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ACCURACY COMPARISON OF MODIFIED AND UNMODIFIED 2.75-INCH (FFAR) ROCKETS FIRED FROM AN AIRBORNE ARMED CHINOOK HELICOPTER

by
William M. Hadawr

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U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama

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by
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ABSTRACT

Twenty pairs of standard rockets and 29 pairs of modified rockets (with MK-1 heads) were fired at a ground target. Also, one 10-round ripple of standard and three 10-round ripples of modified rockets were fired. Nominal test conditions were with helicopter airspeed of 110 knots, altitude of 250 meters, and slant range of 1000 meters. Results indicated angular accuracy improvements of 7 to 40 percent for the modified rocket configurations.

SUMMARY

Low Spin Folding Fin Aircraft Rockets (LS FFAR) with MK-1 inert heads were fired from the CHINOOK helicopter at Redstone Arsenal, Alabama, to compare their accuracy to rockets modified with a small wedge attached to each fin tip. Twenty pairs of standard rockets, 29 pairs of modified rockets, one 10-round ripple of standard rockets, and three 10-round ripples of modified rockets were fired for accuracy comparisons. The CHINOOK helicopter, with a pylon mounted 19-tube XM-159 rocket pod on each side, fired at a ground target while in a dive of about 10 degrees. The helicopter airspeed was nominally 110 knots, the firing altitude was approximately 250 meters, and the slant range to target was 1000 meters.

Results indicated that, with bias removed, the azimuth angular error was 7.0 mils σ (20 pairs) for the standard rocket configuration and 5.0 mils σ (29 pairs) for the modified rocket configuration - a 30-percent accuracy improvement due to the addition of wedges to the fins. Comparisons in the pitch plane (bias removed) indicated angular errors of 7.7 mils σ for the standard and 7.2 mils σ for the modified rockets.

The accuracy of 10-round ripples of wedge modified rockets was degraded in azimuth by a factor of about two from that calculated from single pair firings.

Strong azimuth crossover bias values were in evidence for both configurations fired (30.2 mils bias for the standard round and 18.1 mils bias for the modified round). The smaller bias value of the configuration with wedge fins is attributed to delayed fin opening, thus reducing the sensitivity of the rocket to a strong outward wind flow over the nose of the helicopter.

Consideration should be given to splaying the launchers of the CHINOOK to cancel part of the crossover bias if improvement of the azimuth accuracy is desirable. Of course, the launcher splay angle would be optimized for a particular type of helicopter (CHINOOK or other) and helicopter velocity. Additional firings similar to those reported would be necessary to prove the desirability of such an approach.

All accuracy comparisons between the standard and modified rockets indicated accuracy improvements of from 7 to 40 percent when wedges are added to the fins of the standard LS FFAR configurations.

CONTENTS

ILLUSTRATIONS

Section I. INTRODUCTION

Several CH-47A (CHINOOK) helicopters have been equipped recently with additional armor and a variety of armament. The armament includes the M-5 subsystem, the M-24 subsystem, five 50-caliber machine guns, and a subsystem employing 2.75-inch Folding Fin Aircraft Rockets (FFAR) with an XM-159, 19-tube rocket pod on each pylon. The entire system is referred to as the Armored or Armed CHINOOK.

A test program was conducted at the Army Missile Command (MICOM) Redstone Arsenal, Alabama, to examine problem areas involved in combining the CHINOOK and the FFAR subsystem. Parts of that test program involved rocket firings from the ground and from the air. Firings from the air were augmented to include closely controlled firings of rocket pairs and rocket ripples at a ground target. Rocket impacts were staked after each pass and later surveyed. The resultant data were combined to provide accuracy comparisons for the standard LS* FFAR (with scarfed nozzles) and the standard rocket modified by adding an uncanted wedge at the tip of each fin. Firings were conducted at Range 1, Redstone Arsenal, Alabama, and nominal firing conditions were with the CHINOOK in a slight dive of 10 degrees at 1000 meters slant range to target, 250 meters altitude, and 110 knots helicopter velocity. Inert MK-1 heads were employed for all air firings.

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*Low Spin (for helicopter application)

Section II. BACKGROUND

MICOM recently conducted a test program designed to improve the accuracy of the LS FFAR with only minor changes on the rocket and no changes on the launcher. Those results are reported in Report No. RD-TR-66-2.[1] A modification with 0 degree cant wedges on the fins (Figure 1) increased the rocket roll rate at launch from a nominal 1.8 revolutions per second for the standard rocket to rates between 5 and 6 revolutions per second at launch. Air-to-ground firings of those two configurations (with XM-151 heads and XM-423 fuzes) were made from a UH-1B helicopter under similar test conditions to those herein. Results indicated that the angular accuracy in the pitch plane was improved 23 percent by employment of the wedges to increase launch roll rate. The azimuth comparisons were inconclusive since some of the rockets crossed in flight and some did not. Unfortunately, the determination of which rockets crossed could not be made; therefore, the crossover bias could not be determined for each configuration, and the azimuth accuracy was not considered to be a proper indication of comparative accuracy. The sample sizes were 10 pairs for the standard rocket and 21 pairs for the modification with 0 degree cant wedges. Consequently, controlled firings, from the CHINOOK, of greater sample sizes of the two configurations were considered appropriate to provide a better comparison of the accuracy of the two rocket configurations, thus permitting a better basis for consideration of the rocket modification for tactical usage.

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[1] U.S. Army Missile Command, Redstone Arsenal, Alabama, 2.75-INCH ROCKET (FFAR) ACCURACY IMPROVEMENT STUDY by William M. Hadaway and Ivan H. Shokes, January 1966, Report No. RD-TR-66-2 (Unclassified Report).

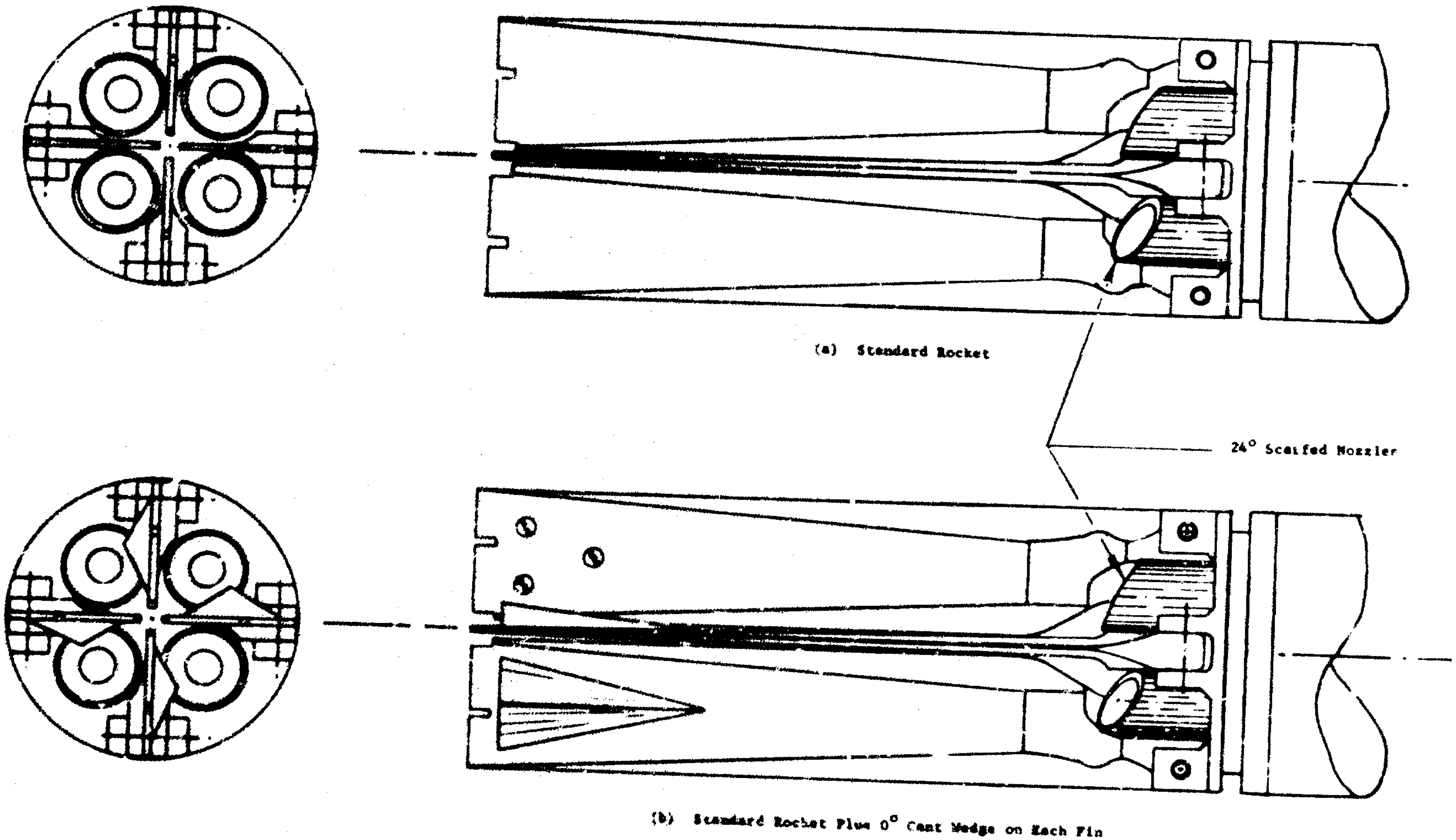

Figure 1. Nozzle and Fin Assembly of the Standard and the Modified LS FFAR

Section III. INSTRUMENTATION

Two 16-mm Milliken motion picture cameras were mounted on the CHINOOK helicopter, one on each 20-mm gun mount directly above the XM-159 launcher pod (Figures 2, 3, and 4). These cameras were used to determine if the rockets crossed.

A chase aircraft (UH-1B helicopter) was also equipped with one 16-mm motion picture camera to monitor rocket impacts. A view of the target from the relative position of the chase ship at time of firing is indicated in Figure 5. The target was laid out on the ground with cheesecloth. The primary target for pair firings was 100 meters long and 50 meters wide and was divided into 25-meter squares. A secondary target, indicated across the road and to the left of the primary target, was used for the ripple fire tests. The center of the grid target was surveyed to be 100 feet right of the range centerline and the center of the alternate target was 200 feet left of range centerline. Both targets were at the station 12,200 feet downrange. The test plan called for the rockets to be fired as the helicopter passed over the station 9035 feet downrange, at an altitude of 250 meters, and an airspeed of 110 knots. This was calculated to provide a nominal slant range of 1000 meters.

Two 35-mm Contraves cinetheodolite tracking cameras were used to record CHINOOK flight conditions at the instant of rocket firing. Figure 6 shows the tracking camera view of the CHINOOK helicopter during a firing pass.

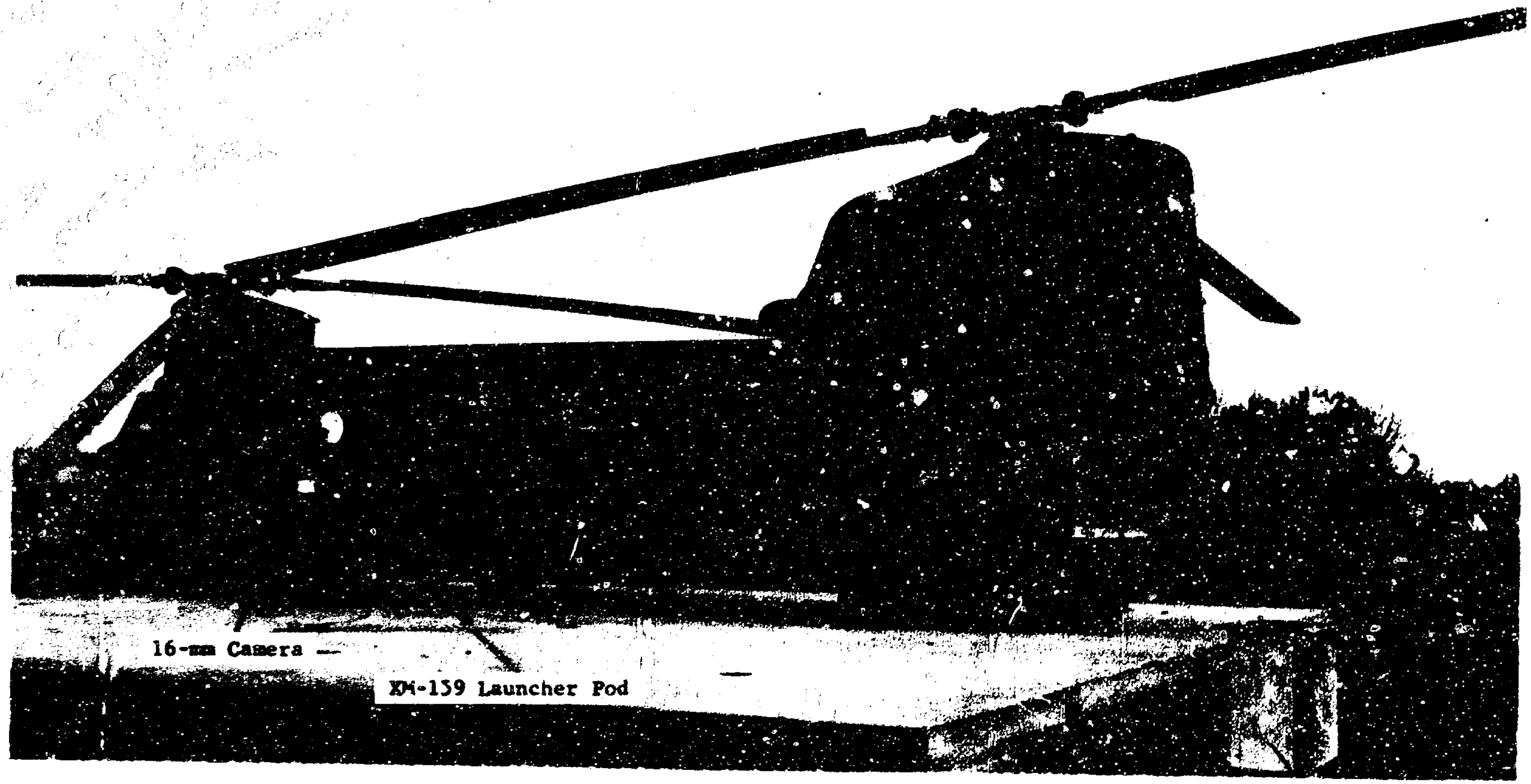

Figure 2. Left Side View of the CHINOOK Helicopter

Figure 3. Front View of the XM-159 Launcher Pod and 16-mm Camera Mounted on the CHINOOK Helicopter

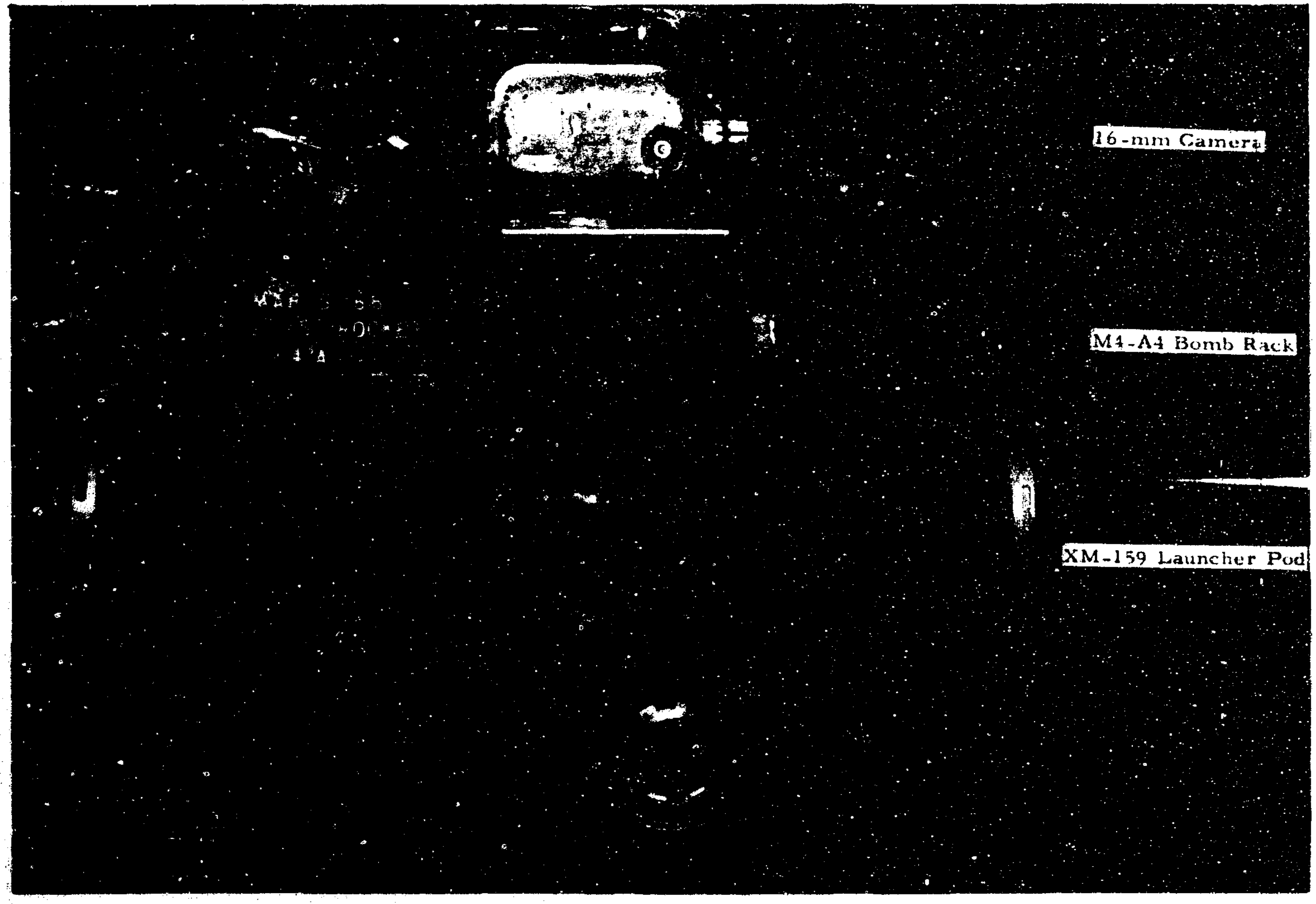

Figure 4. Side View of the XM-159 Launcher Pod and 16-mm Camera Mounted on the CHINOOK Helicopter

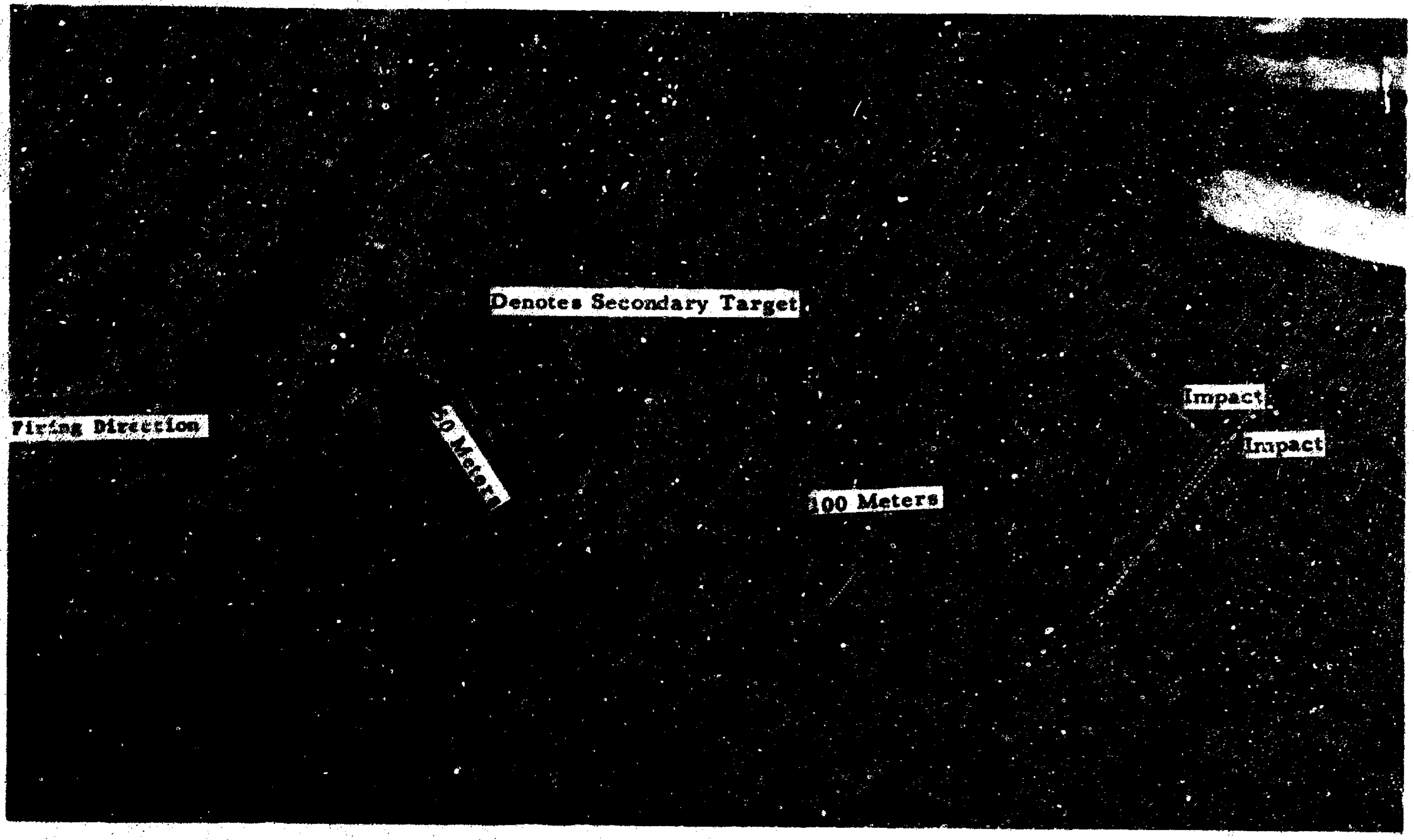

Figure 5. Aerial Photograph Showing Grid Target and Secondary Target

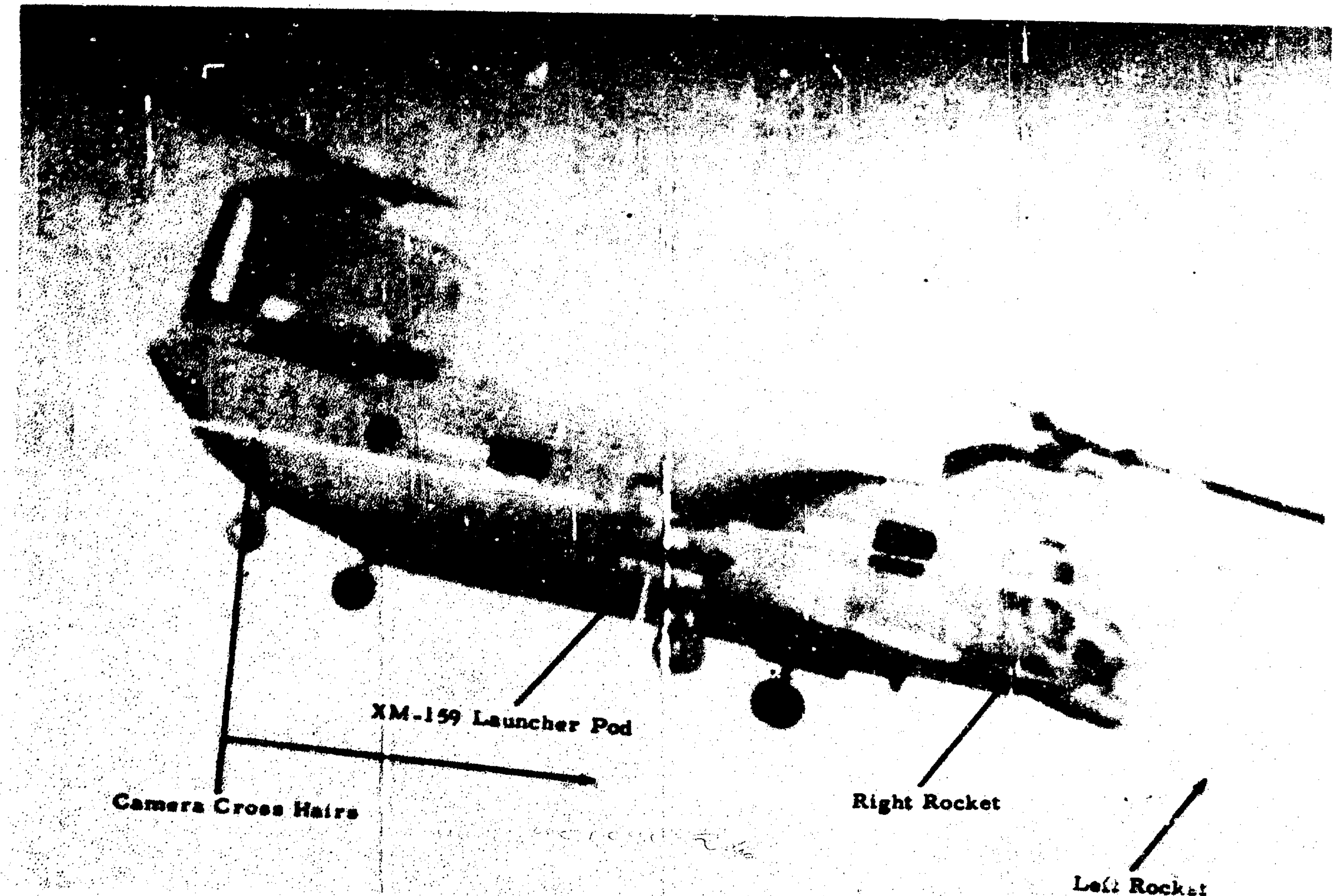

Figure 6. Ground-Based Tracking Camera View of CHINOOK Helicopter During Firing Pass

Section IV. TEST PROCEDURES

Accuracy tests were begun on 5 March 1966. Nine practice firings were conducted to familiarize all personnel participating in the tests with procedures. Both the CHINOOK and the UH-1B chase helicopters participated in the practice tests. After both helicopters landed, the XM-159 rocket pods of the Armed CHINOOK were loaded with rockets of both configurations of the FFAR in a random sequence. Proper identification of impacts was assured by personnel in the chase helicopter which landed after each firing pass. Each impact was properly marked and identified, and the impact coordinates were surveyed after completion of the tests. The firing order of each rocket pod is indicated in Figure 7. The normal firing sequence is indicated on the right pod. The left pod firing sequence is different because of the wiring on the particular CHINOOK helicopter rather than the wiring on the launcher pod. The nose of each rocket with wedges on the fins was painted red in order to aid in proper double checking of tube, firing sequence, and configuration prior to takeoff for each run. Herein, a pass denotes a firing condition (either a rocket pair or a ripple) and a run denotes a condition from pod loading to pod loading.

The rocket firings of 5 March were terminated after 8 pairs had been fired for accuracy (three standard pairs and five pairs with the wedge configuration). The winds were 10 to 25 knots with gusts and the validity of accuracy data under such conditions was questionable.

The helicopter was flown from Fort Benning, Georgia, to Redstone Arsenal, Alabama, on 4 March to permit the accuracy firing program to be conducted on 5 March. It was decided that the helicopter would return to Fort Benning after termination of the tests on 5 March and return again to Redstone Arsenal on 8 March for further testing on 9 March. Because of the small sample size of firings and the prevailing wind conditions, no conclusions of accuracy were made from results of the 5 March firings. The decision was made to begin the tests again on 9 March rather than continue from the point of termination on 5 March. For the 5 March firings, the rocket pods were boresighted to converge 1000 meters ahead of the helicopter. The normal alignment procedure, however, for the XM-159 pods on the CHINOOK is with specific boresighting equipment to align the pods parallel to the helicopter longitudinal centerline. Consequently, the Fort Benning personnel were requested to boresight the pods by normal procedures parallel to the helicopter centerline prior to returning to Redstone Arsenal on 8 March. The boresighting procedures and additional CHINOOK/FFAR test results, other than the accuracy tests reported herein, are documented in Report No. RT-TM-66-31.[2]

For FFAR accuracy tests on both 5 March and 9 March, all CHINOOK armament other than the XM-159 pods was removed at Fort Benning prior to the flights to Redstone Arsenal. A description of the armament is indicated in Appendix A.

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[2] U.S. Army Missile Command, Redstone Arsenal, Alabama, XM-159 2.75-INCH REUSABLE LAUNCHER POD MOUNTED ON THE CH-47A (CHINOOK) HELICOPTER by Jack L Childers, April 1966, Report No. RT-TM-66-31 (Unclassified Report).

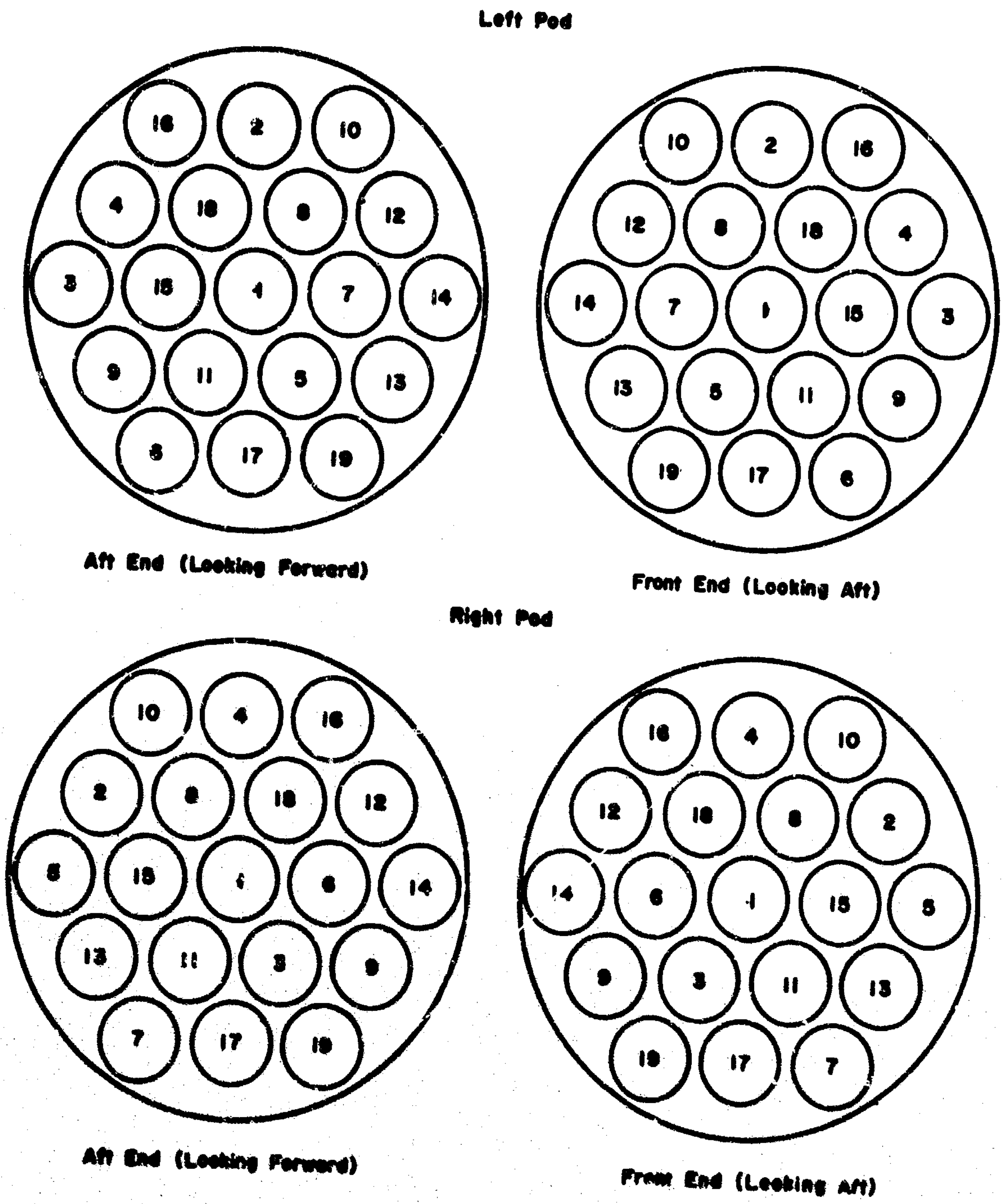


Figure 7. Front and Aft View of the XM-159 Launcher Pods Showing Rocket Firing Order

Section V. TEST RESULTS

On 9 March 1966, the CHINOOK/FFAR accuracy program was conducted at Range 1, Redstone Arsenal, Alabama. The same helicopter crew and test personnel were employed as on the 5 March firing, and the same test conditions and procedures were followed, except for the parallel rocket pod boresighting referred to in Section IV. Twenty pairs of standard rockets and 29 pairs of standard rockets with 0 degree cant wedges on the fin tips were fired at the primary target. Also, four ripples of rockets were fired at the alternate target, one 10-round ripple with standard rockets and three 10-round ripples with the wedge fin configuration. All motors of the accuracy comparion test program were loaded in 1953. Firing order, impact data relative to the target center, meteorological data, and some launch condition data are recorded in Table I for the accuracy firings of 5 March and 9 March. Additional helicopter attitude and rate data are indicated in Table II. The data of both tables were used to determine slant range, angle of fire, and accuracy for both pair and ripple conditions. Accuracy computations for pair firings are shown in Tables III and IV and ripple fire accuracy results are shown in Tables V and VI.

Cameras above each rocket pod indicated that 38 pairs of the 49 pairs which were fired on 9 March crossed prior to impact. Four more pairs probably crossed and no information from either camera was available on the remaining seven pairs because the cameras were aimed too high to pick up the rocket exhausts. No film data were available on the ripple firing of Run 1, but the ripple data of Runs 2, 3, and 4 indicated that each pair in the ripple crossed. For analysis, therefore, it seems proper to assume that all rockets crossed prior to impact.

The data of Table II indicate the position of the center of the top rear rotor at the instant of firing. Therefore, in the process of determining altitude, range, and slant range, 15 feet were subtracted from the altitude and 25 feet were added to the range of each helicopter position indicated on Table II in order to provide data relative to the XM-159 launcher pods. The pods were mounted at CHINOOK longitudinal station 251, 38 inches below the waterline, and 90 inches outboard of the centerline. Overall CHINOOK dimensions and XM-159 pod positions are indicated in Figure 8.

In Table I, the first two passes and pair firings on the first run of 9 March were designated as practice firings and, although all necessary data were obtained for analysis, they were not included in the accuracy analysis. One modified rocket misfired (left pod) on the 10th pass of

Run 1; therefore, only 29 pairs of the modified rocket impacts could be analyzed rather than the planned 30 pairs.

On Run 3, Pass 1, an eight-round ripple was inadvertently fired instead of one pair because the firing selector was not reset after the 10-round ripple at the end of the previous run. The data of the eight-round ripple were not used in the analysis of ripple accuracy because of of a configuration mix, two standard rockets and six modified rockets. The remainder of Run 3 was fired according to the test plan, but the firing order and type configuration apportionment were changed prior to loading the pods for Run 4. This provided the number and type pairs and ripples called for in the test plan, excluding the loss of a wedge pair on Run 1 due to a misfire.

After completion of the accuracy comparison test plan, Run 5 was made which involved four ripples of standard LS FFAR's with new production motors. No impacts were recorded.

Table I. Launch, Impact, and Meteorological Data for the Accuracy Tests

Run No.	Pass No.	Date (1966)	Time (hr)	Aircraft Attitude at Launch (Instrument Readings): Altitude (ft)	Aircraft Attitude at Launch (Instrument Readings): Airspeed (knots)	Launcher Data: Tube No.	Launcher Data: Rocket No.	Meteorological Data: Temperature (°F)	Meteorological Data: Humidity (%)	Meteorological Data: Density Altitude (ft)	Meteorological Data: Winds Direction (°N)	Meteorological Data: Winds Velocity (knots)	Meteorological Data: Barometric Pressure (in. Hg)	Impact Data: Range (ft)	Impact Data: Azimuth (ft)	Rocket Configuration Standard (S) Wedge Fin (W)
(*)		5 Mar.	1000	Ground Firing		1 1	1 2	40	44	806	240	10-24	29.82	NR	NR	S
PR	2	5 Mar	1005	NR	NR	2 2	3 4	40	44	806	240	10-24	29.82	NR	NR	S
PR	3	5 Mar	1010	NR	NR	3 3	5 6	40	44	806	270	10-24	29.82	NR	NR	S
PR	4	5 Mar.	1015	NR	NR	4 4	7 8	40	43	806	270	10-24	29.82	NR	NR	S
PR	5	5 Mar.	1022	NR	NR	5 5	9 10	40	43	806	300	10-24	29.82	NR	NR	S
PR	6	5 Mar.	1025	NR	NR	6 6	11 12	40	43	806	300	10-24	29.82	NR	NR	S
PR	7	5 Mar	1028	NR	NR	7 7	13 14	40	42	806	280	10-24	29.82	NR	NR	S
PR	C	5 Mar.	1030	NR	NR	8 8	15 16	40	41	806	280	10-24	29.82	NR	NR	S
PR	9	5 Mar.	1032	NR	NR	9 9	17 18	40	40	806	290	10-24	29.82	NR	NR	S
1	1	5 Mar.	1121	800	110	1 1	1 2	41	39	806	320	10-24	29.83	400.8 231.9	-86.5 65.5	S
1	2	5 Mar.	1128	715	115	2 2	3 4	41	39	806	320	10-24	29.83	115.9 109.5	NR	W
1	3	5 Mar.	1134	Did not fire		3 3	Did not fire	41	39	806	300	10-24	29.83	NR	NR	
1	4	5 Mar.	1137	800	110	4 4	5 6	41	39	806	300	10-24	29.83	358.0 -252.3	2.2 223.2	S
1	5	5 Mar.	1147	850	110	5 5	7 8	41	39	806	300	10-20	29.83	129.2 672.0	14.8 7.9	S
1	6	5 Mar.	1153	600	115	6 6	9 10	41	39	806	290	10-20	29.83	534.4 147.6	25.7 26.3	W
1	7	5 Mar.	1200	800	110	7 7	11 12	40	41	806	330	10-20	29.83	-67.1 -107.0	100.7 -3.1	W
1	8	5 Mar.	1206	750	110	8 8	13 14	40	41	806	320	10-20	29.83	15.8 -176.8	132.1 174.0	S
(**)	9	5 Mar.	1212	700	110	9 9	15 16	40	41	806	320	10-20	29.83	-447.0 -291.0	160.6 73.0	W

See notes at end of table.

Table I. (Continued)

Run No.	Pass No.	Date (1966)	Time (hr)	Aircraft Attitude at Launch Instrument Readings: Altitude (ft)	Aircraft Attitude at Launch Instrument Readings: Airspeed (knots)	Launcher Data: Tube No.	Launcher Data: Rocket No.	Meteorological Data: Temperature (°F)	Meteorological Data: Humidity (%)	Meteorological Data: Density Altitude (ft)	Meteorological Data: Winds Direction (°N)	Meteorological Data: Winds Velocity (knots)	Meteorological Data: Barometric Pressure (in. Hg)	Impact Data: Range (ft)	Impact Data: Azimuth (ft)	Rocket Configuration Standard (S) Wedge Fin (W)	Observed from Data Film
1	1	5 Mar.	0636	NR	NR	1	1	42	45	1080	120	5	30.59	290.1	101.1	S	
						1	2							312.2	-45.5		
1	2	9 Mar.	0810	NR	NR	2	3	42	45	1080	120	5	30.59	-242.2	102.5	S	
						2	4							-267.2	65.0		
1	3	9 Mar.	0815	900	110	3	5	42	45	1080	120	5	30.59	304.8	-36.7	S	Cross
						3	6							550.0	70.0		
1	4	9 Mar.	0820	800	120	4	7	42	45	1080	120	5	30.59	-107.5	65.7	W	Cross
						4	8							86.0	65.2		
1	5	9 Mar.	0825	750	115	5	9	42	45	1080	120	5	30.59	-173.7	97.5	S	Cross
						5	10							-177.0	170.8		
1	6	9 Mar.	0828	850	115	6	11	42	45	1080	120	5	30.59	35.4	16.3	W	NR
						6	12							23.9	-43.4		
1	7	9 Mar.	0832	800	115	7	13	43	45	1080	120	5	30.59	-300.1	178.2	W	Cross
						7	14							-361.4	58.1		
1	8	9 Mar.	0837	800	115	8	15	43	45	1080	120	5	30.59	136.4	85.2	W	Cross
						8	16							189.9	162.6		
1	9	9 Mar.	0840	800	115	9	17	43	45	1080	120	5	30.59	-261.4	59.1	S	Cross
						9	18							-216.3	107.1		
1	10	9 Mar.	0844	800	110	10	19	43	45	1080	120	5	30.59	252.3	55.9	W	—
						10	Misfire										
1	11	9 Mar.	0847	850	120	11	20	44	45	1080	120	5	30.59	201.1	48.9	W	Cross
						11	21							459.0	120.0		
1	12	9 Mar.	0855	850	110	12	22	44	45	1080	120	5	30.59	-133.6	62.5	W	NR
						12	23							-162.4	126.6		
1	13	9 Mar.	0858	850	110	13	24	44	45	1080	120	5	30.59	-611.0	157.6	S	Cross
						13	25							-533.4	193.7		
1	14	9 Mar.	0902	1008	110	14	26	45	43	1080	120	10	30.59	117.6	103.2	W	NR
						14	27							-90.9	102.5		
1	15	9 Mar.	0906	850	110	15-19	28-37	45	43	1080	120	10	30.59	-114.0	149.7	W	NR
	5-round ripple each launcher													-112.6	148.3		
														172.4	244.9		
														-71.6	207.4		
														-36.8	121.5		
														34.1	147.8		
														-294.3	202.4		
														-287.2	142.3		
														-92.0	81.9		
														-325.0*	240.0*		

See notes at end of table.

Table I. (Continued)

Run No.	Pass No.	Date (1966)	Time (hr)	Aircraft Attitude at Launch Instrument Readings: Altitude (ft)	Airspeed (knots)	Launcher Data: Tube No.	Rocket No.	Meteorological Data: Temperature (°F)	Humidity (%)	Density Altitude (ft)	Winds: Direction (°N)	Velocity (knots)	Barometric Pressure (in. Hg)	Impact Data: Range (ft)	Azimuth (ft)	Rocket Configuration Standard (S) Wedge Fin (W)	Observed from Data Film
2	1	9 Mar.	1045	1000	110	1	1	49	34	550	120	10	30.58	451.0	-1.3	W	Cross
						1	2							347.2	43.7		
2	2	9 Mar.	1050	950	110	2	3	49	34	550	120	10	30.58	69.7	107.4	W	Cross
						2	4							127.6	151.4		
2	3	9 Mar.	1053	1100	100	3	5	49	34	550	120	10	30.58	364.9	8.7	S	Cross
						3	6							594.0	- 97.6		
2	4	9 Mar.	1055	1000	100	4	7	49	34	550	120	10	30.58	41.7	-111.4	S	Cross
						4	8							124.5	48.2		
2	5	9 Mar.	1100	1000	110	5	9	49	34	550	120	10	30.58	145.1	60.1	W	Cross
						5	10							210.6	26.6		
2	6	9 Mar.	1104	800	120	6	11	52	32	550	180	12	30.57	-542.9	133.3	S	NR
						6	12							-315.1	64.6		
2	7	9 Mar.	1107	800	115	7	13	52	32	550	180	12	30.57	60.8	13.1	W	Probable Cross
						7	14							- 53.4	62.2		
2	8	9 Mar.	1111	800	115	8	15	52	32	550	180	12	30.57	-100.4	- 1.1	W	Cross
						8	16							- 92.7	52.4		
2	9	9 Mar.	1115	900	110	9	17	52	32	550	180	12	30.57	-164.4	34.8	W	NR
						9	18							-115.7	109.7		
2	10	9 Mar.	1118	1100	110	10	19	52	32	550	180	12	30.57	- 94.2	46.3	S	Cross
						10	20							- 74.6	134.7		
2	11	9 Mar.	1122	950	110	11	21	52	32	550	130	12	30.57	- 83.6	70.7	W	Cross
						11	22							188.0	0.9		
2	12	9 Mar.	1127	1000	110	12	23	52	32	550	180	12	30.57	26.4	72.6	S	Cross
						12	24							-109.8	- 59.7		
2	13	9 Mar.	1130	1000	105	13	25	52	32	550	180	12	30.57	60.0	59.5	W	Cross
						13	26							450.0	4.0		
2	14	9 Mar.	1134	900	110	14	27	52	32	550	180	12	30.57	- 84.4	4.9	W	Cross
						14	28							-141.2	55.6		
2	15	9 Mar.	1139	900	110	15-19	23-38	52	32	550	180	12	30.57	- 3.9	- 45.0		
														-46.2	- 14.6		
														-113.6	- 3.4		
														-392.8	92.3		
	5-round ripple each launcher													-285.8	57.4	W	All Cross
														-269.5	56.9		
														-266.0	53.7		
														-293.8	26.9		
														-239.4	6.5		
														-270.6	- 41.6		

See notes at end of table.

Table I. (Continued)

Run No.	Pass No.	Date (1960)	Time (hr)	Aircraft Attitude at Launch, Instrument Reading: Altitude (ft)	Aircraft Attitude at Launch, Instrument Reading: Airspeed (knots)	Launcher Data: Tube No.	Launcher Data: Rocket No.	Meteorological Data: Temperature (°F)	Meteorological Data: Humidity (%)	Meteorological Data: Density Altitude (ft)	Meteorological Data: Winds Direction (°N)	Meteorological Data: Winds Velocity (knots)	Meteorological Data: Barometric Pressure (in. Hg)	Impact Data: Range (ft)	Impact Data: Azimuth (ft)	Rocket Configuration Standard (S) Wedge Fin (W)	Observed from Data Film
↑3	1	9 Mar.	1305	900	110	1-4	1-8	55	30	275	230	6	30.51	-195.9	116.6	6 W + 2 S	
	4-round ripple each launcher													224.0	- 42.5		
														13.9	5.7		
														31.3	- 13.2		
														49.3	- 19.5		
														56.1	- 43.6		
														115.5	- 55.1		
														111.5	- 94.3		
3	2	9 Mar.	1310	NR	NR	5	9	55	30	275	230	6	30.51	33.8	44.7	W	Cross
						5	10							1.6	5.7		
3	3	9 Mar.	1314	900	110	6	11	55	30	275	230	6	30.51	165.9	6.4	S	Cross
						6	12							392.5	155.1		
3	4	9 Mar.	1318	1000	110	7	13	55	30	275	230	6	30.51	- 69.4	28.5	S	Cross
						7	14							91.9	- 62.2		
3	5	9 Mar.	1322	800	115	8	15	55	30	275	230	6	30.51	- 74.7	- 5.7	S	Cross
						8	16							-165.8	138.4		
3	6	9 Mar.	1326	1000	105	9	17	55	30	275	230	6	30.51	-310.0	- 0.3	W	Cross
						9	18							-238.0	- 66.1		
3	7	9 Mar.	1329	900	110	10	19	55	30	275	230	6	30.51	-103.4	58.9	W	Probable Cross
						10	20							-398.0	102.6		
3	8	9 Mar.	1333	900	110	11	21	55	30	275	230	6	30.51	- 18.2	170.0	S	Cross
						11	22							42.0	1.1		
3	9	9 Mar.	1336	1000	105	12	23	55	30	275	230	6	30.51	293.9	- 73.8	S	Cross
						12	24							12.5	75.5		
3	10	9 Mar.	1340	900	105	13	25	55	30	275	230	6	30.51	-272.4	87.1	W	NR
						13	26							-333.3	56.4		
3	11	9 Mar.	1344	950	95	14	27	55	30	275	230	6	30.51	-127.9	- 12.5	S	Cross
						14	28							- 37.8	144.4		
3	12	9 Mar.	1355	1000	100	15-19	29-38	55	30	275	230	6	30.51	-140.2	60.6	W	All Cross
	5-round ripple each launcher													113.0	96.4		
														101.1	77.9		
														150.1	57.0		
														153.6	61.[illegible]		
														163.0	95.6		
														141.3	16.4		
														77.3	34.5		
														22.8	71.5		
														326.4	70.2		

See notes at end of table.

Table I. (Continued)

Run No.	Pass No.	Date (1966)	Time (hr)	Aircraft Attitude at Launch Instrument Reading: Altitude (ft)	Aircraft Attitude at Launch Instrument Reading: Airspeed (knots)	Launcher Data: Tube No.	Launcher Data: Rocket No.	Meteorological Data: Temperature (°F)	Meteorological Data: Humidity (%)	Meteorological Data: Density Altitude (ft)	Meteorological Data: Winds: Direction (°N)	Meteorological Data: Winds: Velocity (knots)	Meteorological Data: Barometric Pressure (in. Hg)	Impact Data: Range (ft)	Impact Data: Azimuth (ft)	Rocket Configuration Standard (S) Wedge Fin (W)	Observed from Data Film
4	1	9 Mar.	1439	500	100	1	1	56	29	175	130	8	30.48	37.8	- 12.9	W	Probable Cross
						1	2							2.9	32.4		
4	2	9 Mar.	1442	900	115	2	3	56	29	175	130	8	30.48	33.9	131.7	S	Cross
						2	4							92.8	33.0		
4	3	9 Mar.	1445	800	110	3	5	56	29	175	130	8	30. 8	- 26.0	61.8	S	Cross
						3	6							-144.8	- 18.3		
4	4	9 Mar.	1448	900	100	4	7	56	29	175	130	8	30.48	467.8	45.5	W	Cross
						4	8							135.8	- 17.9		
4	5	9 Mar.	1452	950	105	5	9	56	29	175	130	8	30.48	-362.2	93.3	W	NR
						5	10							- 87.0	30.0		
4	6	9 Mar.	1455	1000	105	6	11	56	29	175	130	8	30.48	109.4	167.4	W	Cross
						6	12							132.4	37.0		
4	7	9 Mar.	1458	850	120	7	13	56	29	175	150	8	30.48	123.2	- 18.2	S	Cross
						7	14							248.5	- 94.8		
4	8	9 Mar.	1502	950	105	8	15	56	29	175	130	8	30.48	-125.9	4.3	W	Cross
						8	16							-221.2	63.1		
4	9	9 Mar.	1505	950	105	9	17	56	29	175	130	8	30.48	- 39.2	96.9	W	Cross
						9	18							170.4	- 14.6		
4	10	9 Mar.	1508	850	100	10	19	56	29	175	130	8	30.48	116.7	- 13.4	S	Cross
						10	20							104.6	83.8		
4	11	9 Mar.	1511	900	105	11	21	56	29	175	130	8	30.48	213.9	129.5	W	Cross
						11	22							6.3	11.4		
4	12	9 Mar.	1514	850	105	12	23	56	29	175	130	8	30.48	245.8	50.9	W	Cross
						12	24							157.6	89.1		
4	13	9 Mar.	1517	950	105	13	25	56	29	175	130	8	30.48	-349.4	33.3	S	Probable Cross
						13	26							13.3	- 23.5		
4	14	9 Mar.	1520	800	105	14	27	56	29	175	130	8	30.48	9.2	137.0	W	Cross
						14	28							20.4	70.1		
4	15	9 Mar.	1523	900	105	15-19	29-38	56	29	175	130	8	30.48	124.3	80.2	S	All Cross
5-round ripple each launcher														122.9	75.0		
														159.9	- 35.4		
														142.5	53.8		
														123.4	- 10.7		
														78.6	- 23.0		
														NR	NR		
														107.2	34.3		
														- 22.0	18.0		
														4.4	- 23.8		

See notes at end of table.

Table I. (Concluded)

Run No.	Pass No.	Date (1966)	Time (hr)	Aircraft Attitude at Launch Instrument Readings: Altitude (ft)	Airspeed (knots)	Launcher Data: Tube No.	Rocket No.	Meteorological Data: Temperature (°F)	Humidity (%)	Density Altitude (ft)	Winds: Direction (°N)	Velocity (knots)	Barometric Pressure (in. Hg)	Impact Data: Range (ft)	Azimuth (ft)	Rocket Configuration Standard (5)
*5	1	9 Mar.	1556	980	100	1-4	1-8	58	26	157	120	6	30.46	NR	NR	New production rockets with 24° scarfed nozzle.
5	2	9 Mar.	1603	1090	95	5-9	9-18	58	26	157	120	6	30.46	NR	NR	
5	3	9 Mar.	1610	1100	100	10-14	19-28	58	26	157	120	6	30.46	NR	NR	
5	4	9 Mar.	1617	1000	105	15-18	29-36	58	26	157	120	6	30.46	NR	NR	

* The first pair firing was conducted with the helicopter on the ground.
** Further testing was cancelled because of high winds.
△ Estimated from film of chase ship.
† On Run 3, Pass 1, a 4-round ripple was fired because the gunner failed to reset the selector switch.
On Run 3, Pass 2, the selector switch had been reset to one pair.
(1) On the last pass of each run, a 5-round ripple was fired at a secondary target (9 March).
(2) On Run 5 new production rockets were fired and a different gunner was used to fire at a different target. The impact data were not requested on these rockets.
(3) On Passes 1 through 14 impact data are with respect to the centerline of the 50 by 100 meter grid, both range and azimuth.
(4) The center of the 50-by 100-meter grid target was located 12,200 feet downrange and 100 feet right of range 1 centerline.
(5) On the last pass of each run the impact data are with respect to a secondary target whose center was 12,200 feet downrange and 200 feet left of range 1 centerline.
The range firing line azimuth is 282° 34' 00" from North.
(6) NR - not recorded.
(7) PR - practice run.

Table II. Helicopter Attitude and Rate Data at the Instant of Rocket Launch (9 March Firings)

Run No.	Pass No.	Coordinates of Center of Top Rear Rotor With Respect to Range Zero X (ft) (Range)	Y (ft) (Deflection)	Z (ft) (Altitude)	Yaw With Respect to a Line Parallel to Range Centerline (deg)	Pitch Attitude With Respect to Horizontal (deg)	Roll Attitude With Respect to Vertical (deg)	No. of Rounds	Rocket Configuration Standard (S) Wedge Fin (W)
Run I	1	Practice	Run	—	—	—	—	—	S
	2	Practice	Run	—	.	—	—	—	S
	3	8449	326	912	*	-11.1	-4.4	2	S
	4	9378	333	737	*	-12.8	-7.2	2	W
	5	8907	357	703	*	- 8.9	-3.0	2	S
	6	8721	287	798	*	-10.4	-4.0	2	W
	7	9449	330	706	**	12.9	-5.8	2	W
	8	9211	331	693	*	-10.6	-5.5	2	W
	9	9604	324	737	**	-13.8	-5.4	2	S
1 Misfire	10	8735	313	875	*	-11.1	-4.2	1	W
	11	8921	342	842	*	-11.7	-4.8	2	W
	12	8625	407	782	*	- 8.3	-5.0	2	W
	13	8989	274	747	**	- 9.4	-6.1	2	S
	14	8011	304	941	**	- 8.3	-7.4	2	W
10-Round Ripple	15	8785	107	857	-6.4	-10.[illegible]	-4.5	10	W
Run II	1	8293	335	1001	*	-11.0	-6.3	2	W
	2	8786	234	956	**	-13.4	-9.7	2	W
	3	8118	336	1105	*	-12.8	-9.1	2	S
	4	8463	342	948	*	-10.8	-5.1	2	S
	5	8757	481	929	*	-11.8	-7.8	2	W
	6	9147	334	676	*	- 9.7	-4.3	2	S
	7	9685	304	656	*	-12.0	-3.1	2	W
	8	9766	377	742	*	-14.1	-7.6	2	W

See notes at end of table.

Table II. (Continued)

Run No.	Pass No.	Coordinates of Center of Top Rear Rotor With Respect to Range Zero X (ft) (Range)	Y (ft) (Deflection)	Z (ft) (Altitude)	Yaw With Respect to a Line Parallel to Range Centerline (deg)	Pitch Attitude With Respect to Horizontal (deg)	Roll Attitude With Respect to Vertical (deg)	No. of Rounds	Rocket Configuration Standard (S) Wedge Fin (W)
Run II (Cont)	9	8925	297	851	-1.6	-12.3	-6.1	2	W
	10	8131	143	1058	**	-12.1	-8.7	2	S
	11	8676	285	862	*	-10.9	-5.4	2	W
	12	8763	229	947	**	-13.4	-7.4	2	S
	13	7975	328	979	*	- 9.3	-8.0	2	W
	14	9604	325	770	**	-14.2	-9.1	2	W
10-Round Ripple	15	9013	-302	816	*	-11.8	-4.8	10	W
Run III									
8-Round Ripple	1	9298	161	[illegible]	**	-14.7	-6.9	8	6W + 2S
	2	8820	254	898	-1.9	-13.0	-3.9	2	W
	3	9105	206	926	-0.9	-14.7	-6.0	2	S
	4	9571	164	765	**	-14.1	-2.6	2	S
	5	8172	287	978	*	-10.8	-5.1	2	S
	6	8486	217	871	**	-11.1	-5.6	2	W
	7	8757	328	809	*	- 9.3	-5.2	2	W
	8	8558	409	949	*	-12.0	-8.7	2	S
	9	8843	260	830	-2.5	-11.0	-4.6	2	S
	10	8572	139	910	**	-11.4	-2.4	2	W
	11	8516	145	921	**	-11.6	-5.5	2	S
10-Round Ripple	12	8234	-220	1009	*	-11.1	-6.1	10	W
Run IV	1	8918	203	881	-1.0	-13.3	-10.6	2	W
	2	9232	289	820	**	-13.1	-7.8	2	S
	3	9213	302	740	*	-10.9	-5.4	2	S
	4	8806	321	923	*	-12.1	-6.6	2	W

See notes at end of table.

Table II. (Concluded)

Run No.	Pass No.	Coordinates of Center of Top Rear Rotor With Respect to Range Zero X (ft) (Range)	Y (ft) (Deflection)	Z (ft) (Altitude)	Yaw With Respect to a Line Parallel to Range Centerline (deg)	Pitch Attitude With Respect to Horizontal (deg)	Roll Attitude With Respect to Vertical (deg)	No. of Rounds	Rocket Configuration Standard (S) Wedge Fin (W)
Run IV (Cont)	5	8423	226	889	**	- 9.9	-11.5	2	W
	6	8522	202	951	**	-12.0	-8.3	2	W
	7	9217	242	768	**	-12.0	-7.7	2	S
	8	8464	206	912	**	-11.0	-5.9	2	W
	9	8301	183	887	**	- 9.4	-7.2	2	W
	10	8771	67	777	**	- 9.4	-6.6	2	S
	11	8365	172	831	**	- 9.0	-8.5	2	W
	12	9347	127	968	**	-13.9	-8.7	2	W
	13	7992	55	920	**	- 9.2	-9.2	2	S
	14	9184	149	757	-0.4	- 9.9	-8.0	2	W
	15	8781	-225	936	*	-14.0	-8.8	10	S
Run V	1	6757	370	911	*	- 4.1	-7.0	10	
	2	4584	649	1067	(Did Not Run Camera)	- 1.9	-6.5	10	
	3	4792	834	1211		+ 0.1	-6.5	8	
	4	(Did Not Track)				(Did Not Track)			

* No helicopter in field of view of yaw camera.

** Helicopter is in field of view of yaw camera, but firing was too early or too late for rockets to appear in field of view of yaw camera.

(1) Negative roll is counterclockwise as viewed from rear of helicopter.

(2) Target Center, Range Station (X) = 12,200 feet; Y = + 100 feet Right (North) of Range 1 Centerline (for Pairs)
Y = - 200 feet Left (South) of Range 1 Centerline (for Ripples)

Table III. Pair Firing Results - Standard LS FFAR (Nominal CHINOOK Airspeed, 110 Knots)

Run No.	Pass No.	Firing Altitude (ft)	Ground Range (ft)	Deflection (ft)	Slant Range (ft)	Δ Azimuth (mils) (Pair)	Δ Range (mils)(Pair)	Δ Pitch* (mils) (Pair)	Δ Az - $\bar{\Delta}$ (mils)	Δ Pitch - $\bar{\Delta}$ (mils)
1	3	897	4031	-37	4130	24.91	57.66	12.18	-5.31	15.43
			4276	70	4369					
	5	688	3094	58	3170	35.80	1.04	- 0.23	5.58	3.02
			3891	171	3167					
	9	722	2310	59	2428	18.96	20.90	6.17	-11.26	9.42
			2361	107	2469					
	13	732	2575	158	2677	21.18	28.57	- 7.71	- 9.04	-4.46
			2653	104	2752					
2	3	[illegible]	4402	9	4534	22.35	53.46	-12.52	- 7.87	-9.27
			4651	-98	4777					
	4	933	3754	-111	3868	40.25	21.18	- 5.06	10.03	-1.81
			3637	65	3948					
	6	661	2425	133	2572	28.74	84.83	-20.95	- 1.48	-17.70
			2713	64	2793					
	10	1043	3910	66	4047	21.69	4.83	1.24	- 8.53	4.49
			3929	135	4065					
	12	932	3438	79	3599	39.18	38.92	9.99	8.96	13.24
			3302	-67	3431					
3	3	911	3236	6	3362	41.42	65.21	17.13	11.20	20.38
			3463	155	3580					
	4	780	2535	29	2643	33.01	59.22	-16.34	2.79	-13.09
			2696	-62	2798					
	5	963	3922	-7	4043	36.64	22.76	- 5.48	6.42	- 2.23
			3837	138	3956					
	8	934	3599	170	3718	45.43	16.06	- 4.00	15.21	- 0.75
			3659	1	3776					
	9	815	3626	-74	3717	41.79	78.53	-17.90	11.57	-14.65
			3345	76	3443					
	11	906	3531	-13	3646	42.62	10.94	- 2.70	12.40	5.95
			3571	144	3684					
4	2	805	2977	132	3084	32.20	18.92	- 4.89	1.98	- 1.64
			3036	33	3141					
	3	725	2934	62	3026	14.14	40.02	9.78	-16.08	13.03
			2817	-18	2909					
	7	753	3081	-38	3172	23.04	38.74	- 9.03	- 7.18	- 5.78
			3207	-95	3294					
	10	762	3521	-13	3602	27.06	3.36	- 0.71	- 3.16	2.54
			3509	84	3591					
	13	905	3834	33	3939	13.92	88.02	-19.39	-16.30	-16.14
			4196	-24	4293					
						$\hat{\sigma}_{Az}$ = 22.43 mils		$\hat{\sigma}_{Pitch}$ = 7.87 mils	$\hat{\sigma}_{Az}$ = 7.91 mils	$\hat{\sigma}_{Pitch}$ = 7.73 mils (About Bias)
						$\bar{\Delta}_{Az}$ (Bias) = 30.22 mils		$\bar{\Delta}_{Pitch}$ (Bias) = -3.25 mils		

* Minus sign indicates rocket from left launcher impacted short.

Table IV. Pair Firing Results - Modified LS FFAR (Wedges) (Nominal CHINOOK Airspeed, 110 Knots)

Run No.	Pass No.	Firing Altitude (ft)	Ground Range (ft)	Deflection (ft)	Slant Range (ft)	Δ Azimuth (mils) (Pair)	Δ Range (mils)(Pair)	Δ Pitch (mils) (Pair)	Δ Az - $\bar{\Delta}$ (mils)	Δ Pitch - $\bar{\Delta}$ (mils)
1	4	722	2690	66	2785	1.66	67.42	16.93	-16.48	-13.56
			2884	65	2973					
	6	783	3489	16	3580	16.89	17.28	3.85	- 1.25	7.21
			3428	-43	3516					
	7	691	2426	108	2523	19.31	24.58	6.81	1.17	10.17
			2365	58	2464					
	8	678	2828	85	2908	27.57	18.64	4.43	9.43	- 1.07
			2774	163	2859					
	10 (misfire)	—	—	—	—	—	—	—	—	—
		—	—	—	—					
	11	827	3455	49	3553	17.86	67.68	15.25	- 0.28	18.51
			3704	120	3795					
	12	767	3416	63	3502	18.15	8.31	1.83	0.06	1.53
			3387	127	3473					
	14	926	4282	103	4381	24.92	48.70	10.54	6.78	- 7.18
			4073	203	4177					
2	1	986	4333	-1	4444	10.35	23.55	5.29	- 7.79	- 1.93
			4229	44	4343					
	2	941	3489	107	3613	11.54	15.90	4.11	- 6.60	7.47
			3547	151	3669					
	5	914	3564	60	3679	9.76	17.38	4.28	- 8.38	- 0.92
			3629	25	3742					
	7	641	2538	13	2617	25.99	43.49	10.88	7.85	- 7.52
			2424	62	2507					
	8	727	2309	1	2420	22.03	3.18	0.95	3.89	4.31
			2316	52	2428					
	9	836	3086	35	3197	22.93	15.12	3.93	6.79	7.29
			3134	110	3244					
	11	847	3415	71	3519	19.85	74.42	17.29	1.71	-13.93
			3687	1	3783					
	13	964	4260	60	4368	12.78	85.47	18.11	- 5.36	-14.75
			4650	4	4749					
	14	735	2487	5	2599	19.97	22.39	6.57	1.83	- 3.21
			2430	56	2544					
3	2	883	3389	45	3502	11.12	9.23	2.34	- 7.02	5.70
			3357	6	3471					
	5	656	3185	0	3298	19.54	23.37	6.00	1.40	- 2.64
			3257	-66	3367					
	7	794	3315	59	3608	15.58	90.09	21.95	- 2.56	-18.59
			3020	103	3123					
	10	895	3332	87	3449	8.61	17.80	4.66	- 9.53	8.02
			3270	56	3390					

Table IV. (Concluded)

Run No.	Pass No.	Firing Altitude (ft)	Ground Range (ft)	Deflection (ft)	Slant Range (ft)	Δ Azimuth (mils) (Pair)	Δ Range (mils)(Pair)	Δ Pitch (mils) (Pair)	Δ Az - $\bar{\Delta}$ (mils)	Δ Pitch - $\bar{\Delta}$ (mils)
3	1	866	3295	-17	3415	13.36	1.51	0.38	- 4.78	2.98
			3260	32	3381					
	4	906	3837	66	3943	16.48	87.79	21.11	- 1.66	24.47
			3505	-18	3623					
	5	874	3490	93	3590	18.62	75.66	18.22	0.48	-14.86
			3665	30	3766					
	6	936	3762	167	3877	33.68	5.89	1.42	15.54	4.94
			3785	37	3900					
	8	897	3585	4	3696	16.35	26.10	6.42	- 1.79	- 3.06
			3490	63	3603					
	9	872	3835	57	3933	28.17	51.91	11.22	10.03	- 7.86
			4044	-15	4138					
	11	816	4025	130	4108	28.61	51.79	10.56	10.47	13.92
			3718	11	3805					
	12	953	3074	51	3218	12.62	27.75	8.33	- 5.52	- 4.97
			2984	89	3135					
	14	742	3000	137	3090	21.73	3.63	0.87	3.59	2.49
			3011	70	3101					
						$\hat{\sigma}_{Az}$ = 13.73 mils		$\hat{\sigma}_{Pitch}$ = 7.49 mils	$\hat{\sigma}_{Az}$ = 4.98 mils	$\hat{\sigma}_{Pitch}$ = 7.25 mils
									(About Bias)	
						$\bar{\Delta}_{Az}$ (Bias) = 18.14 mils		$\bar{\Delta}_{Pitch}$ (Bias) = -3.36 mils		

Table V. Ripple Firing Results - Modified LS FFAR (Wedges) (Nominal CHINOOK Airspeed, 110 Knots)

Run No.	Pass No.	Firing Altitude (ft)	Ground Range (ft)	Slant Range (ft)	Deflection (ft)	Azimuth (mils)	$As - \bar{As}$ (mils)	$R_s - \bar{R}_s$ (ft)	$\Delta R_{\parallel}$ (ft)	$\Delta R_{\perp}$ (mils)	Impact* Order
1	15	942	[illegible]	[illegible]	150	44.3	-7.64	19.3	4.96	1.47	4R
			3277	3384	148	43.8	-8.08	20.7	5.32	1.57	5R
			3276	3384	244	72.1	20.20	20.9	5.37	1.59	2L
			[illegible]	[illegible]	208	60.7	6.83	60.2	15.27	4.46	3L
			[illegible]	[illegible]	122	35.1	-16.76	94.0	23.60	6.83	8R
			[illegible]	[illegible]	148	41.9	-10.01	164.8	40.51	11.49	7L
			[illegible]	[illegible]	202	62.3	10.44	-116.6	-31.31	-9.64	6L
			[illegible]	[illegible]	192	59.2	7.32	-119.2	-32.04	-9.88	1R
			[illegible]	[illegible]	82	24.1	-27.83	39.6	10.11	2.97	10R
			[illegible]	[illegible]	240	75.5	23.58	-183.8	-50.49	[illegible]	9L
							σ_{As} = 16.61 mil			σ_{Pitch} = 8.55 mil	
2	15	801	[illegible]	[illegible]	-65	-13.8	-20.41	207.0	52.50	16.11	NR
			[illegible]	[illegible]	-15	-4.5	-11.14	166.0	42.68	13.27	NR
			[illegible]	3152	-3	-1.1	-7.68	101.0	26.54	8.42	NR
			2769	2883	92	32.0	25.42	-168.3	-48.67	-16.88	NR
			2876	2986	57	19.2	12.62	-65.3	-18.18	-6.09	NR
			2893	3002	57	19.0	12.36	-49.6	-13.73	-4.57	NR
			2896	3005	54	17.9	11.27	-46.3	-12.80	-4.26	NR
			2868	2978	27	9.0	2.43	-73.0	-20.39	-6.85	NR
			2923	3031	7	2.2	-4.42	-20.6	-5.65	-1.86	NR
			2891	3000	-42	-13.9	-20.47	-50.8	-14.07	-4.69	NR
							σ_{As} = 15.38 mil			σ_{Pitch} = 10.22 mil	

* See note at end of table.

Table V. (Concluded)

Run No.	Pass No.	Firing Altitude (ft)	Ground Range (ft)	Slant Range (ft)	Deflection (ft)	Azimuth (mils)	$Az - \bar{Az}$ (mils)	$R_s - \bar{R}_s$ (ft)	$\Delta R_\perp$ (ft)	$\Delta R_\perp$ (mils)	Impact* Order
3	12	994	3801	3929	61	15.4	0.03	-243.3	-63.62	-16.19	2R
			4054	4174	96	23.1	7.70	2.0	0.49	0.12	10L
			4042	4162	78	18.7	3.33	-9.8	-2.41	-0.58	5L
			4091	4210	57	13.5	-1.85	38.0	9.23	2.19	9R
			4095	4214	61	14.5	-0.89	41.6	10.10	2.40	6R
			4104	4223	97	22.9	7.49	50.4	12.21	2.89	1L
			4083	4202	16	3.9	-11.49	29.9	7.28	1.73	8R
			4018	4140	35	8.3	-7.06	-32.6	-8.06	-1.95	3R
			3954	4086	72	17.5	2.11	-86.2	-21.62	-5.29	7L
			4267	4382	70	16.0	0.63	209.0	48.82	11.14	4L
							$\hat{\sigma}_{Az}$ = 5.94 m̸			$\hat{\sigma}_{Pitch}$ = 6.99 m̸	
						Pooled	$\hat{\sigma}_{Az}$ = 13.51 m̸		Pooled	$\hat{\sigma}_{Pitch}$ = 8.63 m̸	

* L = Rocket fired from left launcher.
R = Rocket fired from right launcher.

Table VI. Ripple Firing Results - Standard LS FFAR (CHINOOK Airspeed, 110 Knots)

Run No.	Pass No.	Firing Altitude (ft)	Ground Range (ft)	Slant Range (ft)	Deflection (ft)	Azimuth (mils)	Impact* Order
4	15	921	3518	3637	80	22.1	10L
			3517	3635	75	20.6	6L
			3554	3671	-35	-9.6	4R
			3537	3655	54	14.7	8L
			3517	3636	-11	-2.9	5R
			3473	3593	-23	-6.4	9R
			NR	NR	NR	NR	1L
			3501	3620	34	9.5	2R
			3372	3496	18	5.2	3L
			3398	3521	-24	-6.8	7R

* L = Rocket fired from left launcher.
R = Rocket fired from right launcher.

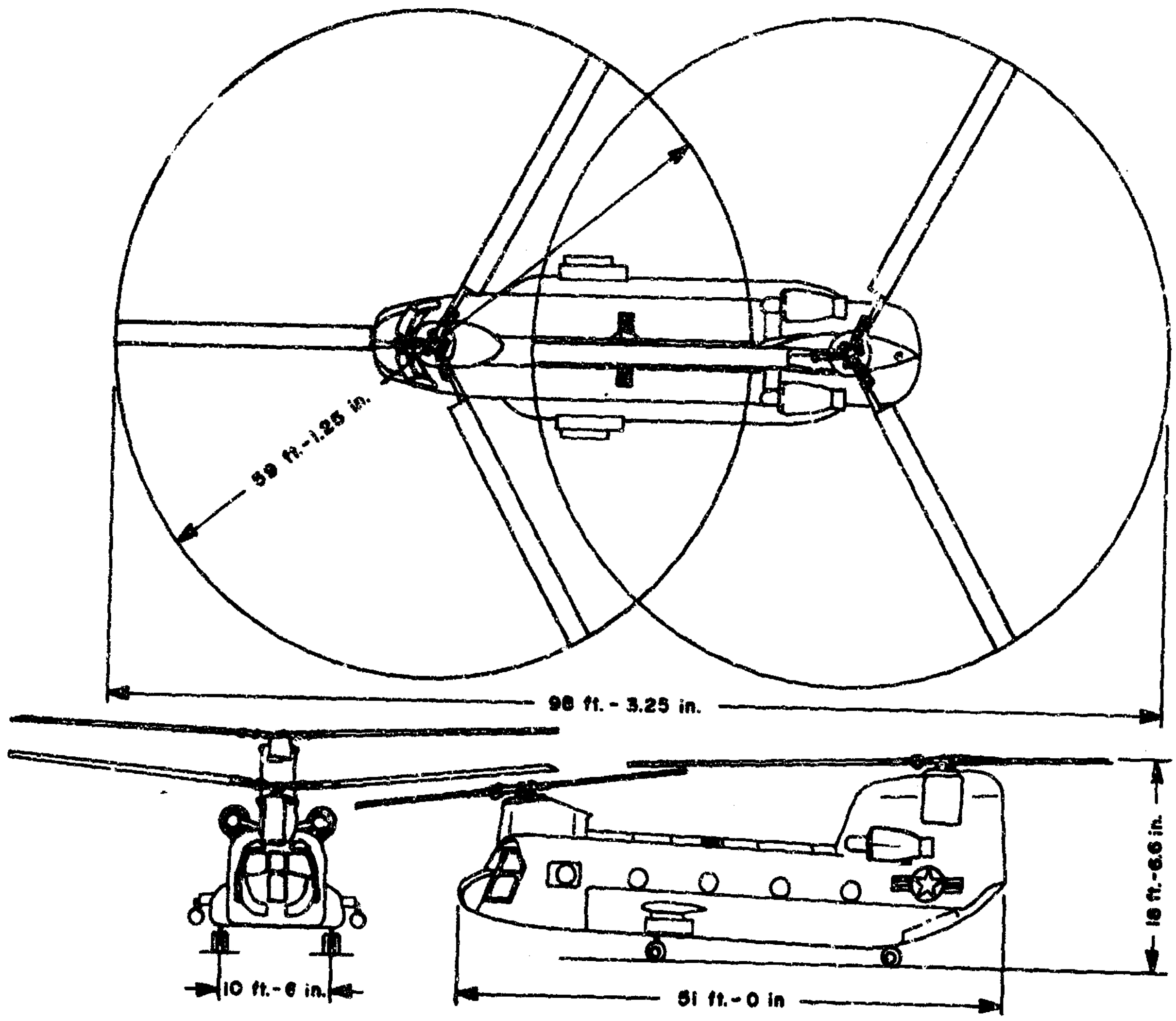


Figure 8. Overall Dimensions of the CHINOOK Helicopter

Section VI. PAIR FIRING ACCURANCY COMPARISONS

The initial accuracy computation and comparison was made by disregarding pod separation and rocket crossover effects. The azimuth pair differences were divided by the average slant range for each pair and the computed azimuth standard deviation indicated the following (Tables III and IV):

1)	$\hat{\sigma}_{Azimuth}$ (standard)	22.4 mils (20 pairs)
2)	$\hat{\sigma}_{Azimuth}$ (wedge)	13.7 mils (29 pairs)

This comparison resulted in a 40-percent azimuth accuracy improvement due to addition of the wedges to fins.

Because of the azimuth crossover of both rocket configurations, the bias due to crossover and pod separation was estimated as follows:

1)	Crossover bias (standard)	30.2 mils
2)	Crossover bias (wedge)	18.1 mils

Upon computing the dispersion about the bias, the following results were obtained:

1)	$\hat{\sigma}_{Azimuth}$ (standard)	7.0 mils (20 pairs)
2)	$\hat{\sigma}_{Azimuth}$ (wedge)	5.0 mils (29 pairs)

This treatment indicates a 30-percent azimuth accuracy improvement for the wedge configuration. These are the values that would be expected under conditions of 110 knots helicopter speed and no outward flow over the helicopter nose to provide a bias trajectory toward the helicopter centerline. The rocket trajectory turns inward (toward the centerline) in the presence of such airflow due to aerodynamic stability; the effect is similar to that produced by a transient crosswind. The crossover bias of the wedge fin configuration is less than that of the standard configuration, probably because the fins with wedges do not open as quickly as standard fins. Therefore, the standard rocket is subject to the outward airflow around the fuselage sooner than the rocket with wedge configuration, resulting with a greater bias for the standard rocket.

The range difference of each pair was multiplied by the sine of the sight angle at mean pair impact between the ground plane and the helicopter at the instant of rocket launch. This converts the range impacts in the ground plane to a plane perpendicular to the helicopter sight line.

The rotated range pair impact differences were divided by the mean slant range, thus providing range angular errors perpendicular to the flight path (sight line). This treatment basically eliminated firing altitude and guadrant elevation from the analysis and provided pitch angular errors for comparison with azimuth angular errors (Tables III and IV).

The resulting pitch angular accuracy computation indicated the following:

1) $\hat{\sigma}_{Pitch}$ (standard) 7.9 mils (20 pairs)
2) $\hat{\sigma}_{Pitch}$ (wedge) 7.5 mils (29 pairs)

This comparison, indicating a 5-percent angular accuracy improvement due to wedge additions to the fins, is not statistically significant.

The bias for the two configurations was estimated as follows for the pitch plane:

1) Pitch bias (standard) -3.3 mils (left launcher low)
2) Pitch bias (wedge) -3.4 mils (left launcher low)

Computation of the pitch dispersion about the bias indicated the following:

1) $\hat{\sigma}_{Pitch}$ (standard) 7.7 mils (20 pairs)
2) $\hat{\sigma}_{Pitch}$ (wedge) 7.2 mils (29 pairs)

The range error in the ground plane can be estimated for either configuration by multiplying the pitch plane error by the ratio of slant range to firing altitude ($\sigma_{range} = \sigma_{pitch} \times \frac{R_s}{Alt.}$).

The pitch and azimuth dispersion for each configuration show reasonable agreement. With no azimuth or pitch bias, the standard rocket angular accuracy with firing conditions of 110 knots from the CHINOOK helicopter is between 7.0 and 7.7 mils σ, and the corresponding accuracy with wedge fin configuration is between 5.0 and 7.2 mils - an accuracy improvement of between 7 and 30 percent. If the azimuth bias is uncorrected, the azimuth precision accuracy for the wedge configuration is 40 percent improved over that of the standard rocket.

The alignment of tubes within each pod and the alignment of tubes between pods was determined by the Ground Support Equipment Laboratory after completion of the test program. Results indicated malalignments of 1 millradian or less, and no corrections for tube alignment were made except in the total bias computations. Tube alignment measurement procedures and results are provided in Appendix B.

Section VII. RIPPLE FIRING RESULTS*

Rocket impact coordinates relative to the alternate target center for three 10-round ripples with the wedge fin modification and one 10-round ripple of the standard rocket configuration are shown in Figure 9. The order of rocket impacts was determined for three of the four ripples from film of the chase helicopter. Film was not available to determine impact order on the remaining wedge configuration ripple of Run 2. Data film from above the launcher pods indicated that for each rocket pair within the ripples, azimuth crossover occurred prior to impact (no information was available on Run 1 because the cameras were aimed too high to pick up the rocket exhausts).

Only nine impacts were recorded for the 10-round ripple of standard rockets (Run 4). The film from the chase helicopter showed only nine impacts. Film from the pod position indicated that the trajectory of the first rocket from the left pod was up and to the right of the other nine rockets for which impacts are recorded in Figure 9. Analysis of data film from both pod and chase helicopter indicate that the impact location of the last rocket had to be at least 350 feet beyond and 125 feet right of the alternate target center. How far beyond these minimum ordinates the rocket impacted is unknown; no attempt was made to compute an accuracy value for the 10-round ripple of standard rockets.

Accuracy for the three 10-round wedge ripples was first determined without consideration of azimuth or pitch bias (Table V). The range impacts were converted to pitch angular errors in a similar manner to that of the pair firing accuracy computation. The following is the results for pooled dispersion computed about the centers of impact.

$\hat{\sigma}_{Azimuth} = 13.5\ \bar{m}$ (three 10-round ripples with
$\hat{\sigma}_{Pitch} = 8.7\ \bar{m}$ wedge modification)

Since these values include biases due to azimuth and pitch plane crossover, Runs 1 and 3 were analyzed to obtain quantitative estimates of these biases. For these two ripple groups, the biases were insignificantly different from the values obtained in the single pairs; therefore, it was assumed that the previously estimated biases were valid for the ripple. Under this assumption, the ripple dispersion about the center of impact with biases removed becomes

*Ripples are sequences of simultaneous pairs.

$\hat{\sigma}$ Azimuth = 10.0 m̸h
$\hat{\sigma}$ Pitch = 8.5 m̸h

Comparing these values to the analogous single pair data, the azimuth dispersion is degraded in ripple firing by about 100 percent while in pitch the degradation is insignificant.

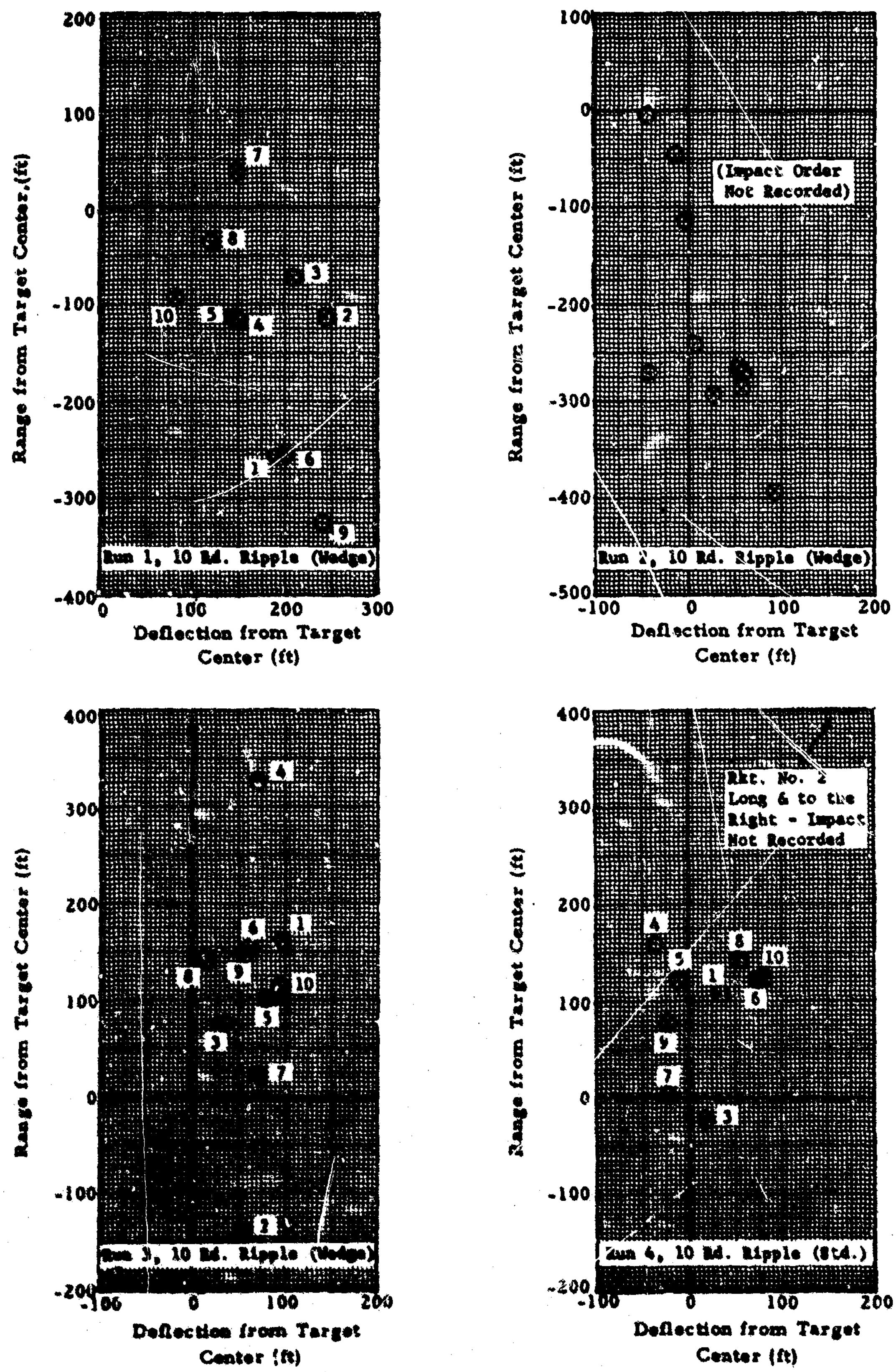


Figure 9. Impact Coordinates Relative to the Alternate Target Center for Three 10-Round Ripples with the Wedge Fin Modification and One 10-Round Ripple with Standard Rockets (Order of Impacts Indicated)

Section VIII. CONCLUSIONS

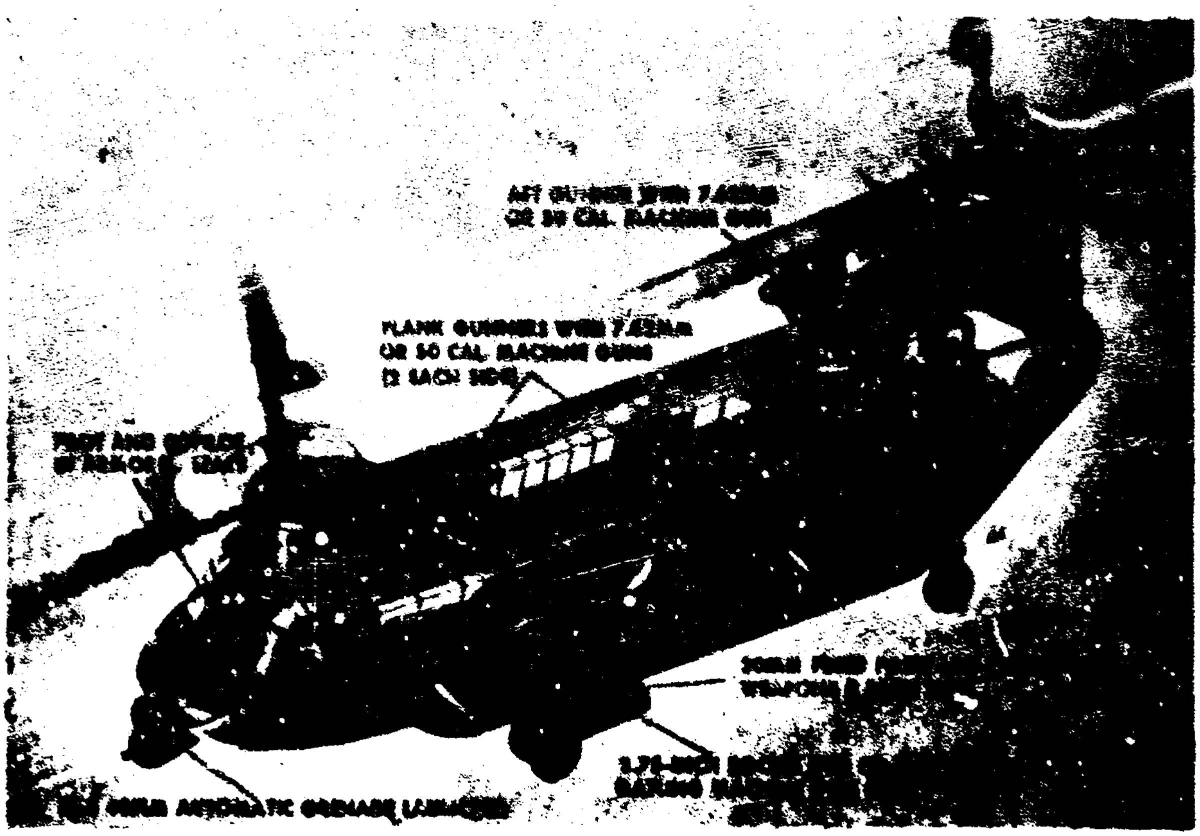
Pair firings and ripple firings of standard and modified LS FFAR (with MK-1 inert heads) from the CHINOOK helicopter at a nominal helicopter velocity of 110 knots indicated the following:

1) With bias removed, the azimuth angular error was 7.0 mils σ (20 pairs) for the standard rockets and 5.0 mils σ (29 pairs) for the modified rockets, a 30-percent accuracy improvement due to addition of wedges to the fins.
2) With bias removed, the pitch angular error was 7.7 mils σ for the standard rockets and 7.2 mils σ for the modified rockets.
3) The accuracy of 10-round ripples of wedge modified rockets was degraded in azimuth by a factor of about two over that calculated from single pair firings.
4) Strong azimuth crossover bias values were in evidence for both configurations fired (30.2 mils bias for the standard rounds and 18.1 mils bias for the modified rounds). The smaller bias value of the configuration with wedge fins is attributed to delayed fin opening, thus reducing the sensitivity of the rocket to a strong outward wind flow over the nose of the helicopter.
5) Consideration should be given to splaying the launchers of the CHINOOK to cancel part of the crossover bias if improvement of the azimuth accuracy is desirable. Of course, the launcher splay angle would be optimized for a particular type of helicopter (CHINOOK or other) and helicopter velocity. Additional firings similar to those reported herein would be necessary in order to prove the desirability of such an approach.
6) All accuracy comparisons between the standard and modified rockets indicated accuracy improvements of from 7 to 40 percent when wedges are added to the fins of the standard LS FFAR configurations. Although all rockets fired in this program had MK-1 heads, it is assumed that similar comparisons with rockets employing the heavier XM-151 head would yield similar qualitative results.

Appendix A

DESCRIPTION OF ARMED AND ARMORED CH-47A (CHINOOK) HELICOPTER

The CHINOOK uses its payload capability to advantage by mounting an extensive array of armament, as well as armor to protect the crew and vital parts of the aircraft against heavy caliber ground fire. Mounted on the nose is an M-5 40mm Automatic Grenade Launcher. This turret-mounted weapon is controlled by the copilot, who is able to cover an extensive area on either side of the flight path. Complimenting this nose turret, pylons on each side of the aircraft carry fixed forward-firing weapons including a 20mm gun and either a 19-round 2.75-inch rocket pod or a 7.62mm high-rate-of-fire Gatling machine gun. The flanks of the aircraft are protected by four gunners stationed two to either side of the cabin. Each of these gunners is provided with either a 7.62 mm or 50 caliber machine gun on flexible mounts. Another gunner is stationed aft with the same type weapon mounted on the rear loading ramp. From this vantage point, the gunner can protect the aircraft from ground fire after the aircraft has passed.



Appendix B

MALALIGNMENT MEASUREMENTS ON TUBES OF XM-159 ROCKET PODS

Measurements were taken on the two XM-159, 19-tube launcher pods after completion of the firing program to determine the relative alignment of 18 tubes with respect to the center tube. Looking forward from the helicopter, the left pod is designated number 1 and the right pod is designated number 2. It was decided not to use a plug gage because it would distort the tubes. Since the tubes were already dented at the ends as a result of rocket firings, the following method was used. The launchers were first placed on a surface plate in the horizontal position with the mounting lugs up. A centerline was established for the No. 1 tube by taking bore measurements at positions one inch inside the tube at both ends. The launcher was then positioned to make the centerline parallel with the surface plate.

Measurements were taken on each tube at one inch inside with vernier height gages to determine center point of bore at both ends of tubes on the "Y" axis with respect to the established centerline of No. 1 tube.

The launcher was then rotated 90 degrees about the pod longitudinal axis and the above procedures were repeated to determine the center point of the bore at both ends of the tubes on the "X" axis with respect to the centerline of No. 1 tube. After the launcher was rotated 90 degrees and prior to any measurements, the centerline of No. 1 tube was realigned with the surface plate.

Figures 10 and 11 show the relative position of the centerlines at the forward end of the launcher, above and below and right or left of the point on the same centerline with respect to the aft end of the same tube. This means that for No. 15 tube on number 1 launcher, the centerline is 0.006 inch lower at the forward end of the tube in the vertical plane than at the aft end. Also, the lateral centerline point at the forward end is 0.016 inch to the left of the aft end point when looking aft at the forward end of the launcher. From the above measurements, Table VII shows the deviation of each tube from the pod center tube, in mils, looking forward. A 46-inch tube length was used, since measurements were taken at one inch inside of both ends of the 48-inch tubes.

Comparisons of alignment of tubes from which rockets were fired as pairs are also made. If the assumption is made that the pods are perfectly boresighted, there is an indication of an elevation angle difference of 1.014 mils in the tube seventh in firing order and 1.087 mils azimuth difference in tubes fired second. All other tubes fired as pairs have less than one mil difference in either plane.

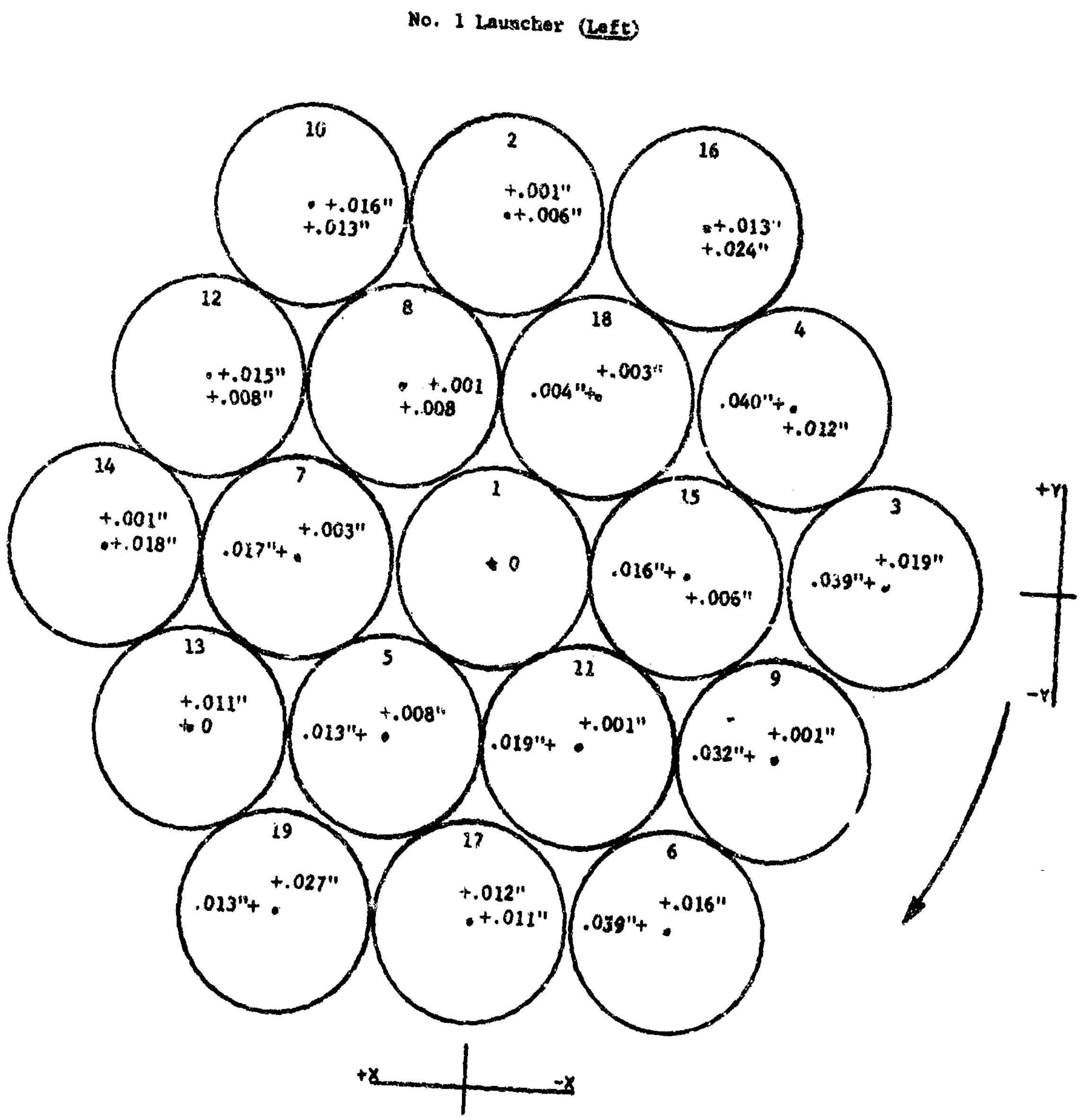


Figure 10. Relative Position of Centerline Points at the Forward End of the Left Pod, Looking Aft (Tube Firing Order Indicated)

No. 2 Launcher (Right)

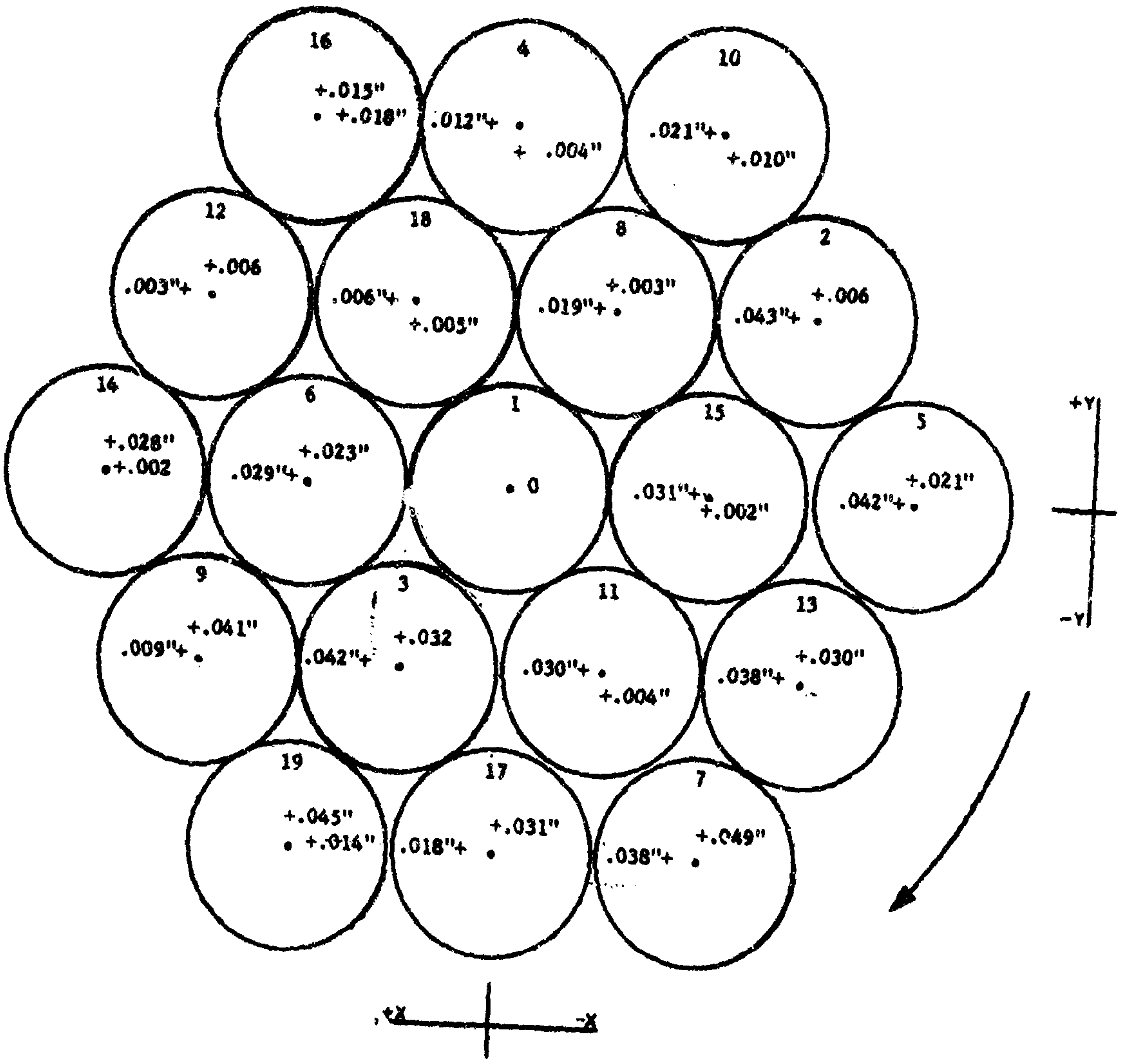


Figure 11. Relative Position of Centerline Points at the Forward End of the Right Pod, Looking Aft (Tube Firing Order Indicated)

Table VII. XM-159 Launcher Tube Alignment Measurement Results

A. Tube of Each Launcher Relative to Center (Boresight) Tube.

B. Tube of Right Launcher Relative to Corresponding Firing-Order Tube of Left Launcher (Assuming Perfect Boresighting).

Tube Firing Order	Launcher No. 1 (Left) Looking Forward		Launcher No. 2 (Right) Looking Forward		Tube Firing Order	Alignment of Tubes From Launcher to Launcher	
	Elevation Deviation (mils)	Azimuth Deviation (mils)	Elevation Deviation (mils)	Azimuth Deviation (mils)		Δ Elevation (mils)	Δ Azimuth (mils)
1	0	0	0	0	1	—	—
2	0.020 up	0.133 L	0.133 up	0.954 R	2	0.113 up	1.087 R
3	0.421 up	0.865 R	0.710 up	0.932 R	3	0.289 up	0.067 R
4	0.266 down	0.888 R	0.088 down	0.266 R	4	0.178 up	0.622 L
5	0.177 up	0.288 R	0.466 up	0.932 R	5	0.289 up	0.644 R
6	0.355 up	0.865 R	0.510 up	0.643 R	6	0.155 up	0.222 L
7	0.066 up	0.377 R	1.080 up	0.843 R	7	1.014 up	0.466 R
8	0.177 down	0.020 L	0.066 up	0.421 R	8	0.243 up	0.441 R
9	0.022 up	0.710 R	0.910 up	0.199 R	9	0.888 up	0.511 L
10	0.288 down	0.355 L	0.222 down	0.466 R	10	0.066 up	0.821 R
11	0.020 up	0.421 R	0.088 down	0.666 R	11	0.108 down	0.245 R
12	0.177 down	0.333 L	0.133 up	0.066 R	12	0.310 up	0.399 R
13	0.244 up	0	0.666 up	0.843 R	13	0.422 up	0.843 R
14	0.024 up	0.399 L	0.621 up	0.044 L	14	0.597 up	0.355 R
15	0.133 down	0.355 R	0.022 down	0.688 R	15	0.111 up	0.333 R
16	0.532 down	0.288 L	0.333 up	0.399 L	16	0.865 up	0.111 L
17	0.266 up	0.244 L	0.683 up	0.399 R	17	0.422 up	0.643 R
18	0.066 up	0.088 R	0.111 down	0.133 R	18	0.177 down	0.045 R
19	0.599 up	0.288 R	0.999 up	0.310 L	19	0.400 up	0.598 L

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13. ABSTRACT

Twenty pairs of standard rockets and 29 pairs of modified rockets (with MK-1 heads) were fired at a ground target. Also, one 10 round-ripple of standard and three 10-round ripples of modified rockets were fired. Nominal test conditions were with helicopter airspeed of 110 knots, altitude of 250 meters, and slant range of 1000 meters. Results indicated angular accuracy improvements of 7 to 40 percent for the modified rocket configurations.

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	ROLE	WT	ROLE	WT	ROLE	WT
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