the 20 ft. tube these are 40 and 59 for the Budd and Revere rockets respectively, while the corresponding figures for the 10 ft. tube on the third day are 59 and 76. The ratio of the first two figures is 1.47, and of the second pair 1.29. Since dispersion depends considerably on burning distance outside the tube, it is easy to see why different results are obtained in the two cases. The fact that with the 10 ft. tube the Revere shows about the same dispersion as the Budd, in spite of the difference in burning distances, leads one to conclude that the Revere has probably less malalignment than the Budd - and would have somewhat less dispersion if the burning distances were equal.

Summary of Conclusions.

1. The Budd 4.5" rocket motor, with 1.75" throat and safety groove set at 6000 lbs./sq.in. is slightly less likely to fail at elevated temperatures than the Revere motor (1.83" throat). The critical region for both is from 110° to 120°F. The Budd can be made stronger by setting the safety groove at 6500 lbs./sq. in., but even then failure would be likely to occur at 120°F in some cases.

*Cf. R. T. Knapp, Memorandum on water tunnel tests of the 4.5" rocket projectile with three different fin tails and with one ring type tail. NDRC, Div. 6, Sec. 6.1; C.I T. Hydraulic Machinery Laboratory Report No. ND-12.1.

2. At low temperatures the smaller throat of the Budd motor gives it a distinct advantage over the Revere. The lower limit of satisfactory burning for the Revere is about 10°F, whereas for the Budd the corresponding temperature is about -15°F.

3. The higher operating pressure of the Budd gives it a 3% greater burnt velocity than the Revere. This gives some increase in range to the Budd, but much more (to a total of 24%) is provided by the more streamlined fin assembly. The two rockets do not differ much in lateral dispersion when fired from a 10 ft. launching tube, but for a 20 ft. tube the shorter burning distance of the Budd, again due to the higher pressure, gives it a dispersion of 9.0 mils standard deviation as against 15.2 mils for the Revere.

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TABLE I

Data on ROW Powder Lot 10015

Composition (percent)	
Nitrocellulose (13.23%N)	58.73
Nitroglycerin	40.07
Ethyl Centralite	1.04
Diphenylamine	0.16
	100.00
Total Volatiles	1.71
Heat of explosion (cal./gm.)	12.02
Length (in.)	5.138
Outside diameter (in.)	0.368
Inside diameter (in.)	0.284
Web (in.)	0.292
Specific gravity (25°C)	1.62

TABLE II

Static Test of Budd and Revere 4.5" Rockets

Motor Type	Revere				Budd			
Motor Number	61C	121C	78D	172B	2947	2952	2979	3003
Throat Diameter (in.)	1.825 ± .010				1.746	1.746	1.754	1.750
Powder Lot	ROW 10015							
Powder Wt. (lb.)	4.80							
No. Grains	35	35	34	30	36	37	30	30
Powder Temp. (°F)	70	70	70	73	70	70	73	73
k	232	232	232	228	253	253	246	246
Burning Time (sec.)	.174	.182	.186	.180	.130	.140	.158	-
Max. Press.(lb./sq.in.)								
Strain Gage	2750	2550	2430	2240	4230	3650	3040	2880
Ball Gage 1	2700	2600	2600	2400	4300	3500	3000	2900
Ball Gage 2	2700	2600	2600	2400	4100	3400	3100	2900
Ave. Pressure	1610	1380	1380	1500	2250	2210	1780	-
Impulse (lb.sec.)	960	960	890	1090	960	1060	1000	-
Eff.Gas Vel.(ft/sec.)	6400	6400	5900	7300	6400	7100	6700	-

Ignition by a single bag containing 35 gm. of A-1 black powder.

TABLE III

High Temperature Test of Budd 4.5" Rockets

Powder Temp. (°F)	No. of Grains of Powder	Throat Diam. (in.)	Copper Ball Pressures (lb./sq.in.)		Behavior
140	30	1.746	7300	7500	Failed at groove
140	30	1.745	3300	-	"
140	30	1.745	5900	7000	"
140	30	1.742	4100	7300	"
140	30	1.745	5900	6600	"
140	30	1.750	5100	6700	"
140	30	1.746	6300	7900	"
140	30	1.742	5900	7300	"
120	37	1.745	4700	4650	Held
120	36	1.747		5750	Failed at Groove
120	35	1.754	6200	5600	Held
120	38	1.748	6800	-	Failed at Groove
120	38	1.750	-	5100	Held
120	35	1.748	5700	5900	Failed at Groove
120	35	1.757	5700	-	Held
120	36	1.749	7500	7500	Failed at Groove
110	35	1.745	4700	2800	Held
110	36	1.745	-	4900	"
110	41	1.748	4800	4900	"
110	40	1.764	4800	4900	"
110	40	1.747	5900	5600	"
110	35	1.754	3700	5100	"
110	43	1.748	-	5200	"
110	40	1.762	4800	2500	"

Rockets loaded with 4.80 lbs. of ROW Lot 10015.
Ignition by a single bag containing 35 gm. of A-1 black powder.
Thickness of wall at safety groove was from .047 to .056 inches

TABLE IV

High Temperature Test of Revere 4.5" Rockets

Powder Temp. (°F)	No. of Grains of Powder	Copper Ball Pressures (lb./sq.in.)		Behavior
120	33	4800	4300	Failed at threads
120	34	-	-	Misfire
120	35	4500	4600	Failed at threads
120	34	5000	5100	Failed at threads and groove
120	34	3700	3800	Failed at groove
120	35	4400	4500	Held
120	34	4500	4600	Failed at threads
120	34	4600	4900	"
110	35	4100	4000	Held
110	35	4200	4300	"
110	34	4500	4600	"
110	34	3900	4000	"
110	35	4100	4100	"
110	35	4300	4200	"
110	35	-	4300	"
110	36	4300	3900	Failed at threads

Rockets loaded with 4.80 lbs. of ROW Lot 10015.

Ignition by a single bag containing 35 gm. of A-1 black powder.

Throat diameters: 1.825 $\pm$ .010. (Total Range)

TABLE V

Low Temperature Test of Budd 4.5" Rockets

Powder Temp. (°F)	No. of Blasts	Burning Time (sec.)	Maximum Pressure (lb./sq.in.)	Comments
-8	1	.320	2320	
-8	1	.304	1600	
-8	2	-	-	
-8	2	-	-	
-13	1	.334	-	
-13	1	.298	-	
-13	1	-	-	
-13	1	-	-	
-13	1	-	-	
-13	1	-	-	
-13	1	-	-	
-13	1	-	-	
-22	2	-	-	About 1 sec. between
-22	2	-	-	blasts "
-22	2	-	-	"
-22	2	-	-	"
-26	2	-	-	
-26	1	-	-	
-26	2	.326*		About 1 sec. between blasts
-26	2	.306* .058**	1710* 1120**	2.4 sec. between blas *First blast. **Second blast

Rockets loaded with 4.80 lbs. of ROW Lot 10015.

Ignition by a single bag containing 35 gm. of A-1 black powder.

Throat diameters: 1.748 ± .007 in. (Total Range)

TABLE VI

Low Temperature Test of Revere 4.5" Rockets

Powder Temp. (°F)	No. of Blasts	Burning Time (sec.)	Maximum Pressure (lb./sq.in.)	Comments
23	1	-	-	
23	1	-	-	
23	1	.248	1980	
23	1	.274	1840	
6	2	-	-	About 1/2 sec. between blasts
6	1	-	-	
6	2	-	-	
6	1	-	-	
0	2	.210* .078**	-	1.6 sec. between blasts
0	1	.286	1870	
0	2	-	-	About 2 sec.between blasts
0	2	-	-	" 1.5 " " "
0	2	-	-	
0	2	-	-	About 2 sec. between blasts
0	2	-	-	" 1.5 " " "
0	2	-	-	
-8	3	-	1880*	
-8	3	.180* .134**	1540* 1280**	3.7 sec. between first and second blasts.
-8	3	-	-	
-8	4	-	-	

* First blast. ** Second blast.

Rockets loaded with 4.80 lbs. of ROW Lot 10015.

Ignition by a single bag containing 35 gms. of A-1 black powder.

Throat diameters: 1.825 ± .010 in. (Total Range)

TABLE VII

Flight Test of Budd and Revere 4.5" Rockets

Date Fired	Type	No. of Rds.	Length of Launcher (ft.)	Range (yds.) M	Range (yds.) σ	Lateral Deflection (mils) M	Lateral Deflection (mils) σ	Burning Dist. (ft.) Mode	Velocity* (ft./sec.) M	Velocity* (ft./sec.) σ	Eff. Gas Vel. (ft./sec.)	Pdr. Temp. (°F)	Air Temp. (°F)
4/27/43	Budd	33	20	3944	78	-2.0	9.0	60	910	30	6850	-	55
4/27/43	Revere	30	20	3139	57	-5.9	15.2	79	878	32	6600	-	55
4/28/43	Budd	29	10	4056	146	0.8	15.6	-	920	23	6920	78	74
4/28/43	Revere	30	10	3311	109	-1.6	17.5	85	886	27	6600	78	74
4/29/43	Budd	45	10	3917	96	-1.4	15.2	69	899	28	6760	65	57
4/29/43	Revere	39	10	3141	119	3.2	17.4	86	885	30	6650	65	57

All rockets loaded with 4.80 lbs. of ROW Lot 10015.

Total weight of Reveres on 4/27/43 and of all Budds: 38.50 ± .05 lbs. (Total Range)

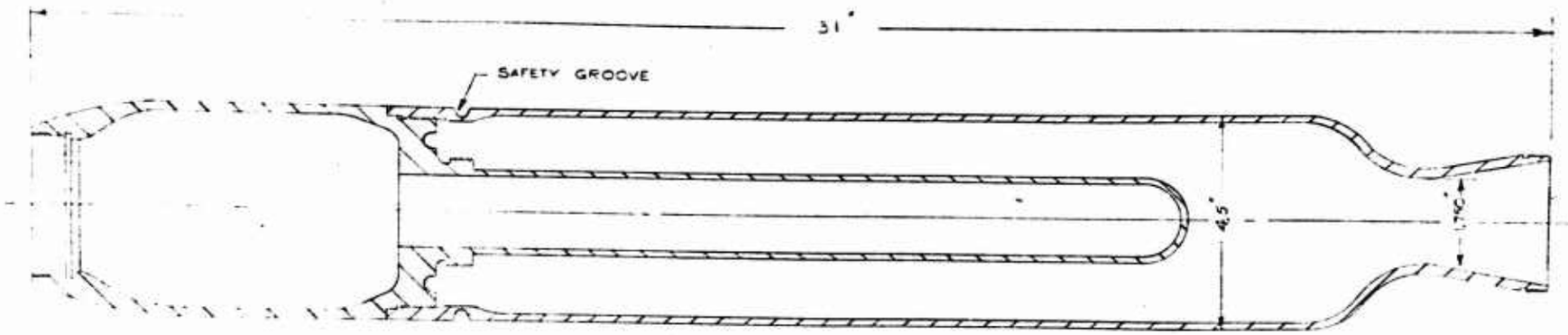
Total weight of Reveres on 4/28/43 and 4/29/43: 38.5 ± .5 lbs. (Total Range)

M = mean value = $\Sigma x_i/N$

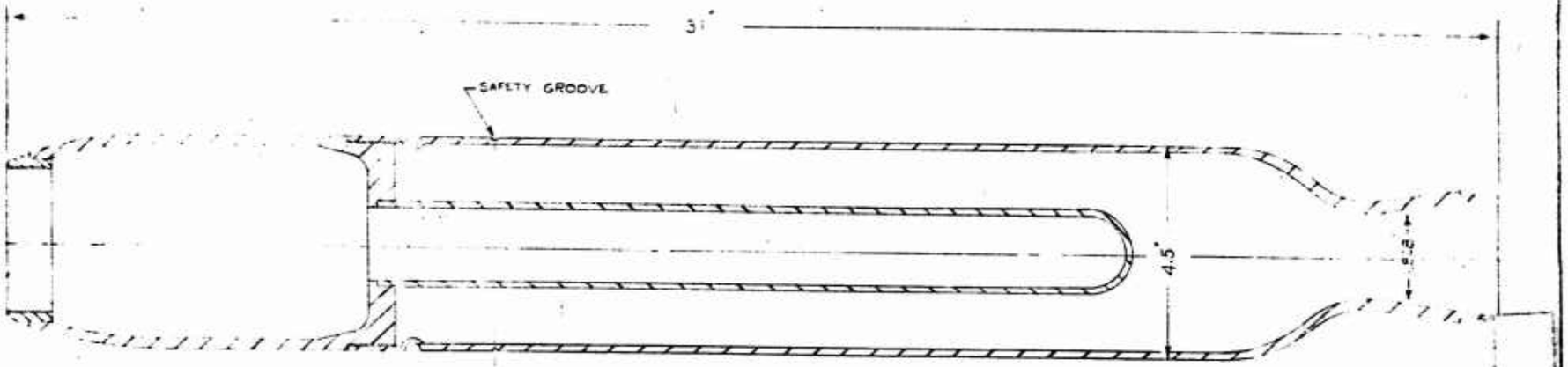
σ = Standard deviation = $\sqrt{\Sigma (x_i-M)^2/(N-1)}$ Probable error = .674 σ .

* Velocity 135 ft. horizontally from breech of launcher.

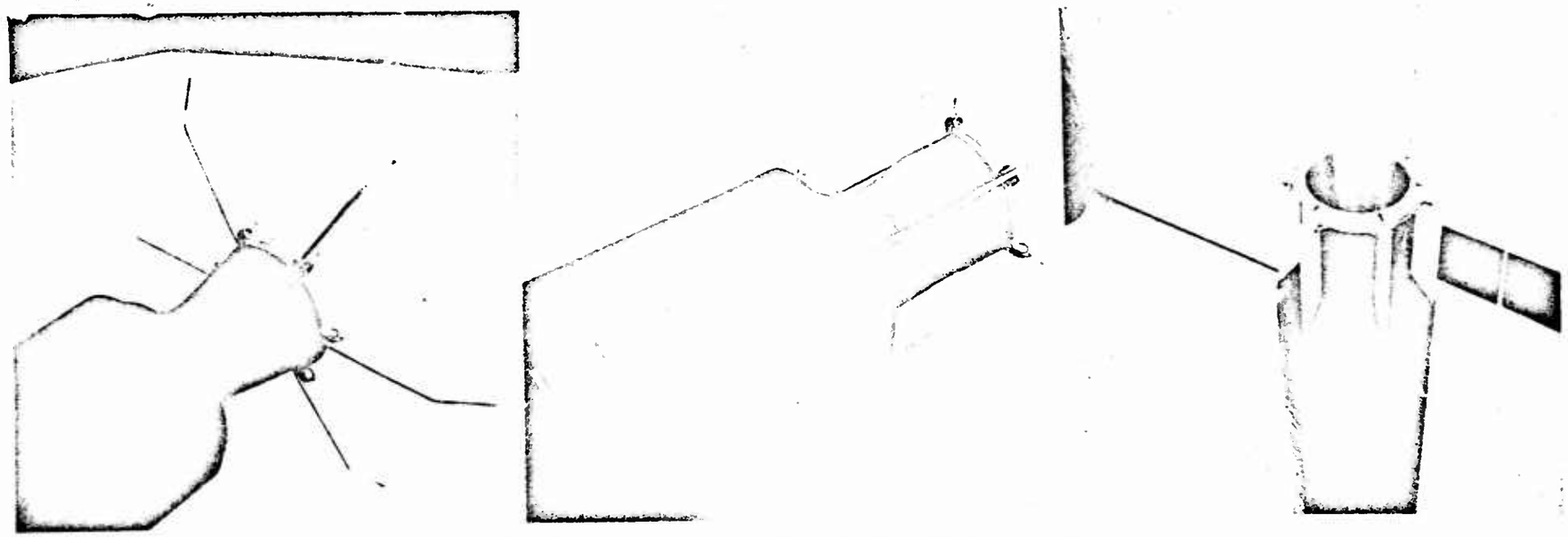
** Effective gas velocity = (Rocket wt. - $\frac{1}{2}$ Powder wt.) Velocity/Powder wt.



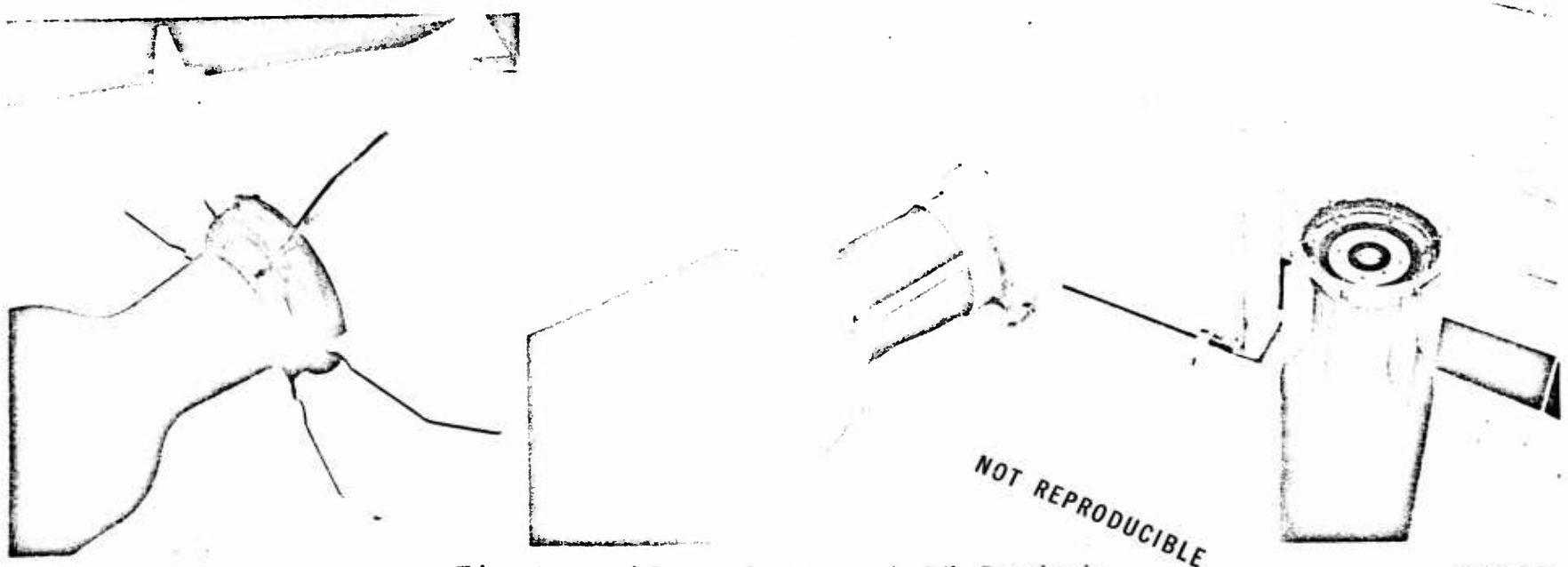
BUDD 4.5 ROCKET



REVERE 4.5 ROCKET



Fin Assembly - Budd 4.5" Rocket



Fin Assembly - Revere 4.5" Rocket

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Fig. 2

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An extended series of tests were conducted to obtain behavior comparisons of the Budd and Revere types of 4.5" rockets. The two types were fired statically and in flight to determine the differences in performance due to differences in design and methods of manufacture of the rocket motors. The complete data of the static tests is presented and discussed, and a summary given of the flight test results. The results indicated that, when fired at high temperatures, the Budd motor is slightly less likely to fail than the Revere motor, and that the Budd rocket outranges the Revere rocket by 24%. The Budd rocket also has a lower temperature limit for satisfactory operation than does the Revere rocket.

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