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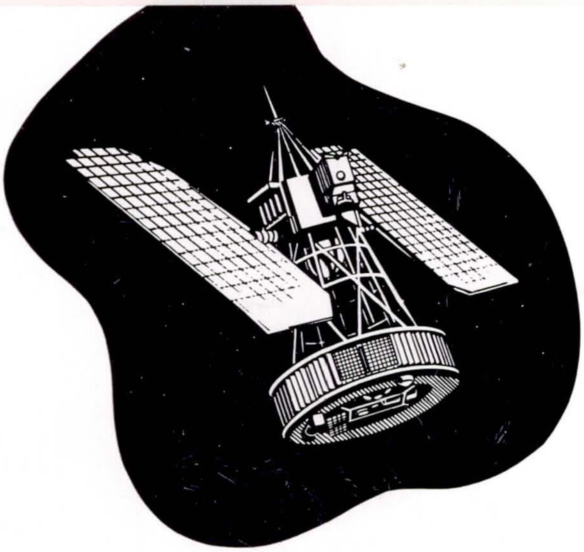

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NIMBUS METEOROLOGICAL SATELLITE

INTEGRATION AND TESTING MATERIALS REPORT NO. 8

CONTRACTS NAS 5-978 and NAS 5-1347

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INTRODUCTION

The NIMBUS Integration and Testing Materials Report No. 8 presents a compilation of the major areas of materials engineering effort on the NIMBUS Program during the period 1 January 1965 through 30 June 1965. It contains information regarding material and environmental effects investigations, failure analyses and quality control practices related to NIMBUS.

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4)	63SD4266	January 1963 through June 1963
5)	64SD4213	July 1963 through December 1963
6)	64SD4318	January 1964 through June 1964
7)	65SD4215	July 1964 through December 1964
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SECTION 1.

SOLAR ARRAY DRIVE

1.1 BACKGROUND

After 26 days in orbit, the NIMBUS A Solar Array Drive ceased rotating. Prior to the final stop, it exhibited a slowing down and interrupted action.

Analysis of telemetered data from NIMBUS A led to the conclusions that:

a. The most probable area of failure lay in the size 8 motor gearhead (MGH) assembly, and

b. Increasing frictional drag in this component had caused the motor to stall. A probable cause of increased drag was surmised to be increased viscosity of the G-300 bearing lubricant.

Programs of investigation were initiated to isolate the component and/or lubricant characteristic responsible for the observed frictional drag increase and motor stall. Among these were:

a. An analysis was made of available literature data with respect to the effect of thermal/vacuum exposure on the properties of G-300 grease and motor life in vacuum achieved to date with G-300 lubricated bearings (Ref. 1). From this, it was concluded that temperature is the predominant parameter affecting both oil loss from the grease and achievable motor life.

b. Failure verification tests were performed in vacuum on eight motor gearheads of the NIMBUS A size-8 motor configuration, six with original Kearfott lubrication practice and two with best available current practice. All units failed in less than 1,300 hours. The predominant failure mode in 7 of the 8 was grease degradation or incipient degradation in the motor bearings which caused high starting and running torques and incipient bearing deterioration due to scuffing. Grease in the failed bearings was found to be dry and discolored, similar in appearance to G-300 samples which had been exposed in preliminary laboratory vacuum tests to temperatures in the 149° C to 232°C range. The rear motor bearing had failed in 7 of the 8 units which gave further evidence that temperature was the predominant failure mode, since this bearing would be expected to run hotter than the forward bearing. In the eighth unit, gear binding, noted on acceptance test, became aggravated.

Based upon conclusions derived from the above analyses, the NIMBUS C Solar Array Drive was redesigned to incorporate greater potential torque capability (size-11 motor) and to effect significant motor bearing temperature reduction by using:

a. Reduced electrical power input

b. Larger rotor clearance and high rotor surface emissivity and

c. Large thermal conductive path for the stator.

Critical items in evaluating the capability of the redesigned NIMBUS C SAD to meet defined mission requirements were to demonstrate that:

a. NIMBUS C motor bearing temperatures at the various operational power inputs were in fact significantly lower than those in the NIMBUS A unit.

b. The maximum operating temperature levels of the NIMBUS C, G-300 lubricated motor bearings were compatible with a predicted life well beyond 10,000 hours. The bases of life prediction were best available literature data on the subject and the results of G-300 weight loss vs time and temperature tests conducted in vacuum

c. A redesigned NIMBUS C SAD unit could be operated at representative orbital conditions in vacuum for the design life of the vehicle.

A parallel NIMBUS C SAD redesign effort was directed to a d-c torquer drive unit, the chief advantages of which are low operational speed and much greater torque capability than the a-c drive motor. A potential problem associated with the d-c torquer is wear of sliding electrical contacts in the tachometer and commutator. The level of effort on the d-c torquer has been reduced following the decision to go with the a-c drive on Flight II.

Investigations were conducted to compare the relative merits of G-300 grease with other high-vacuum capability bearing lubricants and lubrication schemes. A MoS_2 - lubricated MGH was tested in vacuum as part of the overall lubricant investigation.

Problems associated with shipping and spalling of hard-cased 416 stainless steel gears in the MGH resulted in the substitution of 4340 alloy steel for this application.

The results of materials and materials-related investigations associated with the SAD during the current reporting period are described in detail in the succeeding subsections.

1.2 COMPARISON OF VERSILUBE G-300 WITH ALTERNATE HIGH VACUUM LUBRICANTS

1.2.1 SUMMARY

The choice of GE Versilube G-300 silicone grease as the lubricant for SAD bearings and gears was reviewed with respect to its merits in comparison with alternate long-life vacuum lubricants and lubrication schemes. Ball bearing life achievable in vacuum was used as the basis of comparison.

Bearing life in vacuum in excess of 20,000 hours has been reported (Ref. 2.3) with six lubricants: G-300, Aeroshell 15, EG 509, QF-1-0065 (250cs), Apiezon K and Apiezon J. Of these, G-300 has been the more extensively tested and the running torque with this lubricant is comparable to or lower than that with the other five.

Based upon presently available information, it is concluded that SAD ball bearing and gear lives in excess of one year are achievable with G-300 grease provided the temperature of the rotating members $\leq 110^{\circ}C$ and speed does not exceed 8000 rpm. While alternate lubricants and lubrication schemes are available which possess similar capabilities, none has been demonstrated to be appreciably superior to G-300 and performance superior to that of G-300 could not be reliably predicted per se by their incorporation in the SAD.

1.2.2 INVESTIGATION RESULTS

Sixteen grease, oil and special retainer lubricants have been reported to provide bearing lives in vacuum of more than 10,000 hours. Six of these have been successful for more than 20,000 hours. Test conditions employed in the evaluation of these lubricants equalled or exceeded the nominal "worst case" Flight 1 SAD requirements with respect to subsystem interior temperature and bearing speed.

A synopsis of LMSC bearing test results for lubricants providing more than 10,000 hours of bearing life in vacuum is presented in Table 1-1 (Ref. 2 and 3). Each set of data in Table 1-1 represents the evaluation of two similarly - lubricated ball bearings of the type indicated, one on either end of the rotor of a hysteresis synchronous motor rated at 0.01 hp. Bearing failure was considered to have occurred when the motor stalled in operation or had been stopped and could not be restarted because of increased bearing frictional torque. A measure of bearing running torque was made periodically by measuring the time required for coasting from 8000 rpm to full stop after shutting off motor power.

More than 20,000 hours (2.3 years) of bearing life were achieved with G-300, Aeroshell 15, EG 509, QF-1-0065 (250 cs), Apiezon K and Apiezon J. With respect to coast down times, Apiezon K showed ~ 15 seconds, Apiezon J ~ 24 seconds, QF 1-0065 ~ 1.05 minutes and the remaining three ~ 4 to 5 minutes after several thousand hours of operation. The longer the coastdown time, the lower the bearing friction.

TABLE 1-1. LONG-LIFE BEARING TEST DATA FOR LUBRICANTS IN VACUUM (Lubricants Exhibiting > 10,000 hours Life) (Ref. 2,3, and 4)

LUBRICANT	BEARING TYPE*	BEARING HOUSING TEMPERATURE (°C)	COAST TIME (MIN:SEC)	RESULTS
GREASES				
Versilube G-300	1	55 - 104	1:02 - 3:17	9,612 hours - Failed
Versilube G-300	1	63 - 80	2:42 - 14:21	23,233 hours - Still Running (2-1-65)
Versilube G-300	1	105 - 110	2:38 - 10:47	22,694 hours - Unverified Failure (2-1-65)
Versilube G-300	1	143 - 149	1:40 - 3:59	4,359 hours - Failed
Versilube G-300	1	66 - 74		8,741 hours - Still Running (8-64) γ dose of 2.5×10^7 R during test
Aeroshell 15	1	69 - 99	0:34 - 9:50	20,147 hours - Test Discontinued
Aeroshell 15	1	66 - 121	3:25 - 9:23	13,000 hours - Still Running (8-64)
Aeroshell 15	1	82 - 91		5,518 hours - Failed γ dose of 1.7×10^7 R during test
EG429	1	66 - 93	2:46 - 5:15	12,889 hours - Failed
EG509	1	66 - 93	2:33 - 7:43	21,350 hours - Still Running (8-64)
MLG61-92	1	60 - 93	1:53 - 9:06	15,056 hours - Still Running (8-64)
MLG62-142	1	60 - 91	1:43 - 4:54	15,100 hours - Still Running (8-64)
OILS				
Versilube F-50	2	71 - 88		4,574 hours - Failed
Versilube F-50	4	66 - 85	1:04 - 5:38	13,652 hours - Failed
Versilube F-50	3	66 - 121	6:25 - 14:56	7,796 hours - Still Running (8-64)
Versilube F-50	4	66 - 121	6:24 - 19:46	5,571 hours - Failed
Versilube F-50	9	66 - 121	0:32 - 13:58	5,571 hours - Failed
Versilube F-50	9	65 - 121	7:20 - 13:53	7,141 hours - Failed
Versilube F-50	3	77 - 82		5,556 hours - Test Discontinued γ dose of 1.7×10^7 R during test
Versilube F-50	3	66 - 71		8,660 hours - Still Running (8-64) γ dose of 2.5×10^7 R during test
Versilube F-50 (50% more volatile fraction removed)	3	77 - 93	1:06 - 9:19	3,335 hours - Failed
Versilube F-50 (50% more votatile fraction removed)	2	54 - 93		1,856 hours - Failed 409 hours - Replacement Bearing Failed 2,265 hours - One Bearing Still Good
QF-1-0065 (250cs)	3	60 - 88	0:29 - 1:15	21,708 hours - Still Running (8-64)
QF-1-0065 (250cs)	3	60 - 93	0:27 - 0:48	17,492 hours - Failed
ML061-97 (DC7024)	3	71 - 96	1:38 - 2:06	13,141 hours - Still Running (8-64)
Apiezon K	3	71 - 102	0:15 - 0:20	20,091 hours - Test Discontinued
Apiezon K	3	41 - 60	0:08 - 0:58	20,300 hours - Test Discontinued
Apiezon K dissolved in 20% Xylene	1	74 - 99	0:28 - 2:20	8,960 hours - Failed
Apiezon J	3	80 - 104	0:24 - 0:34	19,400 hours - Still Running (8-64)
Teresstic V-78	3	60 - 104	0:47 - 4:03	14,340 hours - Failed
Teresstic V-78	9	71 - 77		8,741 hours - Still Running (8-64) - γ dose of 2.5×10^7 R during test
XRM128C	4	54 - 77	1:00 - 1:34	11,512 hours - Still Running (8-64)
SRM141C	4	54 - 80	1:17 - 3:06	11,411 hours - Still Running (8-64)
DRY FILM LUBRICANTS				
Of 11 types of MoS_2 (with and without self lubricating bearing retainers) and 1 type of graphite coatings tested, none had provided bearing life of 10,000 hours as of 10-64. Maximum life achieved was 7,379 hours (still running) for Hi-T-Lube with Rulon C bearing retainers.				
SPECIAL RETAINERS				
Rulon C	7	52 - 99	2:09 - 5:28	12,108 hours - Still Running (8-64)
Rulon C	7	52 - 82	1:39 - 15:38	8,624 hours - Failed
Rulon C	7	63 - 77	2:18 - 21:30	3,180 hours - Failed
Rulon C	7	54 - 63	0:24 - 6:15	10,771 hours - Failed
Rulon C	7	52 - 60	0:43 - 11:50	11,248 hours - Test Stopped - severe wear

*Bearing Types (All R-3 Size)

1. 440C stainless steel, ribbon retainers, double shielded
2. 52100 chrome steel, ribbon retainers, double shielded
3. 440C stainless steel, Synthane retainers, double shielded
4. 52100 chrome steel, Synthane retainers, double shielded
7. 440C stainless steel, special retainer material, unshielded
9. 52100 chrome steel, balanced linen - base phenolic retainer, double shielded

Test Conditions

Bearing Speed: 8,000 rpm
Pressure: 10^{-6} to 10^{-8} mmHg

In light of the number of bearings tested, lifetimes achieved and measured bearing torques, the performance of G-300 must be considered as being comparable to that of the best of the tested long-life, "high vacuum" lubricating oils and greases.

It should be noted that bearing life with G-300 lubrication decreases with increasing bearing housing temperature. The data of Table 1-1 show that at 145°C the lifetime of 4400 hours is less than half that of the lowest lifetime of 9600 hours at temperatures $\leq 107^\circ$C. In tests at ATL (Ref. 4) wherein the case temperature of a horizon scanner was maintained at 160°C and bearing speed was 11,500 rpm, the lifetimes achieved ranged between 170 and 354 hours. With the exception of Versilube F-50 oil, corresponding temperature range data is not available for the other lubricants mentioned previously.

Little data is available on the long-term performance in vacuum of lubricated gears. It can only be surmised, rightly or wrongly, that those lubricants which perform well in lightly loaded ball bearings will also perform well in small gear trains if proper lubrication practices are adhered to and the gear loads are very low.

Bearings lubricated with bonded films of molybdenum disulfide have shown shorter lifetimes than those lubricated with the above oils and greases. The reproducibility of test results has been poor and the lifetime has been demonstrated to be significantly lowered when bi-directional bearing rotation is employed. Similar considerations apply to the use of special ball bearing retainer materials with the possible exception of Rulon C* which appears to give fairly consistent lifetimes of 5,000 to 10,000 hours.

One lubrication scheme that has been demonstrated to give bearing lifetimes (2750 rpm) in excess of three months under orbital conditions is that employed in the Tiros Radiometer Spindle. Here a relatively high vapor pressure oil ($\sim 10^{-4}$ mm Hg) Winsor Lube L245X per MIL-L-6085A, is used to lubricate a miniature precision ball bearing. (Ref. 5) Lubrication

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*Rulon C - Modified Teflon composition from Dixon Corp.

is dependent upon the flow of oil vapor through and condensation upon the rotating parts of the unshielded bearing. The oil is contained in sintered nylon reservoirs, one of which is in contact with the outer race of the bearing and thereby provides a creepage path for wetting the bearing parts. Directed vapor flow through the bearing is accomplished by the geometry of the assembly and the rate of volatilization of oil from the reservoirs is controlled by means of low clearance, lalyrinth-type seals. Optimum individual bearing and gear lubrication by this means in the SAD would require major redesign of the entire drive.

Hermetically-sealed units or units employing rotating shaft pressure seals have the advantage that conventional lubricants can be employed, but are less efficient and require higher power to the drive and have their own risks.

1.3 POST-TEST ANALYSES OF MOTOR GEAR HEADS USED IN THE NIMBUS FAILURE VERIFICATION TESTING

Failure verification testing of NIMBUS Solar Array Drives and Motor gearheads was performed to reproduce the failure experienced in the first NIMBUS flight. All test failures closely reproduced the flight failure signature. Failures were due to stalled motors resulting from increased bearing and/or gear torque. In each case the lubricating grease was found to be thickened, bearing races were scuffed and some evidence of grease contamination or oxidation appeared. It was concluded that the flight and test failures were due to a lubrication problem caused by elevated operating temperatures. Table 1-2 summarizes typical failure verification test results.

1.4 SOLAR ARRAY DRIVE AC MOTOR BEARING TEMPERATURE MEASUREMENT TEST

1.4.1 INTRODUCTION

Bearing temperature profiles were determined in vacuum for size 8 and 11 SAD a-c motors operated at fixed and control phase voltage inputs representative of orbital conditions. Primary goals of the measurements were to: a) Establish maximum size 8 and 11 motor

TABLE 1-2. FAILURE VERIFICATION TEST RESULTS

		TEST DATA ANALYSIS		
UNIT	TEST DATA	GEAR HEAD	MOTOR	REMARKS
S/N 4 (P1)	Ambient, un-loaded for 110 hrs. Run @ Loaded T/V @ 50^{o}C for 90 hr. Unit stopped re-started when vacuum removed. Stopped when re-evacuated several times. Test terminated at approximately 200 hrs.	Dry Grease on high speed end. Grease color varies from white to black.	Rotor & Stator wet with oil. Wiped degraded oil between stator bars. Both bearings contained heavy black lubricant debris. Motor Torque = 0. 03 in-oz.	Fretting & metal removal on rotor bearing surfaces.
S/N 5 (P1)	Run unloaded in vacuum, stopped after 336 hours. Removed from vacuum it re-started. Returned to Vacuum & run loaded until test terminated after 1200 hr. Unit had stalled approx. 5 times by a feed-through seizure.	Gross amounts of black, hard debris in housing & bearings balls oily. Output gear on shaft has broken tooth	Rotor & Stator wet. Brown deposit between stator bars both brgs. Full of contaminant. Balls oily. Inner bearing rotated on motor rotor.	Fragmentation and cross linking of G/H grease has occurred. Evap. characteristics & residue dissimilar to new G-300 grease.
M/GH No. 3 SAD No. 8 Prototype (P3)	Run to orbital cycles under no load vacuum. Unit stopped; started when vacuum was broken and test was terminated after 1400 hours.	Gear mis-alignment evident. Grease degraded, changing in color from tan to black (low to high Speed end)	Gear mis-alignment evident. Rotor damage. Small amount dry grease on pinion. Rear brg. contained internal debris, scuffing. Motor Torque = 0. 02 in-oz.	Grease analysis disclosed severe degradation (oxidation & ester contamination)
M/GH No. 1 S/A No. 9 (P1)	Unit run at ambient - No accurate records for failure verif. Test unit was run loaded in vacuum for 160 hours.	Not disassembled	Rotor had small pot holes in Al casting. Dark grease on pinion. Dark crust on inner & outer brg. Races (front brg) scutted & pitted. Dark debris & white soap in rear brg. Pinion Torque = > 1 in-oz.	Grease Analysis = degraded G-300 - contamination & oxidation
S/N 8 (P3)	Unusual starting voltages. Run at Ambient unloaded for approximately 25 hours.	Degraded grease 2nd gear pass from motor end. Shaft bearing of this pinion also contained degraded grease.	Lubricant appeared normal.	G/H grease analysis highly oxidized.
MGH No. 3 V2 (SAD No. 1) (P1)	After 138 orbits, rate slowed & then returned to normal.	Lubricant appeared normal. Output bearing shaft had 'hitch', & bearing had crushed ball.	Yellow deposit in stator gap. Dry grease on pinion. Front bearing balls oily w/white deposit. Rear brg. lube black.	White deposit found to be soap. Rear Brg. grease had high soap/oil ratio. Decomposed fluid & thickener. Also contamination found.

rotating bearing temperatures as a function of applied winding voltages and b) Determine the temperature profile across the diameter of the rotating bearings as a function of applied winding voltages.

These temperature measurements were made to: a) Determine the effectiveness of the redesigned NIMBUS C SAD in reducing drive motor bearing operating temperature levels below those in the NIMBUS A SAD, b) provide thermal data upon which NIMBUS C size-11 motor life could reasonably be predicted to be in excess of 10,000 hours based upon absolute bearing temperature levels and best available G-300 lubricant performance data in the literature and c) provide thermal test data which would verify earlier conclusions that high bearing temperature in the size-8 motor was the cause of lubricant degradation and subsequent motor stalling in NIMBUS A and "Failure Verification Test" SADs.

1.4.2 SUMMARY

Size-8 and 11 SAD a-c motor bearing temperature profiles were measured in vacuum over the orbital range of fixed and control phase voltages. A novel adaptation of existing infrared measuring techniques was used to determine the local temperature of the rotating bearing elements. The rear motor bearings were chosen for study since both thermal and failure verification analyses had indicated that this bearing would be hottest during motor operation.

Over the orbital range of motor power inputs, maximum bearing temperatures of the two motors are shown in Table 1-3.

Table 1-3. Maximum Motor Bearing Temperatures

	Maximum Measured Bearing Temperature, °C		
Operating Condition	Orbital Rate	Slew Rate	Max. Power
Size-8 Motor (NIMBUS A)	124	143	143
Size-11 Motor (NIMBUS C)	34	74	83*

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*This is emergency only operation in NIMBUS C design

Based upon a 600 nautical mile NIMBUS orbit, the time to complete one orbit is 107 minutes. Of this time, the motor is operated at the slew rate for 6 minutes.

On the basis of current data, it is concluded that:

a. The present NIMBUS C SAD size-11 motor bearings will operate in space at significantly lower temperature levels than did the NIMBUS A SAD size-8 motor bearings.

b. Size-11 motor bearing maximum temperature can be expected to be less than 80°C for anticipated flight motor power inputs and at maximum spacecraft temperature. Comparing these temperature levels with lubricated bearing life in vacuum test results reported in the literature and thin film evaporation rates, G-300 lubricated size 11 motor bearing life in vacuum may reasonably be predicated to be in excess of 20,000 hours.

c. Conversely, at the measured NIMBUS A size-8 motor bearing temperature of about 150°C, bearing life would be expected to be very much less than 10,000 hours.

d. Both bearing preload and rotor surfaces coated with Wornowink Retma Black Paint reduce operating bearing temperature at constant power input to the size-11 motor. The effectivity of the coated rotor in reducing bearing temperature increases with increasing temperature level.

e. Rotating bearing temperature profile measurements showed the maximum temperature to occur at the bearing shaft and that temperature decreases with radial distance from the shaft center.

f. The infrared radiometer technique of temperature measurement developed for this test is an effective tool in analyzing thermal problems related to lubricated bearings in vacuum. Techniques should be further refined and developed for analyzing a variety of high speed bearing and other critical thermal problems.

1.4.3 DISCUSSION OF RESULTS

1.4.3.1 Analysis of Size-8 and 11 Motor Bearing Temperatures

Test results show clearly that the maximum operating temperature of size-8 and 11 motor bearings are significantly different throughout the range of operational phase voltage inputs, as shown in Table 1-4.

Table 1-4. Maximum Operating Temperatures of Size 8 and 11 Motor Bearings

Phase Voltage Input		Maximum Bearing Temp. (°C)		Bearing Housing Temp. By T/C Meas., (°C)	
Fixed Ø	Control Ø	Size 8 Motor	Size 11 Motor	Size-8 Motor	Size-11 Motor
10	4	-	34	-	29
10	12	-	47-53*	-	34-37*
10	16	-	74	-	39
13	9	84	-	43	-
26	3	124	-	86	-
26	6	127	-	88	-
26	9	136	-	90	-
26	12	139	-	93	-
26	15	-	-	97	-
26	18	143	74-82*	100	61-64*

The lower operating temperatures of the size-11 motor bearings and housing show the effect of motor housing heat strap addition, black coating (Wornowink) of the rotor surface and other present NIMBUS C SAD redesign measures to reduce bearing temperature.

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*Individual results of duplicate configuration measurements

The NIMBUS A size-8 motor bearing temperatures at fixed phase voltage inputs of 26V are all in excess of 120°C and reach 143°C at control phase voltage inputs of 18V (the normal nightime slew input for NIMBUS A). Information to date indicates that: a) operational ball bearing life in vacuum with G-300 lubricant is significantly reduced at high temperatures and b) maximum bearing lifetimes of 20,000 + hours with G-300 were obtained at temperatures below 100°C.

NIMBUS C size 11 motor bearing temperatures at fixed phase voltage inputs of 10V are well below 80°C. For the normal 10V fixed phase and 1-2 volt control phase voltages employed during the great majority of orbital operation, bearing temperature will be in the order of 38°C. At these bearing temperature operating levels, lifetime in excess of 20,000 hours can reasonably be predicted on the basis of presently available literature and test data and expert opinion.

1.4.3.2 Effect on Temperature of Size 11 Motor Design Changes

Two major modifications to the size 11 motor configuration have been made from the time of its original design to the present NIMBUS C configuration. These are:

a. Bearing axial preload via springs was deleted.

b. Rotor was coated with Wornowink Retma Black Paint to increase surface emissivity over the "as supplied" varnished metal coating.*

Each of the three resulting size 11 motor configurations was tested. The tests results are shown in Table 1-5.

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*Comparative emittance values measured on the motor rotors are as follows:

a) Wornowink - Painted: E = 0.868
b) Varnished : E = 0.534
c) Unvarnished : E = 0.104

Table 1-5. Size 11 Motor Configuration Test Summary

Applied Voltages		Varnish Rotor, No Preload			Black Rotor, No Preload			Varnish Rotor, Preload		
		Ball Area	Inner Race	Shaft	Ball Area	Inner Race	Shaft	Ball Area	Inner Race	Shaft
ø1	ø2									
4	10	36	39	44	36-37	39-42	43-45	32-33	34-35	38-39
10	12	40	43	46	40-41	43-44	46-47	38-39	39-40	43-44
18	26	106-107	113-114	117-121	96(106)*	98(108)*	107(117)*	98-100	100-101	108-111

*Temperature values obtained 4/29/65 with recorder gain at 18-3. All other temperatures measured over the period 4/10/65 to 4/21/65 with recorder gain at 14-3. Gain settings are known to affect the absolute temperature readings.

For the duplicate condition runs with varnished rotors, with and without preload, the preload is seen to be effective in lowering bearing area temperatures over the entire voltage operating range. The bearing areas run approximately 2°C to 10°C cooler when spring preload is employed.

For the duplicate condition runs with black and varnished rotors, both without preload, the bearing areas are seen to run at essentially the same temperatures for the two lower voltage pair inputs. At the highest voltage pair input, an appreciable lowering of bearing area temperatures (10°C to 16°C) is achieved with the black rotor, if the bracketed temperature values for the black rotor are ignored. The bracketed temperature values were obtained with a different gain setting than all other data in the table and an offset error most probably exists as explained subsequently in this section. The apparent lack of effect of black rotor finish at 38°C bearing area temperatures and its apparent effect at 93°C + area temperatures is readily explained. Consideration of the dominant heat transfer modes (conduction and radiation) from the rotor at low temperature vs high and the fact that radiative heat transfer is proportional to the fourth power of absolute temperature leads to the conclusion that the black rotor effectivity in reducing rotor temperature should increase as the rotor temperature increases.

The test data presented in Table 1-5 were obtained with reverse-to-normal voltage inputs for the 4V - 10V and 18V - 26V applied voltage tests. The absolute values of bearing area temperatures are appreciably higher for phase voltage input reversal than with normal (as discussed subsequently) and should not be considered representative of NIMBUS C conditions. Since all test data presented above is on the same voltage input basis, however, the temperature differences and relative effects of the three configurations may be considered as being valid.

Test procuedures, results and discussion thereof are contained in full detail in Reference 6.

1.5 THIN FILM GREASE EVAPORATION TESTS

1.5.1 INTRODUCTION

Thin film grease lubricant evaporation rates were measured in vacuum over the temperature range 66°C to 149°C for times up to 1330 hours. Grease lubricants tested were: a) GE Versilube G-300, b) Aeroshell No. 15, c) Shell APL and d) ESSO Beacon 325. Primary goals of the measurements were to: a) determine the weight loss vs time and temperature of G-300 for sufficiently long periods as to permit extrapolation of results to 10,000 hours with reasonable accuracy and b) establish comparative weight loss data for G-300 and the other three greases under identical test conditions.

These vacuum weight loss measurements were made to provide the NIMBUS Control Program with experimental data upon which: a) the condition of G-300 lubricant in the NIMBUS C Solar Array Drive motor could reasonably be predicted at the end of 10,000 hours knowing the operating temperature of the lubricated bearings and b) a decision could be reached as to whether or not an alternate lubricant of the types tested could be expected to be superior to G-300 on the basis of evaporation rate in vacuum.

SUMMARY

Weight loss in vacuum was determined as a function of time and temperature for 15 mil thick films of G-300, Aeroshell No. 15, Shell APL and Beacon 325 greases. The testing was carried out in QC Component Test vacuum facilities. A brief synopsis of the lubricant weight loss data is presented in Table 1-6.

Table 1-6. Lubricant Weight Loss Summary

	Weight (% Grease Evaporated)							
	66°C				149°C			
Lubricant	24 hr	200 hr	10^3 hr	10^4 hr	24 hr	200 hr	10^3 hr	10^4 hr
G-300	1.7	2.0	2.1	2.3*	3.6	5.7	7.3	9.5*
Aeroshell #15	0.5	1.3	2.3*	2.6*	2.0	3.7	5.3*	7.6*
Shell APL	0.7	1.0	1.1*	1.3*	5.3	11.8*	16.7*	23.2*
Beacon 325	18.6	-	-	-	80.0	-	-	-

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*Extrapolated Value

On the basis of the current data, it may be concluded that:

a. G-300 weight loss after 10,000 hours in vacuum may be less than 3% at 66°C and < 10% at 149°C. Since the orbital rate temperature of the size 11 motor bearings has been determined to 38°C (Ref. 6) and the maximum temperature to be 80°C, it may be reasonably concluded that the G-300 bearing lubricant will not be significantly degraded by thermal-vacuum exposure within 10,000 hours.

b. Neither Aeroshell No. 15 nor Shell APL greases are significantly superior to G-300 with respect to evaporate rate in vacuum over the temperature range studied.

c. Beacon 325 is unsuitable for vacuum lubrication applications.

1.5.3 RESULTS

Percentage weight loss versus time and temperature results for G-300 are shown in both tabular and graphical form in Table 1-7, and Figure 1-1.

Full details of the test procedure and test results are contained in Reference 7.

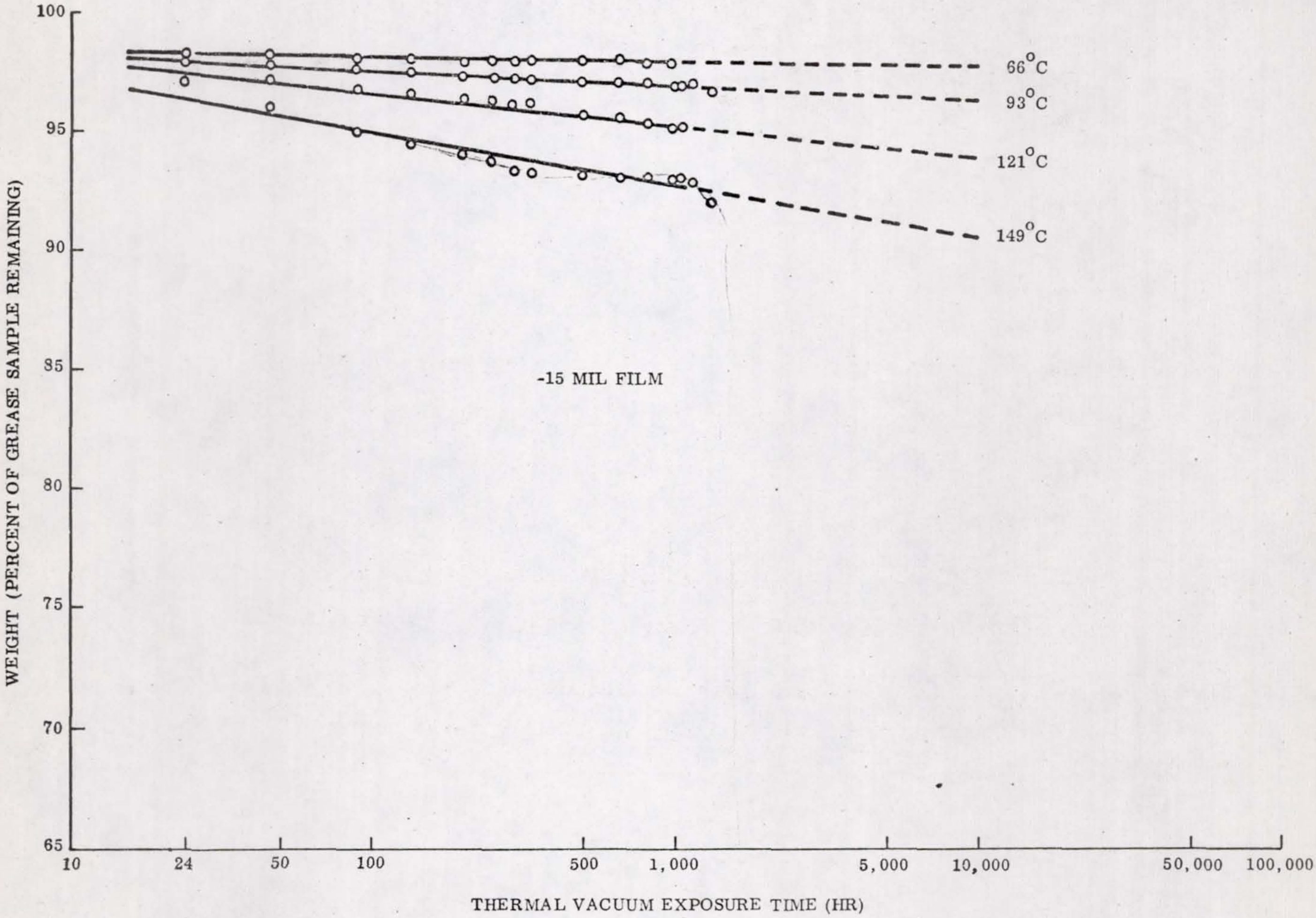

Figure 1-1. Versilube G-300 Weight Loss in Vacuum vs Temperature and Time

Table 1-7. Versilube G-300 Static Thin Film Test Results

Nominal Grease Film Thickness ≅ 15 mils
Grease film area ≅ 52.4 cm^2

Exposure Time (HR)		Temperature (°C)			
		66	93	121	149
0	Initial Sample Wt (gm)	1.5605	1.9077	2.5443	3.1773
24	Weight Loss-gm	0.0261	0.0400	0.0652	0.0850
	% Weight Loss	1.67	2.10	2.56	2.67
	Rate: gm/cm^2-hr	2.08×10^{-5}	3.08×10^{-5}	5.19×10^{-5}	6.75×10^{-5}
46.5	Cum. Wt. Loss-gm	0.0270	0.0408	0.0711	0.1282
	Cum. % Wt. Loss	1.73	2.14	2.80	4.04
	Cum. Rate: gm/cm^2-hr	1.11×10^{-5}	1.68×10^{-5}	2.92×10^{-5}	5.26×10^{-5}
91.5	Cum. Wt. Loss-gm	0.0301	0.0465	0.0818	0.1597
	Cum. % Wt. Loss	1.93	2.44	3.21	5.01
	Cum. Rate: gm/cm^2-hr	6.27×10^{-6}	9.68×10^{-6}	1.7×10^{-5}	3.32×10^{-5}
136.5	Cum. Wt. Loss-gm	0.0299	0.0470	0.0857	0.1730
	Cum. % Wt. Loss	1.92	2.46	3.37	5.45
	Cum. Rate: gm/cm^2-hr	4.18×10^{-6}	6.57×10^{-6}	1.20×10^{-5}	2.42×10^{-5}
203.5	Cum. Wt. Loss-gm	0.0308	0.0495	0.0911	0.1871
	Cum. % Wt. Loss	1.97	2.59	3.58	5.90
	Cum. Rate: gm/cm^2-hr	2.89×10^{-6}	4.65×10^{-6}	8.55×10^{-6}	1.76×10^{-5}
251	Cum. Wt. Loss-gm	0.0316	0.0512	0.0943	0.1978
	Cum. % Wt. Loss	2.06	2.68	3.70	6.21
	Cum. Rate: gm/cm^2-hr	2.40×10^{-6}	3.90×10^{-6}	7.16×10^{-6}	1.50×10^{-5}
296.5	Cum. Wt. Loss-gm	0.0316	0.0516	0.0965	0.2084
	Cum. % Wt. Loss	2.06	2.70	3.79	6.56
	Cum. Rate: gm/cm^2-hr	2.04×10^{-6}	3.32×10^{-6}	6.21×10^{-6}	1.34×10^{-5}
340.0	Cum. Wt. Loss-gm	0.0307	0.0513	0.0977	0.2133
	Cum. % Wt. Loss	1.97	2.69	3.84	6.70
	Cum. Rate: gm/cm^2-hr	1.72×10^{-6}	2.88×10^{-6}	5.49×10^{-6}	1.20×10^{-5}
500.5	Cum. Wt. Loss-gm	0.0306	0.0545	0.1082	0.2166
	Cum. % Wt. Loss	1.96	2.85	4.25	6.82
	Cum. Rate: gm/cm^2-hr	1.17×10^{-6}	2.08×10^{-6}	4.13×10^{-6}	8.25×10^{-6}
666	Cum. Wt. Loss-gm	0.0306	0.0551	0.1148	0.2161
	Cum. % Wt. Loss	1.96	2.89	4.50	6.80
	Cum. Rate: gm/cm^2-hr	8.75×10^{-7}	1.58×10^{-6}	3.28×10^{-6}	6.19×10^{-6}
832	Cum. Wt. Loss-gm	0.0325	0.0578	0.1205	0.2168
	Cum. % Wt. Loss	2.08	3.02	4.72	6.82
	Cum. Rate: gm/cm^2-hr	7.45×10^{-8}	1.32×10^{-6}	2.76×10^{-6}	4.97×10^{-6}
998	Cum. Wt. Loss-gm	0.0325	0.0589	0.1240	0.2180
	Cum. % Wt. Loss	2.08	3.08	4.87	6.85
	Cum. Rate: gm/cm^2-hr	6.21×10^{-8}	1.13×10^{-6}	2.37×10^{-6}	4.16×10^{-6}
1068	Cum. Wt. Loss-gm		0.0594	0.1250	0.2182
	Cum. % Wt. Loss		3.11	4.91	6.86
	Cum. Rate: gm/cm^2-hr		1.06×10^{-6}	2.24×10^{-6}	3.9×10^{-6}
1162	Cum. Wt. Loss-gm		0.0581		0.2255
	Cum. % Wt. Loss		3.04		7.09
	Cum. Rate: gm/cm^2-hr		9.55×10^{-7}		3.7×10^{-6}
1330	Cum. Wt. Loss-gm		0.0630		0.2536
	Cum. % Wt. Loss		3.30		7.97
	Cum. Rate: gm/cm^2-hr		9.04×10^{-7}		3.64×10^{-6}

1.6 ACCERATED ASSURANCE TEST

A redesigned NIMBUS C SAD unit (S/N 6 MGH) has been operated at representative and accelerated orbital conditions for a total of 3110 orbits (1398 hours) as of 1 July 65. The test was halted for an intermediate inspection after a total of 2714 accelerated orbits (679 hours) and 26 normal orbits (47 hours). Results of this analysis were:

a. Motor pinion was evenly worn with the exception of a chipped gear tooth. Chip approximately .015 inch

b. Pinion grease was soft and evidenced no discoloration or degradation

c. Grease around both bearings also evidenced no discoloration or degradation

d. Neither the rotor nor the stator showed signs of contamination or abrasion

e. Several minute black flakes were noted on the rotor shaft near the bearing journal and in the rear bearing race (most probably paint flakes from the end of the rotor)

The unit was re-assembled without adding new or additional grease and the test resumed. Since restart the unit has operated for a total of 370 orbits or 672 hours. To date there has been no noticeable degradation in performance.

1.7 DRY FILM LUBRICANT INVESTIGATION

1.7.1 SUMMARY

One developmental test was conducted to determine if solid dry film lubrication could meet the bearing and gear lubrication requirements of the NIMCO Solar Array Drive*. Although

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*This is described in detail in Reference 8.

there was not any apparant degradation of the lubricant it cannot be concluded at this time that dry film lubricant represents a significant improvement over G-300 grease due to the limited data generated by a single developmental test evaluation.

1.7.2 TEST

1.7.2.1 Unit Configuration

a. Motor-Gearhead - Used size-8 Kearfott a-c motor S/N 19 and used Kearfott gearhead, S/N unkown.

b. Gears - Used 416 stainless steel gears coated with Moly-Disulfide-Graphite, Sodium Silicate Bonded Dry Film Lubricant developed at NAEC as NAMC-AML Formula No. 23.

c. Bearings - New New Hampshire bearings with 0.0008 to 0.0011 radial play. Inner raceways, outer raceways and retainers coated same as gears. Gearhead and rear motor bearings had stainless steel crown retainers. Gearhead output shaft and front motor bearings had two piece stainless steel ribbon retainers.

1.7.2.2 Unit Performance

Running in orbital environment intermittent operational problems were encountered at heat sink temperatures at or above 50°C and at control phase voltages at or below four volts. Total accumulated operational test time of approximately 552 hours included 120 hours of continuous operation and approximately 2769 simulated accelerated orbital cycles.

1.7.2.3 Unit Analysis

a. Motor - Original condition of used parts is unkown. Excessive scoring which was observed on the rotor apparently was the major cause of the intermittent operational problems. This scoring could have been caused by worn used parts, excessive radial play in the new bearings or incompatibility between rotor-stator clearance.

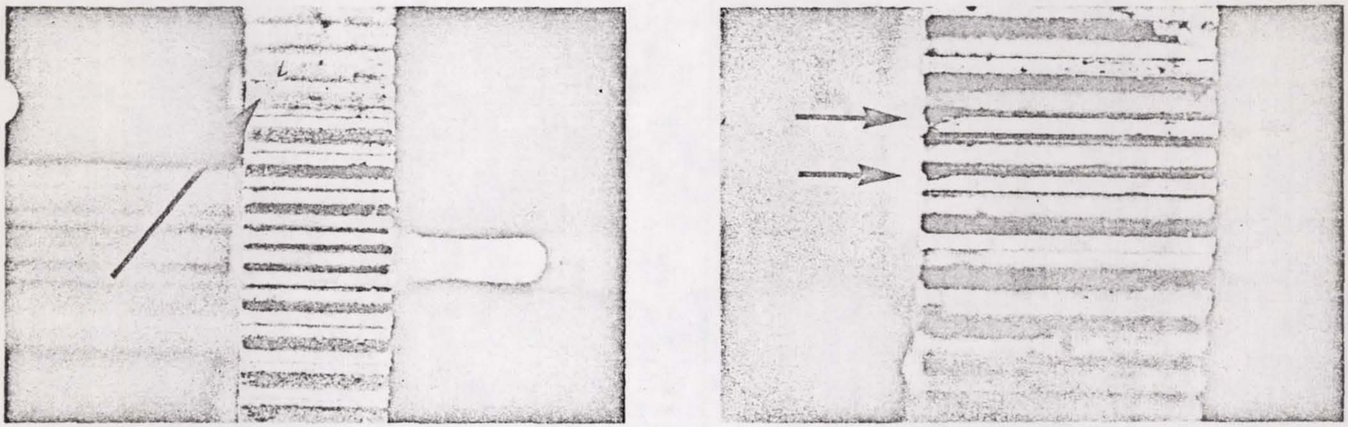
Wear on the rotor rear bearing shaft O.D. and on the bearing I.D. was probably due to an incompatibility between bearing - shaft clearances. The high speed (5000 rpm) resulted in an almost complete transfer of the solid dry film lubricant from the raceway ball tracks to the bearing balls. An incompatibility between bearing - housing clearances probably caused a similar abnormal wear on the motor output shaft bearing O.D. and transferral of lubricant.

b. Gearhead - Observed removal of solid lubricant coating on the edges of two pinions and of the output gear was probably due to incorrect axial alignment resulting from faulty assembly. Transferral of solid film coating from bearing raceway ball tracks to balls appears to have progressed normally with speed increase within the gearhead. Reduction of lubricant wear on the gears appears to be normal from the high speed (5000 rpm) to the low speed end.

1.8 SOLAR ARRAY DRIVE GEAR MATERIALS

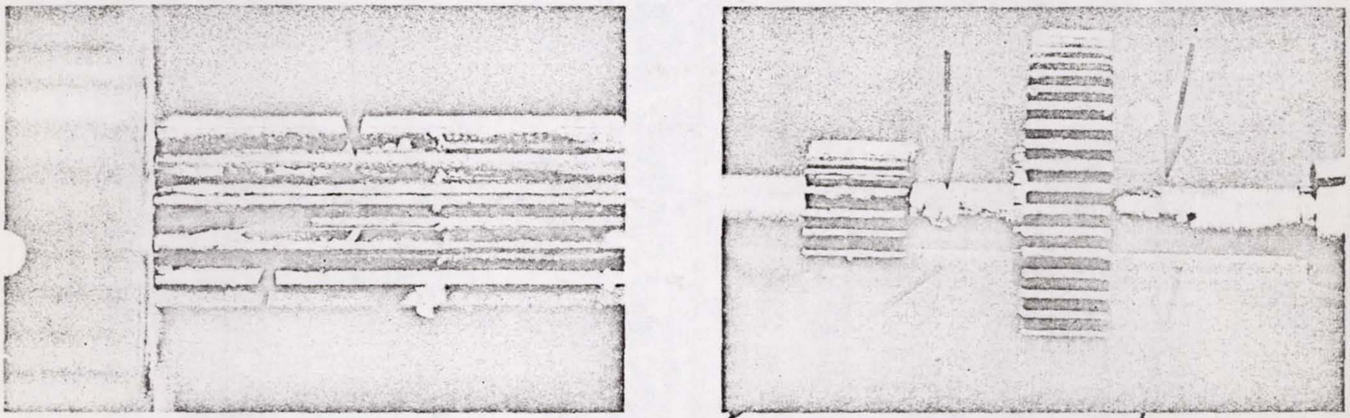
1.8.1 INTRODUCTION

In the course of investigating potential failure modes of the Flight 1 Solar Array Drive, several early NIMBUS A units were torn down and examined. Gears in the Kearfott motor gearhead (MGH) unit were found to exhibit evidence of poor processing and quality control. Among several discrepancies observed with these SAE 416 stainless steel gears, surface hardened by the 'Micro X" nitriding process, were: case spalling, heat treat scale and damaged teeth. Examples of these conditions are shown in Figure 1-2. All these faults were attributed to poor manufacturing and were not caused by wear.



Arrow Shows Tooth Gouge
7X - (a)

Arrows Show Flattened Teeth
15X - (b)



Heat Treat Scale
10X - (c)

Nitride Case Broken
4X - (d)

Figure 1-2. Types of Degradation Found on Micro-x SAE 416 Gears

Metallurgical examination of the gears showed the case and core hardness as well as the case depth to be below standard requirements for surface hardened gears. Excessive ferrite banding was observed in the gear structure.

Although the Flight 1 SAD failure was in no way attributable to gear discrepancies, steps were taken to improve both gear material and quality in redesigned NIMBUS C drives. Strict QC requirements were imposed and completed MGH units were required to pass a 100-hour vacuum "Green Run" without evidence of gear degradation.

1.8.2 "TUFFTRIDED" SAE 416 STAINLESS STEEL GEARS

The manufacturer attempted to improve 416 stainless steel gear quality by employing low ferrite raw stock case hardened by the "Tufftride" process. Best results of extensive metallurgical process investigations was a gear with a case hardness of 70 Rc to a depth of $\sim$ 1 mil and core hardness of $<$ 24 Rc. The microstructure contained excessive amounts of ferrite (Figures 1-3 and 1-4). Difficulty was experienced in maintaining dimensional tolerances after mechanical removal of a soft surface film characteristic of the "Tufftride" process case. Although still less than optimum from an idealistic viewpoint, several MGH units were made up from these gears and subjected to "Green Run" testing.

Post "Green Run" MGH gears exhibited edge chipping of the case. Attempts to eliminate this occurrence by means of mechanically rounding the sharp edges prior to test were not universally successful.

In light of the continuing difficulties with case-hardened 416 gears, a program decision was made to change gear material.

1.8.3 SAE 4340 STEEL GEARS

SAE 4340 steel was chosen for its wide availability, well known processing treatments, good strength and toughness properties. The steel was purchased as aircraft quality consumable

Figure 1-3. Tufftrided Gear Tooth from the Second Set Processed Showing Approximately 30% Ferrite Plus Nitrided Surface (100 x)

Figure 1-4. Tufftrided Gear from the Second Set Processed Showing Approximately 30% Ferrite (500x)

electrode vacuum melted bar stock and was so chosen to avoid any complications due to excessive impurities, imperfection in the raw stock, and to assure the required hardenability and ductility.

The heat used provided for a hardness of Rockwell "C", 50-55. The finished gear teeth were shot peened with 200 mesh glass beads to improve the fatigue resistance of the gears and other surface properties.

The shot-peened SAE 4340 gears have operated successfully in all trial runs to date and are presently incorporated in Flight C SAD motor gearhead units.

1.8.4 NITRIDED NITRALLOY 135 M GEARS

The output pinion gear of the motor gearhead unit and the ring gear of the paddle shaft were observed to be badly worn on the V-2 and prototype solar array drives. These gears were made of Berylco 10 and un-surface hardened 416 stainless steel respectively on both these and the NIMBUS A drives. Both gears meshed with the nitrided Nitralloy 135 M gears exterior to the motor gearhead.

The material of both the pinion and ring gears was changed to nitrided Nitralloy 135M in the redesigned NIMBUS C solar array drive to achieve better wear characteristics.

Nitrided Nitralloy 135 M gears are also employed in the d-c Torquer drive, developed as a backup for the redesigned a-c drive.

SECTION 2.

OUTGASSING ASPECTS OF FLIGHT II VIDEO TARGETS

2.1 SUMMARY

Outgassing/condensation tests were individually performed with RTV-731 and RTV-102 silicone rubbers to determine whether or not a camera lens contamination problem exists with their use in Flight II video targets. Test conditions equalled or exceeded "worst case" camera lens - target conditions with respect to view factor, temperature and time of exposure.

It was found that the camera lens cover glass targets were unaffected by exposure to outgassing products of either silicone rubber with respect to light transmittance and resolution. Although the target glasses showed a very small weight increase as the result of exposure, no evidence of contamination could be observed.

It is concluded that the present use of the above silicone rubbers in Flight II video targets does not constitute a camera lens contamination problem. In view of this conclusion, no action was recommended.

2.2 BACKGROUND

Six video targets (Dwg. 133B1839) are employed in the Flight II spacecraft adapter to check pre-launch operation of the AVCS cameras. The targets are located in direct line-of-sight of the camera lenses and remain in this orientation until the adapter separates from the spacecraft, which is approximately 57 minutes from start of launch. During the interim period between spacecraft launch and adapter separation, the camera lenses are exposed to the outgassing products of the organic materials of construction of the targets. These are: (1) RTV-731 silicone rubber-wire bend reliefs and target mount adhesive; (2) RTV-102 silicone rubber-target mount adhesive and leadwire tack bond; (3) Rayolin

N-leadwire insulation; and (4) PD-454 (Code L)-target lamp encapsulant.

PD-454 is a transparent epoxy encapsulant used on Flight II to meet increased light output requirements. It is identical to the PD-459 encapsulant used on Flight I with the exception that light-diffusing eccospheres are absent. Since PD-459 caused no lens contamination problems with the NIMBUS A TV cameras, no problems are foreseen in the use of PD-454.

Rayolin N wire insulation has previously been evaluated with respect to lens contamination problems (Ref. 7, Section 1) under thermal conditions more severe than those anticipated in the adapter and no problems are anticipated in the video target application.

The silicone rubbers, however, had not been previously evaluated. Whether or not they would have caused a problem with NIMBUS A is also unknown since launch site personnel took exception to their use and wrapped tape around the base of the targets prior to launch to eliminate line-of-sight with the camera lenses. To eliminate the needs for such makeshift action in dealing with potential camera lens contamination problems on Flight II, it was recommended that outgassing tests be performed with the two silicones and corrective design action be taken if found necessary.

2.3 COURSE OF ACTION

An outgassing test was conducted to determine whether or not a lens contamination problem actually exists with the present use of RTV-731 and 102 in the video targets. The effects of outgassing products from both RTV-731 and RTV-102 on AVCS camera lenses were individually determined under geometric and thermal conditions representative of those existing in the adapter during flight. The test plan details are as follows:

2.4 TEST PLAN

2.4.1 SAMPLE DETAILS

a. Outgassing Sources

   1. RTV-731 silicone rubber slab: 2 inches x 2 inches x 1/8 inch
   2. RTV-102 silicone rubber slab: 2 inches x 2 inches x 1/8 inch

b. Target Lens - AVCS lens cover glass (radiation shield).

c. Source-Target Arrangement Geometry - The geometry shown in Figure 2-1 duplicates that present in NIMBUS between the No. 2 AVCS camera and its video targets.

2.4.2 TEST PARAMETERS

a. Vacuum - 10^{-5} to 10^{-6} mm Hg

b. Exposure Time in Vacuum - Three hours. Subsequent to launch, the adapter remains attached to the spacecraft for approximately 57 minutes.

c. Temperatures - 30°C. Thermal engineering roughly estimates the internal adapter temperature prior to separation to range between 20°C and 30°C.

2.4.3 MEASUREMENTS REQUIRED

a. Camera Lens Cover Glass

   1. Visual post-test examination to determine whether or not a contaminant film is present.

2. Pre and post-test transmittance in 0.4 to 1.1 micron operational wavelength band.

3. Pre-and post-test limit of resolution if required.

4. Weight before and after test.

b. Silicone Rubber Samples - Weigh before and after test.

2.5 TEST RESULTS

No visual evidence of camera lens cover glass contamination or loss in resolution could be observed after exposure to the outgassing products of either RTV-731 or RTV-102 silicone rubber, each individually tested.

Cover glass transmittance in the 0.4 to 1.1 micron operational wavelength band was unaffected as the result of exposure to outgassing products of either RTV-731 or RTV-102 silicone rubber. Figure 2-2 shows the transmission vs. wavelength measurement results which were identical both pre-and post-test for both rubbers.

2.5.1 TEST 1: RTV-731 SILICONE RUBBER

Weight loss measurement results for RTV-731 silicone rubber are given in Table 2-1.

Table 2-1. RTV-731 Rubber Samples

	Sample 1	Sample 2	Target Cover Glass
Initial Wt. (gms)	11.8929	14.2534	5.2213
Final Wt. (gms)	11.8804	14.2385	5.2216
Wt. Change (gms)	-0.0125	-0.0149	+0.0003
% Wt. Change	-0.105%	-0.105%	-

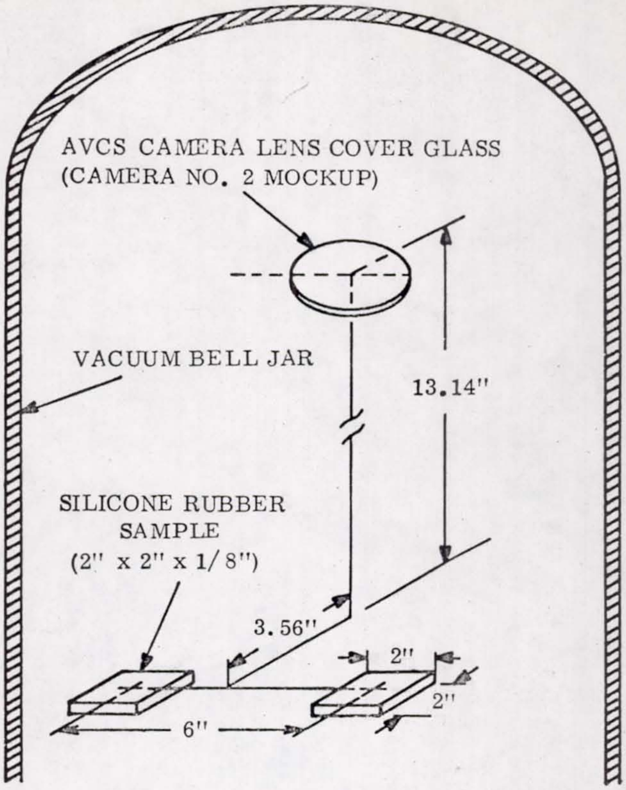


Figure 2-1. Geometric Arrangement of Silicone Rubber Samples and AVCS Camera Lens Cover Glass in Vacuum Chamber During Outgassing Test

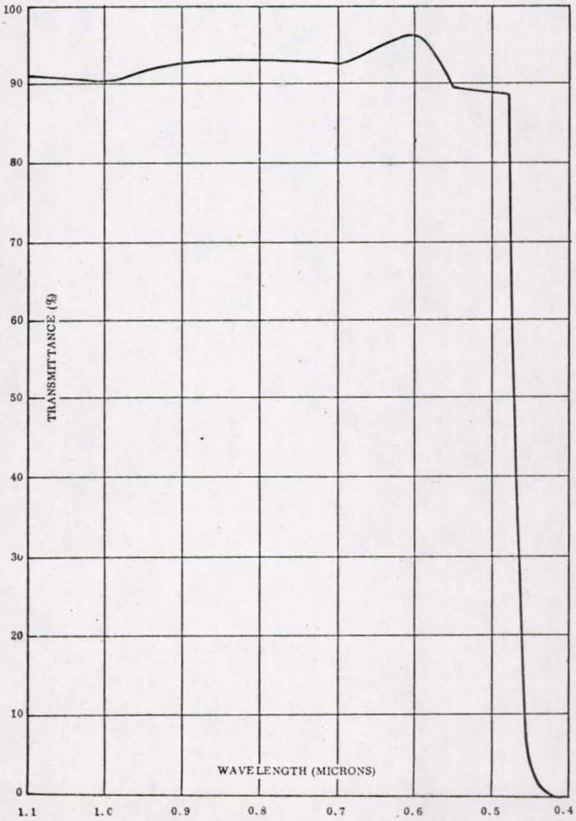


Figure 2-2. Transmittance Test Results

2.5.2 TEST 2: RTV-102 SILICONE RUBBER

Weight loss measurement results for RTV-102 silicone rubber are given in Table 2-2.

Table 2-2. RTV-102 Rubber Samples

	Sample 1	Sample 2	Target Cover Glass
Initial Wt. (gms)	15.1888	13.9575	5.2143
Final Wt. (gms)	15.1374	13.9065	5.2146
Wt. Change (gms)	-0.0514	-0.0506	+0.0003
% Wt. Change	-0.34%	-0.36%	-

2.5.3 TEST 3

A third test was run under identical conditions but in the absence of organic outgassing samples to determine the target cover glass weight change in the absence of outgassing products. The results of this test were:

Initial Wt. (gms)	5.2198
Final Wt. (gms)	5.2194
Wt. Change (gms)	-0.0004

Based on the results of this third test it is concluded that the true weight increase of the target cover glasses was approximately +0.0007 grams. Despite the measured weight increases of target glasses, due presumably to outgassing product condensation, no evidence of contaminant film formation could be seen and no effect on lens transmittance or resolution measured.

SECTION 3.

IR SCANNER STIMULATOR OUTGASSING TEST

3.1 SUMMARY

Thermal-vacuum tests were conducted on an IR Scanner Stimulator to establish the outgassing characteristics of this assembly during simulated "worst case" NIMBUS launch conditions. The primary test objective was to make a preliminary evaluation of potential outgassing/condensation problems associated with the presence of silicone and polyimide materials of construction in this unit. Three test techniques were used to provide measures with which to evaluate the problem potential: (1) net assembly weight loss, (2) mass spectrometer analysis of outgassing products and (3) glass slides placed nearby the silicone material surfaces to serve as condensation sites for the outgassed volatile materials.

Net assembly weight loss for the two vacuum tests conducted was 0.038 grams. The mass spectrometer analysis of outgassing products showed the predominant species to be $(CH_3)_3Si^+$ and ketones. No evidence of glass slide contamination was observed as the result of outgassing product exposure.

Based on the results of these tests, it was concluded that the probability is low that significant spacecraft outgassing/condensation problems exist with the use of the present stimulator design.

3.2 BACKGROUND

The IR Scanner Stimulators (Dwg. 889D721) are designed to be Go/No-Go Targets for NIMBUS Controls IR Scanners during pre-launch tests. The stimulators are mechanically mounted to the LMSC Shroud, and function to provide the IR Scanners with a surface in view, heated to a triggering temperature level. Four stimulators are employed in the

Flight II configuration. Two of these are in direct line-of-sight of the "A" Scanner and the remaining two are blocked from view of the "B" Scanner by the folded Solar Platforms. To function properly, these latter stimulators must warm the inside surface of the Solar Platforms viewed by the "B" Scanner to the appropriate temperature level.

The design temperature rating of the stimulators, based on thermostat settings, is $243^{\circ}C \pm 5.5^{\circ}C$. The selection of materials for the stimulators was therefore restricted to those having $260^{\circ}C$ temperature ratings with or with-stand capabilities for reasonable periods of time. The stimulators are operated under atmospheric conditions only and are inoperative during launch. The shroud remains attached to the Agena Booster for approximately three to four minutes from start of launch corresponding to a separation altitude of 65 miles (2.5×10^{-5} torr); maximum internal surface temperature of the shroud during this time period is approximately $93^{\circ}C$.

The organic materials of construction of the stimulators (see Table 3-1) are blocked from direct line-of-sight of the spacecraft by the front aluminum plate. The entire stimulator assembly is baked at $260^{\circ}C$ for two hours during the manufacturing cycle; this is done to drive out the vast majority of volatile material present in the silicones and polyimide prior to end use.

3.3 TEST OBJECTIVES

a. Determine total weight loss of stimulator assembly resulting from "worst case" simulated launch thermal-vacuum exposure ($93^{\circ}C$, pumpdown from 1 atm to 2.5×10^{-4} torr within three to four minutes).

b. Determine assembly outgassing rate vs. time, composition of outgassing, products and weight loss during outgassing test below 10^{-5} torr (mass spectrometer is operative only at pressures $\leq 10^{-5}$ torr).

Table 3-1. Materials of Constructions of IR Scanner Stimulators

Part	Drawing	Material
1) Plate	133B2881	6061-0 Aluminum per QQ-A-250/11 Finish: Carbon Black-Pigmented Anodize per GE 171A4227
2) Heater	113C8088	600°F Silicone Rubber reinforced with fiber glass (HK Porter Type Q 913)-heated vulcanized to back side of Plate
3) Heater Leadwire	113C8088	No. 20 AWG fiber glass-reinforced silicone rubber
4) Frame	113C8086	Textolite Silicone Glass Laminate: Grade 11617 per MIL-P-997 GSG
5) Bushings	133B2880	DuPont "Vespel" Polymer SP (no filler), a molded Polyimide per GE 171A4232
6) Foam Insulation	889D721	Silicone Rubber: DC Silastic RTV-S-5370 Foam, Catalyst S-5370 per GE 171A4233
7) Insulation Bond Primer	889D721	DC A 4094 Primer per GE 128A5489
8) Insulation Top Coat & Leadwire Encapsulant	889D721	RTV-40 Silicone Rubber per GE 128A4789P3
9) Thermostat	113C8088	Elmwood Sensors, Cranston, R.I., Part #3100-1

c. Determine whether or not outgassing products will condense on target glass slides placed in close proximity to the organic materials of construction.

3.4 RESULTS

3.4.1 WEIGHT LOSS

A total net weight loss of 0.038 grams of organic volatile material was volatilized from the assembly as a result of the two test exposures. This corresponds to an assembly percentage weight loss of approximately 0.15% (initial assembly weight = 253.588 grams). The percent weight loss based on the initial mass of organic material alone (less aluminum plate and other metallic parts) is obviously higher.

3.4.2 GLASS SLIDE CONTAMINATION

No evidence of contamination was found on the glass slides following thermal-vacuum testing.

3.4.3 MASS SPECTROMETER ANALYSIS

Primary peaks above background (m/e) were 73 and 86 with increases indicated at 57 and 77. Most probable sources are silicone components with a $(CH_3)_3\ Si^+$ - moiety and ketones of m.w. 74 and 87. No definite identification was made due to abnormal background and low indicated weight loss.

3.4.4 GENERAL

The low assembly weight loss and absence of contaminant films on the glass slides are primarily due to: (1) short thermal-vacuum exposure time in simulated launch, (2) prebake of assembly at 260°C for two hours during manufacture to drive out volatile material, and (3) low assembly temperature during launch of 93°C max. coupled with 260°C prebake. The test is described in full detail in Reference 9.

SECTION 4.

RAYCHEM HARNESS WIRE INVESTIGATION

4.1 SUMMARY

In the process of installing heat-shrinkable insulation and solder sleeves on typical shielded, twisted pair-type NIMIT harness wires, the conductor insulation is simultaneously exposed to both heat and pressure. Possible deleterious effects of such exposure include:

a. conductor insulation penetration by either shield or adjacent conductor or appreciable deformation

b. fusion of insulation on adjacent conductors or fusion of conductor insulation to sleeve

c. embrittlement or softening of conductor insulation

d. cracking, splitting or tear away of conductor insulation during harness assembly flexure or terminal wire spreading as the result of property degradation and/or fusion.

Any of these defects may produce premature electrical failure in assembled harness.

A program of investigation was conducted on representative NIMIT harness wire assemblies to evaluate the problem potential associated with these effects. Variables studied in the investigation included:

a. wire type (RT, TRT, 44/1121 and 44/1141)
b. shrink sleeve type (RNF, CRN)
c. Solder sleeve type (D101, D121)
d. processing technique - level and duration of applied heat.

High potential tests were applied to the harness test samples before and after flexure. All samples were torn down and examined microscopically for evidence of insulation degradtion. Elongation measurements were made on the RT and TRT wire insulation used to fabricate the samples.

On the basis of test results it was concluded that:

a. There is no conclusive evidence that any particular construction is always more prone to dielectric failure under flexing. There is some evidence that the Type 144/1121 and Type 44/1141 wires may be dielectrically weakened by the heating, whether flexed or not. The two dielectric failures encountered were both with this wire type.

b. There is ample evidence that heat deformation and slight fusion of the wire insulations can and does occur. Because of the high inherent dielectric strength of all these wires, the strength may not be seriously affected, but the use of heat is a weakening factor for all wires. Heat exists principally under the solder shield and may extend beyond the shields when the greater heats are applied. The general construction used tends to weaken the dielectric strength and hence cannot be considered as optimum design.

c. Heat and pressure are the prime causes of difficulty. Flexing may aggravate a dangerous situation.

4.2 BACKGROUND

In late 1964 the Spacecraft Department encountered problems in the use of Raychem Thermorad (TRT) wire on a different spacecraft program. The wire was used in harness assemblies which employed heat-shrinkable Thermofit sleeving and solder sleeves. These were:

a. splitting of conductor insulation beneath CRN shrink sleeving upon flexure

b. fusion of insulation on adjacent conductors beneath and adjacent to solder sleeves

c. low elongation (50-80%) of TRT insulation on wire samples from which the harnesses had been fabricated, indicative of a "bad lot" of wire from the vendor due possibly to radiation processing variations (vendor data stated 200% elongation).

The outcome of various test programs, vendor meetings and program evaluation was a program decision to discontinue use of Thermorad (TRT) wire and return to Rayolin N (RT) wire. This was possible despite the vendor's announced discontinuance of the RT line in favor of TRT since the former product was and is still being produced for various defense programs.

The Raychem TRT wire is an improved version of the older type Raolin N (RT) wire. Major improvements included greater abrasion resistance characteristics, greater insulation elongation, and less volatile material in the insulation, resulting in lesser outgassing products under low pressure environments. The NIMIT harness drawings were changed to include the use of TRT wire and many of the existing harnesses contain this wire.

It has always been the practice on NIMIT harnesses to use the more flexible, thinner walled RNF-100 sleeving rather than the semi-rigid CRN sleeving to terminate shielded wire ends. The CRN sleeving, which may take more heat to apply and becomes very rigid and develops high hoop stresses, had been used on this other spacecraft to terminate shielded wire ends at the time these failures were discovered.

An investigation and test program was initiated to attempt to duplicate and further analyze the type of failures encountered, as they might apply to the NIMIT harness.

4.3 PROCEDURE

Samples of RT and TRT shielded wire were fabricated with solder sleeves and both RNF-100 and CRN thermofit sleeving. Wire samples were taken from varied wire lots. Two types of solder sleeves were used, the Raychem D101 and D121; the D121 having a lower melting point solder. Included in the investigation were samples of Raychem Specification 44 wire, a new development having a dual wall insulation construction (Kynar-jacketed polyolefin). Solder sleeves and thermofit sleeving were installed under conditions of standard and maximum heat application, i.e., overexposed to simulate worse case conditions.

A NIMIT harness, 9B, 111C1399G1, was subjected to the same series of tests as the wire samples. Before flexing the wire samples, each was given a five-second 1,500-volt 60-cps hipot test to be certain that all wires were adequate before flexing.

The wire samples were then flexed 90 degrees in four directions at the shield termination (thermofit sleeving) and similarly in four directions at the solder sleeve, after which a one-minute 1,500-volt 60-cps hipot test was applied between the wire conductors and the shield. In the case of specimens which failed, an additional 1,500-volt test was applied between each conductor and the shield to determine which conductor insulation had failed and a third 1,500-volt test applied between conductors to be sure that only one conductor was involved.

The samples were then torn down and examined visually with the aid of a 20X microscope for evidences of conductor insulation heat fusing under the thermofit and solder sleeves and for fusing of one conductor insulation to another.

A stock flight harness, 111C1399G1(9B), was similarly torn down and visually examined for evidences of fusion.

4.4 RESULTS

Of 72 samples and a fabricated harness tested, two failed the high potential test; one before and the other after flexure. Both failed samples were of the Specification 44 wire type which is not presently in use but was being tested to obtain performance characteristics.

Fusing of the conductor insulation to the thermofit sleeve was most prevalent among the RT wires, with fewer instances among the TRT wires and more among the Type 44/1121 and 44/1141 wires.

There were scattered instances of conductor-to-conductor insulation fusing among the TRT and more among the 44/1121 and 44/1141 wires.

Almost all wires showed heat deformation under the thermofit sleeve and a few instances of deformation extending beyond this sleeve.

Fusing of one conductor insulation to the other under the solder sleeve occurred only among the TRT, 44/1121 and 44/1141 wires.

Some heat deformation of the conductor insulation occurred under the solder sleeve in all but four scattered specimens. Fusion between conductor insulations beyond the solder sleeve ends occurred entirely among the TRT, 44/1121 and 44/1141 wires.

Many of the defects noted in the wire samples were found in the prime harness.

No cracking or splitting of conductor insulation was evident in any of the samples tested.

Elongation of RT and TRT insulation used in the samples ranged between 230% and 400% A minimum elongation of 100% is required by the applicable wire specification, 146A9618.

4.5 RECOMMENDATIONS

a. Continue use of both RT and TRT wire in the NIMIT harness.

b. A specification control drawing for solder sleeves was issued (R2290)

c. Evaluate alternate methods of heat application, such as infra red heating tools, for solder sleeve application. A program has been initiated to evaluate both Raychem and Argus Engineering IR heating tools.

d. Revise Manufacturing Standing Instructions for application of solder sleeves to include the maximum limitations on amount of heat exposure for thermofit sleeving on shielded wire ends and solder sleeves. To aid in operator judgement on determining proper solder flow, a clear set of photographs indicating over-under heated and normal conditions be supplied to and employed by shop personnel.

SECTION 5.

MATERIALS AND PROCESSES SPECIFICATIONS

Materials and processes specifications (see Table 5-1) are written to fulfill specific requirements of the NIMBUS program. These specifications were issued and/or revised during the current reporting period

Table 5-1. Materials and Processes Specifications

Specification Number	Title	Typical Application	Issue Date
171A4161	Coating, Thermal Control D4D, Application of	Thermal Control coating applied to vehicle exterior surfaces	12/22/64
171A4186	Adhesive Polyurethane, MSD-107, Process for Application of	Bonding Insulating Stand-offs to various substrates	6/26/65
171A4224 AN	Grease, Silicone, Super Clean	Bearing and Gear lubrication, Solar Array Drive	3/3/65 6/8/65
171A4227	Coating, Carbon Black Pigmented Anodize	High Temp./High Emissivity coating for IR Stimulator	4/12/65
171A4228 AN	Lubricant, Solid Dry Film Moly-Disulfate, Graphite, Sodium Silicate Bonded	Solid Dry Film lubricant for Bears and Bearings	4/20/65 5/19/65
171A4230	Resin, Acrylic Ester	Used as lacquer and vehicle for pigments	4/8/65
171A4232	Plastic, Polyimide, High Temperature Stability	High Temp. Insulator Bushing for IR Stimulator	4/9/65
171A4233 AN	Foam, Flexible, Low Density, Silicone	High Temp. Thermal Insulator for IR Stimulator	4/12/65 4/26/65

Table 5-1. Materials and Processes Specifications (Cont'd)

Specification Number	Title	Typical Application	Issue Date
171A4234	Application of Flexible Silicone Foam to IR Stimulators	IR Stimulator	4/21/65
171A4235	General Purpose Epoxy Adhesive	Structural Adhesive Bonding	4/15/65
171A4237	Polyurethane Foam, Flexible	Optical Gasket for SASS	5/17/65
171A4238	Wornowink Retma Black Paint, Application of	High Emmissivity coating for SAD Motor Rotors	4/22/65

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SECTION 6.

REFERENCES

1. Integration and Testing Materials Report No. 7, Document No. 65SD4215, Section 1, January 1965.

2. Verbal communication with Dr. F. J. Clauss, LMSC.

3. LMSC - A707712, "Lubrication Evaluation", W. C. Young, J. B. Rittenhouse, 1 October 1964.

4. Technical Documentary Report No. ML-TDR-64-40, "Space Materials Handbook," Goetzel, Rittenhouse & Singletary (LMSC) Editors, March, 1964.

5. Proceedings of Space Lubrication Conference, held May 1963 at the Biltmore Hotel, NYC, Office Of The Director Of Defense Research & Engineering, September 1963.

6. PIR 4375-030, "Solar Array Drive Motor Bearing Temperature Measurement Test Report", dated 5-14-65.

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