T H E   U N I V E R S I T Y   O F   M I C H I G A N
COLLEGE OF ENGINEERING
Department of Aeronautical and Astronautical Engineering
High-Altitude Engineering Laboratory

Final Report

THE STRONGARM SOUNDING ROCKET

W. H. Hansen   F. F. Fischbach

Approved by:
L. M. Jones

UMRI Project 2816-004

under contract with:

DEPARTMENT OF THE ARMY
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

administered by:

THE UNIVERSITY OF MICHIGAN RESEARCH INSTITUTE   ANN ARBOR

May 1960

ACKNOWLEDGMENT

We wish to acknowledge the assistance of the Pilotless Aircraft Research Division of Langley Laboratories of the National Aeronautics and Space Administration. Their cooperation in providing designs, consultation, and advice is greatly appreciated. We appreciate also the assistance and willing cooperation of the personnel as well as the use of the launching facility of the Wallops Island Station of the National Aeronautics and Space Administration. Further, we wish to acknowledge the support of the Ballistic Research Laboratories of the United States Army. Their sponsorship made this project possible.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

ABSTRACT

The Strongarm sounding rocket was developed to meet the requirements of upper-air research for an economical vehicle to carry a 20-pound payload to an altitude of 1000 miles. The report describes Strongarm in detail and gives the results of the first two test flights. The major part of the report is devoted to a manual-type description of the assembly procedures. Parts lists and procurement information are included.

THE UNIVERSITY OF MICHIGAN PROJECT PERSONNEL

(Both Full- and Part-Time)

Braker, David, Assistant in Research
Fischbach, Frederick F., M.S., Research Associate
Funk, Elizabeth L., Secretary
Hansen, William H., B.S., Research Engineer
Harrison, Lillian, Secretary
Howe, Robert M., Ph.D., Professor of Aeronautical Engineering
Jennings, Jack R., M.S.E., Instructor in Aeronautical Engineering
Jones, Leslie M., B.S., Project Supervisor
Mosakewicz, Mary C., Secretary
Robinson, Douglas A., Technician
Schaefer, Edward J., M.S., Research Engineer
Wenk, Norman J., B.S.E., Research Engineer

1. INTRODUCTION

For the past five years, project personnel have been engaged in design and construction of sounding vehicles assembled from existing solid-propellant rocket motors. The Nike-Deacon and the Nike-Cajun,[1] both two-stage vehicles, came first, followed by the three-stage Exos.[2] The Strongarm, described in this report, is the latest in the series. The Strongarm sounding rocket is a five-stage, solid-propellant vehicle capable of carrying a 20-pound payload to an altitude of over 1000 statute miles. In this report payload is defined as all weight forward of the head cap of the last-stage propulsion bottle.

The first three stages, one Honest John prime mover and two Nike-Ajax boosters, are fin-stabilized, while the fourth stage, a Thiokol* Yardbird, and the fifth stage, a Jet Propulsion Laboratory Scale Sergeant, are stabilized by flared skirts. The first stage drag-separates from the remaining four at burnout of the first stage. The second stage ignites, from delay squibs, approximately two seconds after separation of the first stage. Normal burning pressure in the second stage unlocks a device which prevented separation of the second stage from the third until after second-stage burning. At burnout, the second stage drag-separates. Then follows a coast period of approximately 15 seconds after which the third stage fires by means of delay squibs. Pressure decrease at burnout of the third stage triggers the ignition of the fourth stage, and similarly the decrease of pressure in the fourth triggers the ignition of the final stage. A burnout velocity of approximately 17,000 feet per second at an altitude of about 200,000 feet is achieved.

Aerodynamic heating is countered on the nose cone and fifth-stage propulsion bottle by an ablative cover and on the second and third stage fins with Inconel leading edge cuffs. Maximum acceleration of 90 g's occurs near fourth-stage burnout.

The Strongarm is pictured in Fig. 1. Figure 2 shows gross dimensions, weights, and center-of-gravity locations. Table I shows predicted flight parameters. The first flight test verified the flight predictions. The second flight failed because the third stage did not ignite. There is a substantial clue, but not positive evidence, in a broken wire in the ground-to-vehicle ignition wiring. The preparation, assembly, and launching of the Strongarm can be carried out with a small crew and modest handling equipment. The cost of all hardware and propulsion bottles is about $30,000.

A complete description of the parts, equipment, and operations required to launch a Strongarm is given in this report. It is hoped that research groups desiring to use this vehicle will find this a suitable manual.

---

*Thiokol Chemical Corporation, Elkton, Maryland.

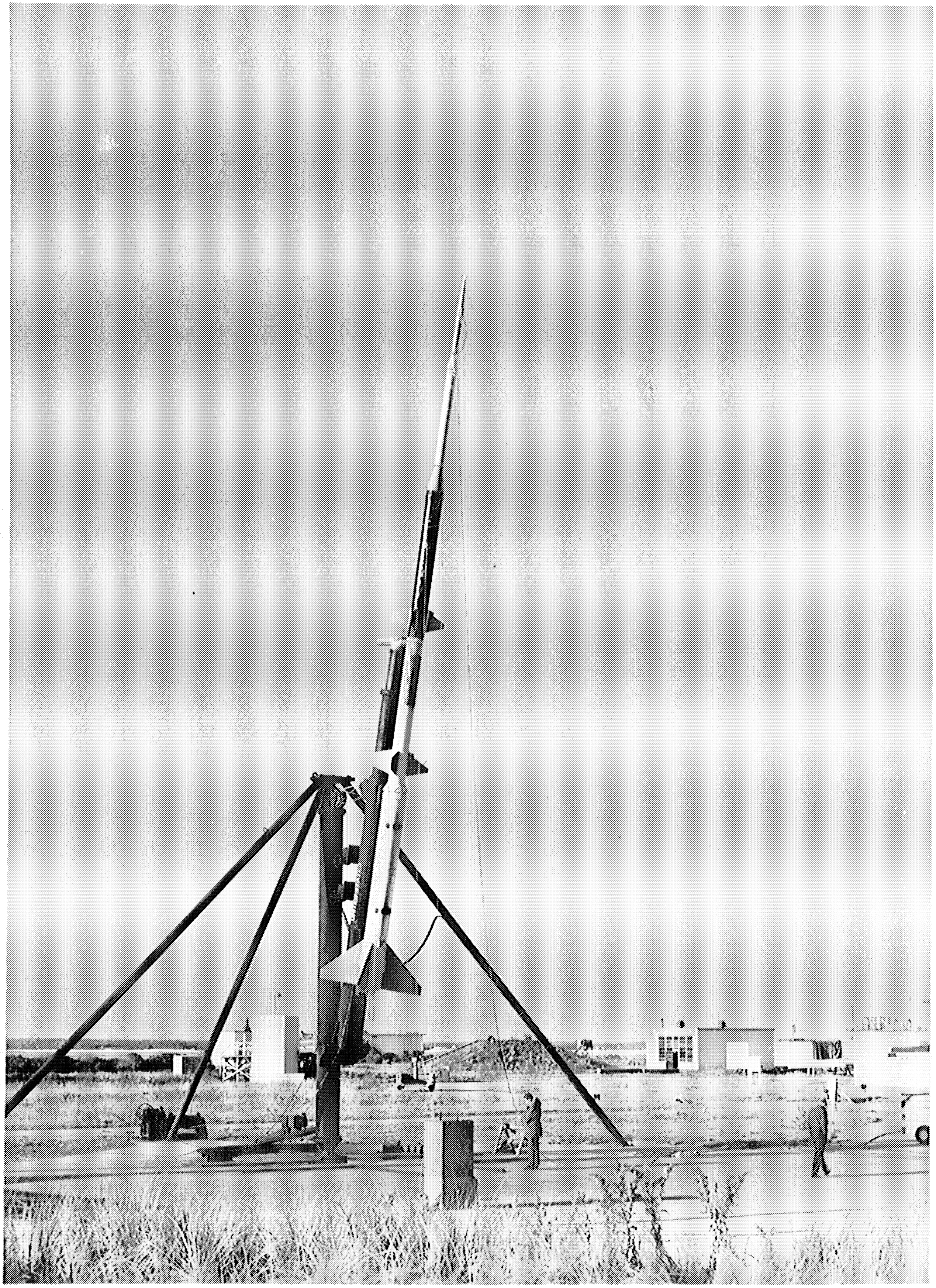

Fig. 1. Strongarm I on launcher.

TABLE I

VERTICAL TRAJECTORY

Time, sec	Altitude, ft	Velocity, ft/sec	Thrust, lbf	Mass, slug	Density x 1000, slug/ft^3	Reynolds No. per ft x 10^{-4} ft^{-1}	Drag Coef. x Frontal Area, ft^2	Acceleration, ft/sec^2
.000	1	0	91429	220.675	2.3767955		.48	382
.125	7	48	91429	218.855	2.3763779	30	.48	385
.250	18	96	91429	217.035	2.3754597	61	.48	389
.375	36	144	91429	215.215	2.3740413	90	.48	392
.500	60	193	91429	213.394	2.3721237	122	.48	396
.625	90	243	91429	211.574	2.3697911	154	.48	399
.750	126	293	91429	209.754	2.3669619	185	.48	403
.875	168	343	91429	207.934	2.3635547	217	.48	407
1.000	217	395	91429	206.114	2.3597379	249	.48	410
1.125	272	446	91429	204.293	2.3554305	281	.48	414
1.250	333	498	91429	202.473	2.3505529	313	.48	418
1.375	402	550	91429	200.653	2.3451910	346	.48	423
1.500	477	603	91429	198.833	2.3393480	378	.48	427
1.625	558	656	91429	197.013	2.3329458	410	.48	431
1.750	647	710	91429	195.193	2.3260707	443	.48	435
1.875	742	764	91429	193.372	2.3187270	476	.48	439
2.000	844	819	91429	191.552	2.3108381	508	.48	443
2.125	952	875	91429	189.732	2.3024906	541	.94	445
2.250	1068	930	91429	187.912	2.2936091	574	1.59	446
2.375	1190	986	91429	186.092	2.2841999	606	2.24	447
2.500	1320	1041	91429	184.271	2.2743500	638	2.41	448
2.625	1456	1098	91429	182.451	2.2639856	670	2.41	451
2.750	1600	1154	91429	180.631	2.2531142	702	2.38	454
2.875	1751	1210	91429	178.811	2.2418223	732	2.35	458
3.000	1909	1268	91429	176.991	2.2300385	764	2.31	461
3.125	2075	1325	91429	175.170	2.2176933	795	2.27	464
3.250	2247	1384	91429	173.350	2.2049515	826	2.24	468
3.375	2427	1442	91429	171.530	2.1918208	857	2.20	472
3.500	2614	1501	91429	169.710	2.1781560	888	2.16	475
3.625	2808	1561	91429	167.890	2.1640441	917	2.12	479
3.750	3010	1621	91429	166.069	2.1494949	947	2.08	482
3.875	3220	1681	91429	164.249	2.1344435	977	2.04	487
4.000	3438	1742	91429	162.429	2.1189763	1006	2.00	491
4.125	3663	1803	91429	160.609	2.1031038	1036	1.96	495
4.250	3895	1865	91429	158.789	2.0868369	1065	1.92	500
4.375	4136	1928	0	95.823	2.0701139	1093	1.48	- 91
4.875	5076	1882	0	95.823	2.0061015	1040	1.50	- 88
5.375	5995	1837	0	95.823	1.9455033	990	1.53	- 84
5.875	6892	1796	0	95.823	1.8880619	943	1.55	- 81
6.375	7769	1755	50272	95.823	1.8335400	900	1.20	457
6.500	7995	1812	50272	94.795	1.8197417	924	1.18	461
6.625	8228	1870	50272	93.767	1.8056031	947	1.16	465
6.750	8469	1928	50272	92.739	1.7911339	971	1.14	469
6.875	8716	1987	50272	91.711	1.7764060	993	1.12	473
7.000	8971	2045	50272	90.682	1.7613041	1016	1.10	477
7.125	9234	2105	50272	89.654	1.7459624	1038	1.08	482
7.250	9504	2165	50272	88.626	1.7302073	1059	1.06	487
7.375	9782	2227	50272	87.598	1.7142328	1081	1.05	491
7.500	10068	2288	50272	86.570	1.6979286	1102	1.03	496
7.625	10361	2350	50272	85.542	1.6814249	1123	1.02	500
7.750	10662	2412	50272	84.514	1.6646137	1144	1.01	505
7.875	10971	2475	50272	83.486	1.6475074	1164	.99	510
8.000	11287	2539	50272	82.458	1.6301759	1183	.98	515
8.125	11612	2603	50272	81.430	1.6125735	1202	.96	521
8.250	11945	2669	50272	80.402	1.5947128	1221	.95	526
8.375	12287	2735	50272	79.374	1.5766067	1240	.94	532
8.500	12636	2801	50272	78.346	1.5583229	1258	.93	537
8.625	12994	2868	50272	77.318	1.5398183	1275	.91	543
8.750	13361	2936	50272	76.289	1.5210523	1293	.90	549
8.875	13736	3005	50272	75.261	1.5020928	1310	.90	556
9.000	14120	3074	50272	74.233	1.4829527	1326	.88	562
9.125	14513	3144	50272	73.205	1.4636451	1342	.86	569
9.250	14914	3216	50272	72.177	1.4441321	1357	.85	576
9.375	15324	3288	0	55.169	1.4244788	1372	.85	-150
9.875	16930	3212	0	55.169	1.3500686	1283	.85	-149
10.375	18501	3142	0	55.169	1.2810297	1203	.86	-130
10.875	20039	3077	0	55.169	1.2168887	1130	.86	-122
11.375	21546	3016	0	55.169	1.1570969	1064	.87	-115
11.875	23025	2958	0	55.169	1.1013260	1003	.88	-108

TABLE I (Continued)

Time, sec	Altitude, ft	Velocity, ft/sec	Thrust, lbf	Mass, slug	Density x 1000, slug/ft^3	Reynolds No. per ft x 10^{-4} ft^{-1}	Drag Coef. x Frontal Area, ft^2	Acceleration, ft/sec^2
12.375	24477	2904	0	55.169	1.0492011	947	.89	- 103
12.875	25903	2852	0	55.169	1.0003865	894	.89	- 98
13.375	27304	2804	0	55.169	.9546142	847	.90	- 93
13.875	28682	2757	0	55.169	.9116405	803	.91	- 89
14.375	30038	2713	0	55.169	.8712745	762	.91	- 85
14.875	31372	2670	0	55.169	.8332813	724	.91	- 81
15.375	32687	2630	0	55.169	.7974769	688	.92	- 78
15.875	33982	2591	0	55.169	.7637207	656	.92	- 75
16.375	35258	2553	0	55.169	.7290842	622	.93	- 72
16.875	36516	2517	0	55.169	.6862329	581	.93	- 69
17.375	37757	2483	0	55.169	.6464450	539	.94	- 66
17.875	38982	2450	0	55.169	.6094564	502	.94	- 63
18.375	40190	2418	0	55.169	.5750284	467	.95	- 61
18.875	41384	2388	0	55.169	.5429267	435	.95	- 59
19.375	42562	2358	0	55.169	.5129954	406	.96	- 57
19.875	43727	2330	0	55.169	.4850380	380	.97	- 55
20.375	44877	2302	0	55.169	.4589104	355	.97	- 54
20.875	46015	2275	0	55.169	.4344649	332	.98	- 52
21.375	47139	2249	0	55.169	.4115963	310	.99	- 51
21.875	48250	2224	0	55.169	.3901506	292	.99	- 49
22.375	49349	2199	0	55.169	.3700563	273	1.00	- 48
22.875	50436	2175	0	55.169	.3511943	257	1.01	- 47
23.375	51512	2151	51659	55.169	.3334811	241	.73	894
23.500	51794	2263	51659	54.145	.3289890	250	.72	911
23.625	52090	2377	51659	53.121	.3243294	259	.71	928
23.750	52402	2493	51659	52.096	.3195000	267	.69	946
23.875	52728	2611	51659	51.072	.3145213	276	.68	965
24.000	53069	2732	51659	50.048	.3094028	284	.67	985
24.125	53425	2855	51659	49.024	.3041431	292	.66	1005
24.250	53797	2980	51659	48.000	.2987418	299	.66	1026
24.375	54186	3108	51659	46.976	.2932097	307	.65	1048
24.500	54590	3240	51659	45.951	.2875577	313	.63	1071
24.625	55012	3374	51659	44.927	.2817868	320	.63	1095
24.750	55450	3511	51659	43.903	.2758990	325	.62	1121
24.875	55906	3651	51659	42.879	.2699160	332	.61	1147
25.000	56380	3794	51659	41.855	.2638309	337	.60	1175
25.125	56872	3941	51659	40.831	.2576566	341	.60	1204
25.250	57383	4091	51659	39.806	.2513970	346	.59	1235
25.375	57913	4245	51659	38.782	.2450655	350	.58	1266
25.500	58463	4404	51659	37.758	.2386670	353	.58	1301
25.625	59033	4566	51659	36.734	.2322069	357	.57	1337
25.750	59624	4734	51659	35.710	.2256917	359	.56	1375
25.875	60237	4906	51659	34.685	.2191359	362	.56	1415
26.000	60872	5083	51659	33.661	.2125389	363	.55	1458
26.125	61529	5265	51659	32.637	.2059233	364	.54	1503
26.250	62210	5453	51659	31.613	.1992824	366	.53	1552
26.375	62916	5647	19377	14.515	.1926323	366	.19	1264
26.500	63641	5805	19377	14.196	.1860274	363	.18	1293
26.625	64386	5699	19377	13.877	.1794725	360	.18	1323
26.750	65152	6132	19377	13.558	.1729721	357	.18	1354
26.875	65939	6301	19377	13.239	.1665491	353	.18	1387
27.000	66748	6474	19377	12.919	.1601845	349	.18	1422
27.125	67579	6652	19377	12.600	.1539061	345	.17	1459
27.250	68433	6834	19377	12.281	.1477077	339	.17	1497
27.375	69310	7022	19377	11.962	.1416046	334	.17	1538
27.500	70212	7214	19377	11.643	.1355916	329	.17	1581
27.625	71138	7412	19377	11.324	.1296834	324	.17	1626
27.750	72089	7615	19377	11.005	.1238847	317	.16	1675
27.875	73066	7824	19377	10.686	.1181914	310	.16	1726
28.000	74071	8040	19377	10.367	.1126134	304	.16	1780
28.125	75103	8263	19377	10.048	.1071554	297	.16	1838
28.250	76164	8492	19377	9.728	.1018187	291	.16	1899
28.375	77255	8729	19377	9.409	.0966120	283	.16	1965
28.500	78377	8975	19377	9.090	.0915363	276	.16	2035
28.625	79530	9230	19377	8.771	.0865964	268	.16	2110
28.750	80716	9494	19377	8.452	.0817908	260	.16	2192
28.875	81936	9767	19377	8.133	.0771244	253	.16	2279
29.000	83192	10052	19377	7.814	.0726017	244	.16	2374

TABLE I (Concluded)

Time, sec	Altitude, ft	Velocity, ft/sec	Thrust, lbf	Mass, slug	Density x 1000, slug/ft^3	Reynolds No. per ft x 10^{-4} ft^{-1}	Drag Coef. x Frontal Area, ft^2	Acceleration, ft/sec^2
29.125	84486	10349	19377	7.495	.0682194	235	.16	2477
29.250	85818	10659	19377	7.176	.0639847	226	.16	2589
29.375	87190	10983	19377	6.857	.0598970	218	.16	2712
29.500	88604	11322	19377	6.538	.0559543	209	.16	2847
29.625	90063	11677	1884	2.766	.0521610	199	.05	585
29.750	91532	11750	1884	2.736	.0486010	186	.05	595
29.875	93009	11825	1884	2.705	.0452665	174	.05	606
30.000	94496	11901	1884	2.674	.0421400	162	.05	617
30.125	95993	11978	1884	2.644	.0392102	151	.05	628
30.250	97500	12056	1884	2.613	.0364687	140	.05	638
30.375	99016	12136	1884	2.583	.0339022	131	.05	649
30.500	100543	12217	1884	2.552	.0314997	122	.05	660
30.625	102080	12299	1884	2.521	.0292541	114	.05	672
30.750	103627	12383	1884	2.491	.0271552	106	.05	683
30.875	105185	12469	1884	2.460	.0251936	98	.05	694
31.000	106754	12556	1884	2.429	.0233615	91	.05	706
31.125	108334	12644	1884	2.399	.0216511	85	.05	718
31.250	109926	12733	1884	2.368	.0200547	78	.05	730
31.375	111528	12825	1884	2.337	.0185662	72	.05	742
31.500	113143	12918	1884	2.307	.0171785	67	.05	754
31.625	114769	13012	1884	2.276	.0158856	62	.05	766
31.750	116406	13108	1884	2.245	.0146818	58	.05	779
31.875	118056	13205	1884	2.215	.0135611	53	.05	792
32.000	119719	13304	1884	2.184	.0125184	49	.05	806
32.125	121394	13404	1884	2.154	.0115486	45	.05	819
32.250	123082	13507	1884	2.123	.0106476	42	.05	833
32.375	124783	13611	1884	2.092	.0098107	39	.05	847
32 500	126497	13717	1884	2.062	.0090338	36	.05	862
32.625	128225	13825	1884	2.031	.0083132	33	.05	876
32.750	129966	13935	1884	2.000	.0076450	31	.05	892
32.875	131721	14046	1884	1.970	.0070258	28	.05	907
33.000	133491	14159	1884	1.939	.0064522	26	.05	923
33.125	135274	14274	1884	1.908	.0059404	24	.05	940
33.250	137073	14392	1884	1.878	.0055699	22	.05	956
33.375	138886	14512	1884	1.847	.0052196	21	.05	973
33.500	140715	14633	1884	1.817	.0048887	20	.05	991
33.625	142559	14757	1884	1.786	.0045762	19	.05	1009
33.750	144419	14884	1884	1.755	.0042813	17	.05	1028
33.875	146295	15012	1884	1.725	.0040031	16	.05	1048
34.000	148187	15143	1884	1.694	.0037408	15	.05	1068
34.125	150096	15277	1884	1.663	.0034936	14	.05	1089
34.250	152023	15413	1884	1.633	.0032607	13	.05	1111
34.375	153966	15551	1884	1.602	.0030413	13	.05	1133
34.500	155927	15693	1884	1.571	.0028350	12	.05	1156
34.625	157907	15838	1884	1.541	.0026410	11	.05	1181
34.750	159904	15985	1884	1.510	.0024587	11	.05	1206
34.875	161921	16136	1884	1.479	.0022874	10	.05	1232
35.000	163956	16290	1884	1.449	.0021266	8	.05	1259
35.125	166012	16447	1884	1.418	.0019756	8	.05	1288
35.250	168087	16608	1884	1.388	.0018341	7	.05	1317
35.375	170184	16773	1884	1.357	.0017014	7	.05	1348
35.500	172301	16941	1884	1.326	.0015772	6	.05	1381
35.625	174440	17114	1884	1.296	.0014608	6	.05	1414
35.750	176601	17291	1884	1.265	.0013520	5	.05	1450
35.875	178785	17472	0	1.212	.0012503	5	.05	- 40
36.375	187510	17452	0	1.212	.0009147	4	.05	- 37
36.875	196227	17433	0	1.212	.0006694	2	.05	- 36
37.375	204934	17416	0	1.212	.0004901	2	.05	- 35
37.875	213633	17398	0	1.212	.0003589	1	.05	- 34
38.375	222323	17381	0	1.212	.0002629	1	.05	- 33
38.875	231005	17365	0	1.212	.0001789		.05	- 33
39.375	239679	17348	0	1.212	.0001179		.05	- 32
39.875	248344	17332	0	1.212	.0000777		.05	- 32
40.375	257002	17316	0	1.212	.0000512		.05	- 32
40.875	265652	17300	0	1.212	.0000338		.05	- 32
41.375	274294	17285	0	1.212	.0000223		.05	- 32
41.875	282928	17269	0	1.212	.0000147		.05	- 31
42.375	291555	17253	0	1.212	.0000097		.05	- 31
42.875	300173	17238	0	1.212	.0000064		.05	- 31
43.375	308784	17222	0	1.212	.0000042		.05	- 31

2. PERFORMANCE

2.1. DESIGN

The Strongarm rocket was designed to carry a 20-pound payload to a 1000-mile altitude. Trajectory calculations were made on the basis of:

1. Static-firing thrust data corrected for pressure at altitude;
2. Empirical drag coefficient data;
3. Atmospheric density from ARDC Model Atmosphere, 1956.

The calculations were made on a Royal-McBee LGP-30 computer using a program which assumes vertical launch. Using this program for the 5 motors comprising Strongarm, a stepwise integration was performed every 1/8 second during a burning phase, and every 1/2 second during a coast; a vacuum trajectory was computed when the drag force had fallen below one-thousandth of the weight. Each trajectory, including the computation and storage of 13 parameters, required 11 minutes of computer time. The effect of variation of coast time on peak altitude was studied and was found to be quite small. Thus the staging program for Strongarm was based almost entirely on aerodynamic heating considerations. Even so, the staging chosen yielded a peak altitude within 2% of the maximum.

Likewise, the variation of peak altitude with payload was studied. Near 20 pounds, the variation is 16 miles per pound.

Table I is a sample trajectory for the staging and payload flown in Strongarm I. (The computer prints out Mach No., Gravitational Acceleration, Dynamic Pressure, and Drag Force in addition.) Table II consists of selected excerpts from Table I.

Since Strongarm is not likely to be launched vertically, an extrapolation of peak altitude at vertical launch to other launch angles must be made. This is readily accomplished by multiplying the peak at vertical launch by a factor equal to the square of the sine of the burnout angle. The burnout angle will not be the same as the launch angle since the trajectory curves in the interim. The curvature can be determined by integrating the equation

$$\frac{d\theta}{dt} = \frac{g \cos \theta}{v}$$

where: θ is the angle of the flight path with the local horizontal,
v is the speed, and
g is the gravitational acceleration.

TABLE II

FLIGHT PARAMETERS AT SELECTED TIMES

(20-lb payload)

Action	Time,* sec	Altitude, ft	Velocity, ft/sec	Mass, slug	Mach No.	Density x 10^3, slug/ft^3	Dynamic Pressure, lb/ft^2	Reynolds No., per ft, millions/ft	Drag, lb	Accel., g's
1st Ignition	0	1	0	220.675	0	2.3768	0	0	0	12
1st Burnout	4.375	4,136	1,928	156.969	1.75	2.0701	3846	10.93	7100	16
Separation	4.425			95.823					5683	- 3
2nd Ignition	6.375	7,769	1,755	95.823	1.62	1.8336	2824	9.00	3381	14
2nd Burnout	9.375	15,324	3,288	71.149	3.12	1.4245	7698	13.72	6525	18
Separation	9.425			55.169					6518	- 5
3rd Ignition	23.375	51,512	2,151	55.169	2.22	.3335	772	2.4	566	28
3rd Burnout	26.375	62,916	5,647	30.589	5.83	.1926	3071	3.6	1620	50
4th Ignition	26.375+			14.515					572	40
4th Burnout	29.625	90,063	11,677	6.219	11.88	.0522	3556	2.0	551	90
5th Ignition	29.625+			2.766					178	18
5th Burnout	35.875	178,785	17,472	1.212	15.92	.0000	191	.05	10	- 1.3
Peak	818	1,217 statute miles	0	1.212	0		0	0	0	- .6

*Time is taken to nearest 1/8 sec for computer solution.

The speed is known as a function of time, θ is launch angle at t = 0, and gravity may be assumed constant for this early portion (prior to burnout) of the flight; thus the solution is straightforward. The results of this computation are shown in Table III. Prior to applying the peak-altitude reduction factor, the peak altitude should be adjusted for the proper payload weight.

TABLE III

HORIZONTAL RANGE

Launch Angle, degree	Peak Altitude Reduction Factor
90	1.000
87.5	.995
85	.981
82.5	.957
80	.925
77.5	.885
75	.838

While parameters such as velocity, acceleration, altitude, drag, thrust, etc., are affected only slightly by small launch-angle variations, horizontal velocity and range are all but proportional to them. In calculating the impact distances, the burnout angle for each stage is computed as described above, and the horizontal velocity is determined. Since few empirical data are available on drag coefficients of burned-out stages the horizontal ranges, or impact distances, given in Table IV must be considered only rough approximations.

TABLE IV

APPROXIMATE IMPACT RANGES, STATUTE MILES

Stage	Launch Angle		
	85°	80°	75°
1	3	5	7
2	7	14	21
3	41	81	119
4	214	419	616
5	472	937	1372

Stability calculations based on supersonic theory show the following static margins:

Five stages:	3 calibers
Final four stages:	2-1/2 calibers
Final three stages:	2-1/2 calibers

Based on hypersonic (impact) theory,[3] the static margins are:

Final two stages:	14 in.
Fifth stage:	11 in.

These static margins apply at ignition of each stage. In each case, during burning the center of gravity moves forward and increases the static margin.

2.2. FLIGHT TEST

The first Strongarm flight test was held at Wallops Island, Va., on November 10, 1959. The nose was instrumented for measurement of ionospheric ion density.[4] One thermistor was carried in the nose, positioned just under the ablative cover. The final stage weighed 90 lb. The launch angle was 80°. Performance of the entire system was normal. Radar skin tracking was maintained through fifth-stage burnout. Telemetry was maintained for 25-1/4 minutes, presumably terminated by reëntry.

The termination of radar tracking soon after burnout did not permit an accurate value of velocity to be obtained. The radar plots of altitude vs. time and velocity vs. time are shown in Fig. 3. Rounding of the velocity curve at burnout and beyond is due to computer smoothing at the time of target loss. The dashed velocity line is the best estimate of the flight, based on doppler velocity, time of flight, theoretical motor performance, and time of burnout. Maximum velocity is estimated at 17,200 ft/sec, and peak altitude, approximately 1120 statute miles. The burnout flight-path angle from radar data was approximately 74°.

That the ablative cover furnished adequate protection for the nose cone was proved by the operation of the telemeter transmitter for the entire flight. A discussion of the nose temperatures as measured by the thermistor is contained in Section 3.5 below.

The second flight test was held at Wallops Island, Va., on November 18, 1959. The rocket and nose cone were identical to the first. The flight failed when the third stage did not ignite. A clue to the nonignition was provided by a broken firing lead on the ground near the rocket which could have been broken prior to takeoff or immediately upon first-stage ignition. The break in this lead is believed the most probable cause of failure, and as a result in all future firings the lead wires to igniters which function subsequent to first-stage ignition will be protected by conduit as close to the rocket as possible.

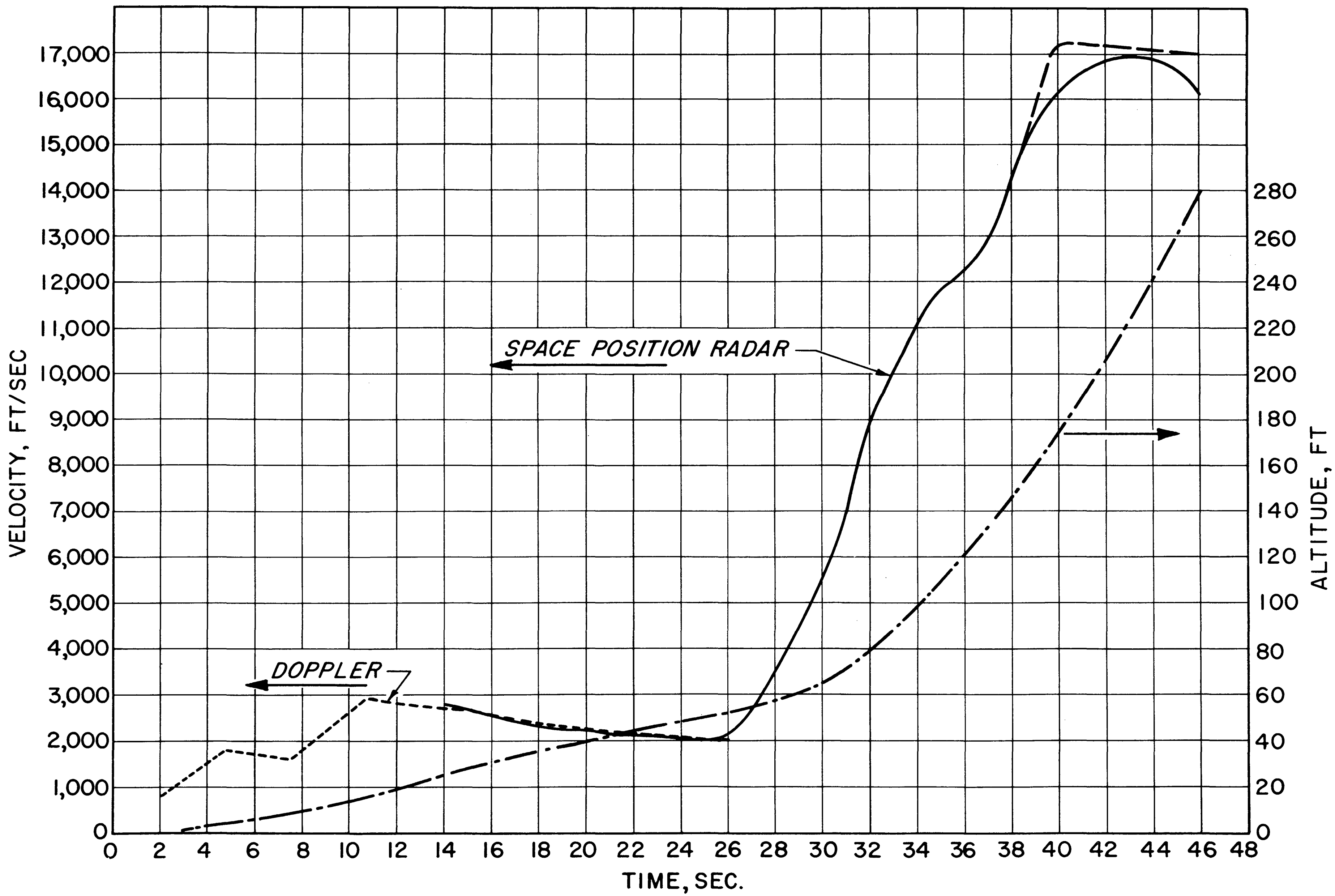

Fig. 3. Flight-trajectory data, altitude vs. time, velocity vs. time.

3. DESIGN FEATURES AND ORIENTATION

3.1. MOTORS

Strongarm is a five-stage solid-propellant vehicle. The first stage is the Honest John rocket motor. The second- and third-stage motors are Nike-Ajax anti-aircraft missile boosters. The fourth stage is the newly developed Thiokol Chemical Corporation Yardbird rocket with an extended nozzle. The fifth stage is essentially the Scale Sergeant as designed and built by the Jet Propulsion Laboratory, with slight modification in its metal parts to make it suitable for use in the Strongarm.

3.2. LAUNCHING

Strongarm was launched from one of the mast and boom type of launchers at Wallops Island (see Fig. 1). The vehicle is suspended under the boom and supported at three points: aft end of first stage, forward end of first stage, and forward end of the second stage. All launching fittings are free of the launcher after two inches of forward motion of the vehicle.

A dolly which can be raised or lowered at either end or both is a virtual necessity for assembly of the vehicle. Practically all preparation of the first three stages is done on dollies of the type shown in Fig. 4.

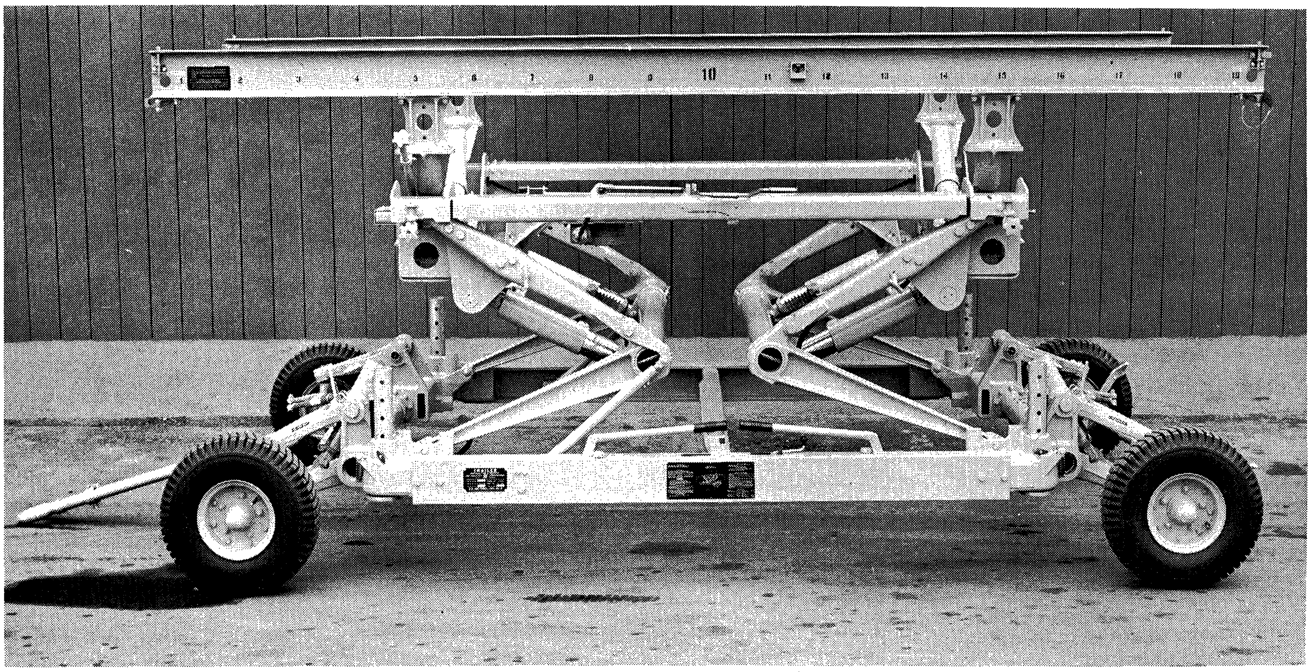

Fig. 4. Handling dolly.

3.3. STABILITY

All stages are aerodynamically stabilized. The first three stages are stabilized by means of fins; the last two stages employ flared skirts both for coupling and stabilization. The standard Honest John fins are used after removal of the roll-producing cant which is built into the fin-mounting bracket. The second stage is fitted with 2.5-square-foot fins similar to those used in the Nike-Cajun (see Fig. 5 and Refs. 1 and 2). Each fin is a weldment of magnesium castings and plates. This weldment is in turn welded to a magnesium shroud. The leading edges are cuffed with Inconel sheet to resist heating. The third stage is fitted with fins of the same design as the second stage. The third-stage fins have, however, only 2 square feet of area and a double, more extensive, Inconel leading edge cuff.

A flared skirt of cast magnesium (Figs. 6 and 11) is used to couple the fourth stage to the third and to stabilize the fourth-fifth-stage combination. This skirt is essentially a truncated cone with a half angle of 10°. It is made from an ordinary magnesium casting alloy (AZ91C) and no coatings are required for heat protection. The cone itself is an adequate heat sink.

The fifth-stage skirt is much the same with the exception that it is cast from one of the high-temperature magnesium alloys (HK31). Again no heat-resistant coatings are employed. This flared skirt also is part of the coupling to the previous stage (see Figs. 7 and 12).

3.4. COUPLINGS AND FLIGHT PROGRAM

The flight program calls for the first stage to separate at burnout due to aerodynamic drag. A large magnesium casting, shown in Fig. 8, is bolted to the thrust face of the Honest John. The Nike is cantilevered from the two cylindrical surfaces, one of which seats in the nozzle throat and the other into a spacer ring that is glued into the Nike nozzle exit. A section is shown in Fig. 9. When differential drag has moved the first stage aft about 2 in., both cylindrical surfaces are freed.

A ground-initiated 7-sec delay squib ignites the second stage after separation of the first stage and an approximate 2-sec coast period. The coupling of the second to third stage is the same in principle as the first- to second-stage coupling. This means that, unless steps are taken to prevent it, separation could occur between the second and third stages at first-stage burnout. The locking device which prevents this premature separation is shown in Fig. 10. It is unlocked by the internal pressure of the burning second stage. At second-stage burnout, separation is desired and occurs through differential drag.

The remaining three stages then coast until a 25-sec delay squib, started at take-off, fires the third stage. This is after a coast period of approximately 15 sec. The third-stage to fourth-stage coupling and the fourth-stage to fifth-stage coupling are shown in Figs. 11 and 12. They are both of the

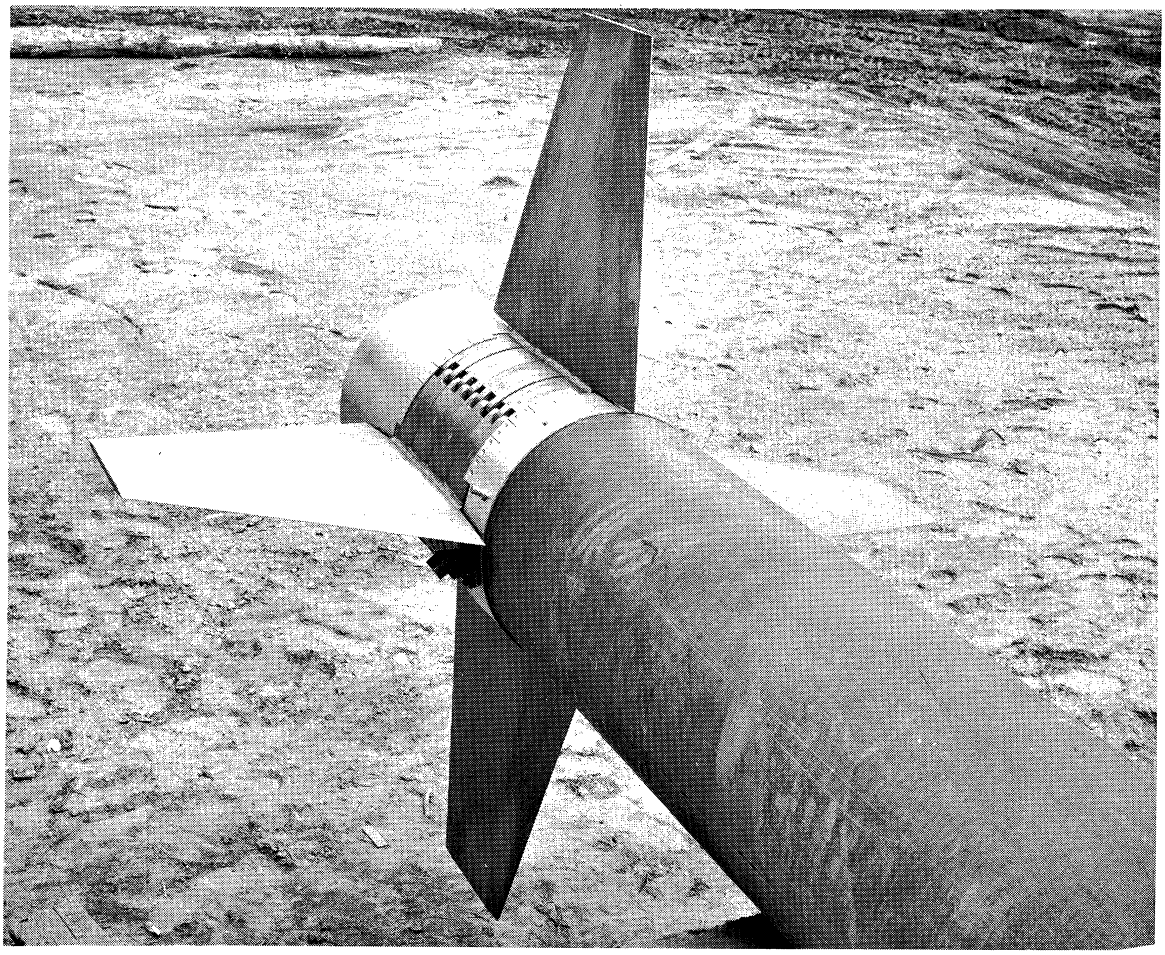

Fig. 5. Second-stage motor with 2-1/2-square-foot fins.

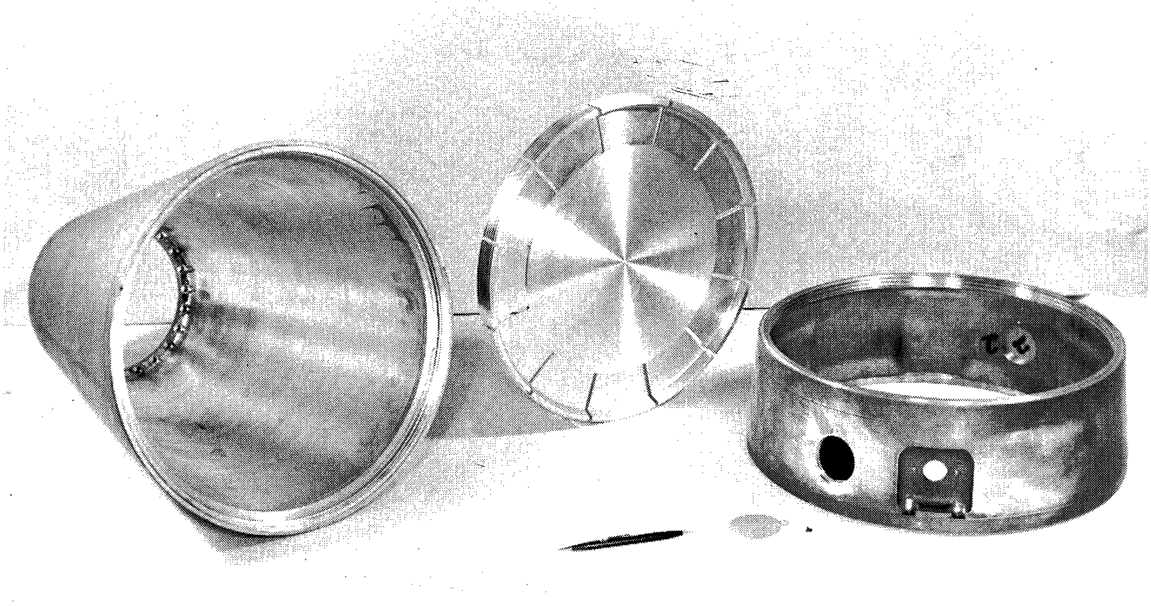

Fig. 6. Third- to fourth-stage coupling parts.

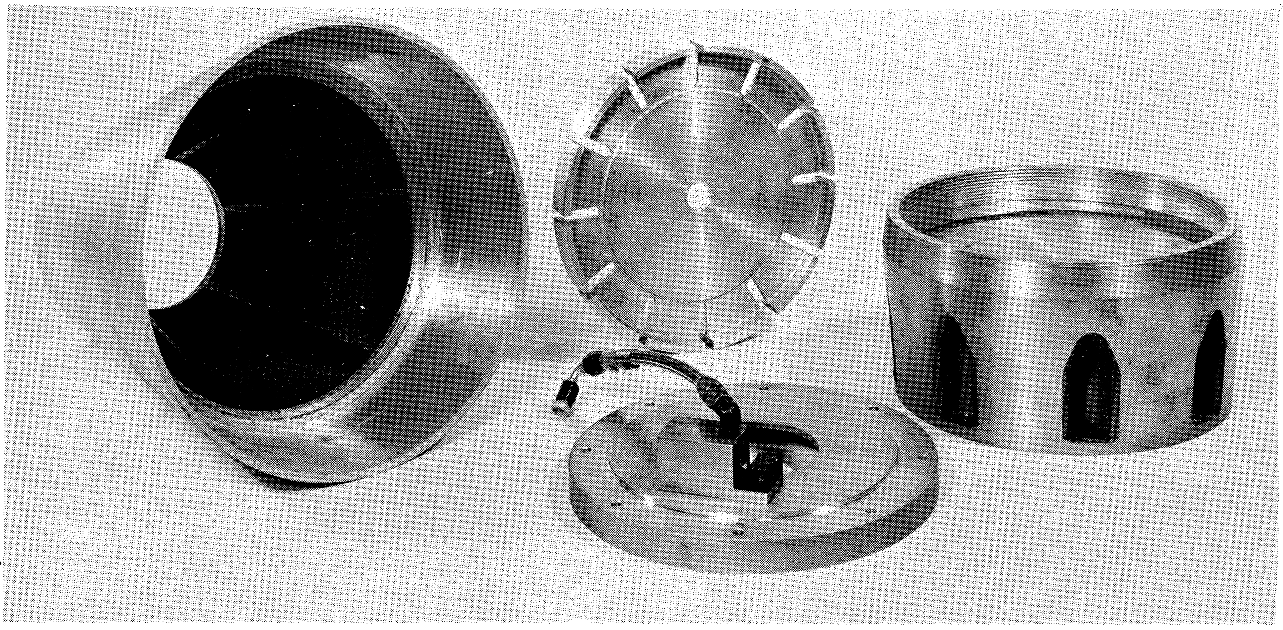

Fig. 7. Fourth- to fifth-stage coupling parts.

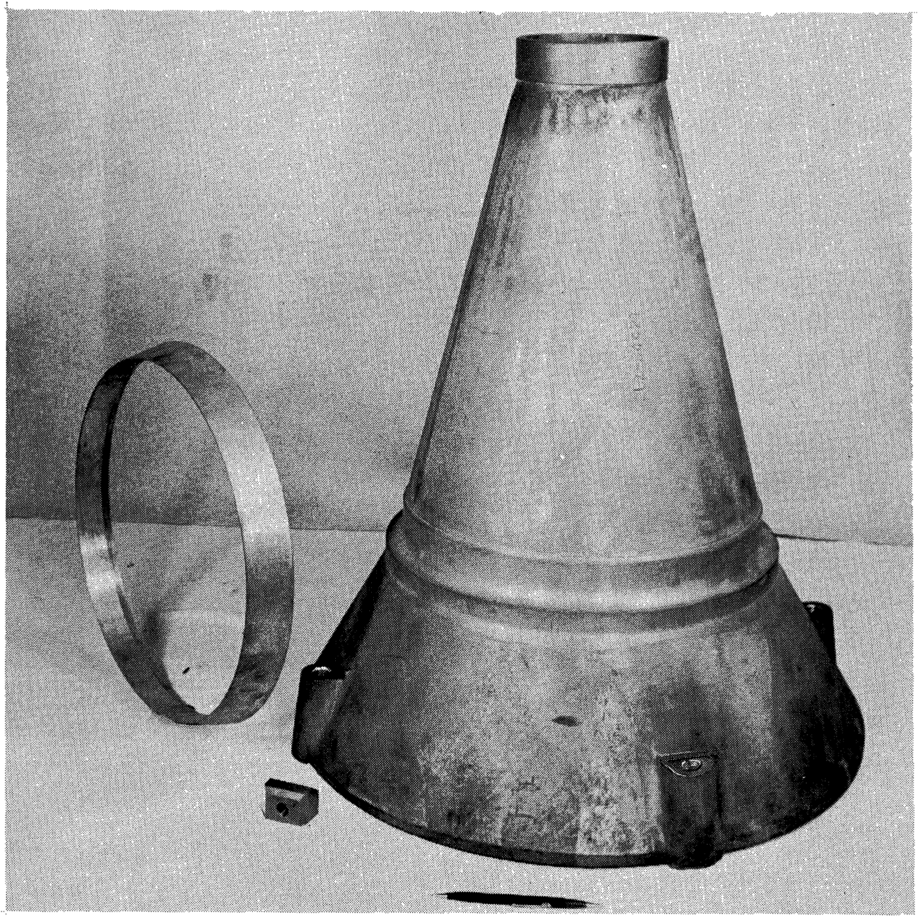

Fig. 8. First- to second-stage coupling parts.

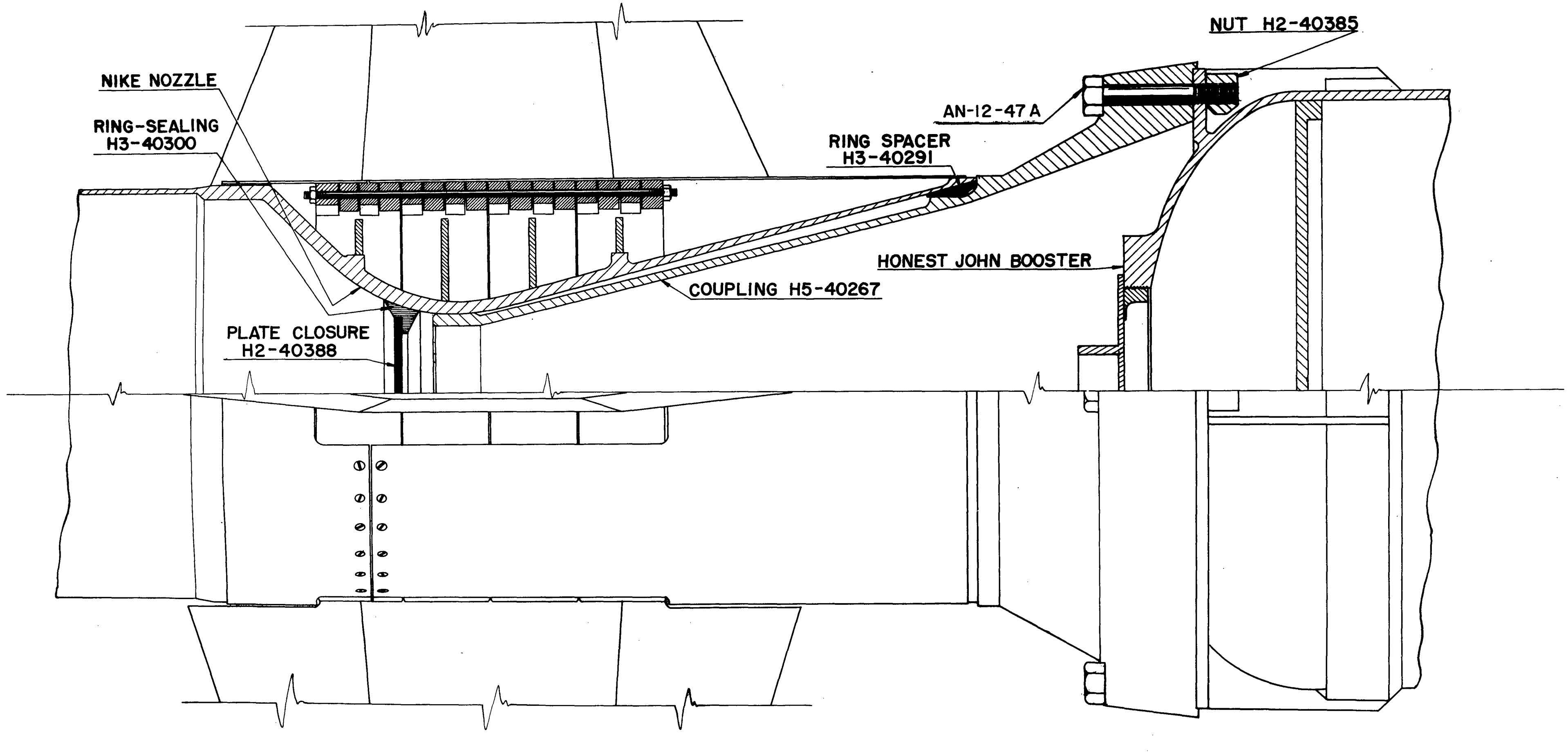

Fig. 9. First- to second-stage coupling assembly.

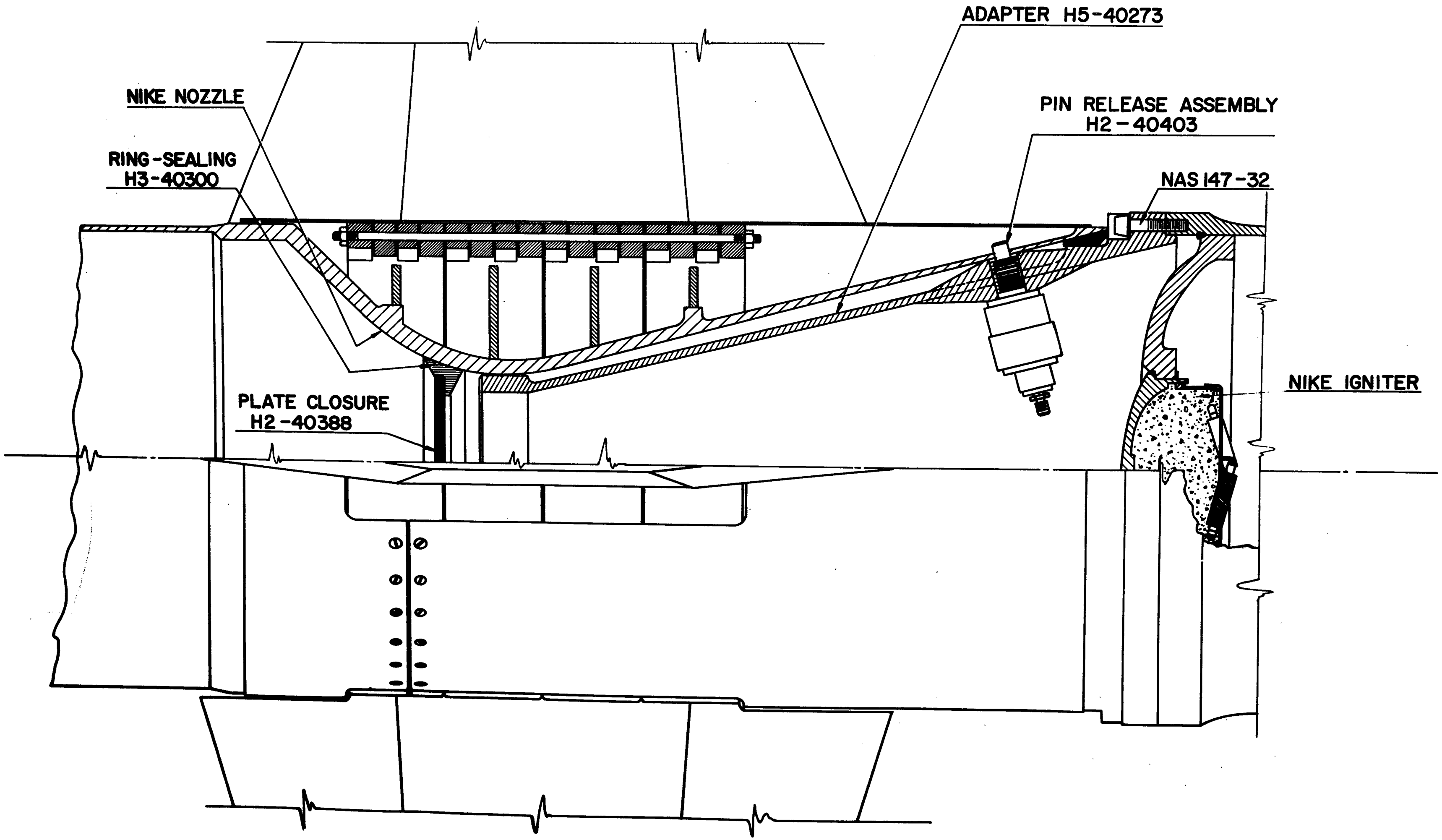

Fig. 10. Second- to third-stage coupling assembly.

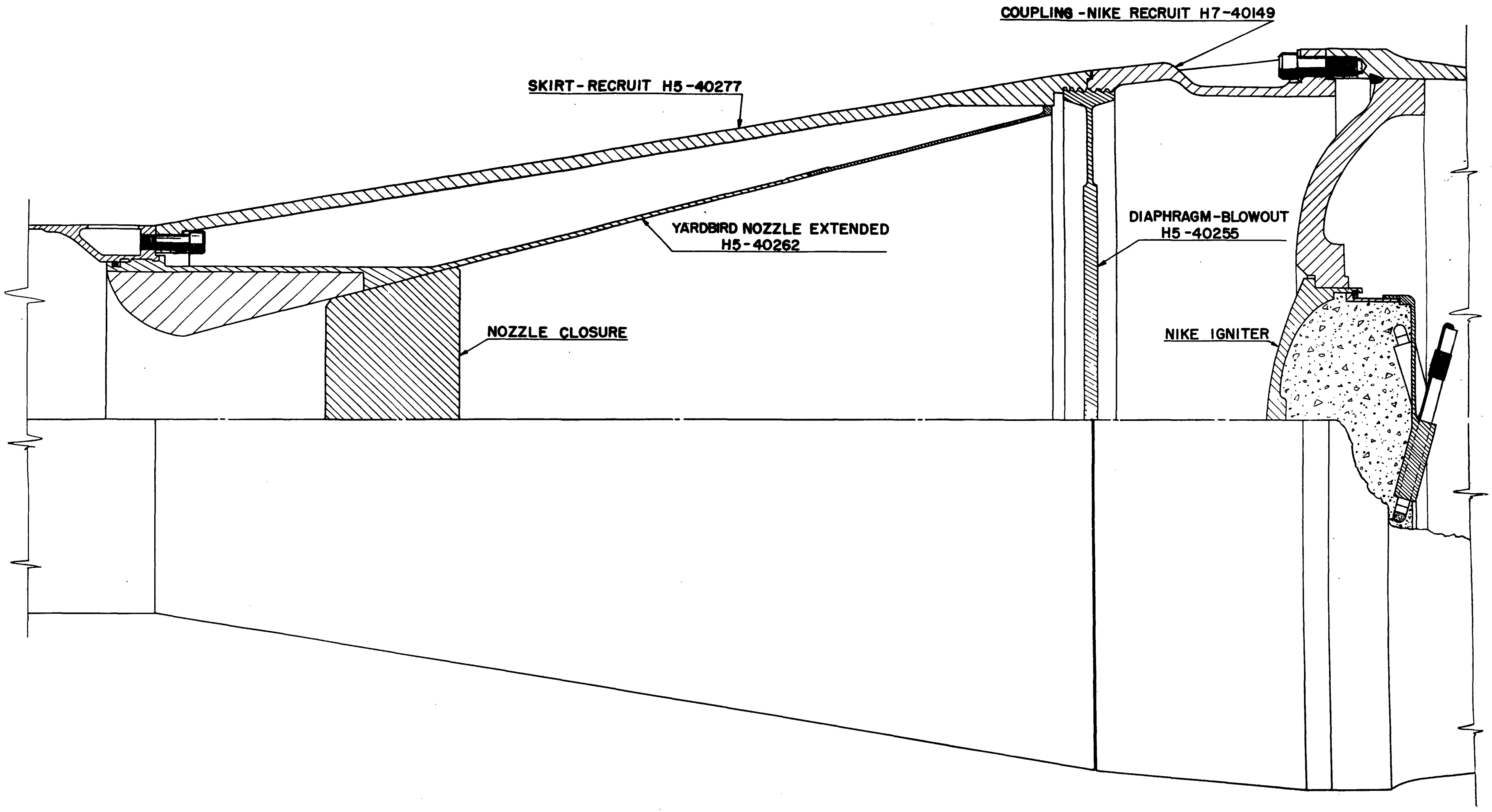

Fig 11. Third- to fourth-stage coupling assembly.

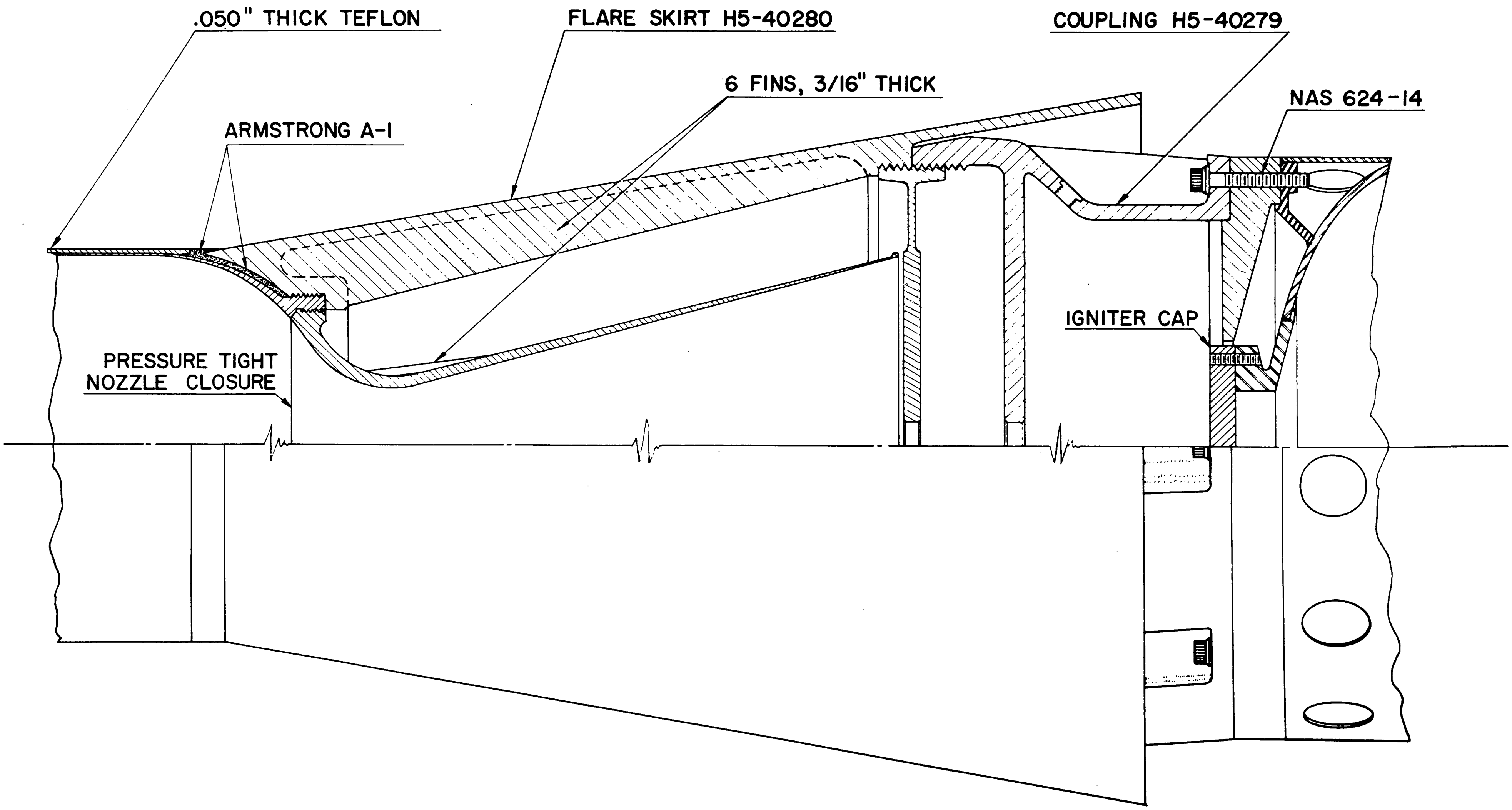

Fig. 12. Fourth- to fifth-stage coupling assembly.

blast diaphragm type which holds two stages together until the stage forward of the coupling fires. Figure 6 is a photograph of the essential parts of the third-stage to fourth-stage coupling. One part is the flared skirt of the third stage. Another is the casting bolted to the second stage. These mate together to form the thrust structure and both have internal threads on their mating surfaces. The third part is a diaphragm with external threads on its periphery. It is screwed halfway into each of the other two parts, thus locking them securely together. However, when the third stage ignites, the pressure of exhaust gases forces the diaphragm into a bowl-shape, freeing the threads. The space behind the diaphragm is used to contain the components of the fourth-stage ignition system.

The fourth stage is fired by the decay of the pressure in the third-stage propulsion bottle. The fifth stage is similarly ignited at burnout of the fourth stage. Thus the last three stages fire in rapid succession with virtually no delay between stages.

3.5. AERODYNAMIC HEATING

One of the problems which arises in connection with the staging of existing solid-fuel rocket motors for high-altitude sounding vehicles is aerodynamic heating. Because the solid-fuel motors burn much more rapidly than liquid-fuel engines and because aerodynamic forces are used to stabilize the trajectory of sounding rockets, the entire powered portion of flight usually takes place within the sensible atmosphere. For final burnout velocities in excess of 10,000 fps, this can mean that sizable heat-input rates occur during the ascent trajectory. Although the maximum heat-input occurs in the region of the nose of the rocket, the most critical requirement may be to protect the solid-fuel grain of the final stage from overheating, since the allowable temperature limit here may be much lower than in the payload compartment and the weight penalty for a given thickness of insulating material may be much more severe.

In connection with the design of the present five-stage sounding-rocket vehicle, we encountered exactly this problem on the final stage, the JPL Scale Sergeant. With 20 pounds of payload (actually 20 pounds above the head cap of the rocket motor, including nose cone and instrumentation), the burnout velocity of the fifth and final stage is in excess of 17,000 ft/sec at an altitude of 160,000 to 190,000 feet, depending on the timing of the various stages. This gives peak heat-input rates earlier in the trajectory of up to 45 Btu/ft^2 sec at the skin of the fifth-stage motor. Since the stainless-steel motor casing is only 0.023 in. thick and the maximum safe allowable temperature at the case liner prior to stage ignition is, according to JPL, only 250°F, some heat-protecting material is obviously needed. It was decided to use a layer of Teflon on top of the stainless-steel casing to provide this protection, because Teflon has the desirable characteristic of a low temperature of ablation ($\sim$ 1100°F) and because the Douglas Aircraft Company has had considerable experience in applying Teflon coatings for heat protection of aerodynamic surfaces.

Since the Thermodynamics Group of the Missiles and Space-systems Division of Douglas Aircraft Company already had an extensive IBM 704 program for calculating temperatures beneath ablating material subject to aerodynamic heating, their services were utilized for the bulk of the heating calculations. For a number of vertical flight programs, including the coast periods finally arrived at, temperatures on the nose cone and on the rocket casing were computed as a function of time. The nose cone itself consisted of a 1/8-in.-thick Fiberglas structure with a 0.080 in. Teflon overlay. The nose tip consisted of a steel core with a Teflon cover varying in thickness from 3/4 to 5/16 in.

The computed temperature history at a point 28.8 in. aft of the tip of the cone at the Teflon-Fiberglas interface is shown in Fig. 13 for the flight program actually used. Temperature histories for other Teflon thicknesses were also computed. Here the object of the Teflon was to prevent the temperature of the Fiberglas surface from exceeding about 600°F, at which point charring could occur. This would have made the nose cone opaque to the antenna radiation. As can be seen in the figure, this temperature was not exceeded. Calculations nearer the nose also showed satisfactory Fiberglas surface protection with the 80-mil Teflon thickness. To be conservative, a turbulent boundary layer was assumed in all these calculations.

Calculations of the solid-fuel liner temperature next to the stainless-steel rocket motor casing were also made with various Teflon thicknesses. It was shown that the 50-mil Teflon thickness would indeed keep the liner temperature below 250°F prior to fifth-stage ignition, providing one used the inter-stage coast programs finally employed. We checked the calculations of the Douglas Aircraft Company, using an analog computer solution, and reasonable agreement was obtained.

As a result of the many calculations made, it is obvious that once the heating rates get above approximately 10 Btu/ft^2 sec, the critical parameter becomes time of heat application and not so much magnitude of heat rate. This is because, once the surface starts to ablate, the surface temperature stays fixed, and the important parameter is the time for the heat to soak into the material. It is also worth noting that the thermal time constant varies as the square of the material thickness, so that a modest increase in protective-coating thickness can provide a fairly sizable improvement in thermal protection.

To summarize, heat protection with Teflon appears to be a very satisfactory solution to the problem of aerodynamic heating on the ascent trajectory of solid-fuel sounding rockets.

Four other Strongarm components were considered from the standpoint of aerodynamic heating. The first two, the second- and third-stage fins, were not analyzed for heating but the same heat protection was added as had been used successfully many times with the same propulsion bottles and similar flight programs. The second-stage fins had a single thickness, .031 Inconel leading edge cuff 1-1/2 in. wide, measured along the chord. The third-stage fins had a double Inconel cuff. The first layer of .031 Inconel

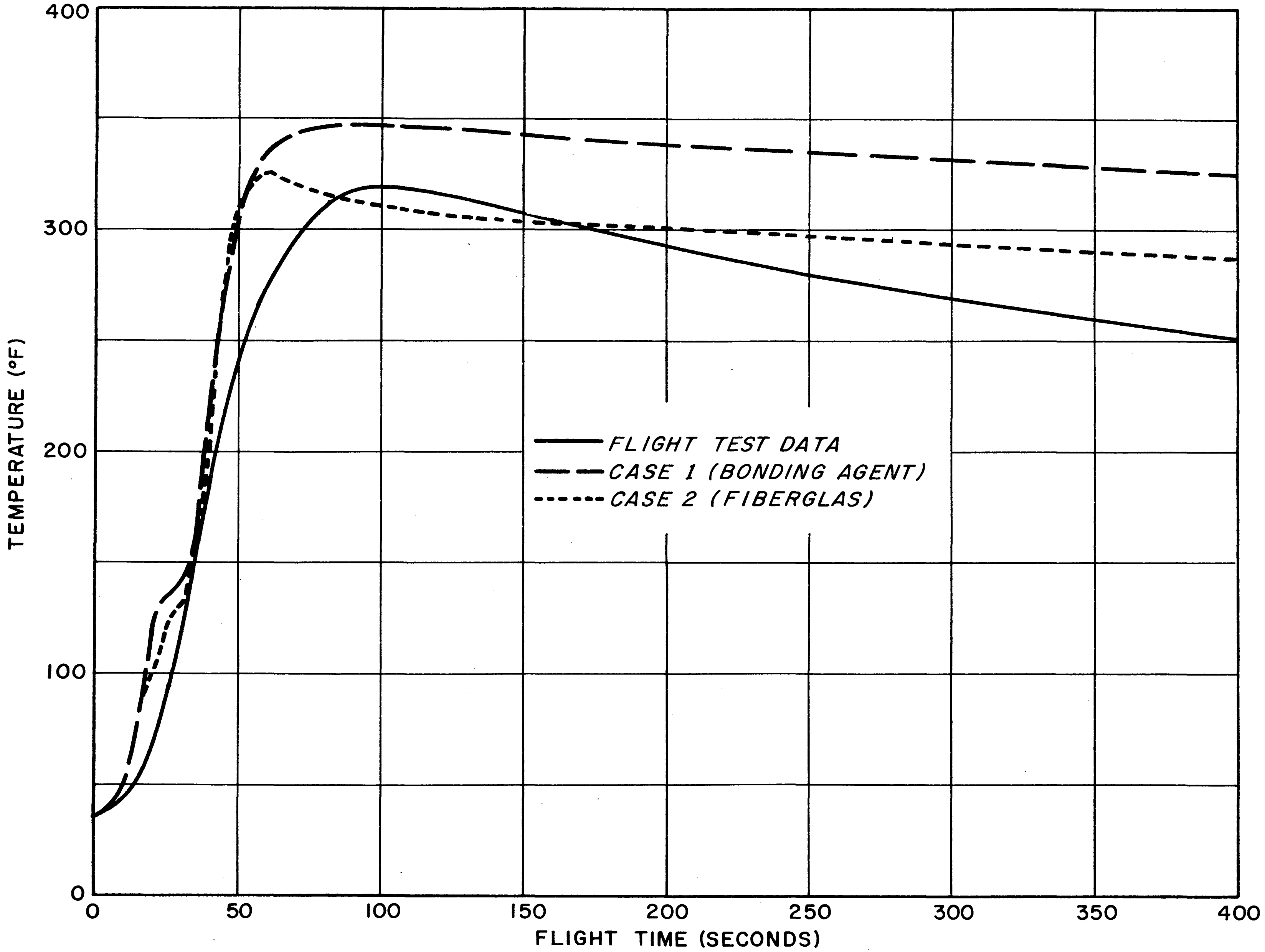

Fig. 13. Nose-cone temperature vs. time—calculated and measured.

covered essentially the entire leading edge wedge. The second layer was .062 Inconel and measured 2 in. in a chordwise direction. The fourth-stage flared skirt was analyzed and found to remain structurally adequate through fourth-stage burning. The finished casting is of sufficient wall thickness to provide an adequate heat sink to survive even in the ordinary AZ91C material. The fifth-stage flared skirt was similarly analyzed and found to be marginal in AZ91C. When re-analyzed using the new high-temperature HK31A magnesium alloy, it was determined that the skirt would survive through fifth-stage burning. At this point the aerodynamic loads and heating are both fast becoming negligible.

3.6. INSTRUMENTED NOSE

The geophysical experiment carried on Strongarm I and II was the Ballistic Research Laboratories' two-frequency ion-density experiment. The Ballistic Research Laboratories designed, assembled, and manned the two ground stations—one at Wallops Island and the second at Aberdeen Proving Ground. The rocket instrumentation package was designed, built, and serviced by personnel of the Electronic Defense Group of The University of Michigan.[4]

The volume available for instrumentation on Strongarm is a truncated cone cylinder as shown in Fig. 14. The cylindrical portion is 5-3/4 in. in diameter and 1-9/16 in. long. The cone diameters are 5-3/4 and 2-1/4 in. over a length of 28-3/4 in. This cone cylinder had an internal volume available for instrumentation of 425 cu in. The instrumentation flown in Strongarm I and II is shown in Figs. 15 and 16. Two crossed loop antennae are mounted over the completely transistorized oscillator and power supply. Exceptional frequency stability is required for this experiment. The frequency drift in this instrumentation was less than 1 part in 10^8. The crystal was temperature-controlled to $\pm$ 0.1°C using a heat-of-fusion technique.

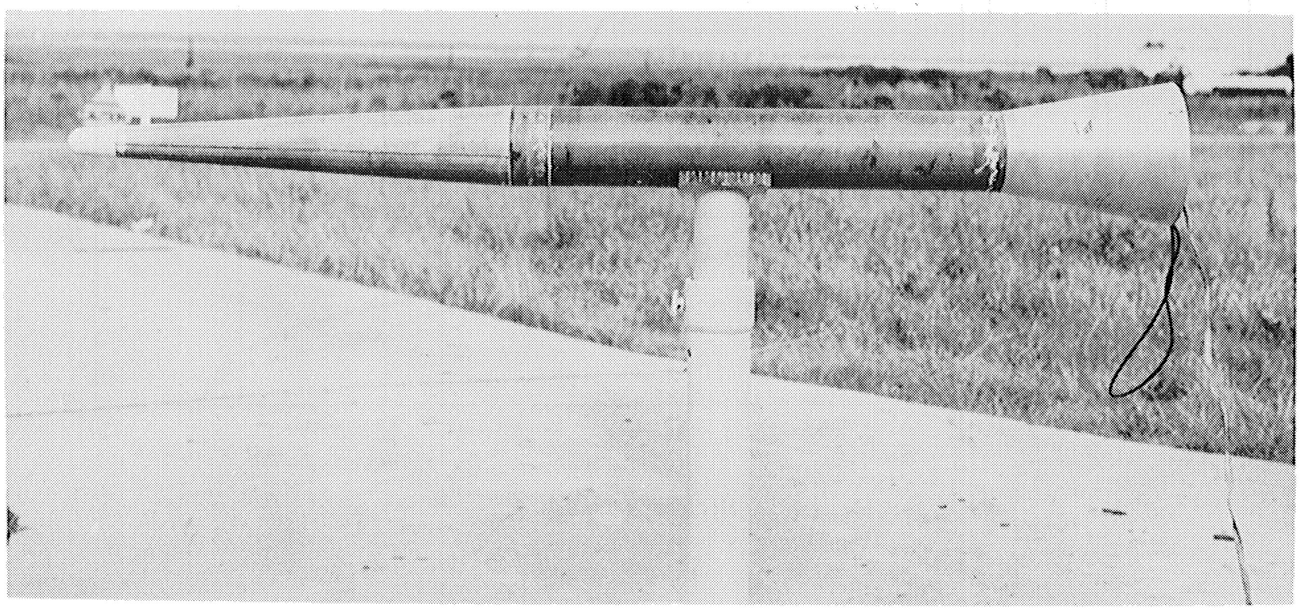

Fig. 14. Fifth stage completely assembled.

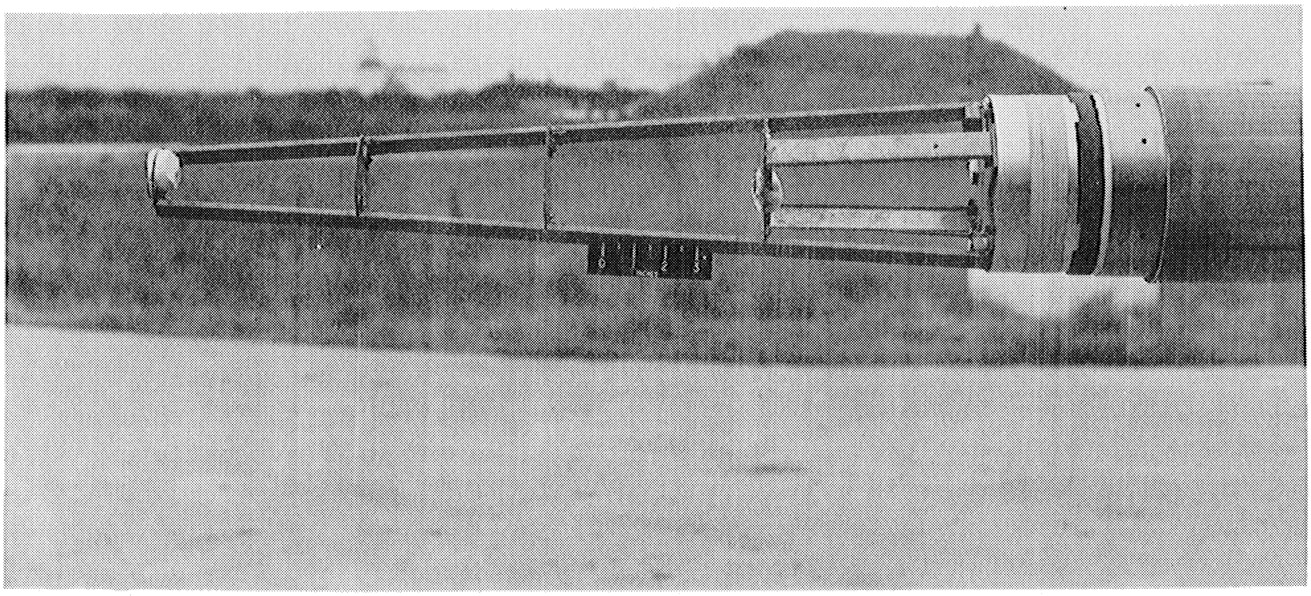

Fig. 15. Instrumentation—nose cone removed.

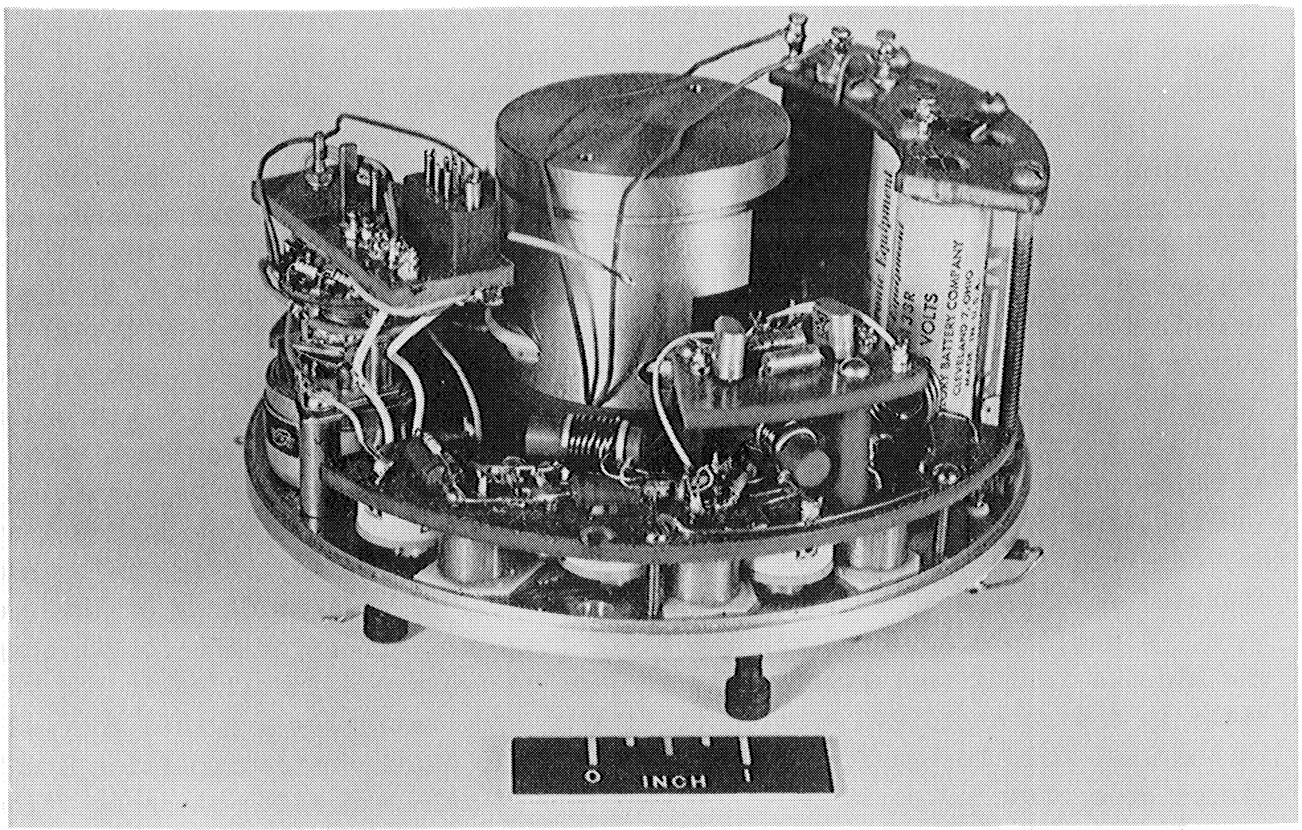

Fig. 16. Instrumentation—electronic package.

3.7. IGNITION APPARATUS

The standard igniter for the Honest John is utilized except that the elaborate mount to support the igniter against lateral accelerations when the rocket is transported in the field is unnecessary. The igniter when installed is simply suspended from its audio-jack type of plug. The circuit runs through the grain and external connection is made at the tail. The igniter is a low-resistance type and any standard firing circuit will suffice.

The second- and third-stage igniters are modified from high-resistance instantaneous types to low-resistance delay types. Four Hercules Powder Company delay squibs SD 39A0, 7-sec delay, are installed in the second-stage igniter and four of the same type, 25-sec delay, are installed in the third-stage igniter. Briefly, the process is as follows. The top of the plastic cup of the standard Nike igniter is cut off with a knife. The powder is removed and the squib-resistor harness is removed from the igniter dome. The delay squibs are previously cemented in the replacement plastic igniter cap. The delay squib wires are connected to the studs in the inside of the igniter dome and the cap is cemented in place. The powder is then replaced in the igniter—the last through a 3/4-in. hole which, in the final operation, is plugged with a cap cemented in.

The firing circuit which normally runs through the grain of the motors is removed as is the nozzle closure. A different nozzle closure designed to withstand an internal pressure of over three atmospheres is installed forward of the minimum nozzle diameter (see Figs. 9 and 10). This procedure eliminates any problems of ignition at reduced pressures. The first three stages are fired from the ground. On Strongarm I and II the voltage for the second- and third-stage igniters was switched on through a relay. The holding circuit of the relay is broken by forward motion of the rocket from first stage firing. Thus in the unlikely event of a first-stage misfire, the second and third stages do not ignite at x plus 7 and 25 sec. The fourth and fifth stages are fired by batteries carried in the third and fourth stages. The program calls for no coast or delay between third-stage burnout and fourth-stage ignition, and similarly no delay between fourth-stage burnout and fifth-stage ignition. The ignition of the fourth stage is accomplished through a spring-loaded piston device which is cocked by the pressure build-up in the third-stage motor and operates to close a switch in the battery-igniter circuit on decay of the pressure. A duplicate device fires the fifth stage on burnout of the fourth stage. The missile-firing batteries in the igniter circuits are installed in the vehicle in a discharged and shorted condition. The batteries are then charged in the last hour before firing, with the vehicle in the raised position and the launch area clear of personnel. In both the fourth- and fifth-stage ignition circuits, the igniter leads and battery leads are brought to externally available binding posts with arming bars so arranged to provide a short circuit on the igniter. Just prior to elevating the launcher and charging the battery, the arming bars are rearranged to connect the igniter to the battery through the pressure-operated switch. Figure 17 is a schematic diagram of the vehicle wiring, exclusive of any instrumentation or instrumentation control wiring.

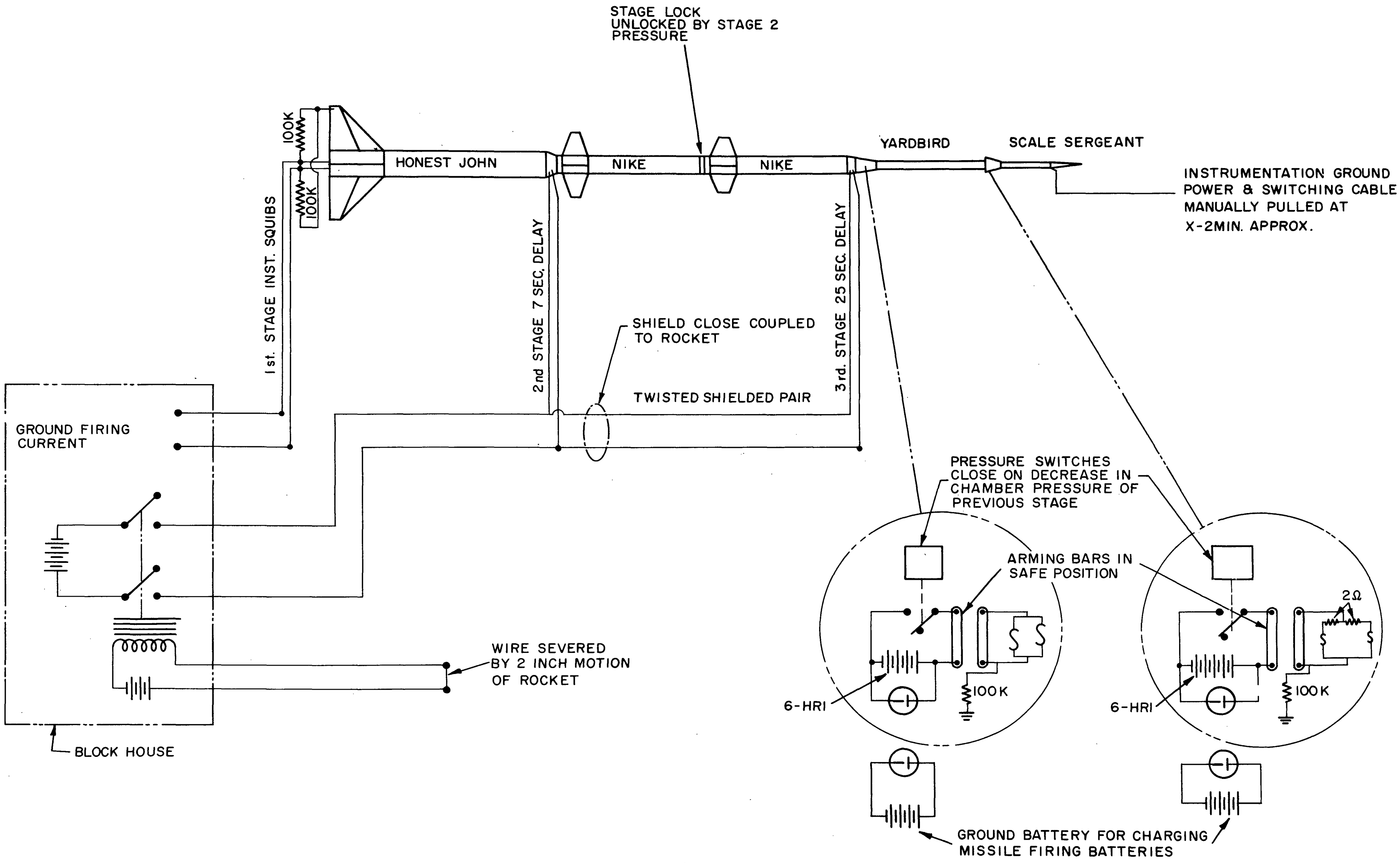

Fig. 17. Schematic diagram of vehicle wiring.

3.8. ORIENTATION

In assembling the Strongarm, some foresight must be exercised to insure proper orientation of all parts with respect to each other and the ground. Further, it is recommended that all mating parts be assembled well in advance of final assembly to verify correctness of fit. Following is a complete list of components requiring special orientation.

First Stage.—The forward launching fittings used on the Honest John in the Strongarm configuration bolt to the Honest John at one of two diametrically opposite locations. Either location is suitable and puts the Honest John fins at 45° to the vertical.

Second Stage.—Fins are to line up with the first-stage fins. Extra tapped holes are required in the outside diameter and forward side of the thrust ring of the Nike booster. The 5/8"-18 tapped hole for the launching fitting is located at 12 o'clock when the standard Nike riding lug holes are centered about 6 o'clock.

Third Stage.—The third-stage fins are in line with the fins of the first and second stages. The battery charging plug on the forward end of the stage should be as near 6 o'clock as possible. The pressure tap on the head cap of the third stage should line up with the pressure switch which is located on the blowout diaphragm. It is not possible to attain all three of these alignments exactly, so the best compromise should be sought. First, the third-stage to fourth-stage coupling is completely assembled. This assembly is then held up to the third-stage Nike to determine which of the three (120° apart) positions of the coupling puts the pressure switch (on blast diaphragm) closest to the pressure tap (on headcap of the Nike). With this done, the stage is rotated to the best one of four positions which exactly aligns the fins and brings the battery charging plug as near 6 o'clock as possible. The exact position of the stage lock pin hole in the third-stage nozzle can then be determined.

The fifth-stage ignition battery charging plug and the instrumentation pull-away should be located as near 6 o-clock as possible. These two points under the most unfavorable situation might assemble 180° apart. If this happens, the two plugs should be located at 3 o'clock and 9 o'clock rather than locating one at 6 o'clock and the other at 12 o'clock.

4. ASSEMBLY

For the sake of clarity in this section, we assign to the parts list of each stage those items which are a part of that stage at the time of final assembly of Strongarm on the launcher. For instance, the coupling casting H7-40149, which bolts to the front end of the third stage, and stays with the third stage throughout the total flight, is, for ease of assembly, mounted originally to the aft end of the fourth stage and is listed in the fourth-stage assembly list. Actually at Wallops Island the second and third stages were mated in the assembly building and transported to the launcher. This double assembly as a unit was then mated to the first stage. Similarly, the fourth and fifth stages were joined and transported as a unit.

4.1. FIRST-STAGE ASSEMBLY

The major operations required to make a Strongarm first stage from a standard Honest John booster (M6) are:

1. Eliminate fin cant.
2. Check fin alignment.
3. Install first- to second-stage coupling.
4. Install launching fittings.

A list of the parts and special equipment on hand for these three operations appears on the following page.

4.1.1. Elimination of Fin Cant.—The first step in eliminating the fin cant is to revise the standard Honest John fin-base fitting by reboring the two 1-in.-diameter bolt holes to a new diameter of 1-1/8 in. on the longitudinal axis of the part per drawing H3-40298. Two bushings are pressed in the newly bored holes in the fin-base fitting.

Reboring the fin-base fitting is not a field operation and makes it necessary to obtain the 4 fittings, which normally come mounted on the Honest John, well before the firing date.

Each H.J. fin has an alignment pin extending radially toward the center of the motor from the root edge of the fin. In the standard H.J. with the fin canted, this pin falls between two of the 1/2-in. socket-head cap screws which hold the nozzle on the motor body. When the cant is taken out of the fin, as in the Strongarm application, a new socket for this alignment pin must be provided. This is accomplished by removing the two appropriate socket-head cap screws and bolting on the alignment clip with two longer bolts, AN8-34A. The first field operation after getting the motor out of its box is to strip off

Part Name	Drawing or Catalog Number	Number Required
Honest John booster	M6A1C	1
Honest John fin	Fin, 762-mm Rocket, M136A2	4
Fin-base fitting	1340-333-0506-S008	4
Bushing, fin-base fitting	H2-40298	8
Bolt	AN8-34A	8
Clip-H.J. fin	H3-40386	4
Bolt	5306-333-0480-S008	8
Bolt	5306-333-0479-S008	4
Washer	5310-333-0544-S008	8
Fairing	1340-334-1229-S008	1
Coupling, H.J. to Nike*	H5-40267	1
Bolt*	An 12-47A	4
Washer - Coupling bolt*	H2-40406	4
Nut - Coupling*	H2-40385	4
Riding lug - H.J. aft	H2-40401	1
Bolt, riding lug, H.J. aft	AN8-36A	3
Riding lug, H.J. fwd	H3-40311	1
Unbrako Socket Head	3/8-24 x 5/8	6
Clinometer*	Watts 90° Clinometer	1
Motor alignment fitting*	H3-40297	1
Fin measuring device*	H5-40268	1
Allen wrench, long handle 1 in. across hex flats		1
Torque wrench 600 ft-lb capacity w/socket for 1-in. hex Snap-On Tool Co.		1
Allen wrench, long handle 5/8 in. across hex flats		1
Allen wrench, long handle 1/2 in. across hex flats		1

*Appears in other parts list.

the warhead pedestal (which contains four live spin rockets). Secondly, take off the fin fairing and remove the fin-base fittings if they have not already been removed for reboring. The motor should be held now on a dolly whose fore and aft ends can be separately raised and lowered. It is very convenient if the dolly is located under a hoist to facilitate rolling.

4.1.2. Fin Alignment.—The motor alignment fitting is bolted on the thrust face of the H.J. so that the table on the front face of the fitting is as nearly horizontal in both planes as possible. (The fitting attached to the Nike is shown in Fig. 18.) The motor is rolled and the dolly ends raised or lowered until this table is exactly horizontal in both planes as measured by the clinometer. Two fins should now be bolted on and should lie in a horizontal plane. The bolts should be good and tight but torquing up is unnecessary.

The next step is to draw three lines on the horizontal fins parallel to the motor axis and spaced span-wise 4 in. from fin root, center span, and 3 in. from fin tip, respectively.

The fin-measuring device is clamped over the leading and trailing edge of the fin at one of the lines just drawn, and when both sets of jaws on the fin-measuring device are seated and the thumb screws tightened, a clinometer reading is taken at the mid-chord point of the bars which connect the two sets of jaws. The setup is shown in Fig. 19. The clinometer is read in minutes of arc and the reading recorded right on the fin at the line being measured. "Plus" readings are deviations which would cause clockwise roll of the rocket in flight. The measurements along the three lines are averaged and a single plus or minus figure is assigned to each fin.

The criteria for acceptance of a single fin alignment are:

a. The difference between any two readings on a given fin shall not be more than 20 minutes.
b. The average of the three readings on a given fin shall not be greater than 10 minutes.

While the writers believe that, if all four fins meet the above two specifications, the set of fins is good enough, it is obvious that less roll will result if the algebraic sum of the four averages is within a few minutes of zero.

It is possible to change the clinometer readings on a given fin by the simple expedient of making one of the holes in the fin-base fitting sloppy by removing the bushing. The fin and fin-base fitting are then canted slightly to take out a few minutes of misalignment.

At the same time the fin alignment clip may be adjusted slightly on its own bolt holes or filed to give a little more adjustment. If and when the fin has been adjusted to an acceptable reading, the 1-in. bolt through the

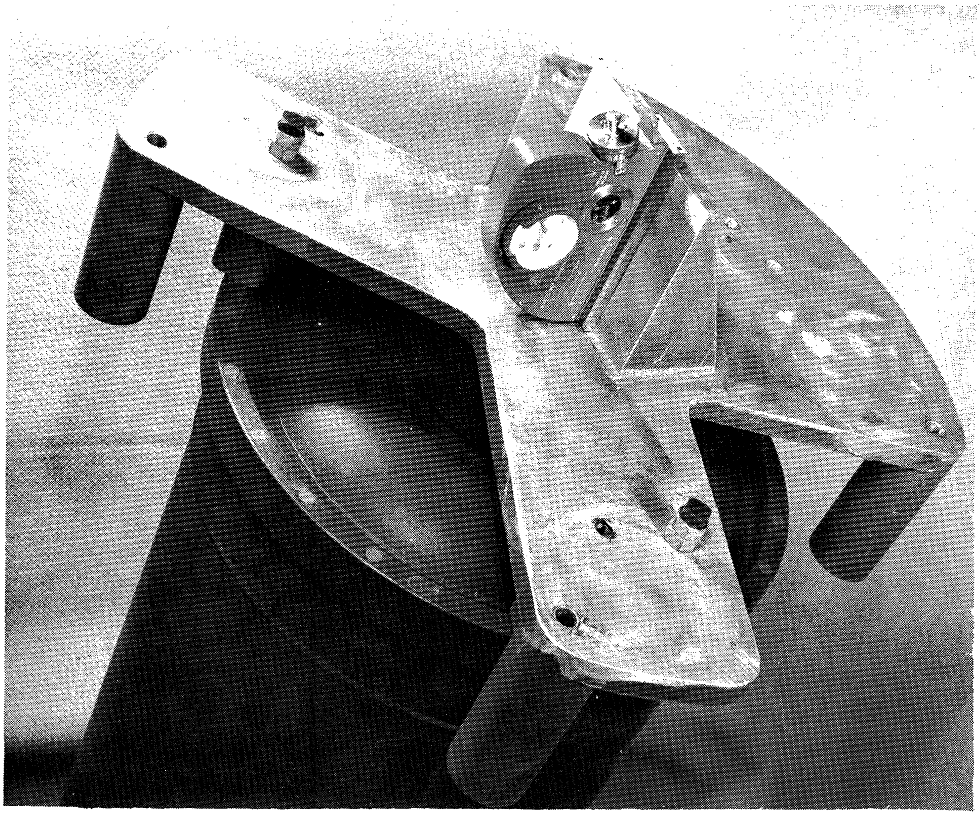

Fig. 18. Motor alignment fitting on second stage.

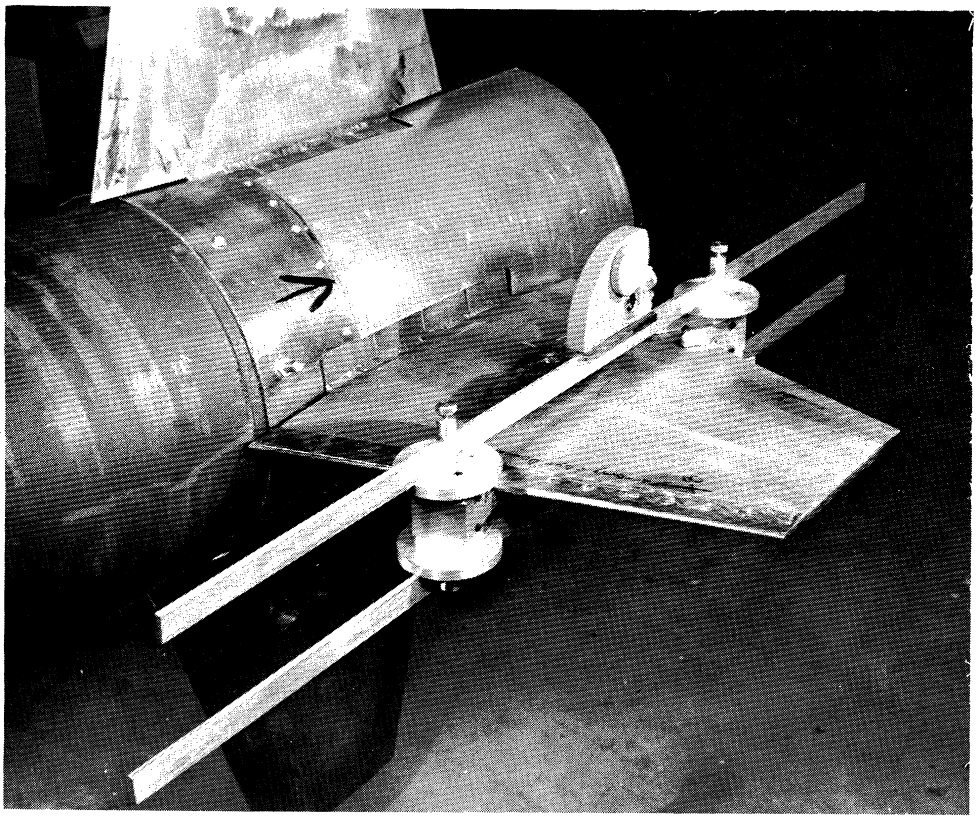

Fig. 19. Fin-measuring device on second-stage fins.

hole that still has the bushing is torqued up and the unbushed bolt is backed almost out. The space in the fin-base fitting around the bolt is filled as nearly as possible with Armstrong A-1 adhesive and the second bolt torqued up. The hardened A-1 is then in effect a nonconcentric bushing.

After the two horizontal fins are installed acceptably, they are marked as to where they go and are removed for a 90° rolling of the motor. The alignment fixture is reset, the leveling checked, and the second pair of fins are fitted. The fairing has four 5/8-in.-diameter holes to pass the fin-alignment pins. These are located to accommodate the standard canted fin and must be elongated to approximately 1 in. by 5/8 in. to pass the fin pin in the uncanted position. The AN8-34A hex-head bolts holding the alignment clip must be tightened so that the points of the hex head allow the fairing to slip on. A switch with a red metal tube is mounted on the fairing. This is removed completely and discarded.

4.1.3. Installation of Coupling.—The installation of the coupling, H.J. to Nike, is straightforward. The 17/64 bolt holes in the thrust face of the H.J. are drilled out to clear a 3/4 bolt. The AN12-47A bolts are inserted through the coupling. The H.J. coupling nuts H2-40385 are held behind the enlarged holes in the H.J. thrust face and the coupling lifted into position so that the AN bolts can be turned into the nuts through the thrust face. Occasionally the enlarged holes in the thrust face are not centered on the cavity formed by two welded-on stiffeners, or the weld bead interferes with the complete seating of the nut on the aft side of the thrust plate. In these instances, some filing, grinding, or machining of the nut is required. After fitting the nuts, they should be marked as to which cavity they go in, to facilitate assembly of the Strongarm on the launcher. The coupling is then removed from the first stage.

4.1.4. Installation of Launching Fittings.—Both sets of forward and aft standard Honest John launching fittings are removed and discarded. The new forward fitting H3-40311 is mounted with six 3/8-24 x 5/8 socket-head cap screws. The three top screws which bolt the nozzle to the Honest John body are removed and the aft launching fitting is bolted in place with three AN 12-36A bolts. The Honest John fin fairing must be notched to clear the aft launching fitting. In the standard Honest John duplicate launching fittings are mounted on the side opposite the launching rail for aerodynamic symmetry. In the Strongarm vehicle this is considered unnecessary.

4.2. SECOND-STAGE ASSEMBLY

To modify the standard Nike-Ajax booster (M5) for use as the second stage, the following operations are required.

1. Remove unnecessary hardware.
2. Attach fins.
3. Install spacer ring in nozzle.

4. Install pressure seal in nozzle.
5. Pressure test.
6. Install grain movement limiting blocks.
7. Install launching fitting and coupling.

A list of the parts and special equipment which should be on hand for these operations appears on the following page.

4.2.1. Removal of Hardware.—After uncrating the motor and placing it on a suitable dolly or horse, the removable hardware is discarded. On the tail this includes the fin shroud, fin attachment brackets (including studs), AN connector and ignition wire, and nozzle seal. On the head end, the thrust structure and Cannon connector are removed. All parts may be discarded except the Cannon connector and the 5/8-in.-18 x 3/4-in. bolts with special heads which are found on the forward end of the shroud. Should the bolts be lost, socket-head cap screws may be substituted. The Cannon connector will be used in the eventual hookup of the igniter.

The booster should be visually inspected by removing the head-end plastic plug and checking for cracks or obvious defects in the grain. The resonance-rods jam nuts should be run up finger-tight on the spider. They are sometimes found loose after shipping and handling.

4.2.2. Fin Attachment and Alignment.—First slip the forward shroud onto the nozzle and slide forward on the motor out of the way. The fin quadrants are assembled together with three hinge pins and six nuts, taking care that the quadrants corners stamped 'A,' 'B,' and 'D' are juxtaposed. Then the fins are placed on and wrapped around the nozzle, holding them forward so that the quadrant lands do not slide off the nozzle lands. The fourth pin is inserted from the rear. This pin should require some driving with a mallet but should not chew out large amounts of magnesium from the quadrant. It is not necessary to screw this pin into the anchor nut until the fitting is satisfactorily completed. When the pin is in, the weight of a man on a fin tip should slightly rotate the fins on the nozzle. If the fins are loose, shimming the nozzle lands is required. In most cases the fins will be tight and the quadrant lands will need to be scraped with a bearing scraper and the paint removed from the nozzle lands. Undersize hinge pins are another remedy, if available. Eccentric pliers to hold the quadrants together while driving in the pin are a great help.

After the fin fit is deemed satisfactory, the fin alignment is checked. The motor alignment fitting is bolted to the thrust face with the table horizontal. Then, with the clinometer on the table measuring in the vertical plane along the longitudinal axis, the motor is leveled.

With one pair of fins horizontal, the fin-measuring device is clamped onto the fin parallel with the longitudinal axis and about 4 in. in from the tip. The clinometer is laid on the device and a reading is taken. Angles of misalignment which tend to rotate the rocket clockwise when viewed from the tail

Part Name	Drawing or Catalog Number	Number Required
Nike-Ajax booster	M5	1
Nike fin, 2.5 sq ft w/cuff	H7-40137	4 (1 set)
Shroud, fwd	H3-40293	1
Shroud, aft	H3-40292	1
Hinge pin	H1-41985	4
Nut	5/16 in.	7
Cap screw, socket-head	3/8 in.-24 x 5/8 in.	4
Cap screw, hex-head	1/4 in.-28 x 5/8 in. w/grip threaded	4
Bolt	5/8 in.-18 x 5/8 in. w/special head	3
Screw, self-tapping, 100°	F.H. 10-32 x 1/2 in.	48
Ring, sealing	H3-40300	1
Plate, closure	H2-40388	1
Ring, spacer	H3-40291	1
Coupling, Nike to Nike*	H5-40273	1
Bolt, coupling*	NAS 147-32	12
Washer*	H2-40405	12
Launching fitting, 16 Motor	H2-40402	1
Bolt, launching fitting	NAS 150-43	1
Bolt, launching fitting	NAS 146-13	2
Motor alignment fitting*	H3-40297	1
Clinometer*	Watts 90° Clinometer	1
Fin-measuring device*		
Pressure-checking assembly, terminating with 1/4-in. flared tube nut*		1
Nike igniter dome*	A.O. No. 8025059	1
Nike igniter spanner wrench*	A.O. No. 8014473	1
Armstrong A-1 adhesive		1 qt
Paint remover*	Fed. Spec. TT-R-2510	1 qt
Pressure seal jig*	H5-40269	1
4-ft furniture clamp*		3
Methyl-ethyl-ketone*		1 qt

*Appears in other parts list.

are considered positive. The clinometer reading is then marked on the fin, and the procedure is repeated at midspan and near the root. Three readings are taken on the opposite fin in the same manner, after which the motor is rotated 90°, the motor alignment fitting relocated, the motor re-leveled, and measurements are taken on the remaining two fins. Reference to Figs. 18 and 19 may be helpful.

No single fin should have average misalignment exceeding 15' and the algebraic sum of the four average misalignments should not exceed 25'. Normally this sum will be less than 15'.

Providing the fins meet the alignment specifications, they are ready for rigid attachment to the motor. The forward shroud is slipped back and the three 5/8-in. bolts, four 3/8-in. socket-head cap screws, and four 1/4-in. cap screws are started in their respective holes, and the fins are rotated on the motor to fit into the shroud notches. The fins should be jockeyed forward as far as possible, and at least far enough so that the after quadrant lands are resting fully on the after nozzle land. The 11 bolts securing the forward shroud may then be tightened. Next the twenty-four 10-32 screw holes are drilled and countersunk, and the self-tapping screws inserted through the shroud into the quadrants.

The assembly is completed by slipping on the after shroud, drilling, countersinking, and driving the self-tapping screws.

4.2.3. <u>Installation of Spacer Ring in Nozzle</u>.—The spacer ring is cemented to the nozzle with Armstrong A-1 adhesive. First, the paint inside the nozzle exit must be removed in a band about 4 in. wide. This is accomplished by use of a good quality paint remover, wire brush, and clean rags. Care should be exercised in getting the paint out of the rather rough grooves in the machined surface. This may require considerable patience and elbow grease.

Next, the ring should be fitted. It is essential that the ring be entirely within the nozzle so that the thrust is applied to the nozzle, not the ring (see Figs. 9 and 10). On the other hand, the ring must not fit so far into the nozzle that its bearing surface is materially reduced. In addition, the adhesive thickness must be greater than .008 and less than .035 in. The recommended procedure is to attach four shims built of electrical tape, each about .020 in. thick and 1/4 in. square to the nozzle, 1 in. from the exit.

Then the spacer ring is inserted and pressed in firmly against the shims. The aft end of the ring should be flush to 1/32 in. inside of the nozzle exit. If it protrudes, then the shims are reduced in thickness and another measurement is taken; if the ring goes in too far, the shims are increased in thickness. The shim thickness must remain between .008 and .035 in. to insure the proper adhesive thickness; therefore if the ring cannot be made to fit properly by varying the shims in this range, the ring must be discarded or machined.

The final step is to mix about 6 oz of the A-1 adhesive according to directions. Coat the inner surface of the ring and the mating surfaces of the coupling with a thin layer of petroleum jelly to facilitate removal of any excess or spilled adhesive, being careful to get none on the external surface of the ring. Coat the external surface of the ring and the internal surface of the nozzle with adhesive and press the ring into place, taking care not to loosen the shims. Press the coupling into the nozzle. Attach the furniture clamps between the after end of the coupling and the heads of the 5/8-in. bolts which hold the forward shroud to the nozzle. Tighten the clamps until the ring is pressed into the same position as when dry-fitted. Use methyl-ethyl-ketone to remove A-1 from skin. Allow several hours at room temperature before removing the clamps and coupling. Allow 24 hr before stressing the ring.

4.2.4. Installation of Pressure Seal in Nozzle.—The pressure seal consists of a rubber ring and a phenolic diaphragm. The diaphragm, ring, and pressure-seal jig should be fitted dry to insure correct mating. Then they are removed and the convergent portion of the nozzle is carefully cleaned with methyl-ethyl-ketone. The external surface of the ring should be wire-brushed until the fibers are well broken. Coat the threads on the diaphragm stud with petroleum jelly. Mix a few ounces of A-1 and coat the cleaned convergent portion of the nozzle, the external surface of the ring, and the mating surfaces of ring and diaphragm. Insert the diaphragm into the nozzle. Then insert the ring. After mating the two, slip the assembly into position by holding the stud. Be careful not to smear A-1 adhesive onto the threads. Thread the center rod of the jig to the stud; then place the jig in the nozzle and tighten the handle. Do not use more than moderate finger pressure, since the purpose of the jig is only to align the seal in the nozzle, and not to extrude the adhesive out of the bonded surfaces. It is important to remove all excess adhesive before it sets—otherwise the coupling when inserted will have insufficient clearance. A few drops of adhesive in the nozzle throat may be enough to cause binding. If adhesive must be removed after setting, the use of a power drill with rotary file will speed the operation. Allow 24 hr to dry before pressure-testing.

4.2.5. Pressure Test.—The motor is pressure-tested to insure that the seal is working properly. The plastic plug is removed from the head-cap and the igniter dome is inserted. The threads should be greased before insertion to insure a good seal. Tighten with the igniter spanner wrench. The regulator assembly is attached to an inert gas supply and to the flared tube nipple on the head cap. The motor is pressurized to 15 psig and allowed to stand for about 5 min. The pressure drop should be less than 1 psi. Then the gas is bled out and the regulator assembly removed. The diaphragm is designed to break between 45 and 60 psig. Do not stand in front of or behind the motor during pressure-testing.

4.2.6. Install Grain Movement Limiting Blocks.—The propellant grain in the Nike-Ajax booster is held aft by a cone-shaped helical spring which is mounted between the forward end of the grain and the inside of the head-cap. The weight of the grain and the stiffness of the spring are such that, during the drag-produced deceleration in the coast periods, the grain can shift forward by further deflecting the spring. It is possible that the grain will move far enough forward to contact and crush the igniter or at least break the delay squibs. To prevent this motion of the grain, it is recommended that blocks of wood or phenolic be installed between the grain or spring and the head-cap of the booster. These can be so arranged that they may be held secure with Armstrong's A-1 adhesive.

4.2.7. Install Launching Fitting and Coupling.—The next operation on the second stage is to locate, drill, and tap three holes for mounting the forward launching fitting. With the orientation established according to 3.8 the center of the 5/8-18 tapped hole is located at 12 o'clock and 15/32 aft of the thrust face. The location of the two 3/8-24 tapped holes is determined from the launching fitting. All holes are tapped through.

The final operation is to mount the second- to third-stage coupling. This requires drilling and tapping of the thrust face of the second stage to provide tapped holes for six additional 7/16 bolts. The coupling is used as a drill jig to locate the holes. It is bolted on, using the existing tapped holes and oriented to bring the stage lock assembly H2-40403 at either 11 or 1 o'clock. Of these two positions, choose the one which makes the lead of the pressure hose from stage lock to pressure tap on the Nike the easiest. The coupling casting may have to be filed slightly to clear that portion of the launching fitting which projects forward of the thrust face. It is recommended that pilot holes of 1/8 and 1/4 diameters be drilled before using the 25/64 tap drill. This requires that three hardened steel bushings each 1-1/2 in. long and $.437^{+.000}_{-.005}$ outside diameter be available. The inside diameters of these bushings will be .391, .251, and .126. The holes must be tapped to a depth of 3/4 in.

4.3. THIRD-STAGE ASSEMBLY

The third stage is almost identical to the second stage. The first six operations described under second-stage assembly are required for the third stage. Only that operation peculiar to the third-stage assembly will be described here. It is entitled "Stage Lock Mating." A list of the parts and special equipment which should be on hand for the third-stage assembly appears on the following page.

4.3.1. Stage Lock Mating.—The orientation of the second- and third-stage bottles is set according to Section 3.8. The orientation of the second- to third-stage coupling is set according to Section 4.2.6. The coupling is used as a drill jig to locate a hole in the divergent section of the nozzle of the third stage. The stages are locked together by bringing the 1/2-in.-diameter pin of the stage lock assembly out radially through the hole in the third-

Part Name	Catalog or Drawing Number	Number Required
Nike-Ajax booster	M5	1
Nike fin, 2 sq ft		
w/Type "C" L.E. caps		1 set
Shroud, fwd	H3-40293	1
Shroud, aft	H3-40292	1
Hinge pin	H1-41985	4
Nut, 5/16 x 24 steel	AN 315-5R	8
Cap screw, socket-head	3/8 in.-24 x 5/8 in.	4
Cap screw, hex-head	1/4 in.-28 x 5/8 in. w/grip threaded	4
Bolt	5/8 in.-18 x 5/8 in. w/special head	3
Screw, self tapping, 100°	F.H. 10-32 x 1/2 in.	48
Ring, sealing	H3-40300	1
Plate, closure	H2-40388	1
Ring, spacer	H3-40291	1
Motor alignment fitting*	H3-40297	1
Clinometer*	Watts 90° Clinometer	1
Fin-measuring device*		
Pressure-checking assembly, terminating with 1/4-in. flared tube nut*		1
Nike igniter dome*	A.O. No. 8025059	1
Armstrong A-1 adhesive*		1 qt
Paint remover*	Fed. Spec. TT-R-2510	1 qt
Pressure seal jig*	H5-40269	1
4-ft furniture clamp*		3
Methyl-ethyl-ketone*		1 qt
Nike igniter spanner wrench*	A.O. No. 8014473	1

*Appears in another parts list.

stage nozzle (see Fig. 10). Pressure from the second-stage bottle shears a safety wire and retracts this 1/2-in.-diameter pin so that the stages can drag-separate at the end of second-stage burning. The coupling is inserted into the third-stage nozzle in its proper orientation and held in place with furniture clamps as in the process of installing the taper ring. A hardened steel bushing threaded 1"-14 NF2A on the outside diameter, 1-1/2 in. long, and 9/16 in. inside diameter is screwed into coupling, and a 9/16-in. hole is drilled through the nozzle and the aft fin skirt. Be sure that the whole stage lock assembly can be screwed out, working from the outside using a screw driver as will have to be done in the final assembly.

4.4. FOURTH-STAGE ASSEMBLY

The four major operations for assembly of the fourth stage are as follows:

1. Install the nozzle.
2. Install the igniter.
3. Install the nozzle closure (see next footnote).
4. Install the blowout diaphragm, coupling and pressure switch mounting plate.

A list of parts and special equipment which should be on hand for the fourth-stage assembly appears on the following page.

4.4.1. Installation of Nozzle.—It is assumed that prior to this operation the orientation of the various stages and couplings has been determined and marked as outlined in Section 3.8.

(a) Clean the threads on the nozzle and on the Yardbird.
(b) Screw the nozzle in tight against the shoulder using the nozzle wrench H5-40270.
(c) Put a mark on the inside of the nozzle near the aft edge which is in line with a mark on the OD of the Yardbird body near the aft end. These marks must be located where they can be seen when the nozzle is finally screwed inside the flared skirt.
(d) Remove the nozzle, keeping track of the number of turns it takes.
(e) Install the flared skirt, using twenty-four 5/16-in. socket-head cap screws. None should be really tightened until all 24 are well started. A speed wrench with proper socket and hex drive is desirable for inserting these bolts.
(f) Try the nozzle in again dry (with no Scotchcast) to determine that there is no interference with the skirt. Screw the nozzle in all the way. Check with the number of turns and with the previously applied reference marks.

Part Name	Catalog or Drawing Number	Number Required
Yardbird rocket	TE-289	1
Igniter	Type XI-10D	1
Pipe plug	Allen 1/4 ANPT	1
Coupling, Nike to Recruit, prepared per 4.6	H7-40149 (prepared)	1
Diaphragm, blowout, wired per 4.6	H5-40255 (wired)	1
Pressure switch support plate, wired per 4.6	H3-40318 (wired)	1
Extended nozzle	H5-40262	1
Flared skirt	H5-40277	1
Nozzle closure*	Thiokol CR-10,215C	1
Bolt, coupling, 4th to 5th	NAS 624-14	8
6-32 x 1/2-in. round-head machine screw		2
6-32 lock nut		2
5/16-in.-24 x 1-3/8-in. socket-head cap screw		24
Wrench-nozzle tightening	H5-40270	1
Strap wrench for 9-in. diameter*		1
Speed wrench with long extension		1
7/32-in. hex-drive socket for above		1
Celvacene grease, medium*		1 jar
Scotchcast resin No. 4 size A		2
Paper cups		6
1-in. paint brush		2
Igniter checker*	Alinco Mod. 101-5A or equal	1
Bushing, reducer	AN 912-1	1
Nipple (flight)	AN 816-3	1
Pressure checking assembly, terminating in 1/4" flared tube nut*		1
Nipple (pressure check)	AN 816-4	1
Permatex No. 2		1 tube

*Appears in another parts list.

(g) Remove nozzle and mix the Scotchcast following instructions on the package. Pour the mixed Scotchcast into a paper cup and immediately apply the resin with a paint brush to the end of the grain, the internal nozzle threads, and the male threads and "O"-rings on the nozzle itself. Insert the nozzle and, keeping track of the number of turns, seat it firmly against the shoulder. This operation must be done quickly as the resin sets rapidly.

4.4.2. Installation of Igniter.—

(a) Test the igniter with the igniter checker. Resistance should be approximately 1 ohm.
(b) Inspect the end of the igniter leads to be sure thay are shorted together with the shorting plug.
(c) Inspect and clean with methyl-ethyl-ketone the igniter seat on the rocket and the mating face of the igniter itself.
(d) Smear the "O"-rings and groove liberally with the Dow silicone grease provided with each igniter.
(e) Tie the string which runs through the grain to the end of the igniter leads and feed the igniter lead through the grain until the igniter is fully inserted. Bring all screws up finger-tight before wrench-tightening any. Tighten up opposite screws in turn a few degrees at a time to a maximum torque of 20 in.-lb.

4.4.3. Installation of Nozzle Closure.*—The nozzle closure is a truncated cone of high-density foam plastic with interconnected AN connectors molded in the forward and aft faces. The first step is to insert a shorting plug on the aft connector. Secondly, remove the shorting plug from the igniter leads and insert the igniter lead connector into the forward side closure plug. Scotchcast resin is used to cement the nozzle closure in place. The resin is mixed according to the directions on the package and then painted on both the nozzle and the closure. The closure is inserted and held in position for approximately 5 min. A 24-hr cure is recommended.

4.4.4. Installation of Blowout Diaphragm and Coupling.—Connect the Yardbird igniter extension cable to the connector on the aft side of the nozzle plug and feed the leads through the 1/2-in. hole in the diaphragm. Install the diaphragm by screwing it into the flared skirt. Attach the Yardbird igniter leads to the terminal strip. Screw the coupling, H7-40149, on the diaphragm

*The Thiokol Chemical Corporation has stated[5] that they "believe the Yardbird rocket engine will ignite satisfactorily at all altitudes without use of pressure sealing nozzle closures." This belief is based on static firings at 10 mm Hg ambient pressure, and experience with similar igniters and propellants in continuous use at high altitudes.

In view of these facts, the authors recommend that the nozzle closure be eliminated in future firings.

and mount the battery-charging socket with 6-32 screws. The pressure switch mounting plate is bolted temporarily to the head end of the Yardbird and the flexible hose connections are made to the igniter plate and to the pressure switch, using Permatex on the pipe threads. This hose must have an electrical insulating cover over its entire length because of its close proximity to terminal strips in the fourth- to fifth-stage coupling.

4.5. FIFTH-STAGE ASSEMBLY

The 5 major operations for assembly of the fifth stage are as follows.

1. Install igniter and nozzle and check pressure.
2. Install flare skirt.
3. Mount instrumentation.
4. Install nose cone.
5. Install blowout diaphragm and coupling to fourth stage.

The list of materials, parts, and special tools which should be on hand for this assembly appears on the following page.

4.5.1. Igniter Installation.—

1. Place the motor on a bench in cradles high enough to allow clearance for the aft-end flared skirt.
2. Remove the nozzle closure and head-end closure.
3. Reach into the grain and pull out bird cage pigtails. Tape the pigtails to the outside of the case at the aft end after inspecting the motor to be sure the igniter passage is clear.
4. Unpack the igniter and check its resistance, using a low current squib checker. The resistance would fall within 10% of the value shown on the container.
5. Pass the igniter insertion rod through the head-end of the motor, through the bird cage grommets and past until end of rod projects about five inches beyond aft end of motor.
6. Remove and discard grommets from igniter.
7. Remove and discard diaphragm protector from igniter.
8. Place metal igniter sleeve around tip of igniter insertion rod and hold in place with 26 or 28 gauge magnet wire. Tape ends of the magnet wire around tip of insertion rod.
9. Draw rod through head-end of the motor, pulling igniter into place. Do not exert undue pressure when fitting igniter through the bird cage.
10. Just before igniter diaphragm is positioned untape pigtail leads and stuff them into grain cavity.
11. Position diaphragm by pulling igniter snugly into place.
12. Apply celvacene or other heavy vacuum grease around edge of diaphragm in thread relief area. Take care not to get celvacene on the threads.

Part Name	Catalog or Drawing Number	Number Required
Scale Sergeant rocket motor	J-9041389	1
Scale Sergeant rocket igniter, instantaneous, nozzle leads		1
Scale Sergeant rocket nozzle	D-41413	1
Flared skirt	H5-40280	1
Diaphragm - blowout	H3-40317	1
Coupling 4th to 5th wired per 4.6	H5-40279 (wired)	1
Nose cone	H3-40319	1
Nose tip	H2-40424	1
Winchester socket A10S modified	H2-40414	1
Socket-head cap screw, 6-32 x 1/2"		2
Igniter checker*	Alinco Mod. 101-5A or equal	1
Celvacene grease		1 jar
Armstrong A-1 adhesive*		1 qt
Forming band - potting	H2-40447	1
Strap wrench*		1
Pressure checking assembly, terminating in 1/4" flared tube nut*		1
Igniter insertion rod	Supplied with Scale Sergeant motor on request	1
Special nozzle wrench	Supplied with Scale Sergeant motor on request	1
Pressure check head-end plug	Supplied with Scale Sergeant motor on request	1
Head-end plug rest	Supplied with Scale Sergeant motor on request	1

*Appears in other parts list.

13. Threadflared skirt on motor but do not tighten.
14. Screw nozzle into position by hand and then backflared skirt off so that the special strap type nozzle wrench can be wrapped around the minimum outside diameter of the nozzle. The nozzle is then seated by tightening the wrench and hitting the wrench sharply with a soft hammer two or three times while the motor is being held by a second man.
15. Remove igniter insertion rod and attach pressure tap head-end plug to igniter sleeve with a roll pin.
16. Insert pressure-tap head-end plug and hold in place with hex nut.
17. Pressure test at 15 psig for five minutes. The pressure should not drop more than 0.5 psig in five minutes.
18. Remove hex nut and pull out and disconnect pressure-tap head-end fitting.
19. Attach flight head-end plug to igniter sleeve with roll pin using head-end plug rest if necessary. The roll pin hole in the flight cap is smaller than the roll pin hole in the pressure-tap fitting or the igniter insertion rod.
20. Insert head-end plug in motor and hold in position with hex nut. This nut should not be torqued too severly. Tape hex nut in position.

4.5.2. <u>The Flared Skirt</u>.—The process of installing the flared skirt provides:

a. structural bond and support between the flared skirt and the motor.
b. thread locking between skirt and motor.
c. a smooth fairing between the Teflon coating on the motor and the outside diameter of the skirt. Reference to Fig. 12 may be helpful.

The installation process is as follows:

1. Screw skirt on until the shoulder at the thread is seated against extreme aft end of motor case and count the number of turns. Check to see that there is at least 1/32-in. clearance between forward end of the skirt and aft end of the Teflon cover. Put a reference mark on the flared skirt in line with the joint in the Teflon.
2. Coat the forming band H2-40447 with a light coat of a parting compound such as Dow Corning D.C. 4 or Vaseline. Position the band so that the inside surface of the band extends the line of the outside of the Teflon aft until this line intersects the surface of the flared skirt in its full on position. Use two small C-clamps to hold the band in this position.
3. Back the flared skirt off the motor as far as it will go and spread a coat of Armstrong A-1 adhesive (prepared with the usual amount of catalyst) on the curved forward inner surface of the flared skirt. A coating of between 1/8 and 1/4 in. is sufficient.

4. While one man holds the motor with a strap wrench at the extreme forward end of the motor, a second man screws the flared skirt back on the motor counting turns as he goes and stopping when the reference mark lines up with the joint in the Teflon. This process will extrude surplus adhesive between the band and skirt and between the two flanges on the band. This surplus should be cleaned off immediately with rags and knives but without the use of solvents. After the adhesive has become hard, the band is removed and any projections may be filed off.

4.5.3. Pull-away.—A ten-pin instrumentation pull-away is located on the inside of the forward skirt of the motor. A flange on the forward skirt has 12 equally spaced 10-32 tapped holes located on a 5-1/8-in. diameter for mounting instrumentation. Figure 15 shows the electron-density instrumentation mounted on the forward end of the motor.

4.5.4. Resin.—The skirt on the forward end of the motor is slightly tapered (0.5° per side) and the nose cone has a matching taper. The diameters are specified to close tolerances and the nose-cone mounting screw holes are offset longitudinally so that the taper on the countersunk screws tend to jamb the cone against the shoulder on the motor. The final buttoning up operation involves applying a Teflon-filled resin over the screw heads and smoothing the patch off after it has set. On the first Strongarm flights the resin took 24 hours to cure at room temperature. A faster curing resin will be used in future flights.

4.5.5. Completion of Assembly.—The fifth-stage assembly is completed by installing the complete fourth stage to fifth-stage coupling on the fifth stage. Pass the shorted igniter cable through the center hole in the blowout diaphragm and thread the diaphragm into the flared skirt until it seats against the skirt shoulder. Next, one end of a two-foot length of lacing twine is tied to the igniter cable connector and the other end passed through the center hole in the coupling casting. This allows one to fish the connector through after the casting is threading on to the blowout diaphragm. The igniter cable connector is then locked into the clamp H1-42288 and the clamp fastened to the aft side of the plate in the coupling casting.

The final operation prior to assembly on the launcher is to connect the fifth stage to the fourth. The temporary bolts holding the pressure switch support plate on the Yardbird are removed and the electrical connection between the pressure switch and the Jones terminal strip made. The 8 NAS624 bolts are then inserted in the coupling, through the pressure switch support plate, and are threaded into the tapped holes in the head end of the Yardbird.

4.6. IGNITION CIRCUIT PREPARATION

Preparation of the ignition circuitry involves:

1. Mounting and wiring the fourth-stage ignition components on the H5-40255 blowout diaphragm and H7-40149 coupling.
2. Mounting and wiring the fifth-stage ignition components on the H5-40279 coupling and the H3-40318 plate.
3. Constructing a battery charger.
4. Modifying the second- and third-stage (XM 24A1) igniters.
5. Making firing lead-in cables for the second and third stages.

1. Parts required for wiring the fourth-stage ignition components:

Part Name	Dwg or Catalog No.	No. Req'd
Coupling, Nike to Recruit	H7-40149	1
Blowout diaphragm	H5-40255	1
Hose assembly	Aeroquip 601002-4-0220	1
Hose support clamp	1/2-in. I.D.	1
Plastic tubing insulation	3/4-in. I.D.	2 ft
Pressure switch assembly	H2-42425	1
Elbow 90°	AN 822-4	1
Battery, Yardney Silvercel	HR-1	
	Stud and nut terminal	6
Intercell connector for HR-1 (long)	YEC 2385	4
Intercell connector for HR-1 (short)	YEC 2387	1
Solder lug, ring type	No. 5 7/16" long	8
Solder lug, ring type	No. 10	4
Two conductor cable	Belden 8478	2 ft
Cinch-Jones barrier terminal strip	6-140	1
Cinch-Jones socket	S-304-FP	1
Plate, arming	H1-42277	1
Plate, lug alignment	H1-42283	1
Bar, arming	H1-42278	2
Rod, threaded	10-32 x 1-3/16"	4
Nut, hex	10-32	16
Flat-head machine screw	10-32 x 1"	1
Flat-head machine screw, steel	6-32 x 3/4"	4
Battery box, 6 cell, w/cover and insulator	H1-42295	1
Mounting block, plug	H1-42164	1
Nozzle closure*	Thiokol CR10, 215C	1
Teflon-insulated stranded wire	No. 18 AWG	25 ft
Resistor, wirewound	100K ± 10% 1/2 w.	1
Socket-head cap screw	1/4"-28 x 1/2"	2
Socket-head cap screw	8-32 x 5/8 in.	2
Truss-head machine screw	10-32 x 3/4 in.	2
Round-head machine screw	6-32 x 5/8 in.	1
Filister-head machine screw	6-32 x 7/8 in.	4
Round-head machine screw	8-32 x 1/4 in.	4
Lock nut	8-32	4
Lock nut	6-32	5
Lock nut	10-32	2

The blowout diaphragm should be screwed into the flared skirt until it bottoms; then the coupling casting screwed onto the diaphragm. A gap of about .020 in. between the parts will show on the outside when the two are properly mated. Make index marks on the three pieces. Drill the diaphragm as per drawing H2-40432. Mount the pressure switch, Jones strip, battery box, mounting block-plug, and hose clamp. Battery packs are constructed in accordance with H1-42174. Wire the components in accordance with H2-40433. Cable the wiring and secure with cable clamps as necessary. Note that the components are on the aft side of the diaphragm and tend to be pulled off as the rocket accelerates. Thus the battery packs are placed in the boxes, terminals down, pressed into the insulators. For initial checkout of wiring, the packs may be set inverted in the boxes relative to flight position. This enables a convenient checkout without danger of battery leakage. Once the packs are installed for flight, a worthwhile precaution is to turn the diaphragm over and let it be suspended with the batteries upright until assembly of the diaphragm to the fourth-stage motor.

Mount the arming plate and lug alignment plate on the coupling. The threaded rods are secured by a nut on each end. The arming bars go on the rods under the plate cover on the outside. For the inside wiring refer to H2-40433.

Remove the AN connector from the cable on the CR 10,215C nozzle closure and splice on a short length of two conductor cable terminated by No. 10 solder lugs. The cable should be long enough to go through the center hole of the diaphragm and reach the arming plate terminals on the coupling. See footnote, p. 44.

2. Parts required for wiring the fifth-stage ignition components:

Part Name	Dwg or Catalog No.	No. Req'd
Coupling	H5-40279	1
Support plate	H3-40318	1
Pressure switch assembly	H2-42425	1
Elbow 90°	AN 822-3	1
Battery box w/cover and insulator	H1-42297	2
Cinch-Jones barrier terminal strip	6-140	1
Battery, Yardney Silvercel	HR-1	6
Intercell connector for HR-1 (long)	YEC 2385	4
Intercell connector for HR-1 (short)	YEC 2387	1
Resistor, wirewound	100K ± 10% 1/2 w.	1
Clamp, igniter plug	H1-42288	1
Connector, Viking	VS416C7	1
Socket, Winchester	M4S	1
Teflon-insulated stranded wire	No. 18 AWG	10 ft
Solder lug, ring type	No. 5 - 7/16"	12
Solder lug, ring type	No. 10	4

Round-head machine screw	8-32 x 3/8 in.	8
Filister-head machine screw	6-32 x 1/2 in.	4
Socket-head cap screw	1/4"-28 x 3/8 in.	1
Socket-head cap screw	1/4"-28 x 3/4 in.	1
Arming block	H1-42281	1
Hose assembly	Aeroquip 601002-3-0080	1
Bar, arming	H1-42282	2
Screw, arming bar	H1-42282	4
Screw, round-head machine	10-24 x 3-1/2 in.	2
Nut, hex	10-24	2
Nut, hex	8-32	12

Install the battery boxes, Jones strip, Winchester socket, igniter plug clamp, and arming block in the coupling and wire them as per drawing H3-40322.

Install the pressure switch on the support plate as shown in drawing H3-40322. Wire the switch with leads of sufficient length to reach the terminal strip when assembled, plus 4 in. This slack is to permit attachment of the wires to the terminal strip as the fifth stage is assembled to the fourth.

Install the hose assembly and elbow on the pressure switch as shown in drawing H3-40322. Cover the hose with plastic tubing.

3. Parts required for constructing a battery charger:

Part Name	Dwg or Catalog No.	No. Req'd
12-v storage battery	Automobile type	2
Aluminum chassis 12 x 8 x 3 in.		1
Cinch-Jones barrier terminal strip	3-142	1
d-c Ammeter 0-15A		2
d-c Voltmeter 0-30V		2
Gang switch, 4-wafer, 3-position		1
Cinch-Jones plug	P-304-FHT	2
Cinch-Jones plug	P-304-FP	1
Cinch-Jones plug	P-304-CCT	1
Cinch-Jones socket	S-304-CCT	1
Cord, rubber jacketed, 4-conductor stranded, No. 18 AWG	Belden 8454	300 ft
Potentiometer, 16Ω, 50 w.		2
Winchester plug	M 4 P	1

Wire the chassis and cable as per drawing H2-40434.

4. Modifying the XM24A1 igniters:

The following description and parts list are for construction of igniters each with two squibs in parallel. Strongarms I and II were flown with four parallel squibs per igniter, which, except for the number of squibs, were identical to the igniters described below. It is the opinion of the authors that, when all factors are considered, reliability is best served by using a two-squib igniter and future firings will be conducted accordingly.

The parts and equipment necessary to modify both igniters are:

Part Name	No. Req'd
XM 24A1 igniter	2
FFFG black powder	2 grams
Squib, 7-sec delay, Hercules SD39A0	12 (incl. tests)
Squib, 25-sec delay, Hercules SD39B0	12 (incl. tests)
Gelatin capsule, No. 0	4
Cap-igniter, H2-40399 Rev. A	2
Solder lug, ring tongue, No. 6	4
Screw, self-tapping, round-head, 6-32 x 1/4"	12
Tape, electrical, 1/2" Scotch 33 or equal	1 roll
Scotchcast Resin No. 4, Size A	4
Cement, fast drying (model airplane)	1 tube
Paper cup	4
Paint brush, 1-1/2", inexpensive	4
Scalpel, heavy, X-Acto No. 6 or equal	1
Soldering iron, electrical, and solder	1
Hand drill with No. 28, No. 36, No. 50 and 21/64" twist drills	1
Long nose pliers	1
Diagonal cutters	1
Spintight wrench 5/16"	1
Bowl or can with lid, 2-qt capacity	1
Safety glasses	1
Igniter tester (Allegany Instrument Co. Model 101-5A or equal	1

Caution: Since this operation involves handling a large quantity of black powder in proximity with squibs, it should be considered hazardous. Observe the usual safety precautions of: no visitors, matches, or lighters. Someone should observe from a distance. Disconnect soldering iron from electrical source while soldering on squib leads. Protect eyes while working on squib harness. A grounded, metal-top work bench is best. Take special precautions to avoid static electrical buildup, such as wearing conducting footwear and grounding hands occasionally.

First test a portion of each batch of delay squibs to insure reliability and correct time delay. It is important that this test be conducted with the firing voltage and current which will be used at actual launch, since wide variations will cause abnormal delays or misfires. Testing at least eight squibs from each batch is recommended; failure of one squib is good cause to reject the batch. Select for installation two squibs with nearly identical resistance from each batch.

The modification is done as follows: Unbox the igniter. Arrange the can and cardboard liners to support the inverted igniter. With the scalpel cut a hole in the top of the phenolic cap and pour the black powder into the bowl. Then cut the top out of the phenolic cap as close to the side as possible. (Do not cut the top off by cutting the side as this will reduce the volume.) Discard the top. Pour out and brush out the remaining powder. Cover the bowl and remove several feet from the bench. Remove the squib harness from the inside terminals using the spintight wrench. Discard the harness. Mix one pack of Scotchcast and pour in cup. Paint the inside of the metal dome (except terminal studs) with Scotchcast, and set aside to dry. To save time, during this drying period the other igniter may be similarly prepared and the squibs installed in the plastic caps. To install the squibs, drill a hole 21/64 in. down the centerline of each boss. Then with a No. 50 drill, drill two holes straight through the cap beneath the entrance to each large hole. Cover the metal portion of each squib from the input (wired) end to 1/2 in. from the output end with Scotch 33 tape. Apply the tape longitudinally—it should not overlap. With this single wrap of tape the squibs should fit snugly in the holes. If not, ream holes or shim with tape as required. When the squibs are properly fitted, push them through the cap so that only the 1/2 in. of untaped output end extends beyond the plastic and into the powder cavity. Cement the squibs in this position. Feed the lead wires through the No. 50 holes into the powder cavity and tape them to the squib input end for protection and support. Cut the squib leads to an appropriate length and solder the lugs to the leads so that the two squibs are connected in parallel. (Leave sufficiently long leads so that the cap can be moved out of the way while attaching the lugs to the terminals.) Attach the lugs to the terminals and replace the rubber insulator caps. Check the igniter for continuity and resistance from the Cannon connector after the leads have had a few minutes to cool. The shorter "half" of the No. 0 gelatin capsule should fit over the output end of the squibs. Fill one of these "half" capsules half full of FFFG black powder and cement over the end of each squib.

Place the cap in position and drill six equally spaced No. 36 holes through the cap edge and phenolic side. Make index mark. Remove cap and ream cap holes with No. 28 drill. When the Scotchcast has hardened, pour most of the powder mixture back into the igniter, tapping, shaking, and pressing to settle the powder. Replace the cap and attach with the self-tapping screws. By pressing gently through the hole in the cap, the remaining powder can be returned to the igniter. If after several attempts a small amount still remains, it may be discarded. Cement the plug in the hole. Check the igniter again for resistance. Mix a pack of Scotchcast and paint liberally over the side, cap, screws, plug, squibs, and wires. This seals and strengthens the igniter. No Scotchcast should be allowed to run onto the threads.

5. Construct firing lead-in cables for the second and third stages out of two-conductor, 18 AWG, rubber-jacketed cable. (Belden 8478 is proper diameter.) On one end splice the Cannon plug which is obtained from the head cap of the Nike booster. On the other end attach solder lugs of proper size to fit the terminals in the launcher terminal box. Cable length should equal the distance from the igniter to the launcher terminal box, plus ten feet. The slack is taken up by taping the cable to the rocket five feet forward of the igniter position.

4.7. STRONGARM ASSEMBLY

The following parts and assemblies should be on hand for the final assembly:

Part Name	Catalog or Drawing Number	Number Required
First-stage assembly		1
Honest John igniter		1
Honest John head-end closure		1
Honest John to Nike coupling*	H5-40267	1
Bolts, coupling*	AN12-47A	4
Nut, coupling*	H2-40385	4
Washer coupling*	H2-40406	4
Second-stage assembly		1
Nike igniter	XM24A1 (Modified per 4.6)	1
Coupling Nike to Nike*	H5-40273	1
Bolt, coupling*	NAS 147-32	12
Washer*	H2-40405	12
Firing lead-in cable, 2nd stage	Per 4.6.5	1
Stage lock assembly	H2-40403	1
Flex hose, Aeroquip	601001-4-0100	1
Third-stage assembly		1
Nike igniter	XM24A1 (Modified per 4.6)	2
Nike igniter spanner wrench*	A.O. No. 8014473	1
Firing lead-in cable, 3rd stage	Per 4.6.5	1
Fourth- and fifth-stage assemblies joined	Per 4.5.5	1
Bolt, coupling	NAS 147-24	6
Washer	H2-40405	6
Igniter Tester Alinco Model 101-5A*		1

*Appears in other parts list.

The dolly shown in Fig. 4 is equipped to position either saddle laterally or vertically. The actual mounting of the first stage on the launcher is accomplished by moving the Honest John aft approximately two inches and simultaneously engaging the forward and aft launching fittings. The adjustments in the dolly greatly facilitate aligning the Honest John with the launcher. Once the first stage is suspended from the launcher the igniter is checked and installed and the flight front end closure screwed in and seated with at least 300 ft-lb torque. Permatex No. 2 should be applied to the male thread prior to installation of the closure. The first- to second-stage coupling is bolted to the thrust face of the Honest John and the AN 12-47A bolts torqued up to approximately 300 ft-lb.

The second stage is now brought to the launcher on the same dolly as was used for the first stage. The actual mating is again an aft motion which simultaneously mates the second-stage nozzle with the coupling and the forward launching fitting with the launcher retracting fitting. Care must be exercised that the taper ring which has been glued in the Nike nozzle is not banged during this loading operation. The second-stage igniter—modified to 7-sec delay—is now installed with Permatex No. 2 on its threads. The igniter cable which connects the igniter with a permanently installed voltage source on the launcher boom is fed out through one of the four 5/16 riding lug bolt holes on the under side of the thrust face of the Nike. This cable has a Cannon connector—previously removed from the Nike head cap—on the inside end and solder lugs which are shorted together on the outside end. A simple overhand knot is tied in the cable at the inside of the riding lug bolt hole. This cable has to part at launch and the knot prevents pulling on the interior wiring.

The pressure hose with stage lock attached is now connected to the pressure tap on the second-stage head cap. The second- to third-stage coupling is now mounted on the second stage using 12 NAS 147-32 bolts and 12 H2-40405 washers. The stage lock assembly is then threaded into the coupling until the 1/2-in.-diameter pin is flush with the outside surface of the coupling.

The third stage is then brought into position and carefully mated to the coupling. A slight rotation of the third stage may be necessary to center the stage lock pin with the hole in the third-stage nozzle. The stage lock pin is then screwed out as far as it will go. The dolly can then be removed and the third-stage igniter with its 25-sec delay squibs and the firing lead-in cable is installed.

The operation of joining the fifth stage to the fourth is much more easily done out of the weather and at bench level. It is recommended that these two stages be joined as described in Section 4.5.5 and brought as a unit to the launcher. Then, with the Yardbird positioned in line with the first three stages and removed axially about 6 in., the pressure hose from the diaphragm mounted pressure switch is connected to the pressure tap on the Nike. The cannon socket on the Nike is mated with the cannon plug on the end of the firing lead-in cable and the coupled connector secured in the Mounting Block-Plug-H1-42164. The fourth-stage coupling is then bolted to the third-stage thrust face.

5. VEHICLE PROCUREMENT AND COSTS

The following table gives the source and costs of the major parts of the Strongarm rocket. These are 1959-1960 costs and do not include tooling costs.

Item	Source	Unit Cost	Total Cost
Honest John w/igniter	Ordnance Corp.	$7,595.00	$ 7,595.00
Honest John fin	Ordnance Corp.	145.00	580.00
Honest John fin mounting fitting	Ordnance Corp.	37.00	148.00
Honest John fin mounting bolts	Ordnance Corp.	3.35	27.00
Honest John fin mounting bolts	Ordnance Corp.	2.00	8.00
Honest John fin fairing	Ordnance Corp.	118.00	118.00
Nike-Ajax booster w/igniter	Ordnance Corp.	2,949.00	5,898.00
Yardbird rocket w/igniter	Thiokol Chem. Corp.		5,800.00
Scale Sergeant metal parts	Cooper Dev. Corp.	1,510.00	1,510.00
Scale Sergeant propellant and igniter	Jet Propulsion Lab.	1,530.00*	1,530.00
Scale Sergeant Teflon coating	Douglas Aircraft Corp.	400.00*	400.00
Nike fins 2-1/2 s.f.	Magline, Inc.	792.00	792.00
Nike fins 2 s.f.	Magline, Inc.	836.00	836.00
Honest John to Nike coupling		245.00	245.00
Nike to Nike coupling		200.00	200.00
Nike to Yardbird coupling (3 parts)		538.00	538.00
Yardbird to Scale Sergeant coupling (4 parts)		700.00	700.00
Pressure Switch	Local Shop	160.00	320.00
Stage lock	Local Shop	200.00	200.00
Pressure hose	Aeroquip	14.00	42.00
Nike sealing ring	Detroit Rubber Prod.	3.00	6.00
Spacer ring	Magline, Inc.	38.00	76.00
Batteries	Yardney Electric Corp.	7.50	90.00
Launching fittings	Miller Tool and Die Co.	105.00/set	105.00
Nose cone	Douglas Aircraft Corp.	750.00*	750.00
Nose tip Teflon	Local Shop	50.00	50.00
Delay squibs	Hercules Powder Co.	125.00/lot	250.00
Misc. bolts, nuts, washers, etc.			150.00
			$28,964.00

*Approximate.

REFERENCES

1. Hansen, W. H., and Fischbach, F. F., The Nike-Cajun Sounding Rocket, The University of Michigan Engineering Research Institute Report 2453-1-F, March, 1957.

2. Hansen, W. H., and Fischbach, F. F., The Exos Sounding Rocket, The University of Michigan Research Institute Report 2595-1-F, December, 1958.

3. Grimminger, G., Williams, E. P., and Young, G.B.W., "Lift on Inclined Bodies of Revolution in Hypersonic Flow," J. Aero. Sci., 17, 675 (1950).

4. Orr, L. W., Cath, P. G., and Darnall, B. R., A Two-Frequency Beacon for High-Altitude Ionosphere Rocket Research, The University of Michigan Research Institute Report 2816-3-F, December, 1959.

5. Thiokol Chemical Corporation, Elkton Division, letter from P. Blumhardt to Univ. of Mich. Ref: PP/507 of April 13, 1960.