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THE EXPLORER XVI MICROMETEOROID SATELLITE SUPPLEMENT II, PRELIMINARY RESULTS FOR THE PERIOD MARCH 3, 1963, THROUGH MAY 26, 1963

Compiled by Earl C. Hastings, Jr.;
Langley Research Center,
Langley Station, Hampton, Va.

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SUMMARY

Through May 26, 1963, 38 of the 0.001-inch- and 10 of the 0.002-inch-thick beryllium-copper pressure cells on Explorer XVI (1962 Beta Chi 1) have been punctured. Corresponding puncture rates are 0.030 and 0.017 puncture/sq ft/day, respectively. These rates are slightly less than the last previously reported rates (data to March 2, 1963). They are still somewhat above the lowest of previously estimated rates for equivalent thicknesses of aluminum (0.002 and 0.004 inch, respectively), and the variation of rate with thickness is somewhat less than the previously estimated variations.

Ninety-eight-percent confidence limits on the puncture rate in the 0.001-inch beryllium copper are estimated to be 0.0198 and 0.0434 puncture/sq ft/day. For the 0.002-inch beryllium-copper cells the estimated puncture rate limits for 98-percent confidence are 0.0071 and 0.0344 puncture/sq ft/day. No punctures of the 0.005-inch cells have occurred through May 26, 1963; from this result the puncture rate upper limit in this thickness of beryllium copper is estimated with 98-percent confidence to be 0.0135 puncture/sq ft/day. None of the 0.002-inch- or 0.003-inch-diameter copper-wire card detectors have been punctured as of May 26, 1963.

On April 19, 1963, a failure occurred in a transistor in the encoder module of one of the two telemetry systems. As a result, a portion of the 0.001-inch pressure-cell experiment was lost and a change in the method of reducing much of the data from that telemeter system was necessary. Telemetry temperatures, as well as sensor and solar cell temperatures, have all remained within acceptable limits through May 26, 1963.

INTRODUCTION

The Explorer XVI (1962 Beta Chi 1) micrometeoroid satellite (fig. 1) was described in reference 1 and some data and analysis were presented for the first 4 weeks in orbit (December 16, 1962, through January 13, 1963). Reference 2 was the first supplement to that initial report and extended the period covered through March 2, 1963. This report is the second supplement to reference 1 and extends the data period through May 26, 1963. Specifically this report presents puncture data for the beryllium-copper pressurized cells and wire card detectors. Additional data on telemetry performance and satellite temperatures are discussed and a brief statistical study of the puncture data through May 26, 1963, is presented as an appendix.

The names and organizations of the experimenters and specialists who have contributed to this report are given in the following list:

Contributor	Contribution
Jose M. Alvarez Langley Research Center	Appendix
Charles A. Gurtler Langley Research Center	Pressurized-Cell Experiment
Lawrence H. Hoffman Langley Research Center	Appendix
Wendell H. Lee Langley Research Center	Temperatures
Walt C. Long Langley Research Center	Telemetry Performance
Luc Secretan Goddard Space Flight Center	Copper-Wire Card Detectors
G. Louis Smith Langley Research Center	Appendix

TELEMETRY PERFORMANCE

Both telemeters operated satisfactorily through the 1717th pass, which occurred on April 19, 1963 (124 days in orbit). The next contact with the satellite was on the 1733rd pass, which occurred on April 21, 1963. The transmission from telemeter A was abnormal and could not be reduced by the automatic data reduction equipment described in reference 1. Subsequent transmissions from telemeter A have continued to be abnormal. Telemeter B has performed satisfactorily through pass 2224, which occurred on May 26, 1963.

Examination of the telemetry receptions revealed that excellent signal levels were being received, with signal-to-noise ratios usually about +25 db, which is 13 db above the threshold required for data reduction. Further examination of the reception from telemeter A revealed that the signal was pulsing normally and that all 16 subcarrier oscillator signals were present, but that the framing time (the time for sequentially pulsing all 16 subcarrier oscillators) was somewhat short. Figure 2 shows a typical telemeter record for normal operation. Duration time, space time, and frequency data are noted. Between April 19 and May 26, data from telemeter A showed that duration times (the time that a subcarrier oscillator is on) were ranging from 4.6 to 8.6 milliseconds instead of the normal 4.6 to 28 milliseconds. Space times (the off times between subcarrier oscillator signals) were from 4.6 to 16.0 milliseconds, which was normal. The framing time had correspondingly decreased from about 290 milliseconds to about 250 milliseconds.

These characteristics of the telemetry receptions indicated that the cause of the abnormal transmissions was a collector-to-emitter short in a commutating transistor in duration time channel D14. This explanation was confirmed by ground studies with a duplicate telemeter. This short placed a 1650-ohm load across the inputs to all duration time channels and caused an appreciable change in the calibrations of the duration time channels and a smaller change in the calibrations of the space time channels. Frequency channels were not affected. Typical calibration curves for the pressure-cell detectors with and without the 1650-ohm shunt load are shown in figure 3. It can be seen that the load causes the duration time calibration curves to become nonlinear, so that the upper two-thirds of all duration time channels are effectively masked out. These channels are readable for the first three punctures only and are unusable afterwards. The slight effect upon the space time channels can also be seen. These channels are readable over their entire range.

Unfortunately, the frame synchronization pulse was on a duration time channel where the masking effect of the 1650-ohm load precludes using the automatic data reduction machinery. Accordingly, new calibration curves have been generated and the data from telemeter A are now being reduced manually. The telemetry signals are reproduced on photographic paper and expanded so the individual subcarrier oscillations are readable. The scale is 1/2 inch per millisecond. A 10 kcps reference signal is also reproduced on the paper so that errors due to tape speed variations or paper stretch can be eliminated. Duration time channels are measured by counting the number of 10 kcps pulses that occur during a subcarrier oscillation. Space time channels are measured by counting the number of 10 kcps pulses that occur between subsequent subcarrier oscillations. Beginnings and endings of subcarrier oscillations can be measured to within one-half cycle of the 10 kcps reference for a total reading error of 0.1 millisecond. This value corresponds to about 1 percent of the channel range.

Frequency channels are measured by counting the number of oscillations in a subcarrier burst and comparing them with the number of 10 kcps pulses that occur in the same time interval. The accuracy is dependent upon the time duration of the subcarrier burst and the frequency of the burst. Accuracies are typically 2 percent.

An examination of the channel allocations shows that the effect of the shorted transistor has not been excessively detrimental. Pressure-cell channel allocations are shown in table I along with the punctures before and after the transistor short.

TABLE I

Time channel	Pressure-cell thickness, in.	Punctures as of the 1717th pass	Punctures as of the 2224th pass	Estimated end limits
S4	0.002	4	5	10
D5	.001	5	[a]---	(a)
S5	.001	1	1	10
D6	.005	0	0	3
S6	.001	6	6	10
D7	.001	4	[a]---	(a)
S7	.002	1	1	10
D8	.001	3	[a]---	(a)

[a]The number of punctures in these channels was already more than the estimated limit (3) when the short occurred. Thus, any punctures occurring since the 1717th pass cannot be detected.

Duration time channels D5, D7, and D8 were rendered useless, with the resulting loss of eighteen 0.001-inch pressure-cell detectors. Duration time channel D6, having no punctures in any of the 0.005-inch pressure-cell detectors, is readable and should remain so for at least three punctures. Space time channels S4 and S7, for 0.002-inch pressure-cell detectors, and space time channels S5 and S6, for 0.001-inch pressure-cell detectors, are readable now and should remain readable until all 10 pressure-cell detectors are punctured. Thus, 38 pressure-cell detectors were still usable even after the transistor short occurred for a total loss of $22\frac{1}{2}$ percent of the original 80 pressure-cell detectors on this telemeter.

PRESSURIZED-CELL EXPERIMENT

During the first $5\frac{1}{3}$ months in orbit 38 percent of the 0.001-inch and 25 percent of the 0.002-inch pressurized-cell detectors have been punctured one or more times. There have been no punctures in the 0.005-inch pressurized-cell detectors. Data have been reduced from a total of 490 interrogations, the last of which was on May 26, 1963, on the 2224th pass. For the period between April 19, 1963, and May 26, 1963, automatic data reduction from only one telemeter is available, as discussed in the preceding section.

Table II shows the first interrogation in which each new puncture was recorded, and the elapsed time since the last previous interrogation. The maximum uncertainty in the time of occurrence of a puncture is 35 hours and 40 minutes. On three occasions, interrogations revealed two new punctures. The first was the interrogation on the 899th pass, which showed two new punctures in the 0.001-inch sensors. These punctures occurred on widely separated columns of sensors so they could not have been caused by a single particle. The second was the interrogation on the 1158th pass, which showed new punctures of an 0.001-inch and

TABLE II

Pass	Greenwich date	Greenwich mean time at interrogation	Time since last interrogation, hr min	Accumulated punctures for detector thickness of -		
				0.001 in.	0.002 in.	0.005 in.
54	Dec. 20, 1962	1223	1 50	1	0	0
77	Dec. 22, 1962	0418	1 49	2	0	0
85	Dec. 22, 1962	1857	1 51	3	0	0
102	Dec. 24, 1962	0055	1 51	4	0	0
137	Dec. 26, 1962	1253	1 56	5	0	0
219	Jan. 1, 1963	1121	14 48	6	0	0
264	Jan. 4, 1963	1822	9 27	6	1	0
297	Jan. 7, 1963	0248	1 56	7	1	0
310	Jan. 8, 1963	0114	5 45	8	1	0
353	Jan. 11, 1963	0408	22 32	9	1	0
378	Jan. 12, 1963	2326	7 33	10	1	0
405	Jan. 14, 1963	2221	9 25	11	1	0
483	Jan. 20, 1963	1512	11 21	12	1	0
520	Jan. 23, 1963	0644	31 30	12	2	0
529	Jan. 23, 1963	2155	6 32	12	3	0
570	Jan. 26, 1963	2118	7 30	12	4	0
598	Jan. 28, 1963	2212	6 52	13	4	0
628	Jan. 31, 1963	0241	11 12	14	4	0
654	Feb. 1, 1963	2333	26 03	14	5	0
698	Feb. 5, 1963	0507	6 17	15	5	0
707	Feb. 5, 1963	2014	15 7	16	5	0
720	Feb. 6, 1963	1857	17 41	17	5	0
722	Feb. 6, 1963	2145	2 48	18	5	0
736	Feb. 7, 1963	2208	18 7	18	6	0
893	Feb. 19, 1963	0812	19 33	19	6	0
899	Feb. 19, 1963	1727	5 20	20	6	0
899	Feb. 19, 1963	1727	7 15	21	6	0
915	Feb. 20, 1963	2153	28 26	22	6	0
1020	Feb. 28, 1963	1222	25 4	23	6	0
1042	Mar. 2, 1963	0307	9 22	24	6	0
1107	Mar. 6, 1963	2012	9 48	25	6	0
1158	Mar. 10, 1963	1144	18 4	26	7	0
1316	Mar. 21, 1963	2301	8 11	27	7	0
1344	Mar. 23, 1963	2301	11 34	28	7	0
1417	Mar. 29, 1963	0608	20 33	29	7	0
1498	Apr. 4, 1963	0248	6 58	30	7	0
1519	Apr. 5, 1963	1627	11 21	31	7	0
1596	Apr. 11, 1963	0544	7 36	31	8	0
1629	Apr. 13, 1963	1551	23 58	32	8	0
1643	Apr. 14, 1963	1448	9 45	32	9	0
1692	Apr. 18, 1963	0444	6 32	33	9	0
1824	Apr. 27, 1963	1739	6 26	33	10	0
1842	Apr. 29, 1963	0158	15 04	34	10	0
2127	May 19, 1963	1647	35 40	36	10	0
2164	May 22, 1963	0833	12 39	37	10	0
2183	May 23, 1963	1849	9 53	38	10	0

an 0.002-inch sensor. These punctures occurred in columns of sensors that were adjacent; however, it cannot be determined whether the two punctured sensors were adjacent to each other since the telemeter identifies only the column in which the sensor is located. It is possible that a single particle could have punctured both sensors. The third was the interrogation on the 2127th pass, which showed two new punctures in 0.001-inch sensors. These punctures also occurred in widely separated columns. Thirty-five hours and forty minutes had elapsed since the last previous interrogation from which data reduction has been completed. Data are currently being reduced from interrogations taken during this time interval in order to determine more accurately the time of puncture for each of these sensors.

Table III shows a history of the 200 interrogations from which data were reduced during the time period of March 2, 1963, to May 26, 1963. One hundred and three of these interrogations contain data from both telemeters and 97 interrogations contain data from only one of the telemeters. When only one of the telemetric transmissions from an interrogation is reducible, data are received in effect from only half of the sensors. Data are not lost in such cases, since they can be recovered in subsequent interrogations; however, there may be less precision in identifying the time of a puncture. The passes marked with an asterisk indicate the interrogations from which only one telemetric transmission was reducible.

Figure 4 is a plot showing the history of the 38 punctures in the 0.001-inch sensors and the 10 punctures in the 0.002-inch sensors that occurred during the first $5\frac{1}{3}$ months of orbit time.

Table IV shows the time-area products and puncture rates. Each time one of the sensors is punctured the area of the experiment is reduced. The reduced area is then used until the next puncture occurs. The puncture rate for the 0.001-inch-thick material is 0.030 puncture/sq ft/day, based on the 38 punctures that occurred up to May 26, 1963. This average rate is slightly less than the puncture rate of 0.035 puncture/sq ft/day based on the first 10 punctures as reported in reference 1, and the puncture rate of 0.034 puncture/sq ft/day based on the first 24 punctures, as reported in reference 2. The puncture rate for the 0.002-inch-thick material is 0.017 puncture/sq ft/day, based on the 10 punctures that occurred up to May 26, 1963. For this material, the first two punctures occurred at approximately 19-day intervals, and then four additional punctures occurred during the next 15-day period, as reported in reference 2. The seventh and eighth punctures occurred after approximately 31-day intervals, the ninth puncture after a 3-day interval, and the tenth puncture after a 13-day interval. The malfunctioning of one of the telemeters after April 19 has made it impossible to monitor 18 previously unpunctured 0.001-inch sensors for punctures. The time-area product accumulated after April 19 for these sensors has not been included in table IV. Puncture data on the remaining unpunctured sensors monitored by the malfunctioning telemeter have been reduced by manual data reduction techniques.

Tests for randomness have been applied to the Explorer XVI puncture data. (See appendix.) The results indicate that the occurrence of punctures follows a Poisson distribution.

TABLE III

Pass	Greenwich date	Greenwich mean time at interrogation	Accumulated punctures for detector thickness of -		
			0.001 in.	0.002 in.	0.005 in.
1052	Mar. 2, 1963	2007	24	6	0
1061	Mar. 3, 1963	1051	24	6	0
1065	Mar. 3, 1963	1839	24	6	0
1074	Mar. 4, 1963	0931	24	6	0
1078	Mar. 4, 1963	1647	24	6	0
1084	Mar. 5, 1963	0419	24	6	0
1088	Mar. 5, 1963	1035	24	6	0
1092	Mar. 5, 1963	1734	24	6	0
1102	Mar. 6, 1963	1024	24	6	0
1107	Mar. 6, 1963	2012	25	6	0
1112	Mar. 7, 1963	0339	25	6	0
1115	Mar. 7, 1963	0848	25	6	0
*1120	Mar. 7, 1963	1822	25	6	0
1127	Mar. 8, 1963	0539	25	6	0
1131	Mar. 8, 1963	1249	25	6	0
*1133	Mar. 8, 1963	1652	25	6	0
*1139	Mar. 9, 1963	0234	25	6	0
1147	Mar. 9, 1963	1740	25	6	0
1158	Mar. 10, 1963	1144	26	7	0
*1161	Mar. 10, 1963	1737	26	7	0
1170	Mar. 11, 1963	0836	26	7	0
*1174	Mar. 11, 1963	1610	26	7	0
*1180	Mar. 12, 1963	0154	26	7	0
1187	Mar. 12, 1963	1436	26	7	0
1195	Mar. 13, 1963	0403	26	7	0
*1209	Mar. 14, 1963	0425	26	7	0
1214	Mar. 14, 1963	1329	26	7	0
1219	Mar. 14, 1963	2251	26	7	0
*1222	Mar. 15, 1963	0259	26	7	0
1228	Mar. 15, 1963	1358	26	7	0
*1233	Mar. 15, 1963	2315	26	7	0
*1242	Mar. 16, 1963	1422	26	7	0
*1252	Mar. 17, 1963	0712	26	7	0
1262	Mar. 18, 1963	0028	26	7	0
1265	Mar. 18, 1963	0536	26	7	0
*1270	Mar. 18, 1963	1534	26	7	0
1283	Mar. 19, 1963	1340	26	7	0
1289	Mar. 19, 1963	2322	26	7	0
*1293	Mar. 20, 1963	0731	26	7	0
*1296	Mar. 20, 1963	1205	26	7	0
*1303	Mar. 20, 1963	2345	26	7	0
1306	Mar. 21, 1963	0454	26	7	0
1311	Mar. 21, 1963	1450	26	7	0
*1316	Mar. 21, 1963	2301	27	7	0
1320	Mar. 22, 1963	0556	27	7	0
*1323	Mar. 22, 1963	1058	27	7	0
*1330	Mar. 22, 1963	2239	27	7	0
1333	Mar. 23, 1963	0349	27	7	0
*1337	Mar. 23, 1963	1127	27	7	0
1344	Mar. 23, 1963	2301	28	7	0
1347	Mar. 24, 1963	0451	28	7	0
1351	Mar. 24, 1963	1152	28	7	0
1358	Mar. 24, 1963	2324	28	7	0
1362	Mar. 25, 1963	0622	28	7	0
1364	Mar. 25, 1963	1015	28	7	0
1371	Mar. 25, 1963	2157	28	7	0
1376	Mar. 26, 1963	0645	28	7	0
1379	Mar. 26, 1963	1237	28	7	0
1384	Mar. 26, 1963	2113	28	7	0
*1388	Mar. 27, 1963	0337	28	7	0
1392	Mar. 27, 1963	1110	28	7	0
1398	Mar. 27, 1963	2052	28	7	0
*1401	Mar. 28, 1963	0156	28	7	0
1405	Mar. 28, 1963	0935	28	7	0
1417	Mar. 29, 1963	0608	29	7	0
1427	Mar. 29, 1963	2317	29	7	0
1432	Mar. 30, 1963	0828	29	7	0

*Interrogations from which only one telemetric transmission was reducible.

TABLE III - Continued

Pass	Greenwich date	Greenwich mean time at interrogation	Accumulated punctures for detector thickness of -		
			0.001 in.	0.002 in.	0.005 in.
1441	Mar. 30, 1963	2339	29	7	0
1445	Mar. 31, 1963	0654	29	7	0
1446	Mar. 31, 1963	0857	29	7	0
1451	Mar. 31, 1963	1815	29	7	0
1454	Mar. 31, 1963	2211	29	7	0
1458	Apr. 1, 1963	0525	29	7	0
1464	Apr. 1, 1963	1646	29	7	0
1467	Apr. 1, 1963	2054	29	7	0
1475	Apr. 2, 1963	1200	29	7	0
*1480	Apr. 2, 1963	1926	29	7	0
*1484	Apr. 3, 1963	0232	29	7	0
1494	Apr. 3, 1963	1949	29	7	0
1498	Apr. 4, 1963	0247	30	7	0
*1505	Apr. 4, 1963	1602	30	7	0
1510	Apr. 4, 1963	2327	30	7	0
1513	Apr. 5, 1963	0506	30	7	0
1519	Apr. 5, 1963	1627	31	7	0
1522	Apr. 5, 1963	2015	31	7	0
1526	Apr. 6, 1963	0338	31	7	0
1529	Apr. 6, 1963	0950	31	7	0
1536	Apr. 6, 1963	2041	31	7	0
1546	Apr. 7, 1963	1520	31	7	0
1551	Apr. 7, 1963	2250	31	7	0
1555	Apr. 8, 1963	0627	31	7	0
*1559	Apr. 8, 1963	1353	31	7	0
1563	Apr. 8, 1963	1942	31	7	0
*1569	Apr. 9, 1963	0651	31	7	0
1574	Apr. 9, 1963	1608	31	7	0
1579	Apr. 9, 1963	2334	31	7	0
*1582	Apr. 10, 1963	0515	31	7	0
1588	Apr. 10, 1963	1630	31	7	0
1592	Apr. 10, 1963	2208	31	7	0
1596	Apr. 11, 1963	0544	31	8	0
1602	Apr. 11, 1963	1613	31	8	0
1606	Apr. 11, 1963	2236	31	8	0
*1610	Apr. 12, 1963	0609	31	8	0
1616	Apr. 12, 1963	1553	31	8	0
1629	Apr. 13, 1963	1551	32	8	0
1633	Apr. 13, 1963	2125	32	8	0
1637	Apr. 14, 1963	0503	32	8	0
1643	Apr. 14, 1963	1448	32	9	0
1647	Apr. 14, 1963	2156	32	9	0
1651	Apr. 15, 1963	0525	32	9	0
*1656	Apr. 15, 1963	1445	32	9	0
1663	Apr. 16, 1963	0154	32	9	0
1668	Apr. 16, 1963	1122	32	9	0
*1674	Apr. 16, 1963	2043	32	9	0
1678	Apr. 17, 1963	0421	32	9	0
1683	Apr. 17, 1963	1339	32	9	0
1688	Apr. 17, 1963	2212	32	9	0
1692	Apr. 18, 1963	0444	33	9	0
1696	Apr. 18, 1963	1207	33	9	0
1701	Apr. 18, 1963	1938	33	9	0
1705	Apr. 19, 1963	0314	33	9	0
1712	Apr. 19, 1963	1450	33	9	0
1717	Apr. 19, 1963	2339	33	9	0
*1725	Apr. 20, 1963	1323	33	9	0
1733	Apr. 21, 1963	0401	33	9	0
*1739	Apr. 21, 1963	1346	33	9	0
*1744	Apr. 21, 1963	2234	33	9	0
1746	Apr. 22, 1963	0234	33	9	0
1764	Apr. 23, 1963	1020	33	9	0
*1771	Apr. 23, 1963	2129	33	9	0
*1773	Apr. 24, 1963	0127	33	9	0
*1774	Apr. 24, 1963	0345	33	9	0
*1778	Apr. 24, 1963	1042	33	9	0
1783	Apr. 24, 1963	1813	33	9	0

*Interrogations from which only one telemetric transmission was reducible.

TABLE III - Concluded

Pass	Greenwich date	Greenwich mean time at interrogation	Accumulated punctures for detector thickness of -		
			0.001 in.	0.002 in.	0.005 in.
*1792	Apr. 25, 1963	1108	33	9	0
1804	Apr. 26, 1963	0747	33	9	0
1820	Apr. 27, 1963	1113	33	9	0
1824	Apr. 27, 1963	1739	33	10	0
*1828	Apr. 28, 1963	0109	33	10	0
*1829	Apr. 28, 1963	0325	33	10	0
1834	Apr. 28, 1963	1054	33	10	0
*1842	Apr. 29, 1963	0158	34	10	0
*1848	Apr. 29, 1963	1117	34	10	0
*1851	Apr. 29, 1963	1732	34	10	0
*1859	Apr. 30, 1963	0727	34	10	0
*1869	Apr. 30, 1963	2341	34	10	0
*1873	May 1, 1963	0750	34	10	0
*1882	May 1, 1963	2236	34	10	0
*1887	May 2, 1963	0814	34	10	0
*1891	May 2, 1963	1403	34	10	0
*1902	May 3, 1963	0906	34	10	0
*1906	May 3, 1963	1712	34	10	0
1909	May 3, 1963	2146	34	10	0
*1914	May 4, 1963	0709	34	10	0
*1923	May 4, 1963	2217	34	10	0
*1935	May 5, 1963	1840	34	10	0
*1950	May 6, 1963	2106	34	10	0
*1955	May 7, 1963	0626	34	10	0
*1965	May 7, 1963	2349	34	10	0
*1969	May 8, 1963	0648	34	10	0
*1983	May 9, 1963	0713	34	10	0
*1991	May 9, 1963	2027	34	10	0
*1996	May 10, 1963	0544	34	10	0
*2005	May 10, 1963	2052	34	10	0
*2015	May 11, 1963	1441	34	10	0
*2018	May 11, 1963	1916	34	10	0
*2030	May 12, 1963	1547	34	10	0
*2033	May 12, 1963	2203	34	10	0
*2040	May 13, 1963	0854	34	10	0
*2042	May 13, 1963	1239	34	10	0
*2046	May 13, 1963	2010	34	10	0
*2056	May 14, 1963	1359	34	10	0
*2059	May 14, 1963	1836	34	10	0
*2065	May 15, 1963	0550	34	10	0
*2067	May 15, 1963	0749	34	10	0
*2070	May 15, 1963	1310	34	10	0
*2083	May 16, 1963	1156	34	10	0
*2086	May 16, 1963	1730	34	10	0
*2088	May 16, 1963	2142	34	10	0
*2101	May 17, 1963	2015	34	10	0
*2105	May 18, 1963	0507	34	10	0
*2127	May 19, 1963	1647	36	10	0
*2132	May 20, 1963	0206	36	10	0
*2137	May 20, 1963	0938	36	10	0
*2142	May 20, 1963	1931	36	10	0
*2151	May 21, 1963	1040	36	10	0
*2153	May 21, 1963	1345	36	10	0
*2156	May 21, 1963	1954	36	10	0
*2164	May 22, 1963	0833	37	10	0
*2168	May 22, 1963	1607	37	10	0
*2173	May 23, 1963	0126	37	10	0
*2178	May 23, 1963	0856	37	10	0
*2183	May 23, 1963	1849	38	10	0
*2192	May 24, 1963	0927	38	10	0
*2196	May 24, 1963	1722	38	10	0
*2201	May 25, 1963	0212	38	10	0
*2205	May 25, 1963	0750	38	10	0
*2209	May 25, 1963	1507	38	10	0
2219	May 26, 1963	0813	38	10	0
*2224	May 26, 1963	1807	38	10	0

*Interrogations from which only one telemetric transmission was reducible.

TABLE IV

Material thickness, in.	Number of punctures	Time-area products for first 161 days, (sq ft)(days)	Puncture rate, puncture/sq ft/day
0.001	38	1268	0.030
.002	10	586	.017
.005	0	342	-----

Figure 5 shows three curves of predicted puncture rate as a function of thickness for aluminum sheet (from ref. 3). The puncture rates of beryllium copper, as shown in table IV, have been converted to estimated puncture rates in aluminum sheet by considerations of the factor discussed in reference 1. The converted puncture rates, increased by 4/3 to correct for earth shielding (ref. 1), are shown in figure 5. The width of the bar extending through each point corresponds to the variation in thickness of the test material. As reported in reference 1, examination of the test material indicated that the deviation of thickness from the nominal value ranged from 0.0000 to +0.0003 inch. This range represents a percentage variation that is twice as much for the 0.001-inch material as for the 0.002-inch material. If a line is passed through the middle of the bars and is extrapolated to the material thickness corresponding to the 0.005-inch beryllium-copper sensors (0.01 inch of aluminum) a puncture rate of 0.007 puncture/sq ft/day is indicated. With this puncture rate and a time-area exposure of 342 (sq ft)(days), 2 punctures would be expected in the 0.005-inch material. However, if a line is passed through the data point for the 0.001-inch material parallel to the Watson and Whipple curves, a puncture rate for the 0.005-inch material of 0.00024 puncture/sq ft/day is indicated and no punctures would be expected. The most probable curve corresponding to the data (for beryllium copper without the correction for earth shielding) is derived in the appendix.

Confidence limits (confidence coefficient = 0.95) for the Explorer XVI data points plotted in figure 5 have been indicated in the figure. The limits were computed by using the χ^2 distribution in the manner discussed in the appendix. Based on the 38 punctures in the 0.001-inch material and a time-area product of 1268 (sq ft)(days), one can expect with 95-percent confidence that the puncture rate will lie between 0.021 and 0.041 puncture/sq ft/day. With 10 punctures in the 0.002-inch material and a time-area product of 586 (sq ft)(days), these limits are 0.008 and 0.031 puncture/sq ft/day, and with no punctures in the 0.005-inch sensors and a time-area product of 342 (sq ft)(day), these limits are 0 and 0.011 puncture/sq ft/day. The upper and lower puncture rates have been converted in the same manner as the observed puncture rates for plotting in figure 5. Limits for 90-percent and 98-percent confidence are also derived and discussed in the appendix.

The comparison shown in figure 5 indicates that the puncture rate for the 0.001-inch sensors lies between the lower and the middle estimated curves. The

Explorer XVI data indicate a puncture rate about $2\frac{1}{2}$ times greater than that given by the lower curve, 10 times less than that given by the middle curve, and several hundred times less than that given by the upper curve. The puncture rate for the 0.002-inch sensors, on the basis of 10 punctures, is relatively higher. This rate, however, was influenced considerably by the high puncture rate that occurred between January 23, 1963, and February 7, 1963.

COPPER-WIRE CARD DETECTORS

Through pass 2224 on May 26, 1963, no breaks had occurred in either the 0.002- or the 0.003-inch-diameter copper-wire card detectors.

TEMPERATURES

During the period from March 3, 1963, to May 26, 1963, the temperatures of the telemetry, solar cells, and sensors of Explorer XVI have remained well within the range of predicted values. This restricted temperature range would be expected since the satellite has not encountered any fully sunlit orbits since those discussed in reference 2 and the minimum-temperature conditions of the longitudinal spin mode ended during the first part of January 1963, as pointed out in reference 1.

Figures 6 to 9 show the variation of solar cell and sensor temperature boundaries between December 16, 1962, and May 26, 1963. These curves were obtained by using all the recorded temperature data available during this period, including data from interrogations in both sunlight and darkness. Since they are externally located, the solar cells and sensors are exposed to varying thermal radiation during any given orbit (except for 100-percent sunlit orbits) and experience a fluctuation in temperature (between the boundaries) which is dependent upon their thermal lag and the percent time in sunlight.

Figure 10 shows the variation of telemetry temperature for the same period of time. As before, all available data were used in obtaining the curve. Since the telemetry is internally located, it does not experience large variations in heat flux throughout a given orbit but follows the mean temperature of the pressurized cells and, therefore, remains essentially at a constant temperature throughout an orbit. For this reason no boundaries are shown in figure 10.

Shown with all the temperature histories (figs. 6 to 10) is the variation of percent time in sunlight, obtained from the satellite ephemeris provided by the Goddard Space Flight Center. Also shown are the prelaunch estimates of expected maximum and minimum temperatures in the tumbling mode (ref. 4), indicated by horizontal lines drawn across the figures.

In all, temperature performance has been very satisfactory. In particular, out of 161 days in orbit, the telemetry temperature has exceeded the expected maximum for about 7 days and then by only 4° C. Telemetry temperature has never been below the expected minimum value.

CONCLUSIONS

The Explorer XVI data discussed herein indicate the following conclusions:

1. Through May 26, 1963, there have been 38 punctures of the 0.001-inch-thick beryllium-copper pressure cells, yielding a puncture rate of 0.030 puncture/sq ft/day. With 98-percent confidence, the puncture rate in 0.001-inch beryllium copper is estimated to lie between 0.0434 and 0.0198 puncture/sq ft/day.

2. Through May 26, 1963, a total of 10 of the 0.002-inch-thick beryllium-copper pressure cells have been punctured. The corresponding puncture rate is 0.017 puncture/sq ft/day. With 98-percent confidence, the puncture rate in 0.002-inch beryllium copper is estimated to lie between 0.0344 and 0.0071 puncture/sq ft/day.

3. No punctures have occurred in the 0.005-inch-thick beryllium-copper pressure cells through May 26, 1963. The puncture rate is estimated with 98-percent confidence to be no greater than 0.0135 puncture/sq ft/day.

4. Experimental puncture rates, expressed in terms of equivalent thicknesses of aluminum, have not changed significantly from those determined through March 2, 1963. The values continue to lie near the lower rate estimates and also continue to show a more gradual decrease of puncture rate with increasing skin thickness than previously estimated between 0.002 and 0.004 inch.

5. Statistical tests of the data show that the occurrence of punctures follows a Poisson distribution.

6. No breaks have occurred in the 0.002-inch- or the 0.003-inch-diameter copper-wire card detectors through May 26, 1963.

7. The failure of a transistor in the encoder module of one of the two telemetry systems occurred on April 19, 1963. This failure resulted in the permanent loss of some 0.001-inch pressure cells and required a change in the data reduction technique for much of the data transmitted by that telemeter system.

8. Spacecraft temperatures through May 26, 1963, continued to remain within acceptable limits. A comparison of measured maximum and minimum temperatures for the period December 16, 1962, through May 26, 1963, with prelaunch estimates of maximum and minimum temperatures indicates excellent agreement.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., August 16, 1963.

APPENDIX

STATISTICAL STUDY OF PUNCTURE DATA

Introduction

This appendix is divided into three sections which treat various aspects of the statistical analysis of the Explorer XVI puncture data through May 26, 1963. The first section deals with two tests for randomness of the data. The second section describes the method of estimating the puncture-rate confidence limits from the data. The third section derives the most probable curve of puncture rate against skin thickness. All the analysis presented in this appendix deals with measured data in beryllium copper and does not consider earth shielding effects or conversion of data to materials other than beryllium copper.

Symbols

A	effective area of one pressure cell
a	constant in assumed power law
$\hat{a}$	maximum-likelihood estimator of a
e_i	expected number of punctures in ith time-area interval
$F_\alpha(\nu_1,\nu_2)$	right critical point of F-distribution with ν_1 degrees of freedom in numerator and ν_2 degrees of freedom in denominator for $100(1 - \alpha)$ confidence level
$f(\ )$	probability function
K	number of pressurized cells punctured
m	power in assumed power law
$\hat{m}$	maximum-likelihood estimator of m
N	initial number of pressurized cells of given thickness
o_i	observed number of punctures in ith time-area interval
S	sum of time-area products
T	total time-area product
ΔT	time-area interval between punctures

T_i time-area product before ith puncture

t time

x number of pressurized cells punctured

$1 - \alpha$ confidence coefficient

μ mean

ν expected number of punctures

σ standard deviation

τ thickness of pressurized cell skin, 10^{-3} inch

ψ puncture rate, punctures/sq ft/day

Randomness of the Data

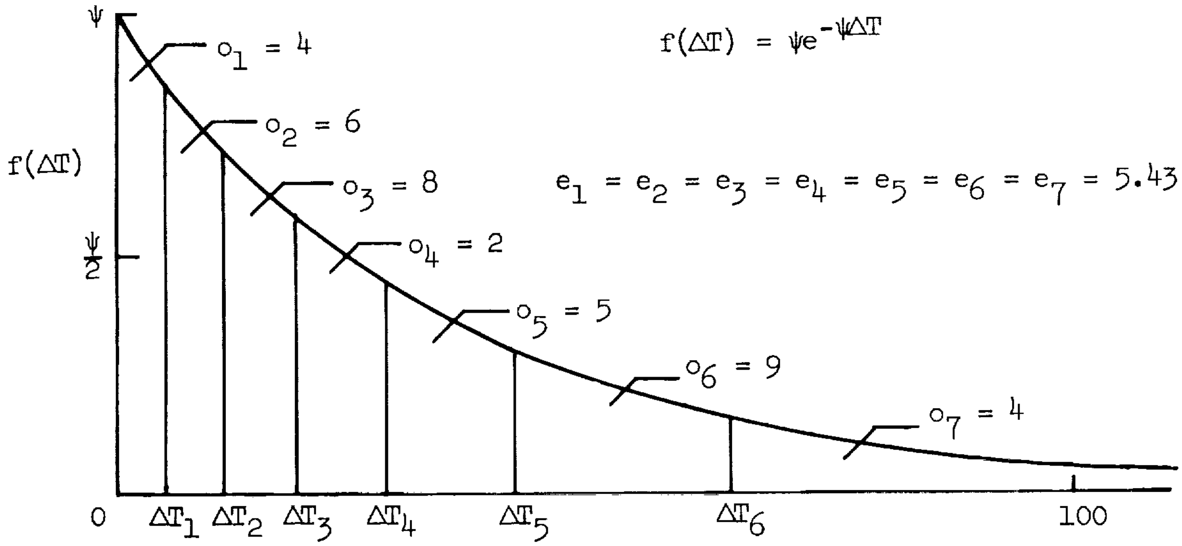
One purpose of testing the data for randomness (that is, testing that the data result from a Poisson process) is to verify the applicability of the method used for estimating the confidence limits for the puncture rate. If the data result from a Poisson process, then confidence limits based on such a process may be used; otherwise nonparametric or "distribution-free" statistics would have to be used.

For a Poisson process the time-area intervals ΔT between punctures are distributed according to an exponential probability density function

$$f(\Delta T) = \psi e^{-\psi \Delta T}$$

where ψ is the puncture rate. A χ^2 test for goodness of fit of this expected distribution of time-area intervals to the observed distribution will then serve as a test of randomness.

The test was applied to the 0.001-inch-thick pressure-cell data by the following procedure. With ψ set equal to the experimental value of 0.030 (taken as a maximum-likelihood estimate), ranges of ΔT were determined that divide the area under the $f(\Delta T)$ curve into 7 equal areas, as indicated in sketch a. (Seven was chosen so that the expected number of intervals falling in each range would be greater than 5, as is required for a χ^2 test.) Then time-area intervals have equal probabilities of falling within any of the 7 interval ranges $0-\Delta T_1$, $\Delta T_1-\Delta T_2$, . . ., $\Delta T_6-\infty$. Since there were 38 time-area intervals (corresponding to the 38 punctures) the expected number of time-area intervals in each range is 38/7; that is, $e_1 = e_2 = . . . = e_7 = 5.43$. The observed numbers of



Sketch a

time-area intervals in the 7 ranges, o_1, o_2, . . ., o_7 were 4, 6, 8, 2, 5, 9, and 4, respectively.

The significance of the variation of the observed from the expected distribution was determined by comparing the χ^2 statistic

$$\chi^2 = \sum_{i=1}^{i=7} \frac{(o_i - e_i)^2}{e_i}$$

with values tabulated in reference 5 for five degrees of freedom. (The difference between this number of degrees of freedom and 7 measures the extent to which the expected distribution is known in advance to agree with the observed distribution. In the present case, two degrees of freedom are lost because the parameter ψ is estimated from the data, and because the observed and expected numbers of interpuncture intervals, 38, are made equal.)

The calculated value of χ^2 was 6.57. Table XIV of reference 5 indicates that χ^2 with 5 degrees of freedom will most likely (probability = 0.90) lie between 1.15 and 11.1. Thus, the hypothesis of randomness cannot be rejected by this test. No χ^2 test was made for the data of the 0.002-inch and 0.005-inch pressure cells.

The second test for randomness makes use of the fact that if one observes a Poisson process for a fixed total time-area product T, and if K punctures occur during $(0,T)$ at time-areas $T_1 \leqq T_2 \leqq \ldots \leqq T_K < T$, then these time-areas can be considered as K observations on a random variable uniformly distributed over $(0,T)$. Thus, the sum

$$S = \sum_{i=1}^{i=K} T_i \tag{2}$$

is approximately normally distributed (ref. 6) with mean

$$\mu = \frac{KT}{2} \tag{3}$$

and standard deviation

$$\sigma = T\sqrt{\frac{K}{12}} \tag{4}$$

If S lies within a suitable distance (2σ or 3σ) from the mean μ, then there is no reason to doubt that the process is Poisson. For both the 0.001-inch and 0.002-inch pressure cells, S was found to lie well within the interval $\mu \pm 2\sigma$, which supports the hypothesis of a Poisson process.

Confidence Limits on the Derived Puncture Rate

As used herein, the term "confidence limits" means that with a given observed puncture rate (based on a certain number of punctures) it can be concluded that with a desired confidence the true rate will lie between certain limits. The true rate is that which would be observed with a very large (or infinite) time-area product.

Since the hypothesis of a Poisson process has been found to be compatible with the data, one can construct a two-sided interval of confidence X using the X^2 test. This interval is given by

$$\left[\frac{X^2_{\frac{\alpha}{2}}(2K + 2)}{2T}, \frac{X^2_{1-\frac{\alpha}{2}}(2K)}{2T}\right] \tag{5}$$

as shown in reference 6. This technique is valid even though all the cells could not be sampled. This was the technique employed to obtain the 95-percent confidence limits shown in figure 5.

Two methods of determining confidence limits have been used. The method using the χ^2 distribution will, in general, give somewhat different confidence limits than other methods and a comparison with limits derived from another method was deemed advisable. The method selected for comparison is a distribution free technique presented in reference 6.

The two-sided $100(1 - \alpha)$ percent confidence level adapted from this reference for the estimate of ψ is given by

$$\left\{\frac{1}{At}\log_e\left[1 + \frac{K+1}{N-K}F_{\frac{\alpha}{2}}(2K+2,2N-2K)\right], \frac{1}{At}\log_e\left[1 + \frac{K}{N-K+1}F_{1-\frac{\alpha}{2}}(2N,2N-2K+2)\right]\right\} \tag{6}$$

There is an $\alpha/2$ probability of ψ being below this interval and an $\alpha/2$ probability of ψ being above this interval. This method unfortunately becomes extremely cumbersome when applied beyond the time of the malfunction of telemeter A which effectively eliminated a number of 0.001-inch pressure cells, and hence it was virtually impossible to determine a puncture-rate confidence interval for the 0.001-inch cells through May 26, 1963, by this method.

There have been no punctures in the 0.005-inch pressure cells. The lower bound of the puncture rate is obviously zero. The upper bound was determined by noting that for an exponential distribution the probability of no punctures $e^{-N\psi At}$ is equal to the confidence level, 100α percent, so that

$$\psi = \frac{1}{NAt}\log_e \alpha \tag{7}$$

Table V presents a comparison of confidence limit bounds as established by the two methods. Beryllium-copper pressure-cell data as of April 19, 1963 (the last date on which all cells could be sampled) were used.

TABLE V

Beryllium-copper thickness, in.	Confidence limit, percent	Upper bound punctures/sq ft/day		Lower bound punctures/sq ft/day	
		χ^2 method	Distribution free method	χ^2 method	Distribution free method
0.001	98	0.0453	0.0466	0.0195	0.0200
.002	98	.0401	.0458	.0075	.0090
.005	98	.0174	.0148	0	0
.001	95	.0427	.0447	.0209	.0221
.002	95	.0365	.0427	.0088	.0093
.005	95	.0139	.0128	0	0
.001	90	.0408	.0414	.0223	.0225
.002	90	.0336	.0368	.0100	.0112
.005	90	.0113	.0087	0	0

Presented in table VI are the same parameters established with the pressure-cell data as of May 26, 1963.

TABLE VI

Beryllium-copper thickness, in.	Confidence limit, percent	Upper bound punctures/sq ft/day		Lower bound punctures/sq ft/day	
		X^2 method	Distribution free method	X^2 method	Distribution free method
0.001	98	0.0434	------	0.0198	------
.002	98	.0344	0.0408	.0071	0.0074
.005	98	.0135	.0148	0	0
.001	95	.041	------	.021	------
.002	95	.031	.0399	.008	.008
.005	95	.011	.0125	0	0
.001	90	.0393	------	.0224	------
.002	90	.0289	.0387	.0093	.0091
.005	90	.0088	.0087	0	0

Figure 11 shows Explorer XVI data for 0.001-inch and 0.002-inch beryllium-copper pressure cells, and the confidence limits from table VI for thicknesses of 0.001, 0.002, and 0.005 inch.

Curve of Puncture Rate Against Thickness

If the puncture rate varies inversely as the cube of the thickness, as indicated by various theoretical studies (ref. 3) and if nominal values of cell thickness are used, then extrapolation from the observed rate for the 0.001-inch cells would give a puncture rate for 0.002-inch cells only about one-fourth as high as the observed rate. On this basis the probability of obtaining exactly 9 punctures in the forty 0.002-inch pressure cells would be less than 0.0001. It is possible, however, to find a curve with some variation other than cubic that will provide a best fit to the experimental data. This fit of a power law to the data is described in the following analysis.

It is assumed that the puncture rate ψ is expressed as a function of thickness τ by a simple power law

$$\psi = a\tau^{-m} \tag{8}$$

For a Poisson process, the probability that x punctures occur is

$$f(x) = \frac{e^{-\nu}\nu^x}{x!} \tag{9}$$

where ν is the expected number of punctures

$$\nu = \psi T \tag{10}$$

The probability of getting the set of data obtained in the 0.001-, 0.002-, and 0.005-inch-thick pressure cells is

$$f(x_1,x_2,x_5) = f(x_1)f(x_2)f(x_5) \tag{11}$$

where subscripts 1, 2, and 5 refer to the 0.001-inch, 0.002-inch, and 0.005-inch pressure cells, respectively. Equations (8) to (11) may be combined to give $f(x_1,x_2,x_5)$ as a function of a, m, and the data. Maximizing $f(x_1,x_2,x_5)$ with respect to a and m yields the following equations

$$\hat{a} = \frac{x_1 + x_2 + x_5}{\tau_1^{-\hat{m}}T_1 + \tau_2^{-\hat{m}}T_2 + \tau_5^{-\hat{m}}T_5}$$

$$\hat{a} = \frac{x_1 \log_e \tau_1 + x_2 \log_e \tau_2 + x_5 \log_e \tau_5}{T_1\tau_1^{-\hat{m}}\log_e \tau_1 + T_2\tau_2^{-\hat{m}}\log_e \tau_2 + T_5\tau_5^{-\hat{m}}\log_e \tau_5}$$

These equations were solved simultaneously to give the maximum-likelihood estimates of $\hat{a}$ and $\hat{m}$:

$$\hat{a} = 2.78 \times 10^{-6}$$

$$\hat{m} = 1.35$$

The maximum-likelihood fit of a power-law curve to the pressure-cell data is thus found to be

$$\psi = 2.78 \times 10^{-6}\tau^{-1.35} \tag{12}$$

This equation is plotted in figure 11 as a dashed line.

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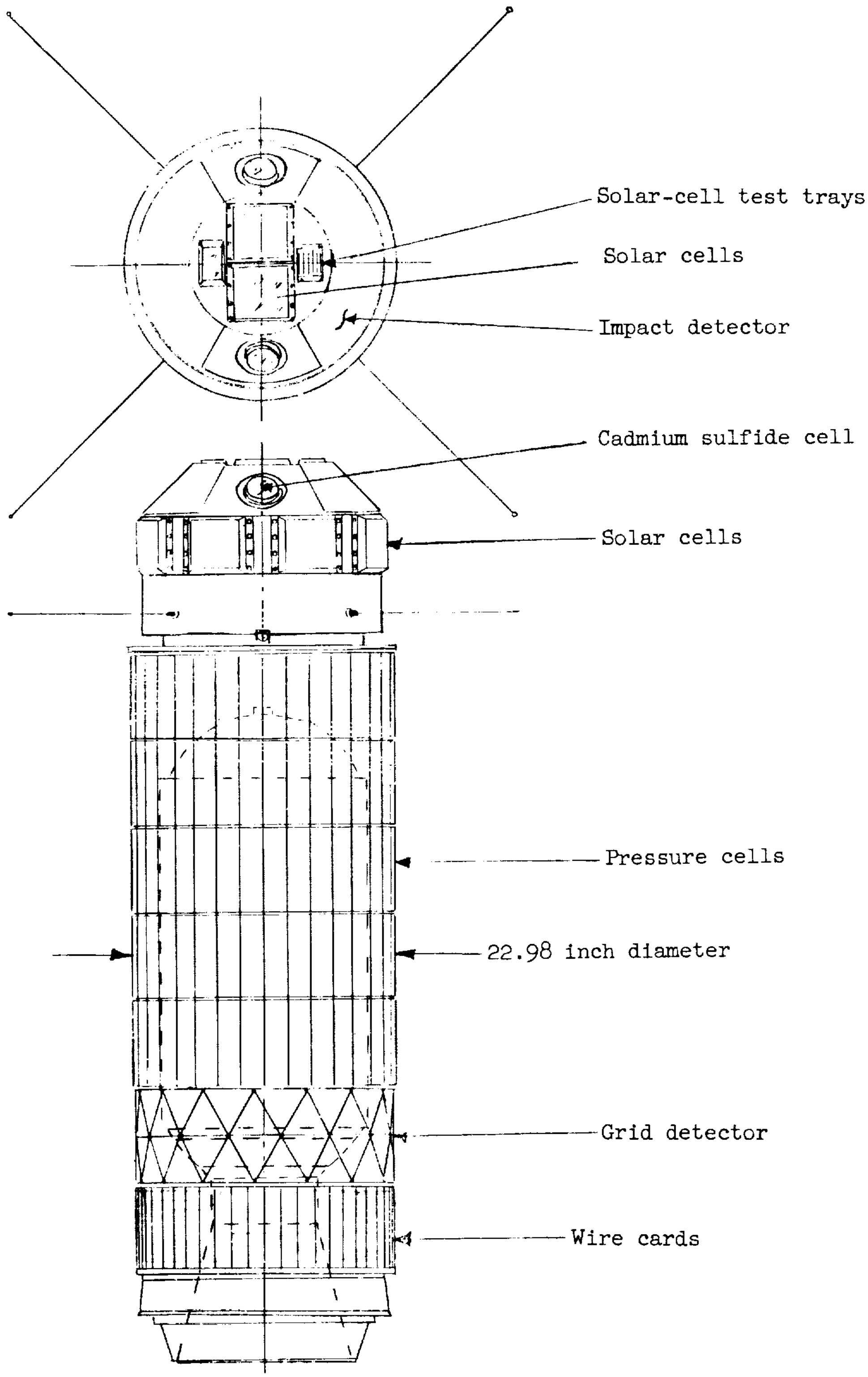
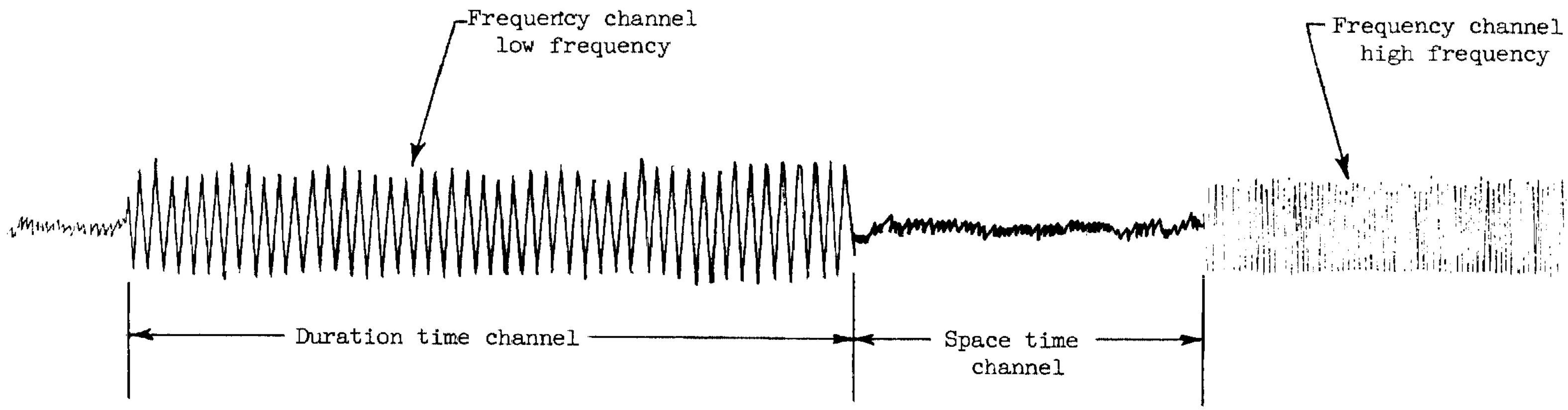


Figure 1.- Sketch of Explorer XVI showing locations of sensors.



Typical 10 kcps reference signal

Figure 2.- Typical telemeter record.

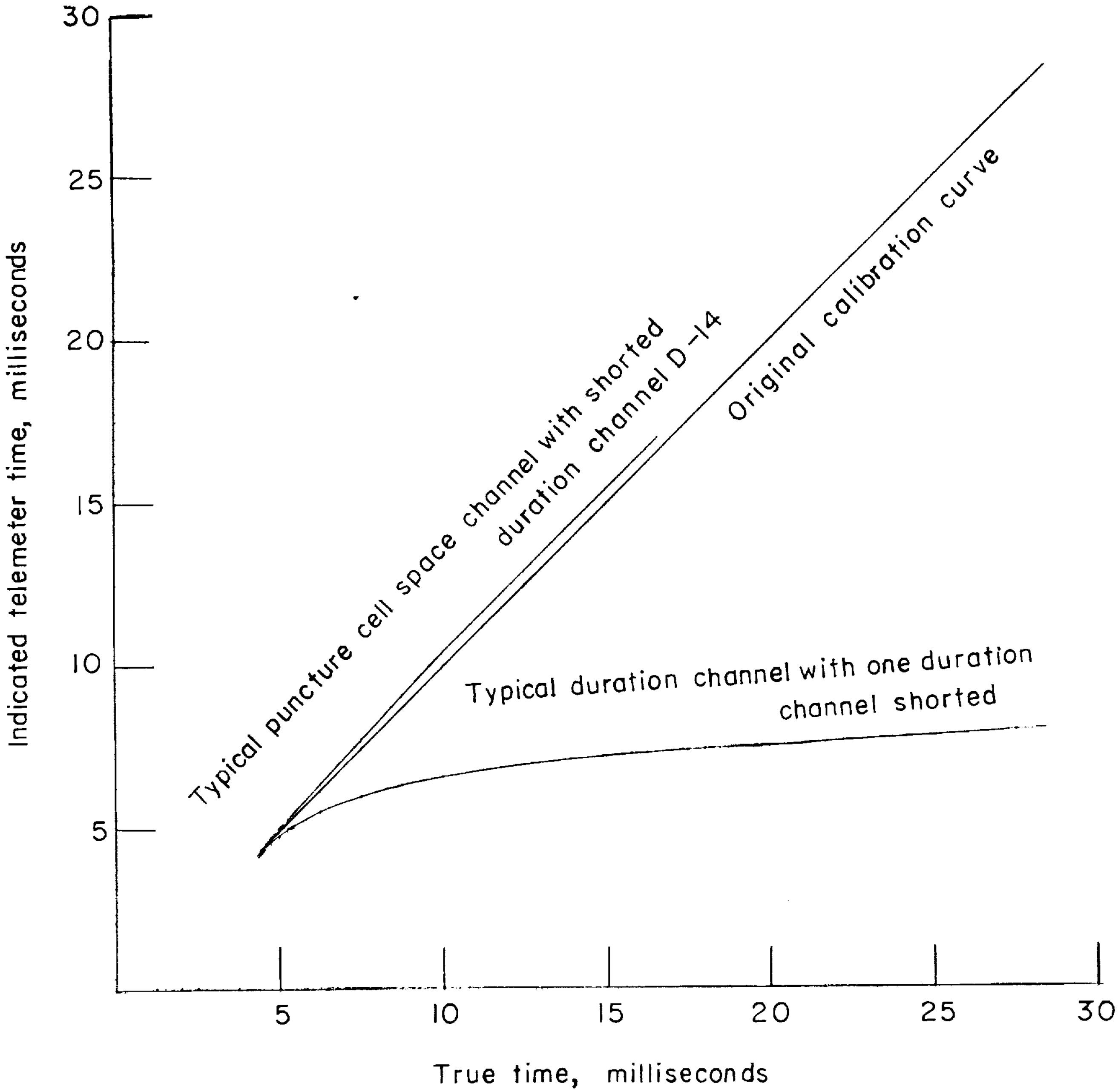


Figure 3.- Altered calibration curve due to shorted duration time channel.

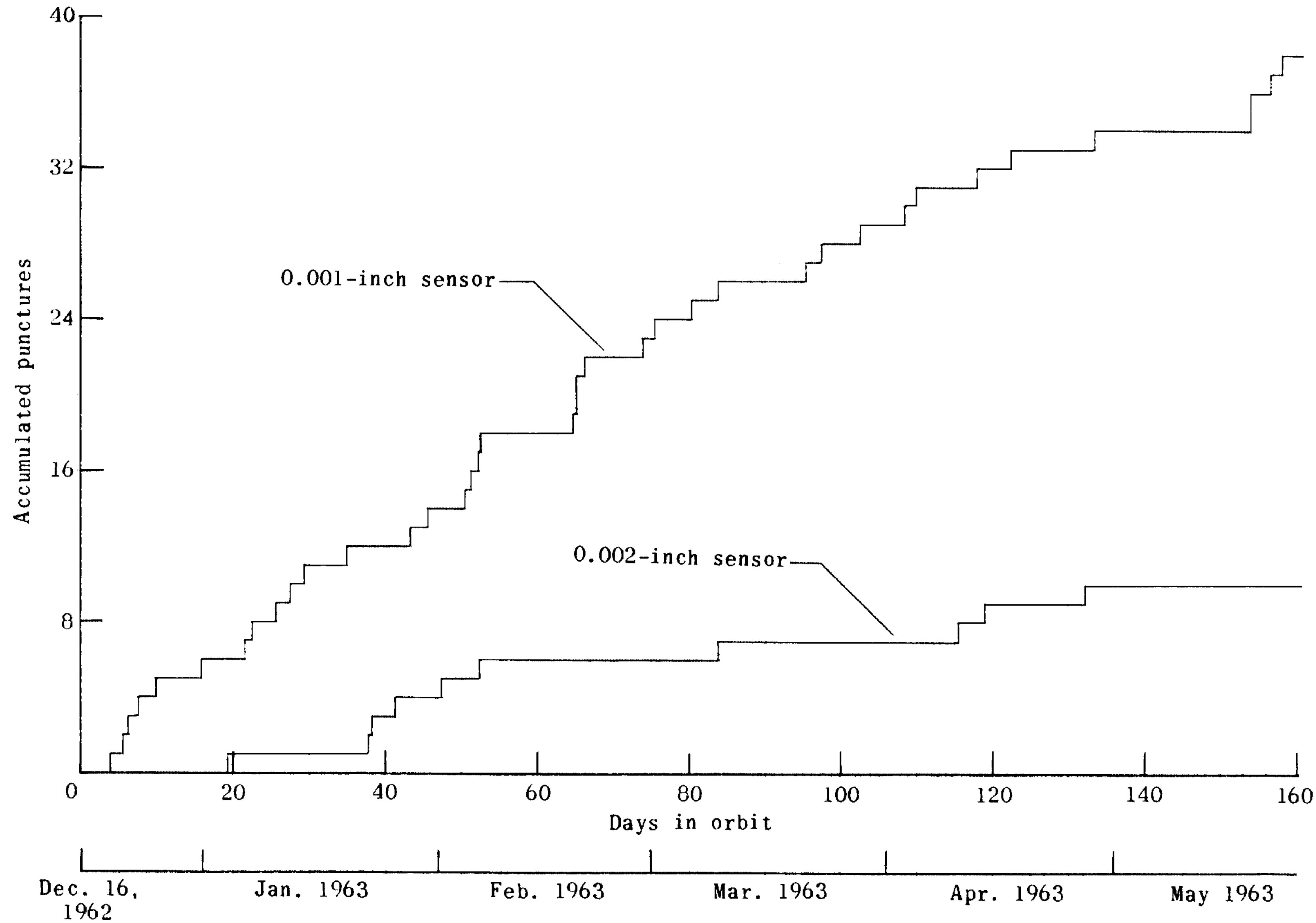


Figure 4.- History of punctures for 0.001- and 0.002-inch-thick sensors.

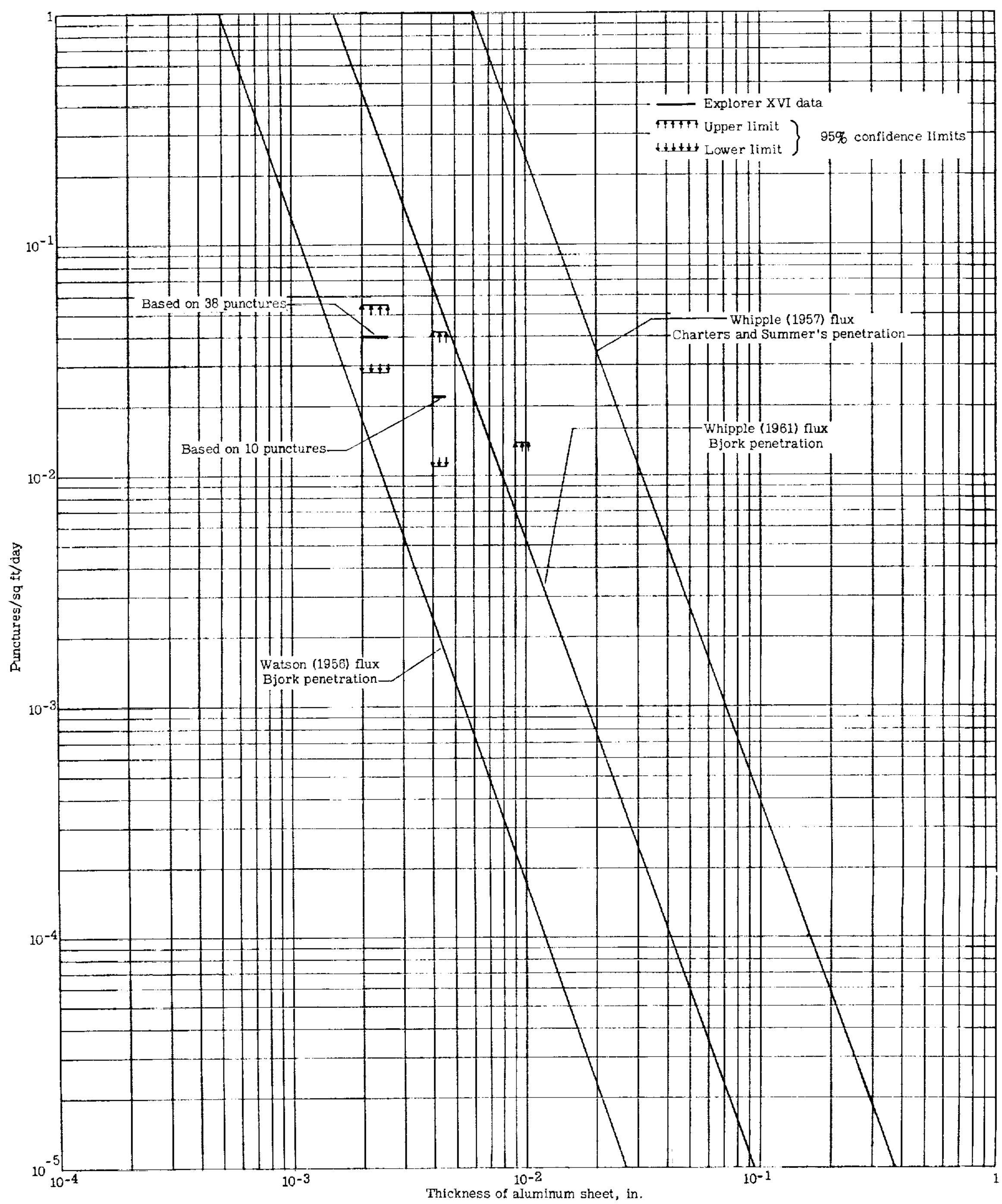


Figure 5.- Most probable rate of puncture of aluminum skin as a function of skin thickness, based on application of Bjork penetration theory to Whipple (1961) and Watson (1956) fluxes and Charters and Summers penetration theory to Whipple (1957) flux. Bars represent data from beryllium-copper pressure cells on Explorer XVI, as of May 26, 1963, tentatively interpreted in terms of aluminum with 95-percent confidence limits noted.

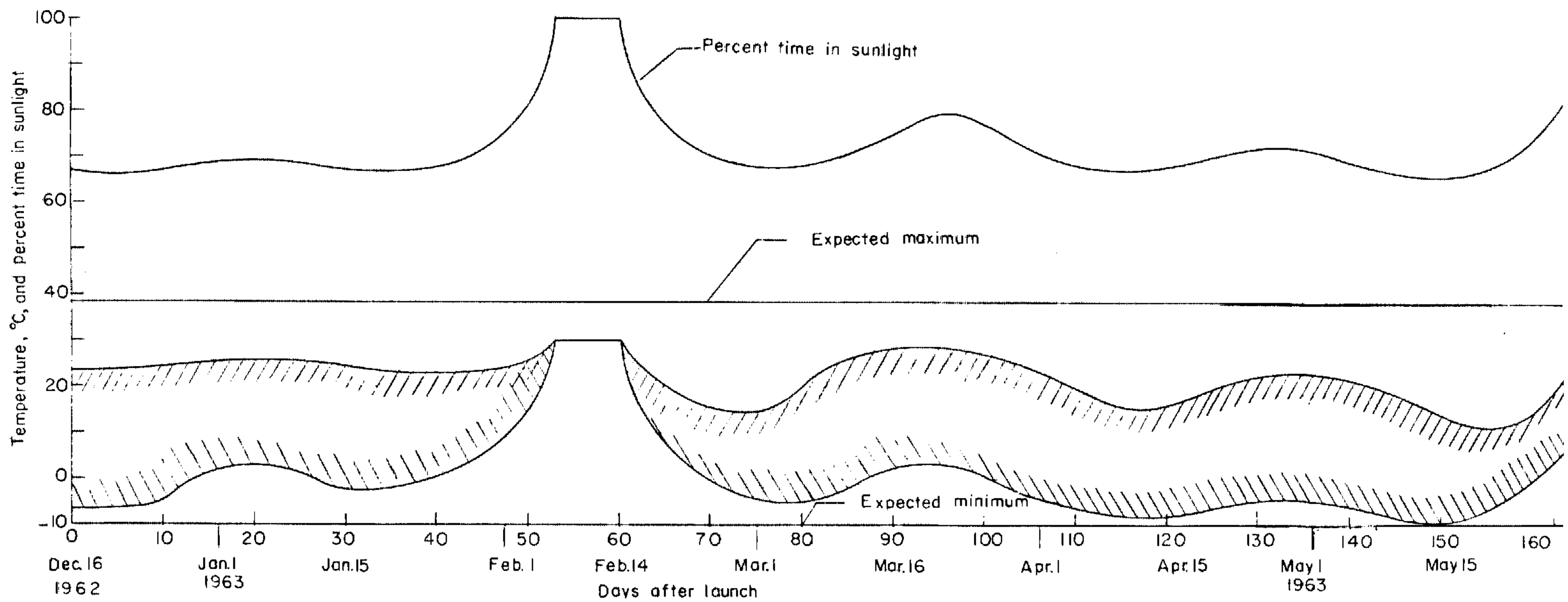


Figure 6.- Temperature history of solar cells and comparisons with percent time in sunlight and with predicted maximum and minimum temperatures.

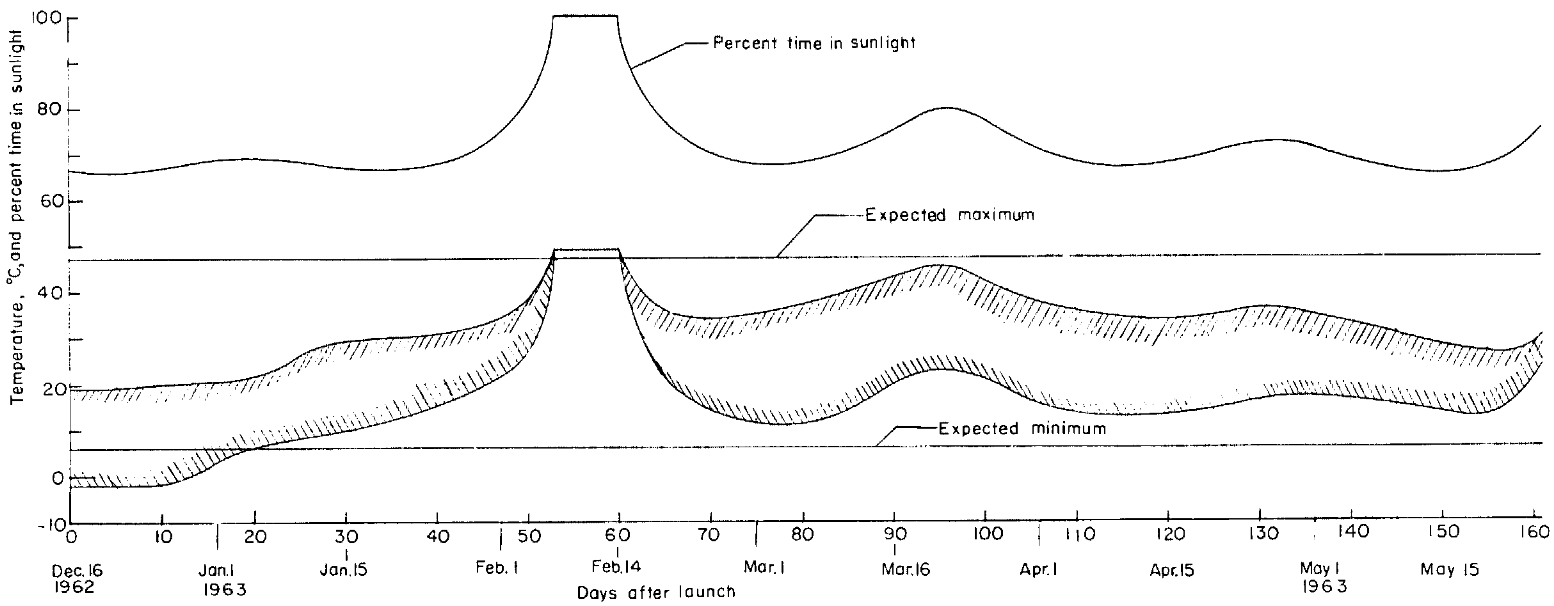


Figure 7.- Temperature history of pressurized cells and comparisons with percent time in sunlight and with predicted maximum and minimum temperatures.

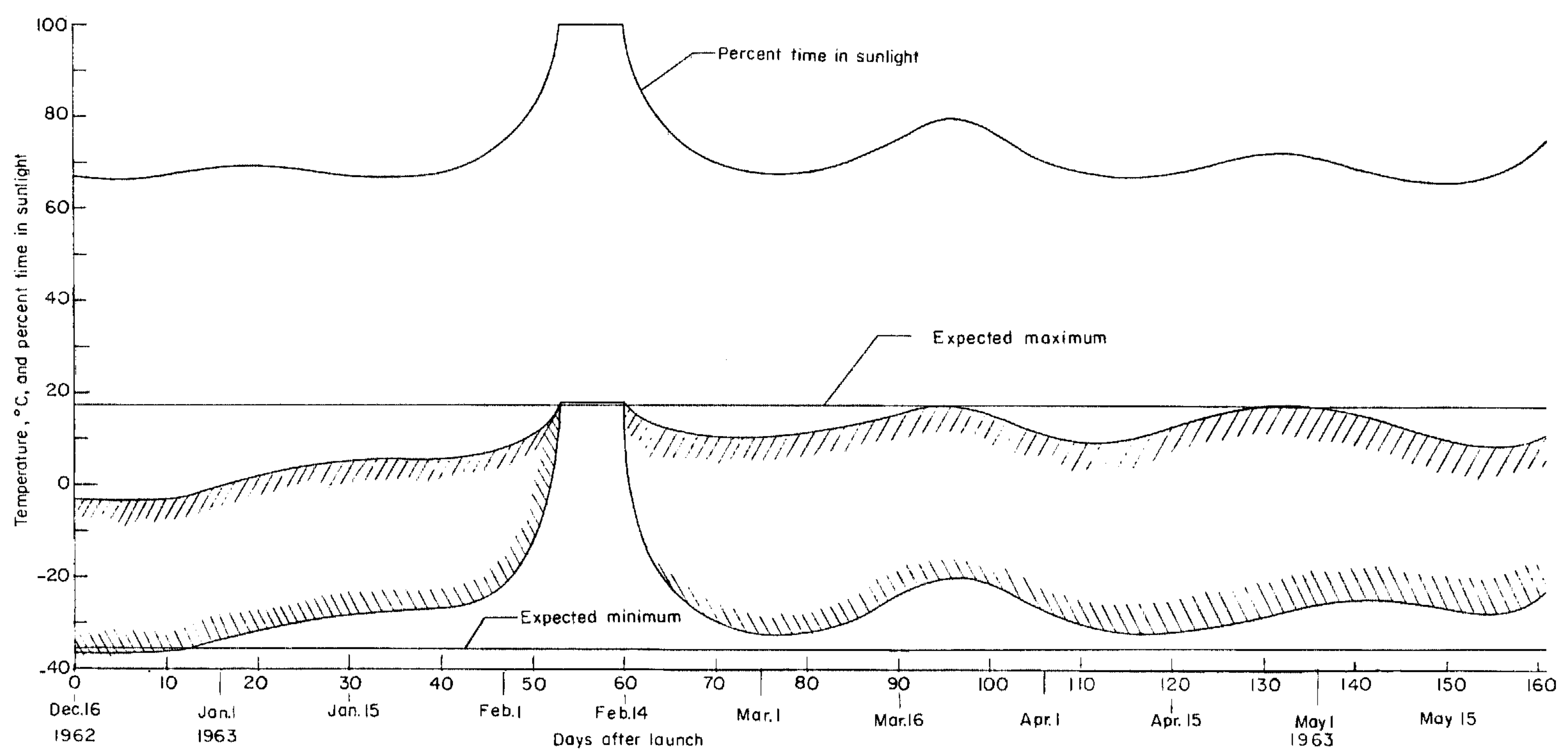


Figure 8.- Temperature history of steel-covered grid detectors and comparisons with percent time in sunlight and with predicted maximum and minimum temperatures.

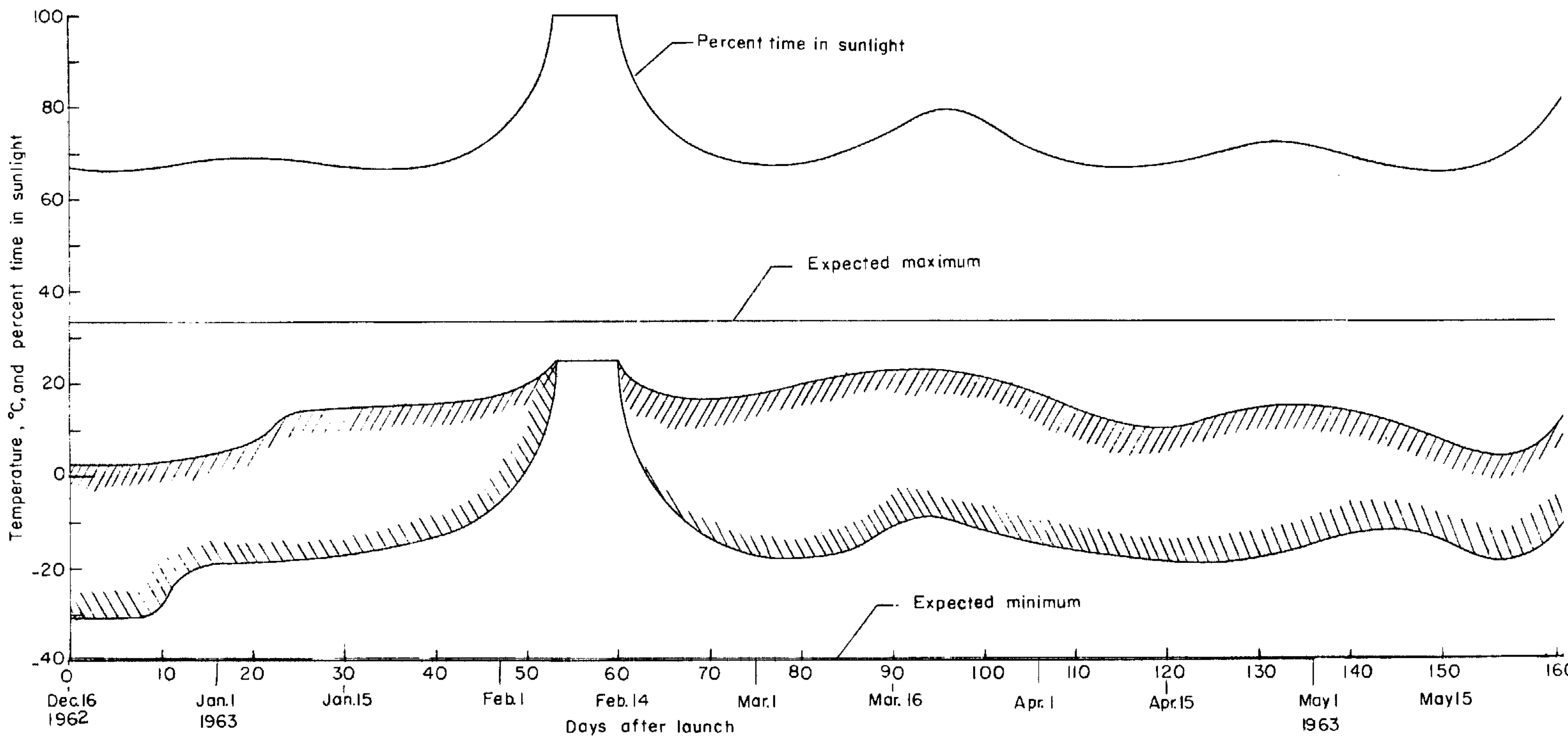


Figure 9.- Temperature history of wire card detectors and comparisons with percent time in sunlight and with predicted maximum and minimum temperatures.

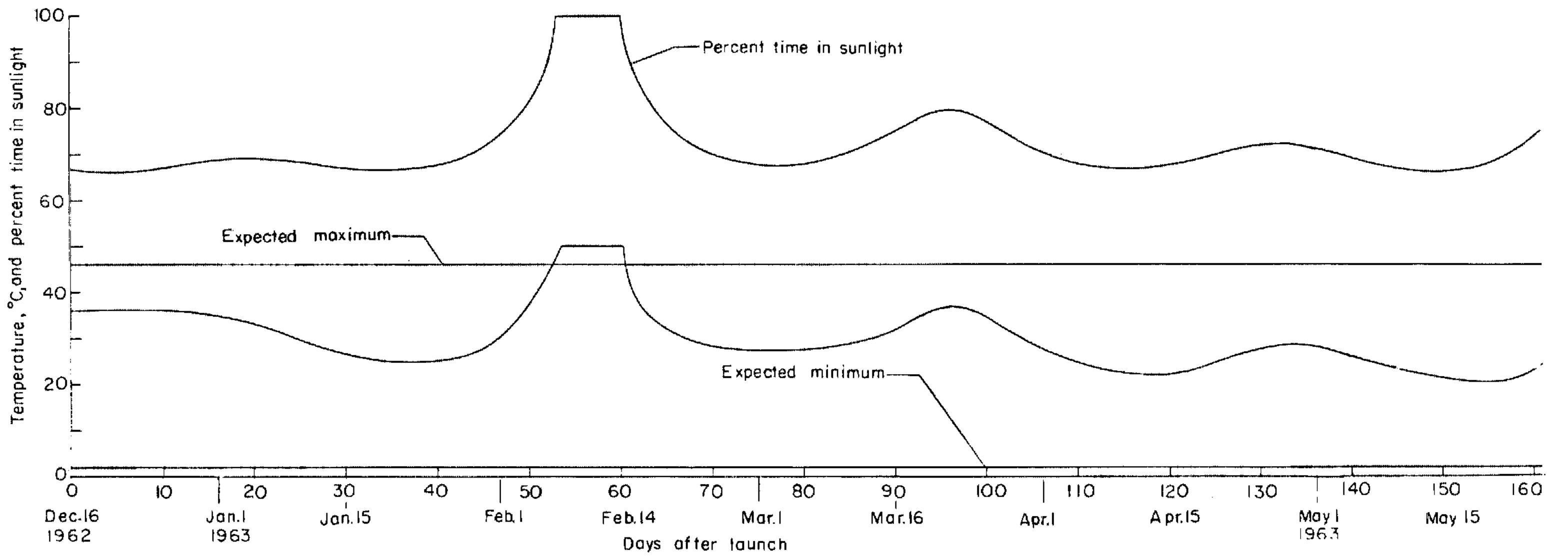


Figure 10.- Temperature history of telemetry systems and comparisons with percent time in sunlight and with predicted maximum and minimum temperatures.

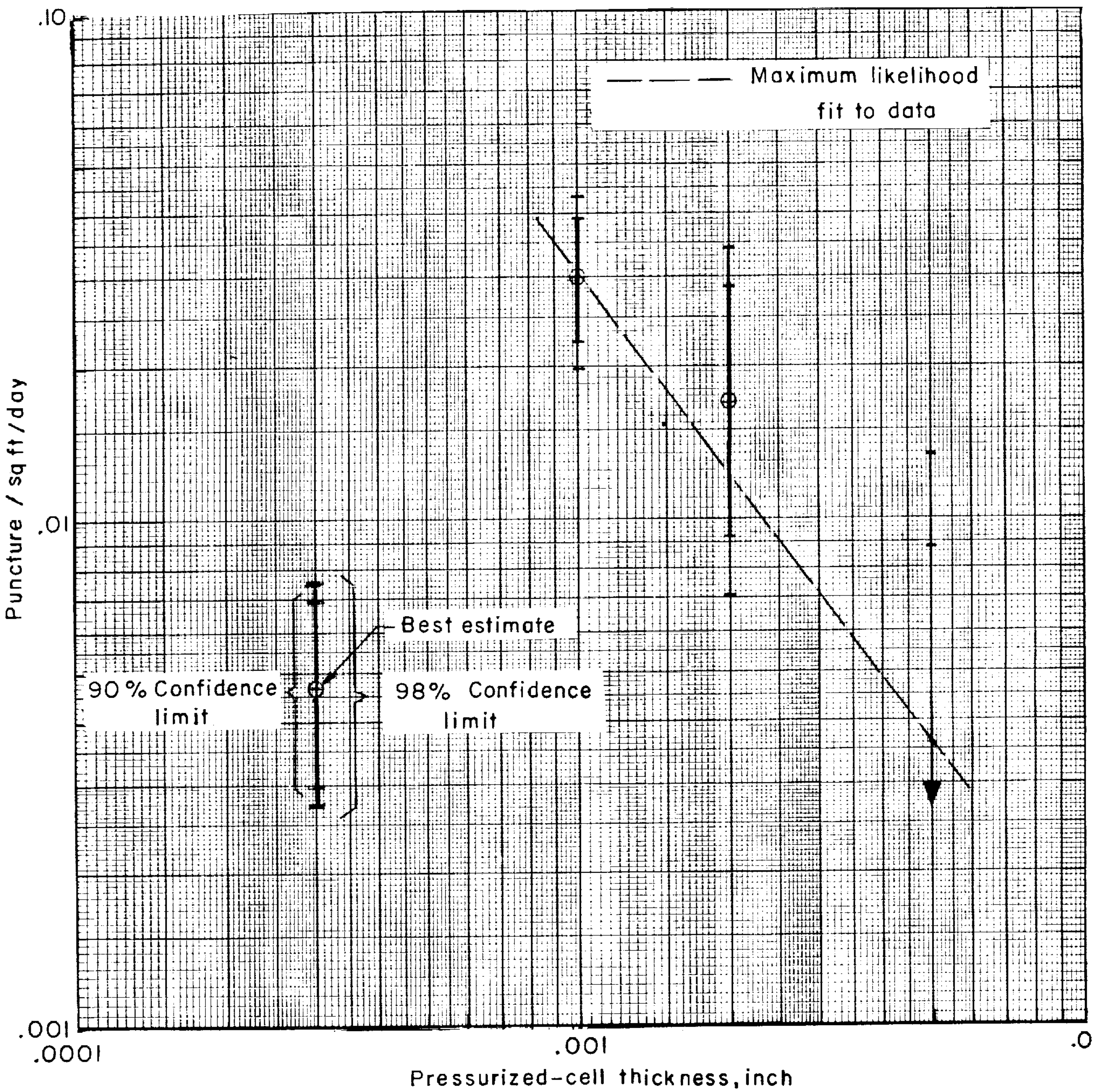


Figure 11.- Confidence intervals on pressure-cell data points. (Nominal thickness is assumed.)