Tup

DRA

(NASA-CR-138948) LONG-DURATION LIFE TESTS
OF SLIP RING CAPSULE ASSEMBLIES FOR
INERTIAL GUIDANCE PLATFORMS Final Report
(Poly-Scientific Div.) ~~23~~ 24 p HC $4.25
CSCL 17G G3/21

N74-29117

Unclas
16947

POLY-SCIENTIFIC
Litton

POLY-SCIENTIFIC DIVISION OF LITTON SYSTEMS, INC. • 1213 NORTH MAIN STREET • BLACKSBURG, VIRGINIA 24060

TELEPHONE (703) 552-3011 • TWX 910-494-1231

FINAL REPORT

NAS 8-29199

LONG-DURATION LIFE TESTS OF SLIP RING CAPSULE ASSEMBLIES FOR INERTIAL GUIDANCE PLATFORMS

BY

S.R. COLE

E.W. GLOSSBRENNER

SUBMITTED TO:

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

MARCH 6, 1974

MO 16673

LONG-DURATION LIFE-TESTS OF SLIP RING CAPSULE ASSEMBLIES FOR INERTIAL GUIDANCE PLATFORMS

S.R. Cole and E.W. Glossbrenner
POLY-SCIENTIFIC, LITTON SYSTEMS, INC., Blacksburg, Virginia USA

Eight slip ring capsules, each having 80 or 100 circuits, were operated for time periods ranging from 14,300 hours to 24,700 hours. The test mode simulated the motion of gimbal axes of the Saturn inertial guidance platform in an organic free nitrogen environment. Computer-compiled noise data (approximately 45,000 recordings) were graphed as a function of test time and position within the capsules and as extreme probability distributions. Greater than ninety-nine percent of the noise measurements for the capsules with sufficient lubrication were less than 10 milliohms. Capsules with glass dielectrics did not perform significantly differently than those with filled epoxy dielectrics. The initial wear mode of prow formation was followed by rider wear. After 10^8 wipes, ring wear depth did not exceed the surface finish and the radial rider wear depth was less than 13 microns.

LONG-DURATION LIFE-TESTS OF SLIP RING CAPSULE ASSEMBLIES FOR INERTIAL GUIDANCE PLATFORMS

S.R. Cole and E.W. Glossbrenner
POLY-SCIENTIFIC, LITTON SYSTEMS, INC., Blacksburg, Virginia, USA

Introduction

Slip ring capsule assemblies enjoy a wide usage in a variety of commercial and military inertial guidance systems and other precise instruments. Perhaps the most critical of these applications is on the stabilized platform for the highly successful Saturn booster in the Apollo and Skylab programs. Approximately 8 slip ring capsules are required for each system, all of which have exhibited failure-free performance.

Earlier work by Lowe and Glossbrenner[1] described the development, design details and reliability of the slip ring capsules for Saturn flight units. This paper presents the results of tests conducted on more recent capsules by Marshall Space Flight Center of NASA. These tests were conducted over periods from 14000 to 25000 hours in a simulated gimbal mode of operation in a clean environment of dry nitrogen. Following these extended tests, the slip rings were subjected to a complete tear-down analysis at Poly-Scientific.

Operational Test Capsules

The capsules used in this test were of the basic design specifically developed for Saturn and described previously. Two of the capsules were of an experimental type having glass barriers[2] in lieu of the filled epoxy barriers typically used in Saturn and other critical applications. The capsules were of the 80 circuit (3 units) or the 100 circuit (5 units) configuration. As in all Saturn units, the ring surfaces were of a 1% nickel-hardened gold, approximately 250 HK_{10}, and the wipers were of an alloy equivalent to ASTM B 477, Temper B. The brush forces were 3 grams (80 ckt) and 4 grams (100 ckt).

All capsules but one (SN 2) were lubricated with a blend of four- and five-ring polyphenyl ethers, (PPE)[3]. The polyphenyl ether blend was applied as a neat oil so that the contact areas were heavily lubricated. Serial number 2 was lubricated with a thin film of a diester oil that was applied with a solvent carrier. (Table I)

TABLE I: Description of Test Capsules and Results of the Lubrication and Wear Measurements.

SN	NUMBER CIRCUITS	ROTOR INSULATION	OIL TYPE	OIL QTY (mg)	HOURS OF LIFE TEST	WIDTH OF BRUSH FLATS (Microns)	LOOSE WEAR DEBRIS (μg)	PREDOMINANT TYPE WEAR AT END OF TEST	PREDOMINANT DEBRIS COLOR
180	80	ES 218*	PPE	16	24,700	104	87	RIDER	BLACK
203	80	ES 218	PPE	45	16,600	86	-	PROW	GOLD
212	80	ES 218	PPE	35	16,200	67	300	PROW	GOLD
101	100	ES 218	PPE	35	14,300	94	230	MIXED	BLACK, GOLD
103	100	ES 218	PPE	37	14,300	92	240	RIDER	BLACK
105	100	ES 218	PPE	27	25,700	97	240	RIDER	BLACK
2	100	GLASS	DIESTER	1	23,200	96	200	RIDER	GOLD
8	100	GLASS	PPE	52	19,700	87	-	RIDER	BLACK

* Ceramic filled aromatic amine cured epoxy.

Operational Life Tests

The slip ring capsules were life tested at George C. Marshall Space Flight Center in an atmosphere of gaseous nitrogen (3 psig) at a temperature of 50C. The closed chambers were designed to contain a minimum of organic components. The slip ring rotors were oscillated relative to the brushes at 6-8 Hz at a fixed location with an excursion of 2 $\pm$ 1 degrees double amplitude, except when noise tests were being performed. A 0.010 ampere current was passed through the circuits during the periods of rotor oscillation at an open circuit potential of 10 volts. The noise was recorded on strip charts as the capsule rotors were servo-driven at 1/2 RPM for approximately 365° in a clockwise direction and then reversed for 365° at the same rate. The 32 channel recorder had a frequency response of DC-200Hz. The initial noise test intervals were approximately 100 hours; however, after several thousand hours of testing, the intervals were extended first to 200 hours and later to 300 hours. The capsule assemblies were harnessed so that the noise could be measured in each circuit pair. Thus, 40 or 50 noise recordings were obtained from each capsule during a given test period.

Storage Life Tests

Seven Saturn slip ring capsules that had been tested for 1100 to 3300 hours in 1968 or 1969 were stored in semisealed containers until 1973. Most of the storage time was in a warehouse without temperature or humidity control. MSFC noise tested the capsules after the storage periods and returned them to Poly-Scientific along with the test data. Five of the capsules had been lubricated with a neat blend of polyphenyl ethers and two had been lubricated with a thin diester film.

Post Life-Test Analyses

Noise, Operational Life Tests

The maximum noise levels from each of the recordings were punched into IBM cards along with the capsule serial number, lapsed test time and circuit location within the capsule. These data were processed so that the mean, low, high, standard deviation and coefficient of variation were calculated at each test period for each of the capsules. The mean noise values were charted as a function of time along with the percentage of the noise values that exceeded an arbitrary level of 30 milliohms (Figure 1). The frequency of occurrence of each noise value throughout the test was determined and graphed on extreme probability paper that was proposed by Gumbel[4] (Figure 2).

The mean noise from each circuit pair was graphed as a function of circuit position within the capsule (Figure 3). Recordings representative of the noise at the conclusionof the tests are shown in Figure 4.

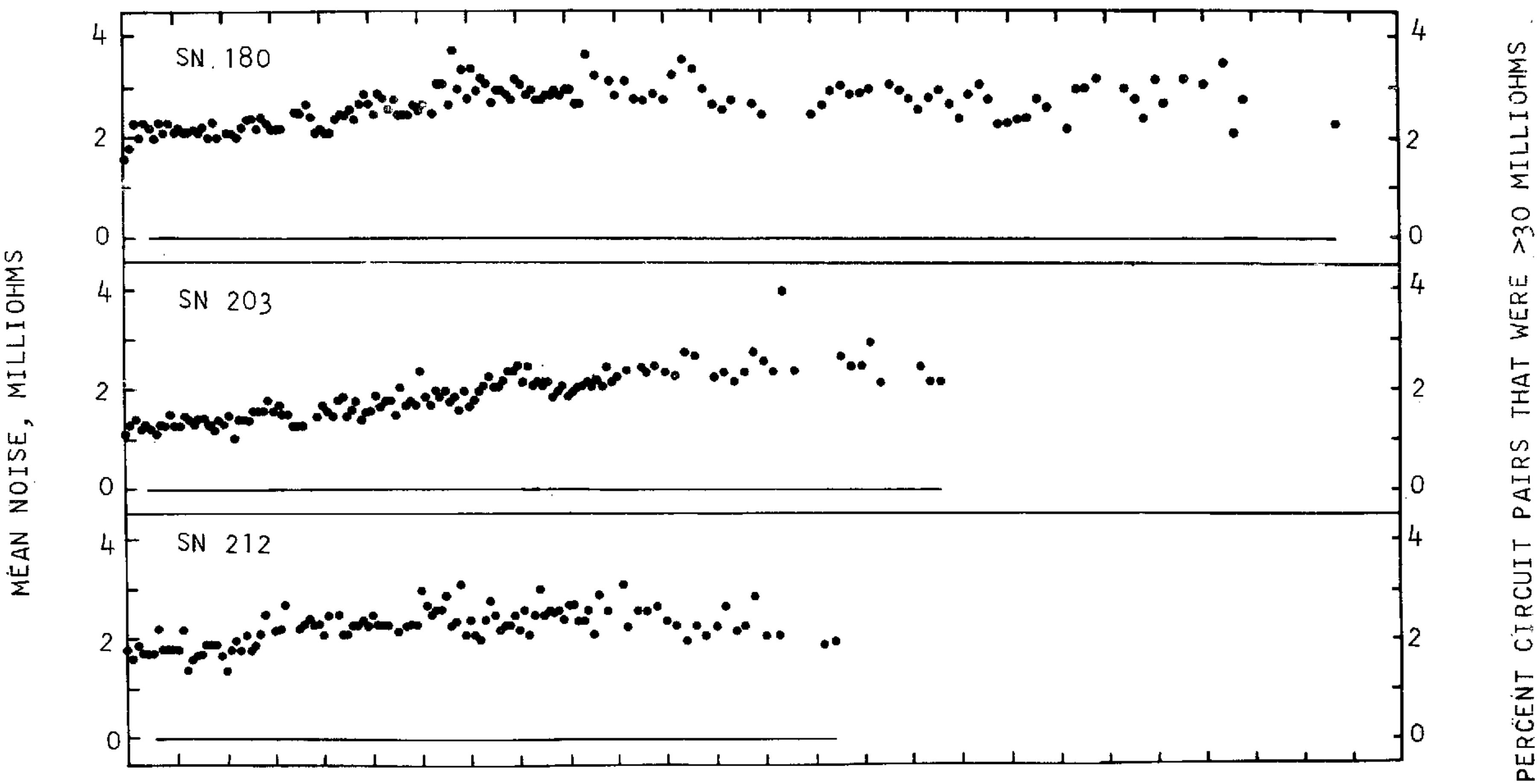

FIGURE 1a: Mean noise as a function of test time (dots) and percent of the circuit pairs that were ≥30 milliohms (lines).

-7-

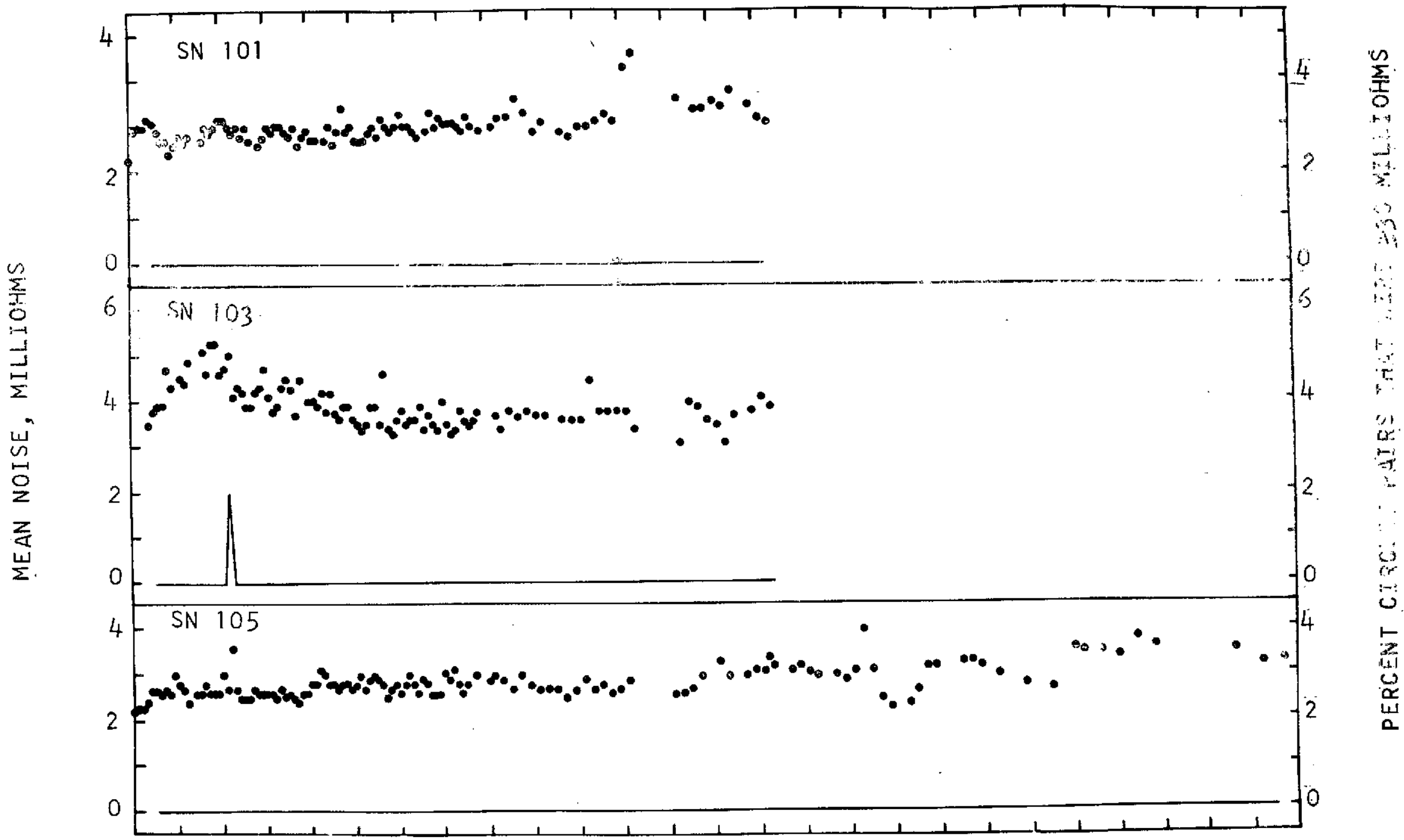

FIGURE 1b: Mean noise as a function of test time (dots) and percent of the circuit pairs that were ≥30 milliohms (lines).

-8-

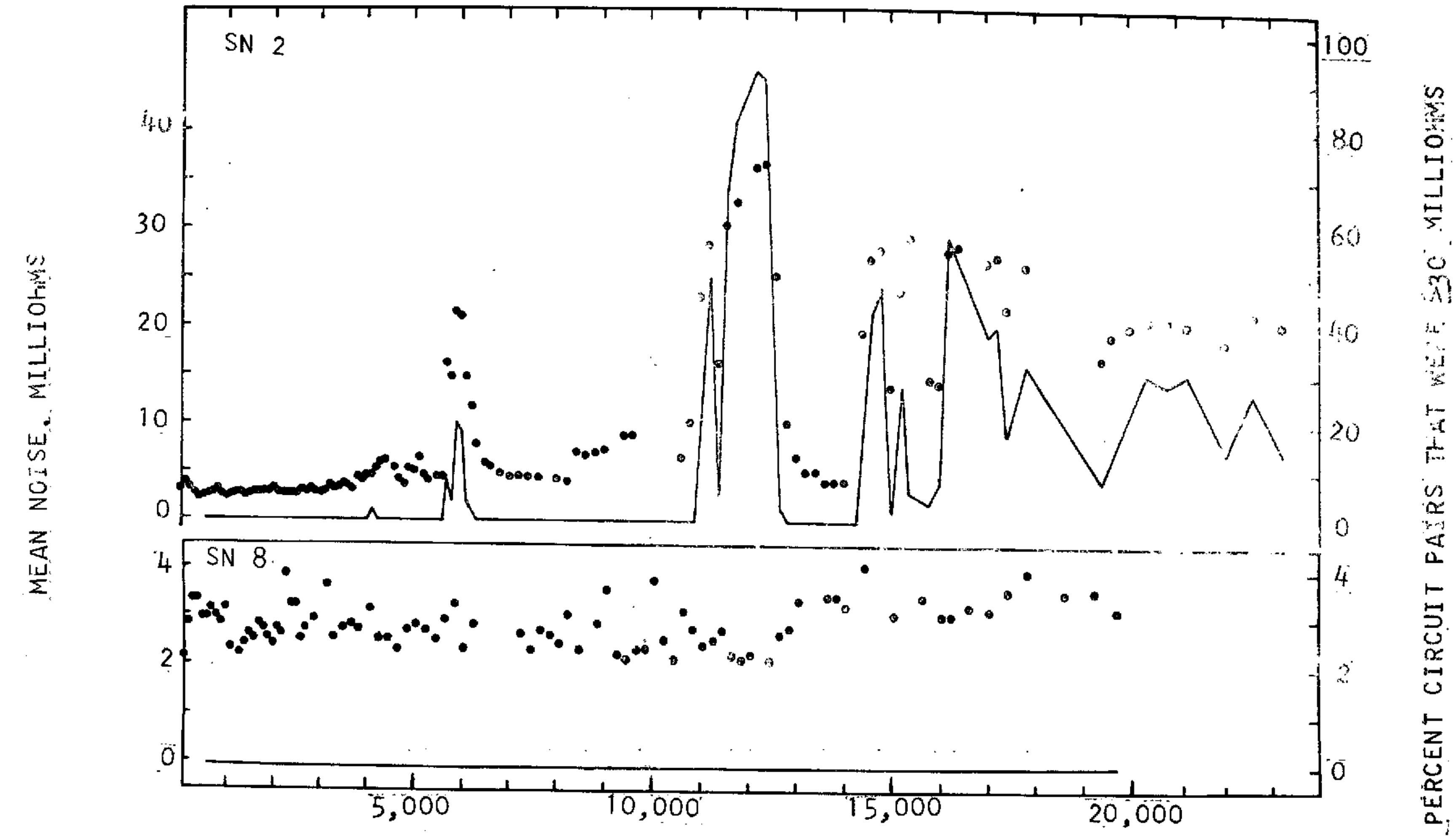

FIGURE 1c: Mean noise as a function of test time (dots) and percent of the circuit pairs that were ≥30 milliohms (lines).

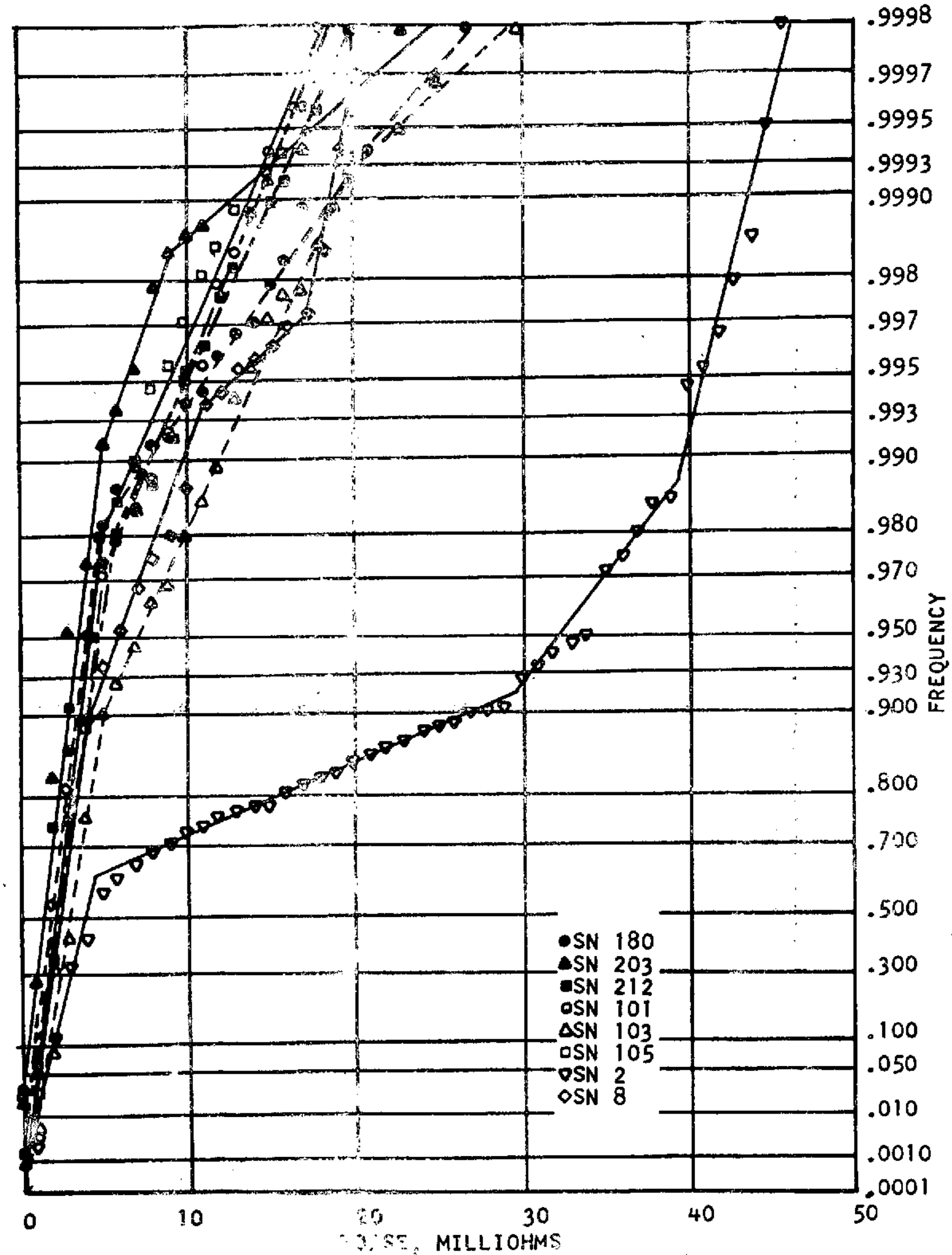

FIGURE 2: Ext-eme probabi.ity (Gumbel) distributions of noise data.

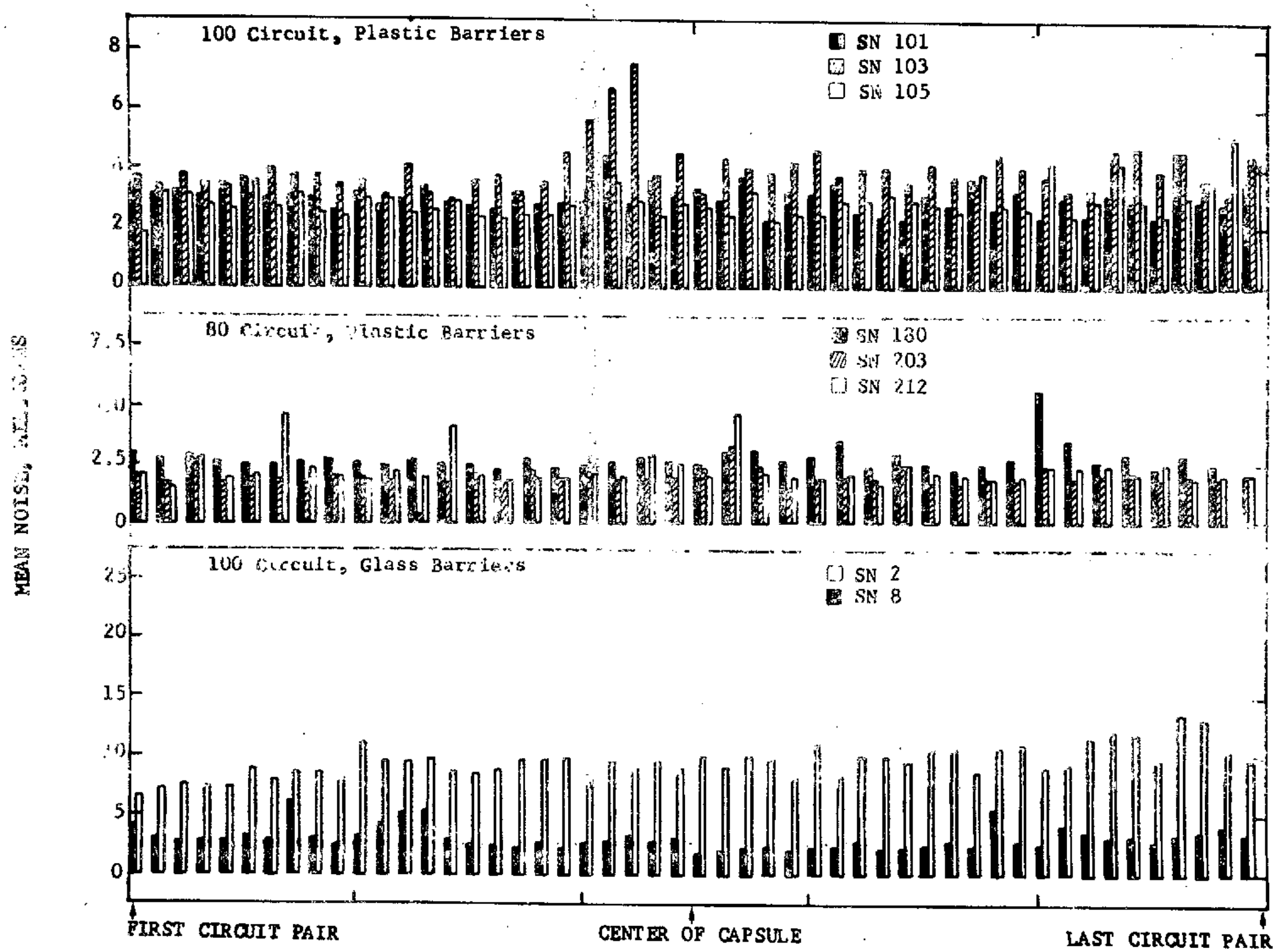

FIGURE 3: Noise of individual circuit-pairs as a function of ring location along the axis of the capsule. The first-circuit pair (nearest the large bearing) is at the left margin, the last circuit pair is at the right margin.

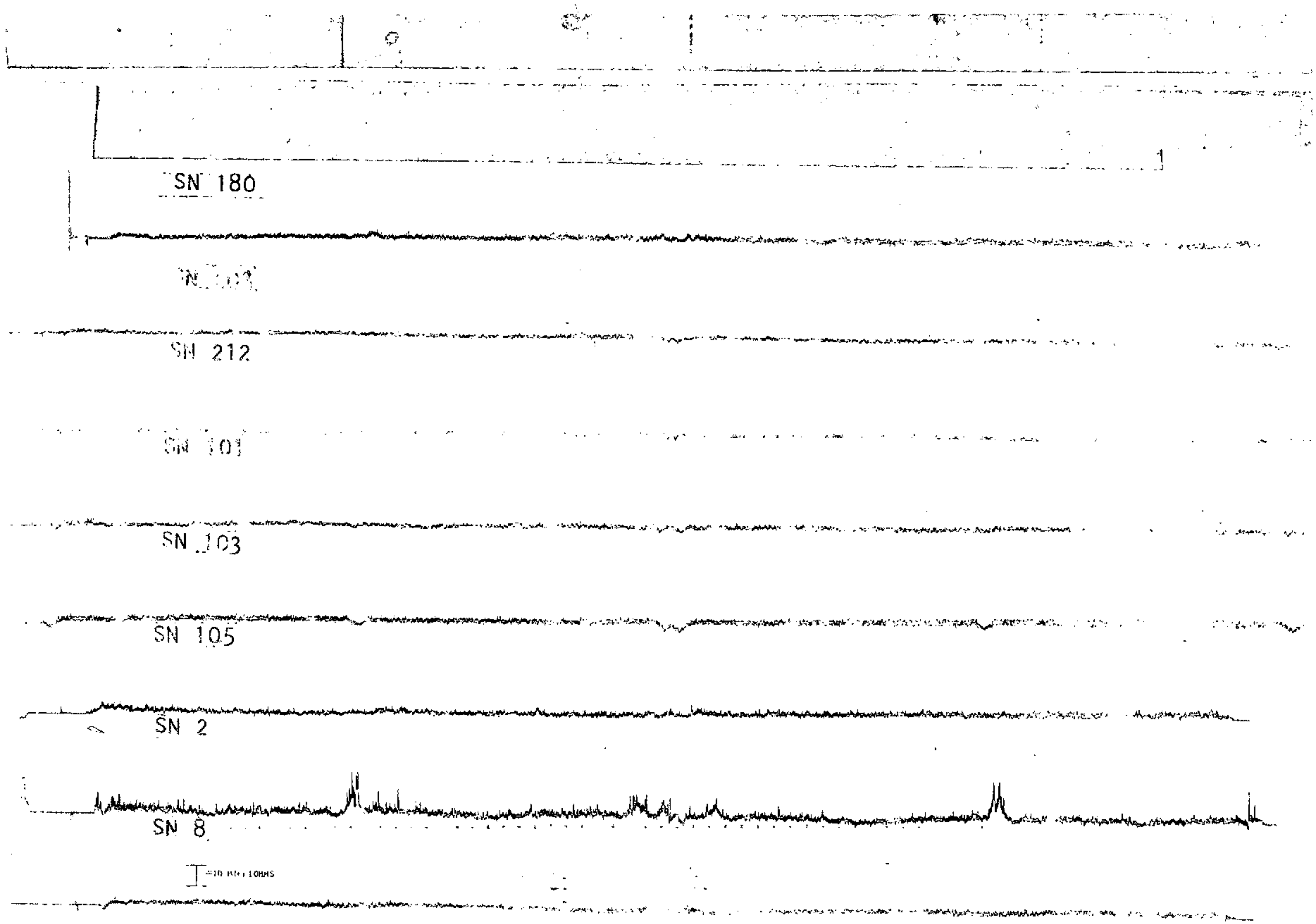

FIGURE 4: Selected noise traces at the time that the slip ring capsules were removed from life-test. The arrow denotes the points of reversal after the rotor was rotated slightly more than 360°.

Lubrication and Wear, Operational Life Tests

The lubricant and loose wear debris were removed from the test capsules and measured quantitatively by infrared and atomic absorption techniques, respectively. The depth of the ring wear, and the amount of brush wear were estimated and the modes of contact wear were examined.

Storage Life Tests

The noise data that had been obtained before the capsules were placed in storage were compared with the post storage noise data. Also, the residual lubricant and loose wear debris quantities were measured.

Results

Noise, Operational Life Tests

The noise of the heavily lubricated capsules (all but SN 2) remained low throughout the live tests (Figure 1). There was only one noise peak that exceeded 30 milliohms (Figure 1, SN 103). Virtually all of the noise measurements were much less than 30 milliohms; 99.9%, less than 20 milliohms; and 95%, less than 7 milliohms (Figure 2).

The lightly lubricated capsule (SN 2) had significantly higher noise than was observed on the heavily lubricated capsules (Figure 1). The noise remained about as low as that generated by the heavily lubricated capsules for approximately 5,000 hours of test and then increased in a cyclic manner. Some cyclic nature of the noise as a function of test time is noted on the heavily lubricated capsules. The highest noise at a given test period occurred as the brush legs passed over the wear spots, due to the oscillatory motion. This is evidenced on noise recordings (Figure 4, especially SN 2) by peaks near the points of reversal and at points approximately 180° from the points of reversal. The noise peaks tended to form mirror images about the points of reversal. The rise and fall of noise with test times was probably caused by debris piles being built to a maximum, broken down (minimum noise) and rebuilt again. The higher noise on the lightly lubricated capsule was probably caused by the coherence of wear debris that tended to be compacted at the ends of the wear spots; In heavy lubricant the wear debris that formed was quickly covered with oil and was dispersed by the lubricant so as not to form tenacious high resistance accumulations.

The extreme probability (Gumbel)[4] distributions indicated the number of noise recordings that exceeded each particular level and gave some insight as to what might have caused the noise peaks. Breaks in the graph of the distribution could in some cases be correlated with a physical mechanism. All of the distributions in Figure 3 have breaks at approximately 5 milliohms that could have been caused by a high resistance on one side of a vee groove.

The breaks in the vicinity of 20 milliohms are close to the increase in circuit resistance that would be caused by one brush leg lifting while the other remained in closed contact.

The noise of each circuit was studied as a function of its position within a slip ring capsule. All of the noise data from the eight life tests are represented in Figure 3. No trends are evident to indicate that a given ring position is more likely to generate higher noise than any other position.

Wear, Operational Life Tests

The total amount of wear on all the capsules was quite small. In no case was the original surface finish of the hard gold rings worn away (Figure 5). This type finish has been measured to have a 28 microinch (0.71 micron) CLA roughness with a mean peak height of 17.2 microinches (0.44 microns).[5] Examination of the ring surfaces showed that much of the surface finish remained even in the most severely worn tracks after a billion wiper (brush) passes. This indicates that the maximum ring wear depth was about 1 micron.

The wear modes corresponded well with the findings of Antler[6]. This has been related to slip ring surfaces by Morris, et al[7] and defined in the model described by Glossbrenner[8]. The wear at the termination of the test was prow type on two units (Figure6), mixed on a third and of the rider type (Figure 7) on the remainder (Table I).

The adhesive type prow wear mode apparently existed early in the wear process, because some gold prow debris was observed on virtually all units. Those which remained in the prow mode still had brushes with retained symmetrical prows, loose prows (Figures 6 and 8), material that was back-transferred to the ring surface (Figure 5), and predominantly gold colored debris. Those units in the rider wear mode had predominantly black debris resulting from the abrasive wear of the hardened surfaces.

The black debris was quite adherent to both the rings and brushes adjacent to the oscillation area. Neither extraction in carbon tetrachloride nor ultrasonic cleaning in trichlorotrifluoroethane would remove it. Chromic-sulfuric acid slowly dissolved the black binding material, leaving fine gold particles. When treated with aqua-regia, the gold dissolved leaving only a brown tissue-like substance.

Storage Life Tests

The results of the storage (shelf) life tests are included in Tables II and III. Both the residual oil and loose wear debris quantities are near those reported for the long term operational tests (Table II).

FIGURE 5: Ring surface (SN 203) after approximately 840 million brush passes. Note that the original surface finish of the ring has not been worn away. Some back transferred material is visible.

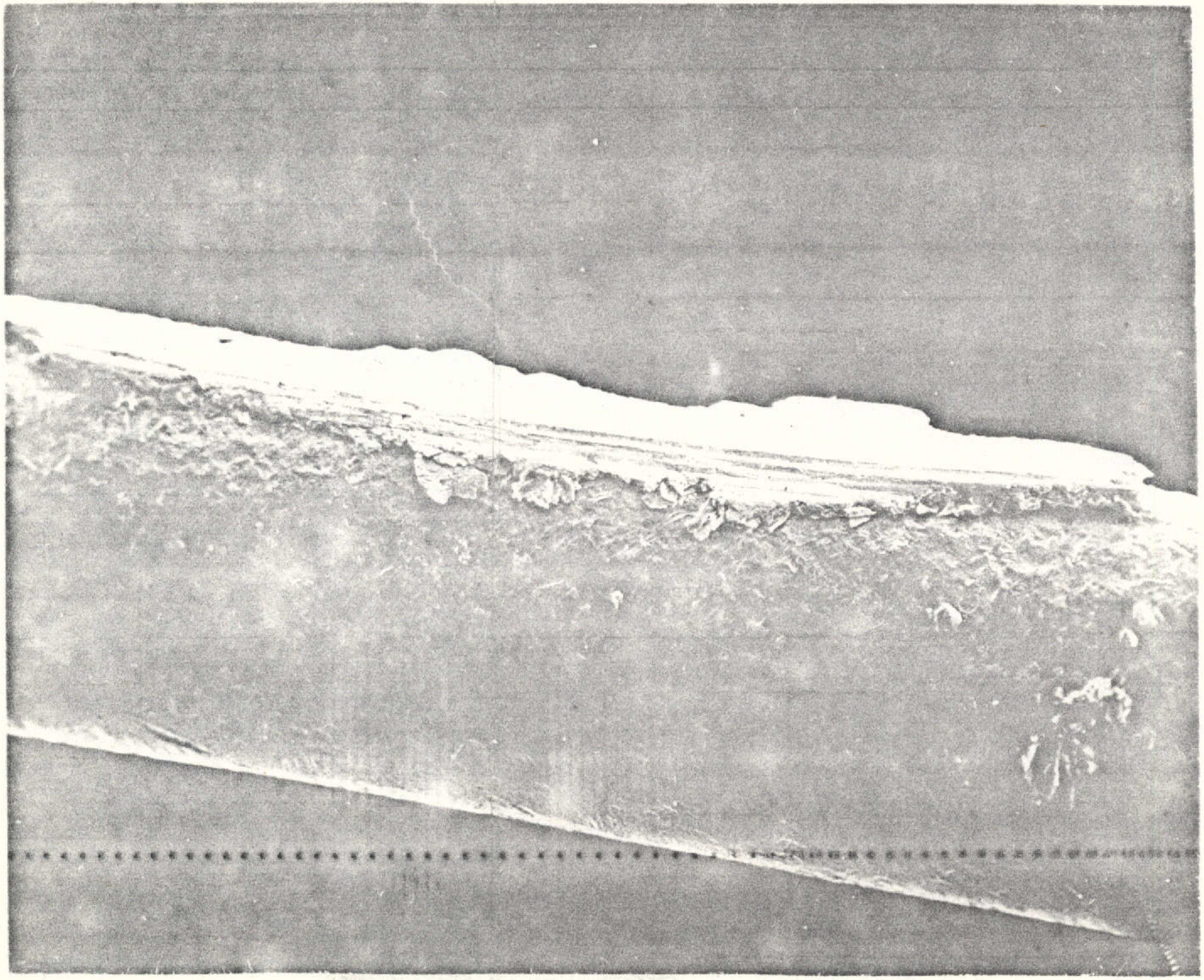

FIGURE 6: Scanning electron micrograph of a brush showing predominant prow formation. Original magnification, 190X.

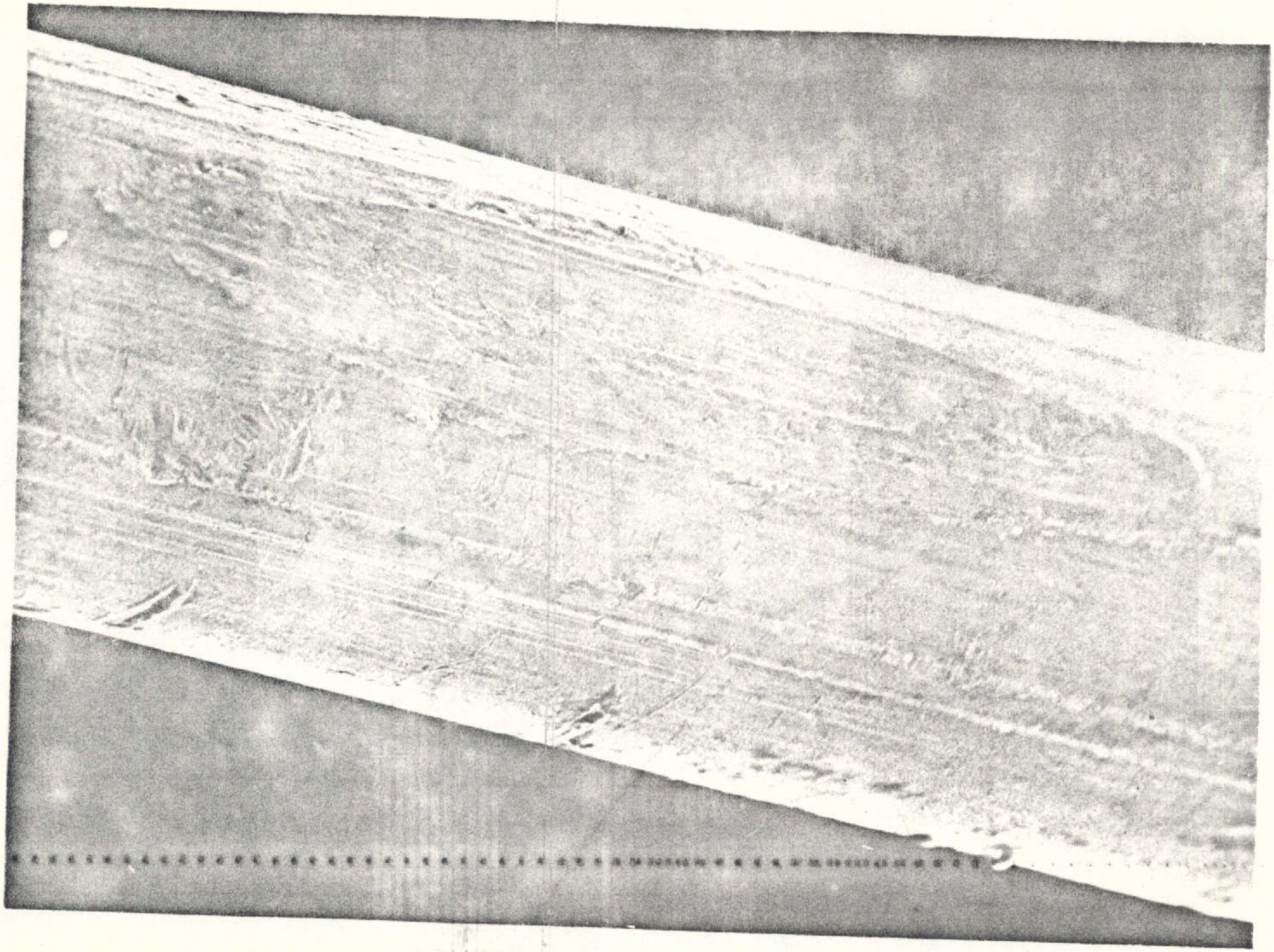

FIGURE 7: Scanning electron micrograph of a worn brush exhibiting predominant rider wear. Original magnification, 190X.

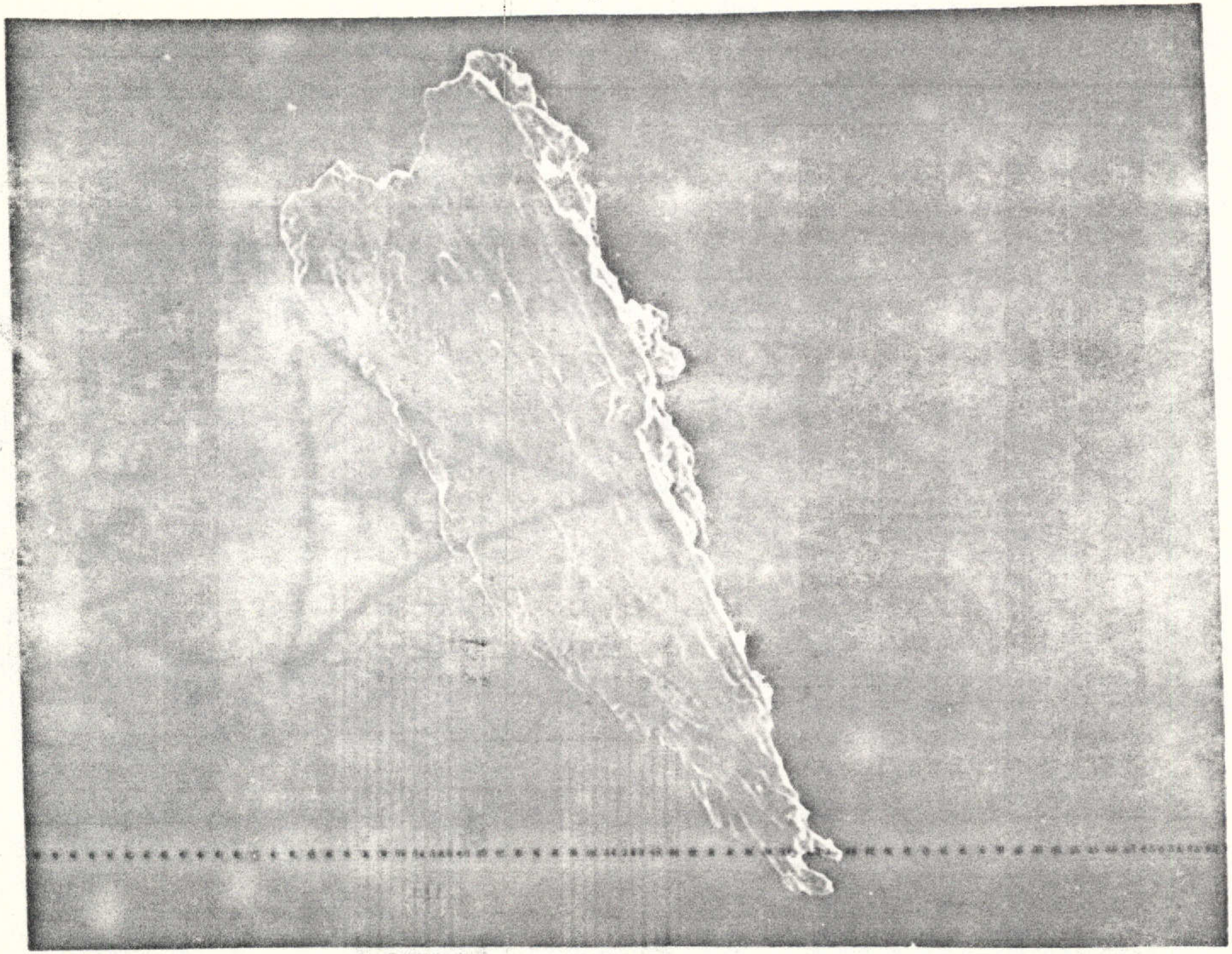

FIGURE 8: Scanning electron micrograph of a loose particle removed from SN 203 at the end of the life test. Original magnification, 450X.

TABLE II: TEST DATA FROM CAPSULES THAT HAD BEEN STORED FOR APPROXIMATELY FOUR YEARS

SN	NO. CRTS	TYPE OIL	HOURS OF OPERATION BEFORE STORAGE	NOISE AT END OF PRE SHELF LIFE TESTS, mΩ		SHELF LIFE MO	NOISE, MILLIOHMS					
							OFF SHELF		AFTER 50 REVOLUTIONS		AFTER ≈20 HOURS OF OSCILLATION	
				MEDIAN	MAX		MEDIAN	MAX	MEDIAN	MAX	MEDIAN	MAX
195	80	PPE*	2000	5	16	47	4	6	4	7	4	6
196	80	PPE	2300	5	5	48	2	6	2	4	2	5
208	80	PPE	2000	5	5	47	4	10	-	-	3	17
81	100	PPE	2100	5	27	56	5	14	6	15	[illegible]	16
107	100	PPE	2000	<10	<10	40	4	10	-	-	***	-
AVG.		PPE	(2100)	(<6)	(<13)	(48)	(4)	(9)	(4)	(9)	(4)	(11)
171	80	DE**	3300	5	10	53	5	23	5	27	7	16
61	100	DE	1100	>35	>35	51	27	41	9	37	37	53
AVG.		DE	(2200)	(>20)	(>23)	(52)	(16)	(32)	(7)	(32)	(22)	(35)

* Blend of four and five ring polyphenyl ethers.

** Diester

*** The median and maximum noise after storage of SN 107 were as follows: 500 hours - 5,18 mΩ; 1000 hours - 5,17 mΩ; 1500 hours - 5,17 mΩ; 2500 hours - 6,28 mΩ.

TABLE III RESIDUAL LUBRICANT AND GOLD WEAR DEBRIS ANALYSES AFTER BOTH OPERATIONAL AND STORAGE-LIFE TESTS.

SN	NO. CRTS	TYPE OIL	LOOSE WEAR DEBRIS, μg Au	RESIDUAL OIL, mg
195	80	PPE	356	28
196	80	PPE	160	46
208	80	PPE	450	27
81	100	PPE	41	9
107	100	PPE	334	20
AVG.		PPE	(251)*	(28)*
171	80	DE	185	0.7
61	100	DE	105	1.3
AVG.		DE	(145)	(1.0)

* EXCLUDES DATA FROM SN 107 WHICH WAS OPERATED FOR 2500 HOURS AFTER STORAGE.

Discussion

This study sheds light on several frequently expressed concerns regarding slip ring performance and reliability.

1. What life can be expected before wear through of the relatively thin 0.0003 inches (7.5μm) gold plate? With the PPE lubrication used on these capsules, up to 1.3 X 10^9 wipes without wear-through were obtained. SN 203 (Figure 5) shows less than 0.00017" (0.4μm) wear after 8.4 X 10^8 wipes.

2. Can lubricant be expected to last for long exposure? When applied in maximum quantities, the PPE lubricant was retained in large quantity. However, excess lubricant which bridges barriers has been observed to trigger dielectric breakdown by particle migration in high dielectric fields.

3. Does a slip ring contact oscillated at one location cause noise resulting from the accumulation of debris at the reversal points? This test has shown that this is the most likely mode of noise generation. Where lubricant quantities are adequate, this debris is dispersed with no significant effect on noise. However, where lubricant quantities are small, the wear collection and hence the noise may become significant at times, as on SN 2.

4. Do unwiped or infrequently wiped surface areas develop films which cause high noise? No such film or noise was detected in the 14,000 to 25,000 hours of testing in which there were 100 to 300 hours between wiping operations (4 revolutions). This shows that in the absence of external contaminating organic vapors there is no degradation of slip ring contact performance.

5. What is the origin of gold particles often seen on worn slip rings? Frequently the gold colored particles (Figure 8) found on worn slip rings are mistaken for burrs, chips or other particles from the manufacturing operations. It is readily shown by micro-section (Figure 9) that the gold particles are built-up structures of microparticles and therefore typical of the wear process.

6. What is the effect of long term storage on slip ring capsule performance? Capsules stored in nominally contamination free containers for over four years exhibited no increase in noise levels.

7. Will glass dielectrics effect lower noise than epoxy barriers? The glass surface slip ring capsules did not effect lower noise than similarly lubricated capsules with ceramic-filled epoxy barriers.

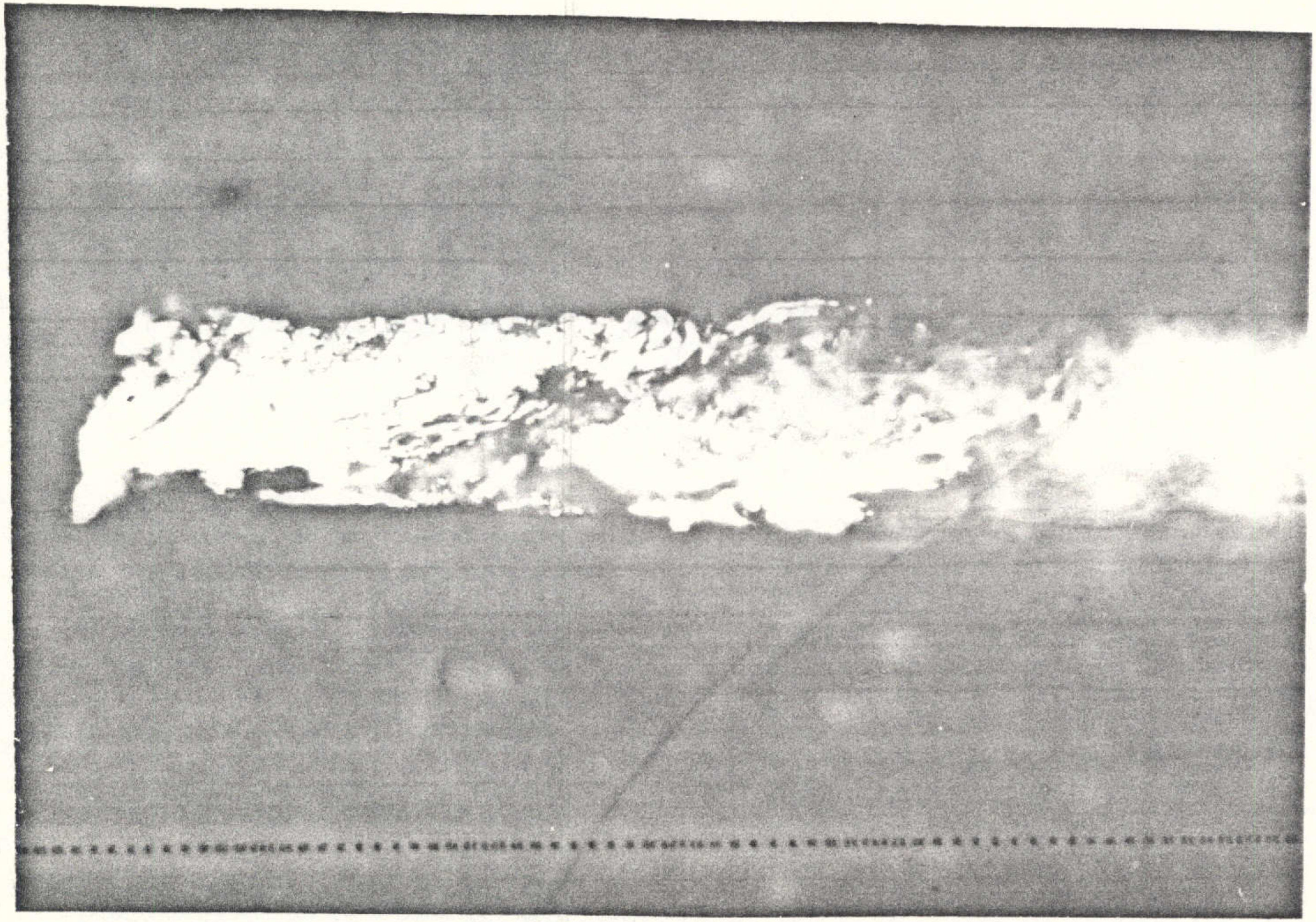

FIGURE 9: Section of a loose particle that was removed from a capsule. Note that the particle is a build-up of many smaller particles.

Conclusions

1. Slip ring capsules can be expected to operate effectively under the inertial guidance condition described above for 20,000 hours if they are adequately lubricated and operated in a clean environment.

2. Glass surface dielectrics do not appear to offer an advantage over ceramic-filled aromatic amine-cured epoxy dielectrics for inertial guidance type slip rings.

3. Circuit noise is not a function of position within a uniformly lubricated capsule in a clean environment.

4. The mechanisms of prow generation, prow dislodgement and subsequent rider wear as described by Antler for a hemisphere on a flat apply to 18 karat gold round brushes riding on hard gold-plated vee grooves.

5. Slip ring contacts can operate effectively in a flood of boundary lubricant, but noise appears to occur after the lubricant has been depleted.

6. Infrequently wiped contact surfaces are not subject to noise-producing films in the absence of organic vapors that originate from outside the slip ring capsules.

7. Slip ring capsules of the type examined in this study can be stored in a nominally contamination-free atmosphere for over four years without adversely effecting the dynamic contact resistance (noise) upon reoperation.

Acknowledgements

The authors wish to thank James T. Rogers, MSFC, for conducting the life tests; Jody Clemons, for the noise data reduction; Mary Guynn, Clyde Lance and Barry Witherspoon for the post test analyses; and Linda Clemons for the manuscript typing.

References

1. E. Lowe, E. Glossbremer, "Slip Ring Capsule Assembly Development and Reliability for Saturn Guidance Platforms", Symposium on Precision Sliding Contact Devices, Roanoke, Virginia, November 1-3, 1965.

2. R.L. Van Auken, W.D. Hensley and S.R. Cole, "Totally Inorganic Assemblies - An Approach to Contamination-Free Sliding Contacts", Electrical Contacts, Nov. 6-9, 1967.

3. NAS 8-11403, NASA, MSFC, "Analytical Studies and Investigations in the Areas of Stabilized Platform and Gyro Gimbal Design and Manufacture", Battelle Memorial Institute, 1965-1968.

4. E.J. Gumbel, "Statistical Theory of Extreme Values and Some Practical Applications", National Bureau of Standards Applied Mathematics, Series 33, 1954.

5. R.T. Hunt, "Surface Texture Analysis of Slip Ring Components", Brundy Research Division, September 28, 1966. Report to Poly-Scientific, Litton Systems, Inc., Blacksburg, Va.

6. M. Antler, "Tribological Properties of Gold for Electric Contacts", Proc. of the Holm Seminar on Electric Contact Phenomena, November 9-12, 1970.

7. C.G. Morris, W. Hensley, P. Reed, "Certain Materials and Processes for Sliding Contacts", Symposium on Precision Sliding Contact Devices, Roanoke, Virginia, November 1-3, 1965.

8. E.W. Glossbrenner, "Wear in Sliding Contacts and Its Effects on Performance. A Physical Model", Proc. of the Holm Seminar on Electric Contact Phenomena, November 9-12, 1970.