THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING
Department of Aeronautical and Astronautical Engineering
High Altitude Engineering Laboratory

Final Report

THE NIKE-YARDBIRD SOUNDING ROCKET (VERTIGO)

Prepared for the Project by:

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ABSTRACT

The Nike-Yardbird (Vertigo) sounding rocket was designed to fill a need in upper-air research for an economical vehicle capable of carrying an 80-pound payload to an altitude of 140 statute miles. The report describes the vehicle in detail and gives the results of the first two test firings. Parts lists and procurement information are included.

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1. INTRODUCTION

The Vertigo sounding rocket is a two-stage, solid-propellant, aerodynamically stabilized vehicle capable of carrying a payload of 80 pounds to an altitude of 140 miles. It is the latest in a series of designs by this laboratory. Nike-Deacon[1], Nike-Cajun[2], Exos[3], and Strongarm[4] were previously designed and constructed here.

Vertigo consists of a Nike-Ajax booster and a Thiokol* Yardbird, both of which are relatively short-duration solid-propellant motors. Both stages are fin stabilized, and the coupling is of the simple post type with separation accomplished by differential drag. The burn-out velocity of the second stage is approximately Mach 7. Both stages are ignited on the ground with the second-stage burning initiated through 27-sec delay squibs.

The Vertigo is pictured in Fig. 1. Figures 2 and 3 show the gross dimensions and predicted trajectory. Two flight tests have been carried out to date. Both failed during second-stage burning. Post-flight analysis showed that both failures were probably caused by a failure at the separation joint in the nose structure. This structure was peculiar to the instrumentation carried and not to the sounding rocket system, therefore additional flights with a conventional nose cone are indicated.

The preparation, assembly and launching of Vertigo can be carried out by a small crew with modest equipment. The total cost of the vehicle is approximately $11, 000. The vehicle may be readily launched from either a slightly modified Nike-Ajax launcher or boom-type zero length launcher.

2. PERFORMANCE

2.1 Designed

The Vertigo rocket was designed to carry payloads of 80 pounds to 140 statute miles altitude. Simple trajectory calculations based on a vertical launch show a variation of 2/3 mile altitude per pound change in payload. Figure 4 is a graph of payload vs altitude. From the general characteristics of the rocket system payloads from 60 to 110 pounds are considered most practical, though certainly not limiting.

A summary of flight parameters for critical points of the trajectory with vertical launch and an 80-lb payload are given in the table below.

*Thiokol Chemical Corporation

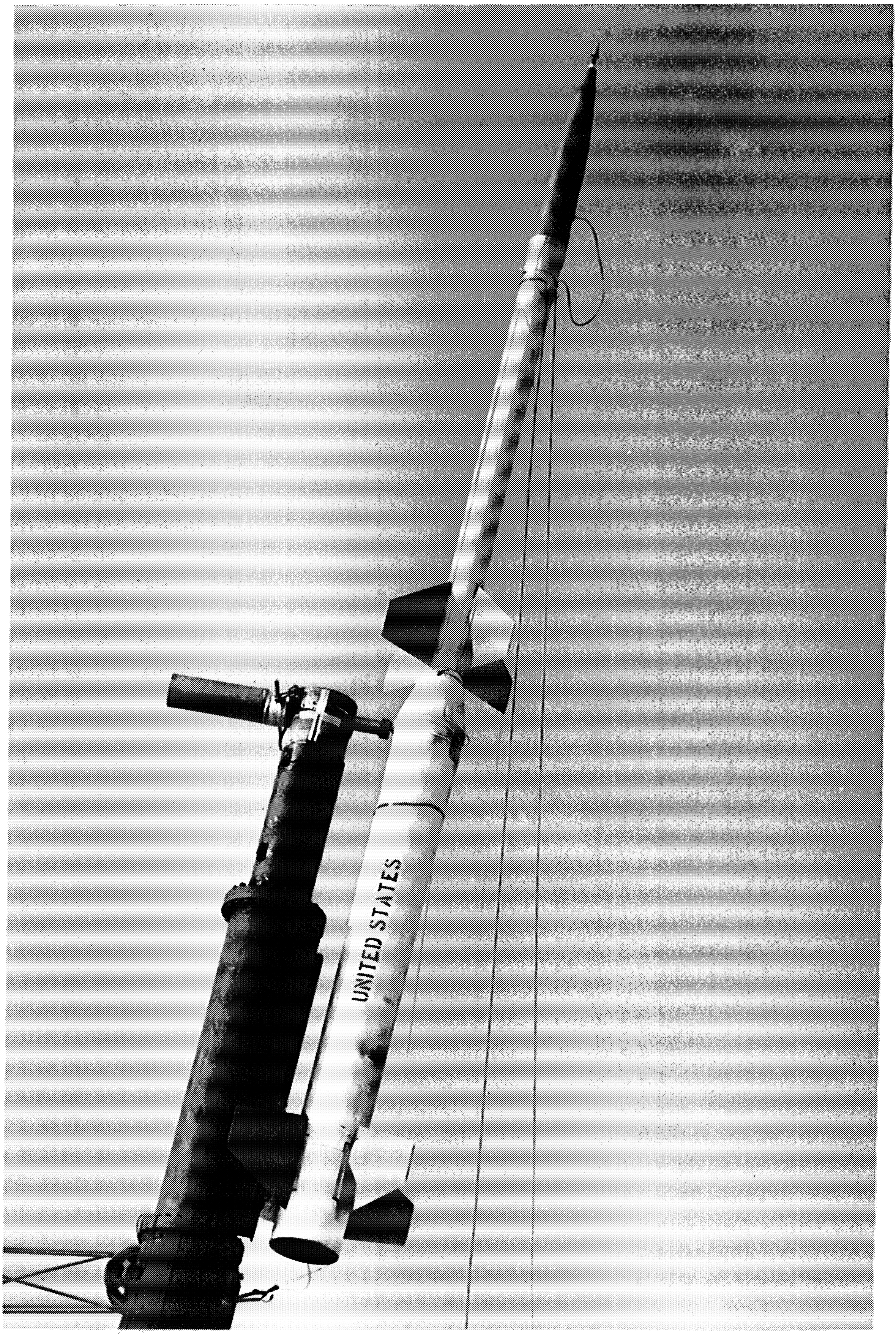

Figure 1. Vertigo on Launcher.

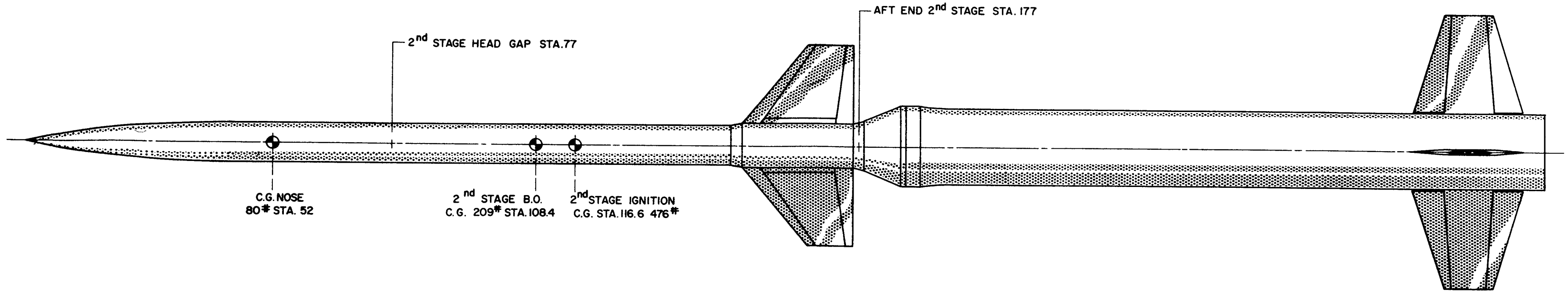

Figure 2. Vertigo Weights, Centers of Gravity and Gross Dimensions.

Figure 3. Estimated Trajectory of Vertigo with Vertical Launch.

VERTICAL TRAJECTORY
(80 lb. Payload)

Time (sec)	Altitude (ft)	Velocity (ft/sec)	Thrust (lbf)	Mass (slugs)	Density x 10^3 (slugs/cu ft)	Reynolds No. per ft x 10^{-4} (ft^{-1})	Drag Coef. x Frontal Area (ft^2)	Acceleration (ft/sec^2)
.000	1	0	39838	55.013	2.3767955		.16	692
.125	12	86	39838	54.069	2.3759605	54	.16	705
.250	33	175	39838	53.125	2.3742915	111	.16	718
.375	66	264	39838	52.181	2.3717069	167	.16	731
.500	110	356	39838	51.237	2.3682097	225	.16	745
.625	165	449	39838	50.293	2.3638039	284	.16	759
.750	233	544	39838	49.349	2.3584946	343	.16	774
.875	312	640	39838	48.405	2.3522052	403	.16	789
1.000	404	739	39838	47.461	2.3450262	464	.16	805
1.125	509	840	39838	46.517	2.3368015	526	.18	821
1.250	626	942	39838	45.572	2.3277058	588	.57	829
1.375	756	1046	39838	44.628	2.3176682	650	.80	837
1.500	899	1151	39838	43.684	2.3065390	713	.79	852
1.625	1056	1257	39838	42.740	2.2944957	776	.76	868
1.750	1226	1366	39838	41.796	2.2814729	839	.74	884
1.875	1410	1476	39838	40.852	2.2674882	902	.71	900
2.000	1609	1589	39838	39.908	2.2524809	966	.68	918
2.125	1821	1703	39838	38.964	2.2365512	1029	.65	936
2.250	2048	1820	39838	38.020	2.2196421	1094	.63	954
2.375	2290	1940	39838	37.076	2.2017775	1158	.61	974
2.500	2547	2061	39838	36.132	2.1829827	1221	.59	994
2.625	2820	2186	39838	35.187	2.1631319	1285	.57	1016
2.750	3109	2313	39838	34.243	2.1424075	1349	.56	1038
2.875	3414	2442	39838	33.299	2.1206893	1412	.54	1062
3.000	3735	2575	39838	32.355	2.0980114	1477	.52	1087
3.125	4073	2711	39838	31.411	2.0744825	1540	.50	1114
3.250	4429	2850	0	15.168	2.0499927	1603	.26	-117
3.750	5809	2761	0	15.168	1.9575710	1495	.27	-164
4.250	7148	2679	0	15.168	1.8719450	1398	.27	-153
4.750	8449	2603	0	15.168	1.7923300	1311	.28	-142
5.250	9714	2532	0	15.168	1.7181522	1231	.28	-133
5.750	10946	2465	0	15.168	1.6488393	1159	.28	-125
6.250	12147	2402	0	15.168	1.5839913	1094	.28	-118
6.750	13319	2343	0	15.168	1.5231915	1033	.29	-111
7.250	14462	2288	0	15.168	1.4661155	977	.29	-106
7.750	15579	2235	0	15.168	1.4123688	927	.29	-100
8.250	16671	2185	0	15.168	1.3618358	879	.29	- 95
8.750	17739	2137	0	15.168	1.3140800	835	.30	- 91
9.250	18784	2092	0	15.168	1.2689794	795	.30	- 87
9.750	19808	2048	0	15.168	1.2262881	757	.30	- 83
10.250	20811	2007	0	15.168	1.1859077	722	.31	- 80
10.750	21793	1967	0	15.168	1.1475825	688	.31	- 77
11.250	22757	1928	0	15.168	1.1112375	658	.31	- 75
11.750	23701	1891	0	15.168	1.0767242	629	.31	- 72
12.250	24628	1855	0	15.168	1.0439062	602	.32	- 70
12.750	25537	1820	0	15.168	1.0126576	576	.32	- 67
13.250	26430	1786	0	15.168	.9828968	552	.32	- 65
13.750	27306	1753	0	15.168	.9545471	530	.33	- 64
14.250	28167	1722	0	15.168	.9275037	508	.33	- 62
14.750	29012	1691	0	15.168	.9016700	488	.33	- 60
15.250	29841	1661	0	15.168	.8770178	468	.33	- 59
15.750	30656	1631	0	15.168	.8534594	451	.34	- 57
16.250	31457	1603	0	15.168	.8309424	433	.34	- 56
16.750	32244	1575	0	15.168	.8093606	417	.34	- 55
17.250	33017	1547	0	15.168	.7887273	401	.34	- 53
17.750	33777	1521	0	15.168	.7689441	387	.34	- 52
18.250	34524	1495	0	15.168	.7500259	372	.35	- 51
18.750	35258	1469	0	15.168	.7290842	358	.35	- 50
19.250	35979	1444	0	15.168	.7042097	342	.35	- 49
19.750	36688	1419	0	15.168	.6805903	325	.35	- 48
20.250	37385	1395	0	15.168	.6581329	309	.36	- 47
20.750	38071	1372	0	15.168	.6367744	293	.36	- 46
21.250	38744	1349	0	15.168	.6164771	279	.36	- 45
21.750	39407	1326	0	15.168	.5971205	266	.36	- 45
22.250	40058	1304	0	15.168	.5786969	254	.37	- 44
22.750	40699	1282	0	15.168	.5611177	242	.37	- 44
23.250	41328	1260	0	15.168	.5443784	230	.37	- 43
23.750	41947	1239	0	15.168	.5283983	220	.37	- 42
24.250	42556	1218	0	15.168	.5131577	209	.37	- 41
24.750	43154	1197	0	15.168	.4986019	200	.38	- 41
25.250	43742	1177	0	15.168	.4846802	192	.38	- 40
25.750	44319	1157	0	15.168	.4713957	183	.38	- 40
26.250	44887	1137	0	15.168	.4586847	175	.38	- 40
26.750	45445	1117	0	15.168	.4465361	167	.38	- 39

FIGURE 3 (continued)

Time (sec)	Altitude (ft)	Velocity (ft/sec)	Thrust (lbf)	Mass (slugs)	Density x 10^3 (slugs/cu ft)	Reynolds No. per ft x 10^{-4} (ft^{-1})	Drag Coef. x Frontal Area (ft^2)	Acceleration (ft/sec^2)
27.250	45993	1097	17126	15.168	.4349231	161	.29	1092
27.375	46147	1234	17126	14.893	.4317108	179	.28	1112
27.500	46318	1373	17126	14.619	.4281609	197	.27	1132
27.625	46507	1514	17126	14.344	.4242973	216	.26	1153
27.750	46714	1658	17126	14.070	.4200846	234	.25	1175
27.875	46939	1805	17126	13.796	.4155632	253	.24	1198
28.000	47183	1955	17126	13.521	.4107151	270	.23	1221
28.125	47446	2108	17126	13.247	.4055386	287	.22	1246
28.250	47728	2263	17126	12.972	.4000758	304	.21	1271
28.375	48030	2422	17126	12.698	.3943124	321	.20	1298
28.500	48353	2585	17126	12.423	.3882362	337	.20	1326
28.625	48696	2750	17126	12.149	.3818644	353	.19	1355
28.750	49061	2920	17126	11.875	.3752278	368	.18	1386
28.875	49447	3093	17126	11.600	.3683182	383	.17	1418
29.000	49855	3270	17126	11.326	.3611549	397	.16	1452
29.125	50286	3452	17126	11.051	.3537330	410	.16	1488
29.250	50740	3638	17126	10.777	.3460986	424	.15	1525
29.375	51218	3828	17126	10.503	.3382247	435	.14	1565
29.500	51721	4024	17126	10.228	.3301469	447	.14	1607
29.625	52249	4225	17126	9.954	.3218547	458	.13	1651
29.750	52802	4431	17126	9.679	.3133962	467	.13	1697
29.875	53382	4643	17126	9.405	.3047742	476	.12	1747
30.000	53989	4862	17126	9.130	.2959940	484	.11	1800
30.125	54625	5087	17126	8.856	.2870832	491	.11	1856
30.250	55289	5319	17126	8.582	.2780496	497	.10	1917
30.375	55983	5558	17126	8.307	.2689126	503	.10	1981
30.500	56708	5806	17126	8.033	.2596924	508	.09	2051
30.625	57466	6063	17126	7.758	.2504009	510	.09	2122
30.750	58256	6328	17126	7.484	.2410519	513	.09	2198
30.875	59081	6603	17126	7.210	.2316773	514	.09	2281
31.000	59941	6888	0	6.931	.2222764	514	.13	-131
31.500	63352	6822	0	6.931	.1886338	433	.13	-114
32.000	66734	6765	0	6.931	.1602970	364	.13	-101
32.500	70091	6715	0	6.931	.1363847	308	.13	- 90
33.000	73425	6670	0	6.931	.1161659	260	.13	- 80
33.500	76739	6630	0	6.931	.0990419	221	.13	- 73
34.000	80035	6593	0	6.931	.0845134	187	.13	- 66
34.500	83315	6560	0	6.931	.0721744	159	.13	- 61
35.000	86579	6530	0	6.931	.0616824	134	.13	- 57
35.500	89829	6501	0	6.931	.0527508	112	.13	- 53
36.000	93066	6475	0	6.931	.0451426	94	.13	- 50
36.500	96291	6450	0	6.931	.0386535	79	.13	- 47
37.000	99504	6427	0	6.931	.0331158	67	.13	- 45
37.500	102705	6404	0	6.931	.0283874	57	.13	- 43
38.000	105896	6383	0	6.931	.0243461	48	.13	- 41
38.500	109077	6362	0	6.931	.0208911	41	.13	- 40
39.000	112248	6342	0	6.931	.0179346	35	.13	- 38
39.500	115409	6323	0	6.931	.0154036	28	.13	- 38
40.000	118561	6304	0	6.931	.0132358	25	.13	- 37
40.500	121703	6286	0	6.931	.0113779	21	.13	- 36
41.000	124836	6268	0	6.931	.0097855	17	.13	- 35
41.500	127961	6250	0	6.931	.0084196	15	.13	- 35
42.000	131077	6233	0	6.931	.0072472	12	.13	- 34
42.500	134184	6215	0	6.931	.0062406	10	.14	- 34
43.000	137282	6198	0	6.931	.0055282	9	.14	- 34
43.500	140373	6181	0	6.931	.0049490	8	.14	- 34
44.000	143455	6165	0	6.931	.0044317	7	.14	- 33
44.500	146528	6148	0	6.931	.0039698	7	.14	- 33
45.000	149593	6131	0	6.931	.0035570	5	.14	- 33
45.500	152650	6115	0	6.931	.0031882	4	.14	- 33
46.000	155699	6098	0	6.931	.0028583	4	.14	- 33
46.500	158739	6082	0	6.931	.0025635	3	.14	- 33
47.000	161771	6066	0	6.931	.0022997	3	.15	- 33
47.500	164795	6049	0	6.931	.0020636	3	.15	- 32
48.000	167811	6033	0	6.931	.0018523	2	.15	- 32
48.500	170819	6017	0	6.931	.0016631	2	.15	- 32
49.000	173819	6001	0	6.931	.0014937	2	.15	- 32
49.500	176810	5985	0	6.931	.0013419	2	.15	- 32
50.000	179794	5969	0	6.931	.0012059	1	.15	- 32
50.500	182769	5952	0	6.931	.0010840	1	.15	- 32
51.000	185737	5936	0	6.931	.0009747	1	.15	- 32
51.500	188697	5920	0	6.931	.0008767	1	.14	- 32
52.000	191649	5905	0	6.931	.0007887	1	.14	- 32
52.500	194593	5889	0	6.931	.0007098	1	.14	- 32
53.000	197529	5873	0	6.931	.006389		.14	- 32
53.500	200457	5857	0	6.931	.0005753		.14	- 32
54.000	203377	5841	0	6.931	.0005182		.14	- 32
54.500	206289	5825	0	6.931	.0004669		.14	- 32
55.000	209193	5809	0	6.931	.0004207		.14	- 32

FIGURE 3 (concluded)

Time (sec)	Altitude (ft)	Velocity (ft/sec)	Thrust (lbf)	Mass (slugs)	Density x 10^3 (slugs/cu ft)	Reynolds No. per ft x 10^{-4} (ft^{-1})	Drag Coef. x Frontal Area (ft^2)	Acceleration (ft/sec^2)
55.500	212090	5793	0	6.931	.0003793		.14	- 32
56.000	214978	5777	0	6.931	.0003420		.14	- 32
56.500	217859	5162	0	6.931	.0003085		.14	- 32
57.000	220731	5746	0	6.931	.0002783		.14	- 32
57.500	223596	5730	0	6.931	.0002512		.14	- 32
58.000	226453	5714	0	6.931	.0002227		.14	- 32
58.500	229302	5698	0	6.931	.0001942		.13	- 32
59.000	232143	5683	0	6.931	.0001694		.13	- 32
59.500	234976	5667	0	6.931	.0001478		.13	- 32
60.000	237801	5651	0	6.931	.0001290		.13	- 31
60.500	240618	5635	0	6.931	.0001126		.13	- 31
61.000	243428	5262	0	6.931	.0000984		.13	- 31

143.5483 statute miles peak altitude

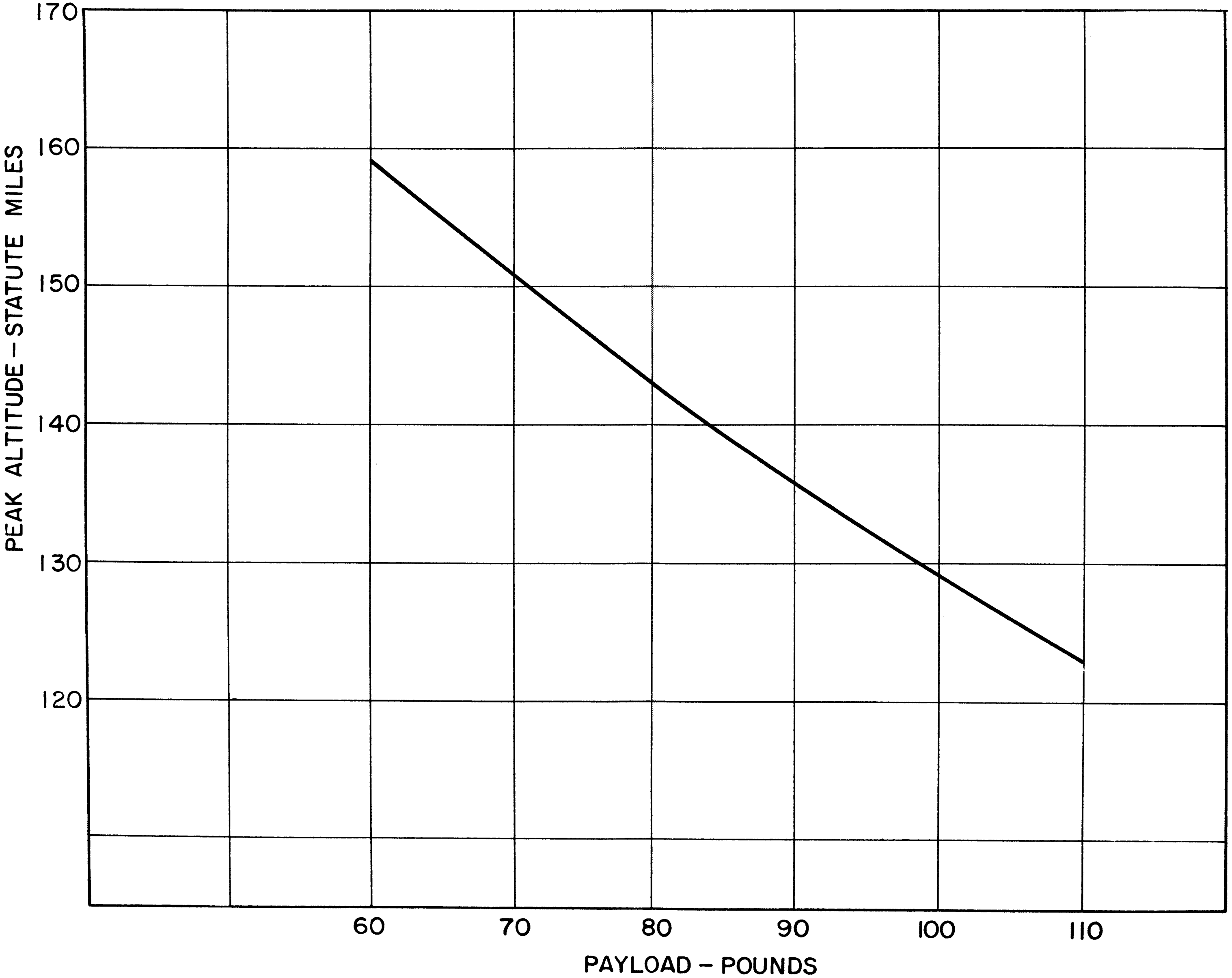

Figure 4. Peak Altitude vs Payload

FLIGHT PARAMETERS

	Time (sec)	Mass (slugs)	Drag (lb-ft)	Altitude (ft)	Velocity (ft/sec)	Acceleration (g's)
1st Ignition	0	55.01	0	0	0	22
1st Burn-out	3.25	31.41	3848	4429	2850	35
Separation	3.30	15.17	2200	4570	2842	-5.5
2nd Ignition	27.25	15.19	76	45993	1097	34
2nd Burn-out	31.00	6.93	474	59941	6888	74
Peak	245	6.93	0	143.5 mi	0	-1

Incorporation of the long, 24-sec, coast period was not for optimizing the altitude, but for reduction of aerodynamic heating. The fin leading edges were specially built to resist heating effects, and the nose cone was constructed of a Fiberglas-phenolic laminate. Just aft of the nose cone an aluminum alloy cylinder 19 in. long, formed the base of the instrumentation compartment. The alloy was 5086-0 (annealed condition) because no other was available in a suitable extrusion.

Temperature calculations were made on the cylinder and the fin leading edge, and are shown in Fig. 5. Temperatures on both appeared to be satisfactorily low.

The fin design was based on maintaining better than 1 caliber of static margin at Mach 8 with a typical nose shape.

2.2 Flight Test

To date, the Vertigo has had two flight tests. Both flights were conducted at Wallops Island, Va., at a launch angle of 80 degrees. Instrumentation was primarily to determine rocket performance: An angle of attack gauge was attached to the nose tip; two longitudinal accelerometers were carried; and a thermocouple and four thermistors were mounted in the fins and nose cone. Telemetry was FM/FM, three continuous channels and one commutated. A falling-sphere experiment to determine atmospheric density was also carried.

The first flight test went normally until 0.4 sec after ignition of the second stage, when an abnormally large yaw occurred. The yaw magnitude increased, and at 2.0 sec after ignition the rocket tumbled and

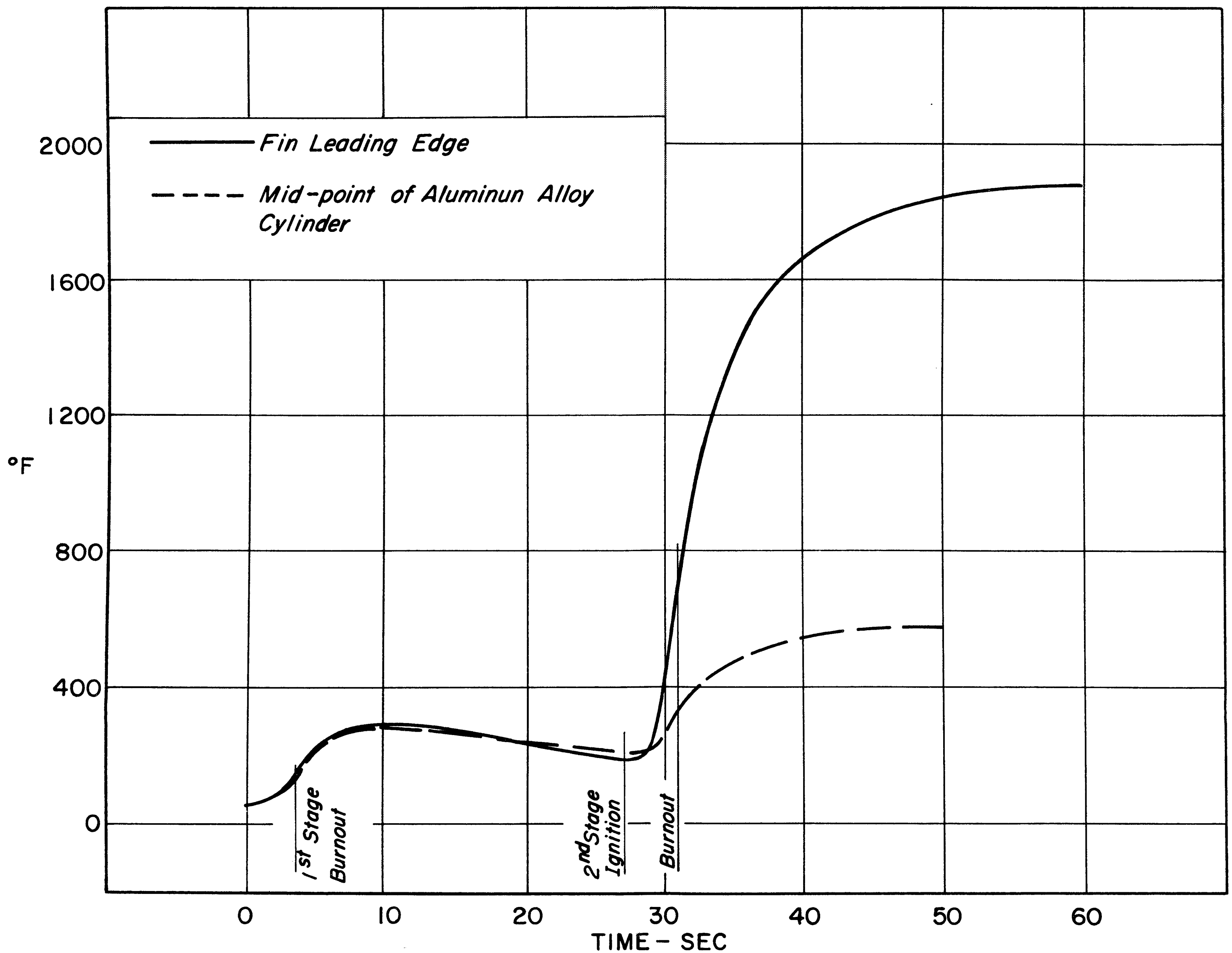

Figure 5. Skin Temperatures: Fin Leading Edge and Aluminum Cylinder

broke into several pieces. The telemetry equipment functioned throughout and data was received until impact.

Data reduction is completely described in the following memorandum report issued July 20, 1961:

"MEMORANDUM REPORT

Flight Test of First Nike-Yardbird Sounding Rocket

A. Flight History

"The first Nike-Yardbird (Vertigo) rocket was launched at Wallops Island, Virginia, on June 1, 1961, at an elevation angle of 80 degrees.

"The boost phase was normal.

"Separation occurred normally between 3 and 4 seconds. Rocket and booster were separated in space at 4.1 seconds by many yards. At 4.1 seconds telemetry shows a definite disturbance in the pitch and yaw channels and the drag accelerometer. The thermocouple and thermistor signals from the fin were normal before 4.1 seconds, showing a leading edge rise of roughly 160 degrees F. After 4.1 seconds the indications are those of an open circuit.

" The only explanation advanced of the irregularities at 4.1 seconds is that the RTV shroud containing the wires was wrenched from the rocket due to high dynamic pressure at this time.

"The coast period was normal with respect to yaw and drag. During the coast period, at 10.5-10.6 seconds the FPS-16 and Mod. II radars both detect an object separating from the rocket. This object was tracked sufficiently long for it to exhibit high drag to weight character but not as high as the particles typically left at ignition.

"This object would seem to be one of four things:

1. The dummy RTV shroud,
2. The wired RTV shroud which broke at 4.1 seconds and dangled since,
3. The frangible ring prematurely broken,
4. A layer of fiberglas-phenolic nose cone.

No other possibilities have been suggested. The Wallops Island radar operator is strong in his contention that the dummy RTV shroud would make no radar target whatsoever. No abnormalities occur subsequent to 10.6 seconds which appear to be a direct result of the object's separation.

"Between 12 and 13 seconds the falling sphere apparently began to function as if the ball switch had closed. The ball switch was designed to remain open as long as the sphere remained in the nose cone. The nose cone remained on the rocket at this time, thus the operation of the sphere is an unexplained anomaly and presumed to be unrelated to any other failure occurring on the flight.

"Telemetry functioned well throughout the flight and was excellent throughout boost, separation and coast. All functions telemetered were normal prior to Yardbird ignition except as noted above. In particular, the yaw and pitch were less than 1 degree; the drag acceleration was approximately as predicted; and the thrust acceleration was normal during boost. And the temperature measurements were as predicted except for the tail fin measurements which were interrupted at 4.1 seconds as previously noted.

"The Yardbird ignited at 28.77 seconds. The accelerometer indicates that the rocket engine reached the proper thrust level in about 35 milliseconds. The thrust rise was smooth but marked by a brief pause in the rise curve at about 12 g's (a similar pause was noted in the booster acceleration rise). The initial level of acceleration is about 42 g's and increases slowly for 1.4 sec to about 50 g's at 30.2 sec. The acceleration remains at 50 g's until the accelerometer record becomes grossly abnormal at 30.8 seconds.

"Returning to the situation at Yardbird ignition, 28.77 seconds, the alpha and beta records show virtually no yaw or pitch. These channels continue to show only small fluctuations, perhaps $\frac{1}{4}$ degree for .4 sec, when at 29.15 both pitch and yaw records show a decided saw-tooth character resembling severe vibration. (For the sake of a better name this saw-tooth record character will be called "vibration". Coincident with the beginning of this vibration (29.15 sec) the rocket begins to yaw abnormally and within $\frac{1}{4}$ sec is yawing 2-3/4 degrees. The vibration as well as the abnormal yaw continues until 30.8 sec when the rocket apparently tumbles, both pitch and yaw channels showing maximum readings.

"The FPS-16 radar detects an object separating from the rocket at about 29.15 sec, or nearly coincident with the beginning of vibration and abnormal yaw. It would appear that this separation is likely the primary cause of failure. The object's trajectory indicates a high drag-to-weight ratio, but not as high as ignition residue. The object requires 2 seconds to lose its velocity.

"The radar records show the sphere was ejected from the rocket and nose cone at 31.55 and tracked to splash at 218 sec by the FPS-16 radar. This means the nose cone separated from the rocket at the frangible ring joint between 30.8 and 31.55 seconds, presumably at the first tumble.

"Visual tracking and boresight cameras show second-stage ignition clearly at 28.7-28.8 sec. The smoke trail appears straight or slightly curving until about 30.8 seconds when the trail describes a helix of six turns during the next 1.2 seconds. No definite change of character of the smoke trail is noted at any time. The smoke trail fades into contrail gradually.

"Thus the rocket seems to have operated normally for .4 sec after Yardbird ignition, when a separation occurred accompanied by some type of vibration and a large yaw. The rocket failed to recover from this yaw and within 2.0 seconds after ignition had begun to tumble. The nose cone separated from the rocket in this tumble and the sphere was ejected.

B. Conclusions

"Based on the data above, the following conclusions are drawn:

1) Failure of the wired RTV shroud occurred at 4.1 sec due to high dynamic pressure. This failure was unrelated to the subsequent trouble.

2) The separation that occurred at .4 sec after Yardbird ignition was directly related to the failure. Immediately after this event the rocket yawed to destruction and there is indirect evidence of severe vibration. The yaw had to be caused by misalignment. (Wind shear is ruled out by the object which separated.) This suggests nozzle, fins, or nose cone trouble.

3) The time of the flight at which this failure occurred is significant, shortly after second-stage ignition. At this time the chamber pressure and acceleration are most likely to cause trouble as they are near the design maxima, while both dynamic pressure and aerodynamic heating are an order of magnitude less than their design maxima.

4) Since the rocket survived similar acceleration during boost phase, the failure is most probably associated with chamber pressure, i.e. operation of the second-stage engine. A rocket case failure is impossible since thrust continued, therefore a nozzle failure is indicated. This failure had to be minor enough to be scarcely noticed on the acceleration record but the cause

of a catastrophic misalignment, thus the carbon insert and phenolic lining seem to be the only possibilities.

5) Since both time and nature of the catastrophe point to nozzle trouble, this must be accorded the highest probability of cause of failure. It must be noted that this explanation does not account for the following:

a) Separation at 10.5 sec,

b) Apparent vibration encountered, and

c) Lack of thrust level change

6) Vibration and misalignment might both have been caused by a delamination of the nose cone due to aerodynamic heating. Although the heat input rates are modest and short in duration up to the time of failure, the low conductivity of the structure allowed the surface layer to become quite hot. One layer might be the object separating at 10.5 sec. This is considered the second most probable cause of failure.

7) Aerodynamic heating and vibration during boost might have loosened the frangible separation ring and allowed the nose cone to vibrate and tilt. This is believed the third most probable cause of failure.

8) Aerodynamic heating might have caused a primer to explode prematurely at 10.5 sec and remove the frangible separation ring. The nose cone might be presumed to be stable but misaligned at second-stage ignition due to an unlikely combination of drag, lift, deceleration, and acceleration. This explanation is accorded a small probability.

9) The fins or their leading-edge caps could cause misalignment if warped due to heating. This too is considered unlikely from theoretical considerations and past experience.

C. <u>Remedial Action</u>

"Because of the conclusions above, the following remedies are being undertaken on the second flight:

1) A new nozzle was strength tested and subjected to x-ray examination. Certain "planing" was seen in the graphite insert but it was not considered abnormal nor weakening. Strength testing was limited to the maximum expected load, which is the horizontal cantilever on the launcher.

2) The nose cone manufacture process was modified, and it is believed that the interlaminar strength was improved. In addition, the nose tip was revised to prevent the possibility of airstream impingement on the

edges of the laminate at the tip. Also, Emerson Electric Co. Thermo-Lag ablation material was sprayed over the nose cone and fairing ring.

3) The frangible ring was coated with Thermo-Lag and will be shrunk on at assembly. The ability of the primers to break the ring when so coated was tested.

4) A monitor to detect separation of the frangible ring was added to the instrumentation.

5) The fin and leading edge cap designs were reviewed but not changed.

Frederick F. Fischbach
July 20, 1961"

In addition to the remedies noted, a signal-strength roll record was taken on the second flight.

The second flight test was held on July 26, 1961. The gross results were identical to the first flight except that the abnormal yaw began immediately with ignition of the second stage; the rocket tumbled and broke 2.0 sec later. Again the telemetry survived and continued until splash. However, on this flight the frangible ring monitor indicated that the ring was in place at ignition of the Yardbird and detached within 1.2 sec afterward. An anomaly in the monitor circuit prevented a specific determination of the time of detachment, but the most probable time was between .9 and 1.1 sec.

The fact that the ring was definitely broken off so early is most significant. The existing yaw and dynamic pressure should not have broken the ring--thus a weakness is apparent either in ring strength or in the ejection timer circuit. In either case, a failure of the ring earlier in the flight which would cause the rocket failure would be consistent with the data.

Since testing showed that explosion of the primers would normally blow the broken ring parts well off the nose cone, the assumption of a timer failure alone could not explain the data. Therefore, the only hypothesis wherein a single failure accounts for all data is that the frangible ring was loosened by vibration or cracked by overstress at Yardbird ignition or before (probably near booster burnout). The resulting lack of rigidity precipitated abnormal yaws which resulted in breaking the ring completely off at 1 sec after Yardbird ignition and causing a tumble at 2 sec.

The next simplest explanation is that the timer failed at Yardbird ignition and exploded the primers immediately in the second flight (at .4 sec in the first). This explanation requires that the ring monitor switch was unexpectedly held open for 1 sec or that the monitor data is being misinterpreted.

The other explanations advanced after the first flight are still possible; but in light of the positive indication of frangible ring separation, this failure must be added in every case. Furthermore, three of these explanations were virtually ruled out by corrective measures, these being: 1) delamination of the nose cone due to aerodynamic heating, or 2) explosion of a primer due to aerodynamic heating of the ring since nose cone and ring were coated with Thermo-Lag, yet the flights were almost identical and 3) fin or fin-cap warping would have induced roll, but the roll record shows little or no roll throughout.

In summary, the possible causes of rocket failure were:

1) Frangible ring loosened by vibration or cracked by overstress prior to, or at, Yardbird ignition.

2) Premature explosion of primers due to timer failure plus either anomalous operation of monitor switch or misinterpretation of monitor switch data.

3) Failure of nozzle insert or lining causing thrust misalignment, plus premature loss of frangible ring due to timer failure or overstress.

Each of these possibilities furnishes a logical and consistent explanation of all data obtained from both flights. The simplicity of the first makes it most probable. The monitor switch data between Yardbird ignition and 1.2 sec afterward are difficult to interpret, while few theoretical grounds exist for suspecting the nozzle insert or lining; therefore, the second possibility is deemed considerably more probable than the third.

3. DESIGN FEATURES

3.1 Motors

The first stage of Vertigo is the booster motor of the Army's Nike-Ajax antiaircraft missile system. The Army designation is either M-5 or M-5 E1.

The second stage of Vertigo is the Thiokol Chemical Corporation's Yardbird. The Thiokol designation is TE 289.

3.2 Launching and Handling

The Vertigo can be assembled on and launched from the standard Nike-Ajax system launcher. Slight modification to the transporter rail is necessary. This modification is completely described in Ref. 2. The Vertigo, because of its high initial acceleration, is admirably suited for zero length launching. Figure 1 shows Vertigo in the firing position on such a launcher.

No unusual handling equipment is necessary although neither stage is light enough to be safely man-handled. A fork lift truck or a dolly which can be adjusted vertically is a virtual necessity.

3.3 Stability

Both stages are stabilized by means of cruciform fins. The first-stage fins are $2\frac{1}{2}$ sq. ft. in area per fin and are a weldment of cast and wrought magnesium. These fins are shown in Fig. 6 and are more fully described in Ref. 2.

The second stage or Yardbird fins are a clipped-tip delta planform of 2 sq-ft area shown in Fig. 7. The leading edge is at a 50° angle to the longitudinal axis of the rocket. The fin is tapered from 5/8 in. thickness at the root to $\frac{1}{4}$ in. thickness at the tip. The fin also has leading and trailing edge tapers. The material chosen for the fin is the thorium alloy of magnesium HK 31 A. This has significantly better high-temperature strength characteristics. It was felt that for the first four rockets the added cost of the material and the added inconvenience of working with a radioactive material was justified.

The calculated skin temperature for the second stage fin leading edge was so high that protection for the magnesium fin was called for. Figure 8 shows a cross section through the leading edge. The .031 Inconel sheet is die formed to give a smaller radius than is possible with a brake, and also makes a more symmetrical part. The copper heat sink was machined from bar stock, annealed and then silver plated.

Figure 6. First-Stage Fins.

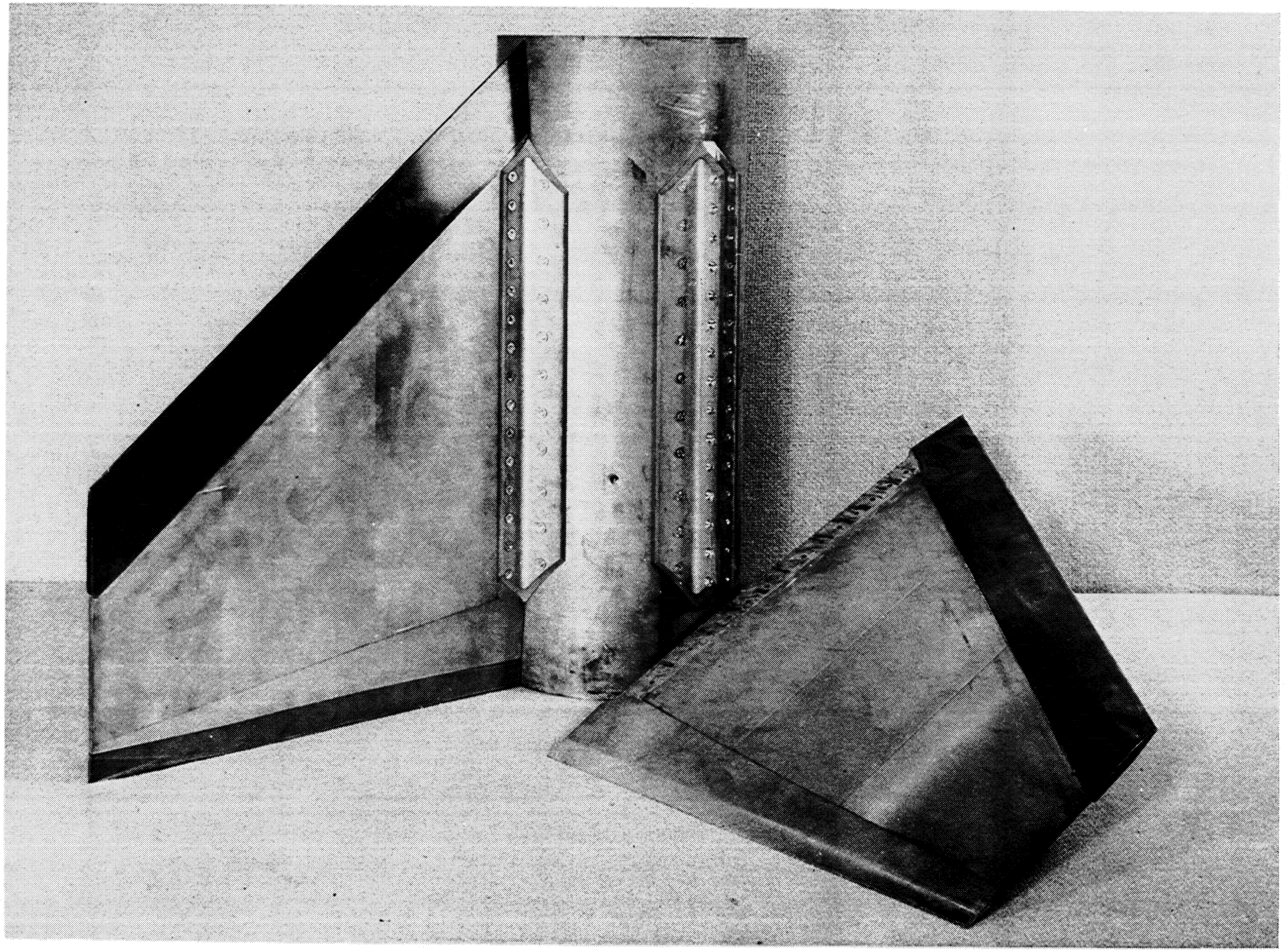

Figure 7. Second-Stage Fins.

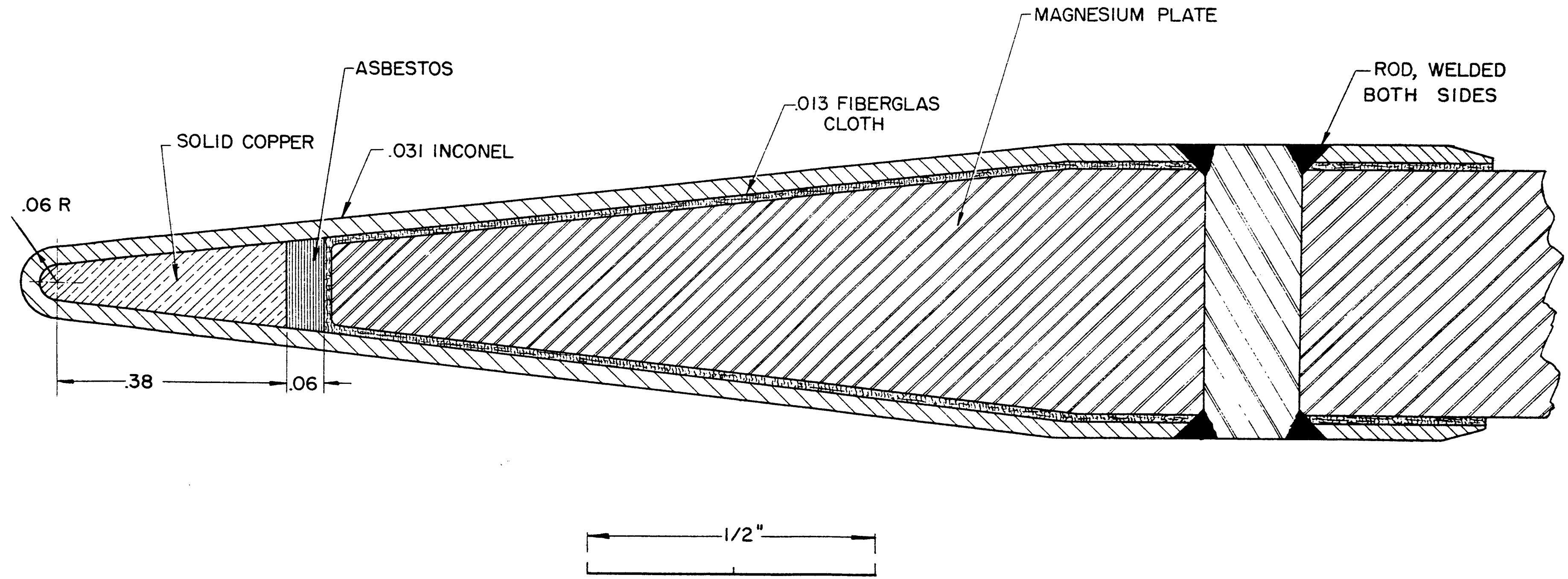

Figure 8. Yardbird Fin: Leading Edge Cross-Section.

The formed Inconel part was also annealed, and then the copper strip forced into the Inconel in the forming die. The copper-Inconel assembly was then oven brazed, the silver plate acting as the braze material. This cuff then is installed over .013-in Fiberglas cloth with a 1/16-in strip of asbestos insulation between the copper and the Fiberglas cloth. The fastenings to the fin consist of short posts of Inconel welding rod inserted in holes drilled through the cuff and fin and welded to the Inconel sheet on both sides. The fastening is then ground down flush with the Inconel.

3.4 Coupling and Flight Program

The coupling between the first and second stage, Figs. 9 and 10, is basically the simple post type with no locking device. The coupling is a magnesium casting tapering from the Nike diameter at the base to a short post on the forward end, which is a few thousands of an inch less in diameter than the Yardbird nozzle throat. A second cylindrical fit is provided between the exterior surface of the nozzle and a steel ring which is bolted to the magnesium casting. Separation of the two stages occurs automatically when the first stage ceases to thrust, due to different drag-weight ratios.

The flight program calls for first-stage burning of about 3 sec followed immediately by separation and a coast period of 24 sec, at which time the Yardbird ignites. The first-stage igniter contains instantaneous squibs, and the second stage has 27-sec delay squibs. Both sets of squibs are ignited on the ground with a simple circuit employed to prevent the application of voltage to the second-stage squibs until after the first stage has started to move. The long coast period is used to reduce the heating rather than simply to maximize the peak altitude. Vertigo's peak altitude varies only 0.4 mile per sec variation in coast period, when the coast period is near 24 sec.

3.5 Instrumented Nose

The nose cone, Figs. 11 and 12, consists of an aluminum cylinder topped by a Fiberglas laminate cone with a modified 22-caliber tangent ogive shape. The aluminum cylinder and the Fiberglas cone are joined by a frangible threaded ring. This particular arrangement was used to accommodate two geophysical experiments, both requiring an ejectable nose cone, and one requiring the absence of metal in the ejected part.

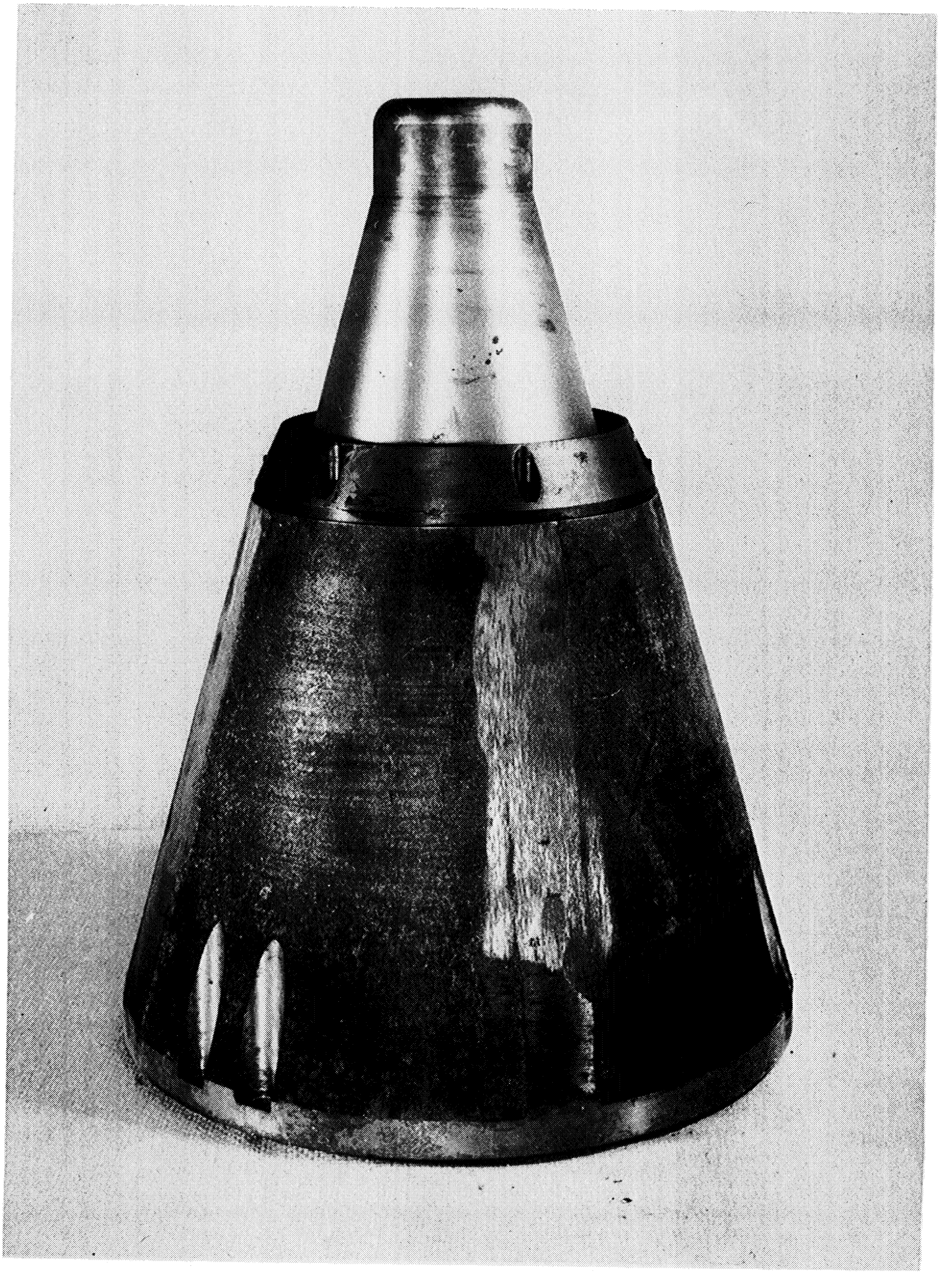

Figure 9. Coupling Parts.

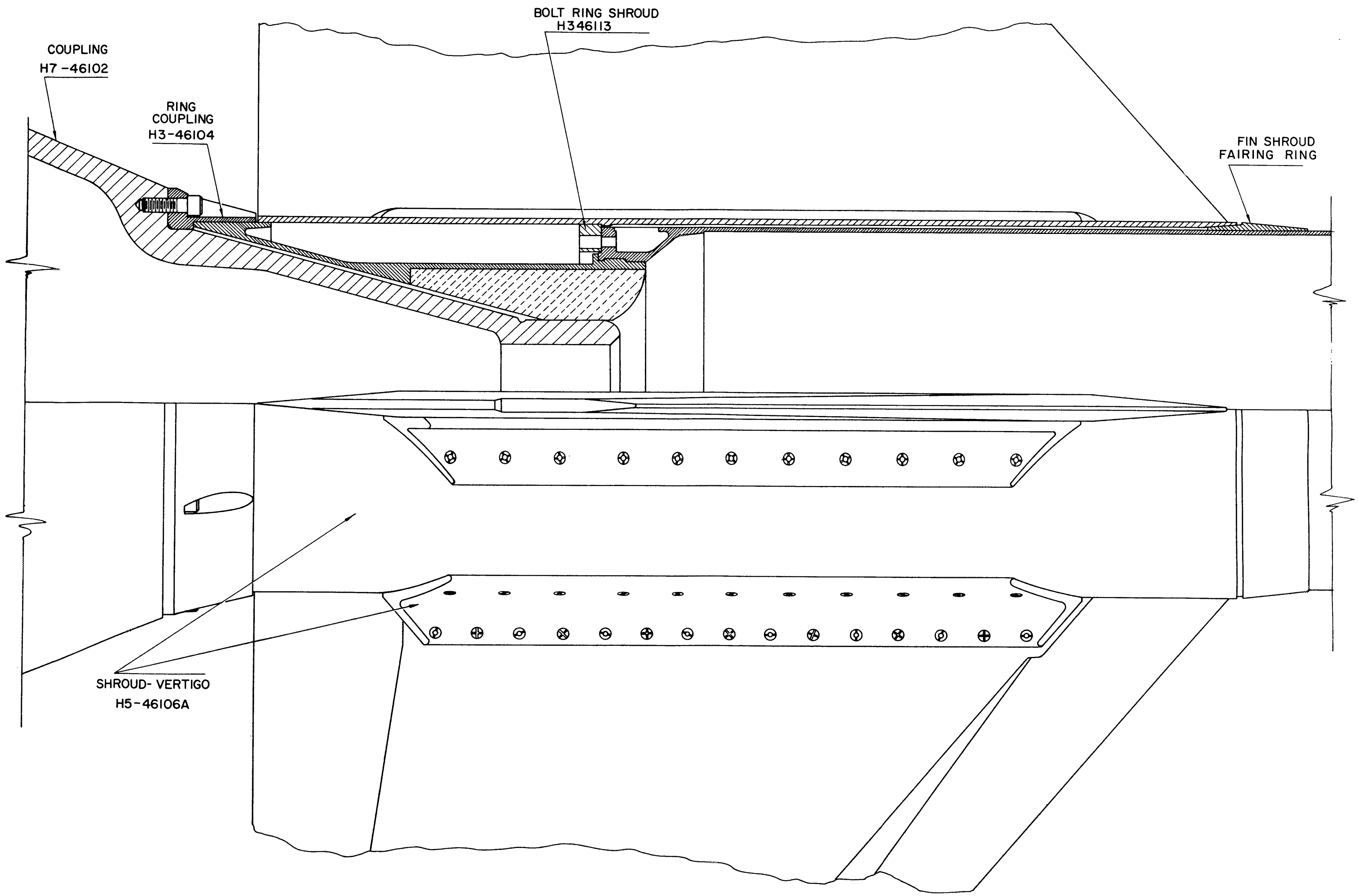

Figure 10. First- to Second-Stage Coupling Assembly.

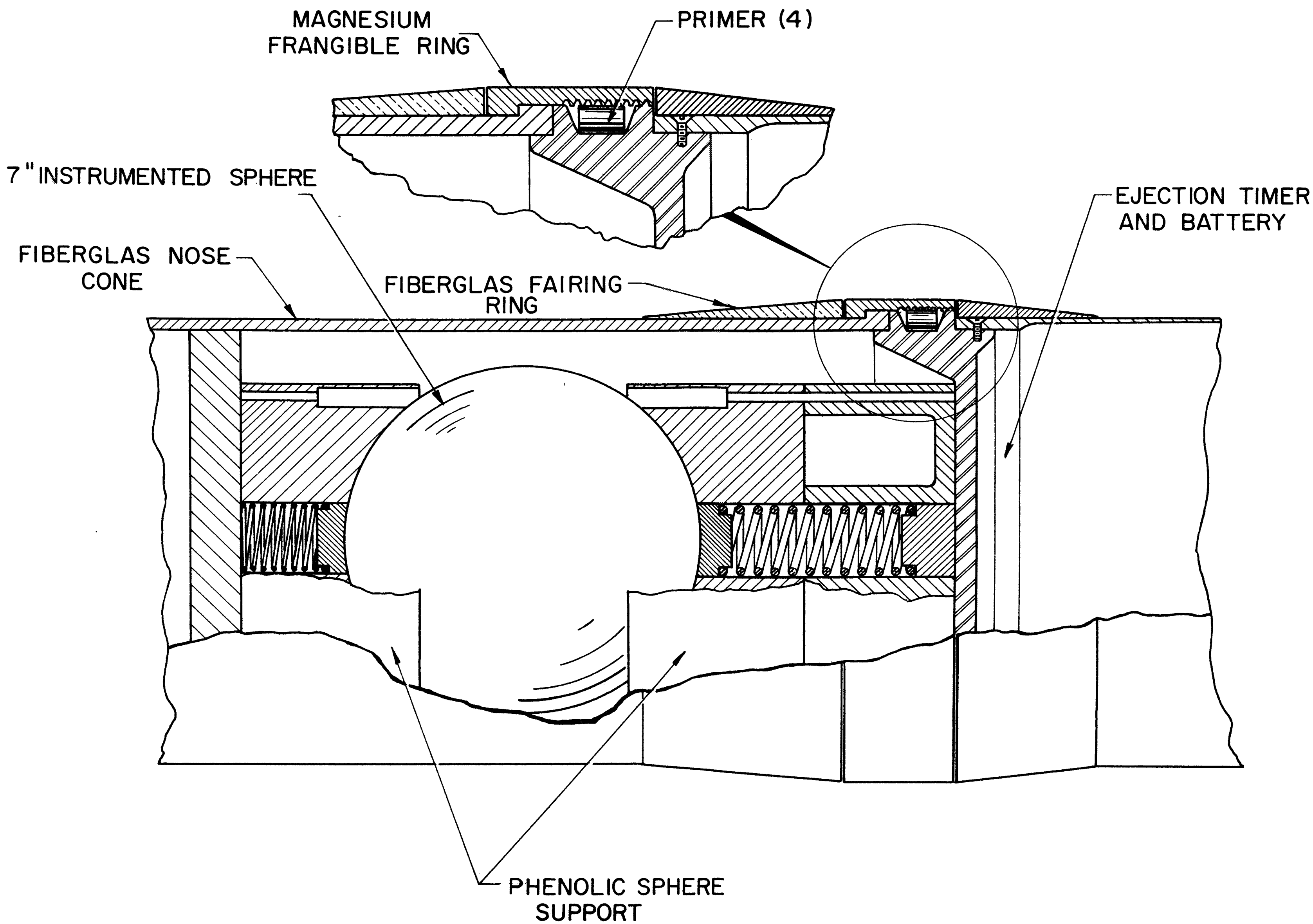

Figure 11. Nose Cone Ejection Assembly.

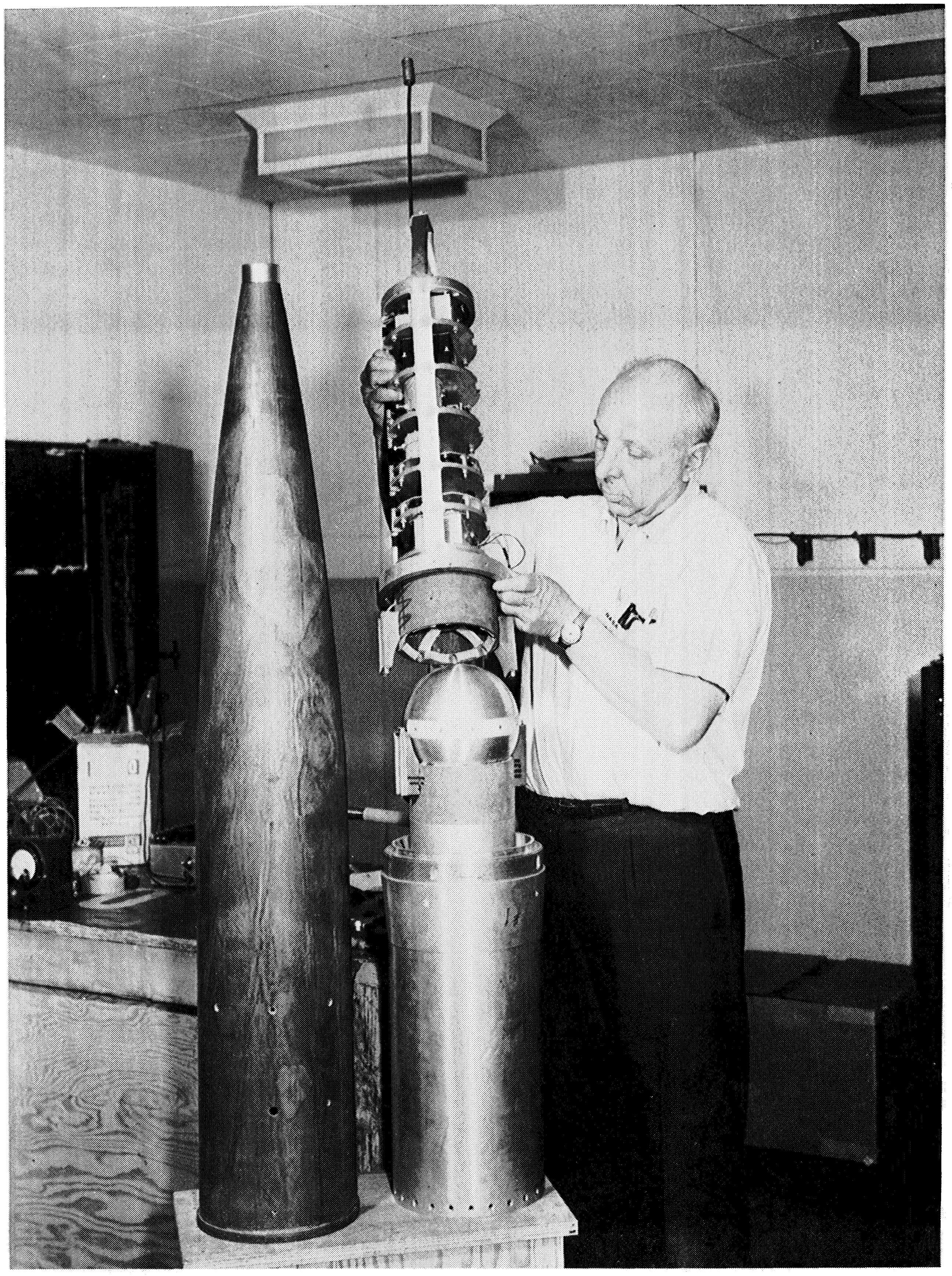

Figure 12. Nose Cone and Instrumentation.

The usable volume within this total nose cone is approximately 1.7 cubic feet.

The first two Vertigo test flights carried the small-sphere[5] experiment for upper air density. This requires the opening of the nose cone and ejection of a rigid 7-in-diameter sphere. The sphere contains an omnidirectional time-of-flight accelerometer and a transmitter for relaying the data to ground receivers.

The first flights also carried vehicle-performance instrumentation consisting of the following:

1) A 235-mc transmitter with internal antenna radiating through the Fiberglas nose cone.

2) An attitude indicator developed at and furnished by Langley Research Center of NASA. This used two of the four telemeter channels.

3) A 0- to 80-g axial accelerometer on the third channel.

4) Three temperature sensors located in one fin (two thermistors and a chromel-alumel thermocouple), two thermistors in the instrumentation package, and -12 to +4-g axial accelerometer were commutated on the fourth telemeter channel.

In the second test flight of Vertigo, a switch was added to monitor the position of the frangible coupling ring. This was added to the commutated channel.

4. PREPARATION AND ASSEMBLY

4.1 First-Stage Preparation

To modify the standard Nike-Ajax booster M-5 or M-5 E1 for use on the first stage of Vertigo, the following operations are required:

1) Remove unnecessary hardware;
2) Attach and check alignment of fins; and
3) Attach coupling.

The first two of these operations are fully described in Ref. 3, p. 28-9. The third operation consists of bolting the coupling to the Nike thrust face, using six NAS 147. bolts. If the vehicle is to be launched from a boom type launcher using launching fitting H2-40402, a shallow recess will have to be filed in the coupling casting to avoid interference with this fitting.

4.2 Second-Stage Preparation

The three general operations required is preparation of the Vertigo second stage are as follows:

1) Assemble and install the fin-shroud assembly and nozzle;
2) Check fin alignment; and
3) Install the igniter.

4.2.1. Fin Shroud and Nozzle Assembly and Installation

The screws and special nuts which hold the fin mounting channels, H5-46120, on the shroud, H5-46106A, are checked to be sure that they are tight and that the screw heads do not project above the inside surface of the shroud. The fairing ring, H3-46114, is sawed through and slipped over the aft end of the motor. The inside of this ring is filed parallel to the saw cut to clear the weld bead. When this has been done, the ring is slipped well forward and left there. The nozzle mounting threads, both on the motor and on the nozzle, are cleaned with methyl-ethyl-ketone and a brush and inspected for burrs. The nozzle is then screwed into the motor and the circumferential position of the nozzle when the thread first engages and when the nozzle shoulder seats on the motor are marked relative to the weld bead. These marks should be placed on the inside of the nozzle exit cone so that one can see them during the final assembly when the nozzle is installed inside the fin shroud. The nozzle is then removed and number of turns required carefully noted.

The fin shroud is then mounted on the motor, all bolts installed before any are tightened. Then after the bolts are tightened with a torque of approximately 50 ft-lb, the nozzle is screwed in again to be sure that there is no interference with the shroud. The nozzle is then removed to apply the 3M sealant, provided with the motor, to the aft end of the grain and the metal surfaces forward of the nozzle threads. Only a small amount of the sealant should be allowed on the thread. The nozzle is then installed, using the previously noted number of turns and seated hard against the shoulder. A special nozzle wrench and strap wrench to hold the engine are required for this operation.

The fins are now installed in the fin mounting channels. The fins have been previously assembled to specific channels and both parts stamped with corresponding numbers. All screws and special nuts are installed and tightened. The fairing ring is slipped aft under the forward edge of the shroud. The ring is then hammered aft until it is seated evenly and tightly between the motor case and shroud.

4.2.2. Fin Alignment Check.

The fin alignment is checked with the equipment shown in Ref. 3, Fig. 16. The method is completely described in the same reference on pages 24 and 26.

4.2.3. Igniter Installation

In the Vertigo rocket, the Yardbird igniter leads come out to the ground firing leads through the coupling. The first step then in the installation of the igniter is to feed the igniter lead aft from the head end through the grain. A stick or metal rod 10 ft long and small enough to go through the igniter hole in the head cap facilitates getting the igniter wire through. The standard AN connector on the igniter is not used and is cut off so that no problem of having the connector get wedged in the grain exists. With the lead in place through the engine and with the mating surfaces of the igniter and engine cleaned the sealing O-ring is greased and the igniter screws installed and drawn up tight. Care should be exercised to balance the forces by pulling down a little at a time on each screw.

4.3 Final Assembly

After assembly is complete on the second-stage motor, the instrumentation is installed and final weight and center-of-gravity measurements taken. The two stages are then put on dollies and taken to the launcher. The Nike without the coupling is lifted to the proper height under the beam of the launcher and mated to the launcher by simply rolling the dolly back a few inches.

The coupling is mated to the Yardbird and oriented circumferentially so that the bolts line up approximately with the tapped holes in the Nike thrust face. The Yardbird is then raised on its dolly to proper height and the dolly moved back until the coupling is mated with the Nike. The six bolts are pulled up tight and the dolly carefully lowered and removed. A slight rotation of the second stage may be necessary to align the fins with the booster fins.

The vehicle is now complete on the launcher; and the usual procedure is to have a horizontal check of the instrumentation, elevate the launcher, have a vertical check of the instrumentation, make final corrections in launcher azimuth and elevation and launch.

RECOMMENDATIONS

The need for a rocket with the capability of Vertigo remains. Many two-stage solid propellant sounding rockets have been successful and there is no inherent reason why Vertigo should not be as well. Further flight tests with a strengthened frangible ring are recommended.

ACKNOWLEDGMENT

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