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R-644

Final Report on Assembly and
Test of Five Apollo 1 IRIG's
(Inertial Reference Integrating Gyros)
Incorporating the size R-4 (SR4HX88)
Instrument Ball Bearing

by
Bertram Rockower
September 1969

**INSTRUMENTATION
LABORATORY** ●

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Cambridge 39. Mass.

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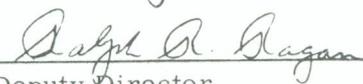
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Also, the author expresses thanks to Hubert A. Vernon for his contributions to this report on gyro performance. Mr. Vernon was responsible for the gyro testing and evaluation.

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ABSTRACT

A program was conducted to build and test five Apollo I IRIG's incorporating a wheel design using the size R - 4 ball bearing with a nylasint retainer material. Eight SR4HX88K and five X88L bearing assemblies were used in the program. The X88K bearing is 440C, conventionally hardened by a heat treatment aimed at maximum hardness ($\sim R_c 60$) consistent with the desired dimensional stability. The X88L bearing is 14-4-1 (Cr - Mo - V), a compositional variant that gives somewhat greater hardness and tempering resistance than 440. The bearings were developed under Task No. 5 of Contract NAS 9 - 3079 with the Instrumentation Laboratory of Massachusetts Institute of Technology.

The wheel assembly and evaluation phase of this program was successful. Wheels were assembled and tested with an overall process yield of 43%.

Gyros were tested in accordance with the existing MIT Instrumentation Laboratory Report R - 348 (Rev. B). Five gyros were delivered against the contract to the Apollo Systems Group at MIT.

Gyro test results showed good cooldown and temperature sensitivities. Results also showed ball beat and g^2 sensitivity problems which should be resolved before further use is made of the Apollo R - 4 gyro configuration.

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September 1969

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SECTION 1

INTRODUCTION

1.1 Scope of Program

This program is one of a continuing group of activities related to the spin axis support of the Apollo IRIG. The initial spin axis bearing design of the Apollo IRIG incorporated an R-2 sized ball bearing made of 52100 steel lubricated with V-78 oil, utilizing a synthane retainer, and operating under a nominal 3-lb. pre-load. NASA, under Contract NAS 9-4576, supported the development of a spool-type gas bearing design using solid ceramic wear surfaces and helium as the working gas.

In the current program a 440 C material, R-4 sized ball bearing with a nylasint retainer has been adapted to the same gyro design. G.F.P. consisted of 16 sets of SR4HX88 bearings, and 9 failed Apollo I IRIGs. Actually only 13 SR4HX88 bearing assemblies were used to build, assemble and test 5 gyros. The bearings were delivered from Task No. 5 of Contract NAS 9-3079 and consisted of eight SR4HX88K and five X88L bearing assemblies.

Of the five accepted wheels used for gyro assembly, three were assembled using Combo K bearings and two using Combo L. All of the bearings were double honed with the exception of one Combo L bearing which was ball lapped. Nylasint, staggered pocket, inner race riding retainers (M.I.T. Dwg. #C-127491) were included in the assemblies.

Originally, it was planned to build and test 6 gyros. This number was reduced to 5 gyros per agreement with NASA MSC. Screening of bearings at wheel and float assembly levels was accomplished using a differential milliwattmeter. Also, retainer stability was evaluated by visually observing retainer motion using a microscope and strobotac. Simultaneous to visual observation, the retainer beat frequency was recorded by use of a crystal accelerometer, cathode follower and wave analyzer. A torque to balance dynamometer was not used because the relatively high torque level associated with the R-4 bearing when compared to the R-2 bearing required the use of a suppression circuit. To resolve calibration problems associated with the suppression circuit would have seriously delayed the

program. The friction torque for the R-4 bearing is about five times greater than the R-2 bearing. Refer to Fig. 2 for a comparison of friction torques and other wheel parameters.

Gyro testing was performed per the schedule of Spec R-348, Rev. B. There was no required performance criteria. Extended performance tests such as long term IA vertical tests, compliance testing, etc. are described in detail in Section 4 of this report.

Originally, 2 gyros were to be vibration tested at 15 g's per the schedule of PS2021500 and coefficient stability across vibration was to be measured. Per agreement with NASA, MSC, this test was performed on only 1 gyro.

1.2 Physical Description

1.2.1 Configuration

A cross sectional view of the wheel assembly is shown in Fig. 1. A comparison of data for R-2 and R-4 wheels is shown in Fig. 2. The wheel was designed to rotate at a synchronous angular velocity of 24,000 RPM. Required pre-load range setting at operating temperature of 137°F is 5 to 7 pounds.

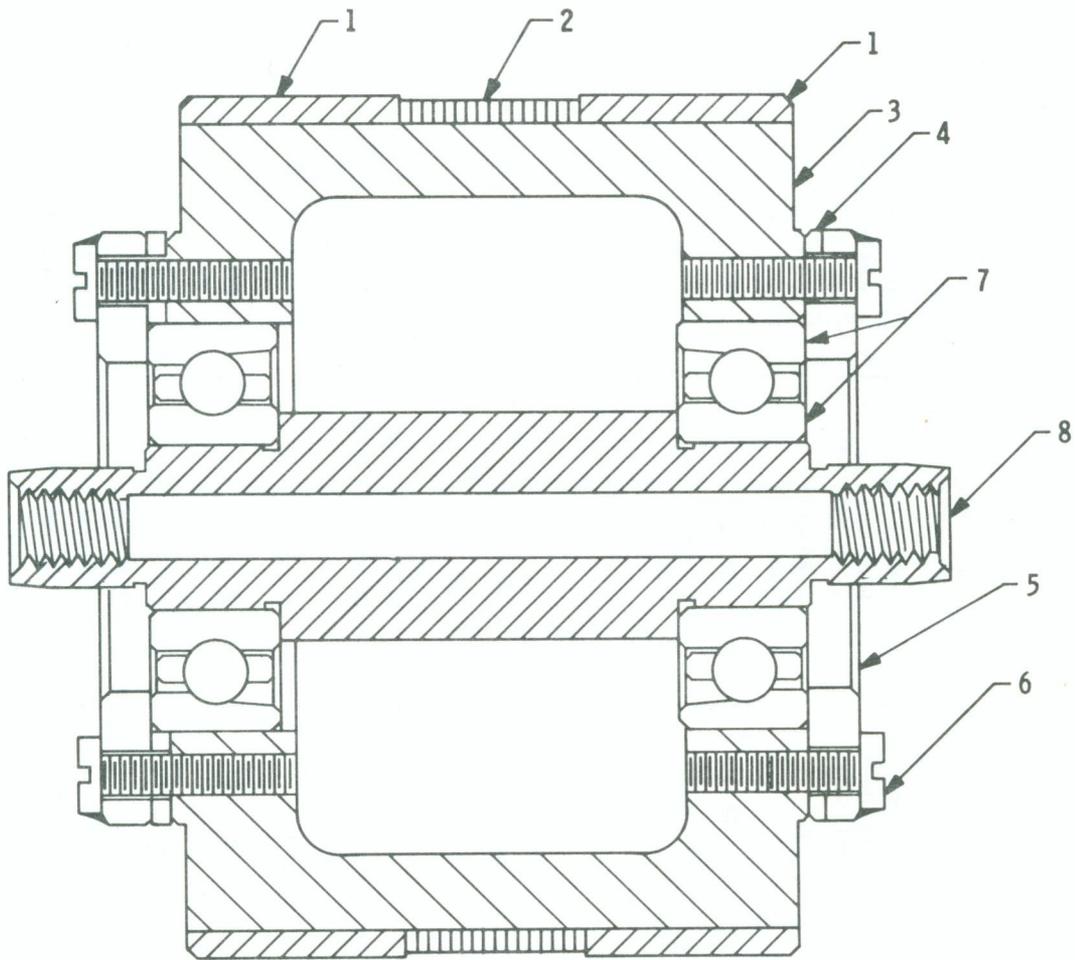
The wheel hub material was machined from the titanium alloy (13V-11Cr-3Al) and the shaft from Brush S-200 beryllium. Materials for these parts were selected so as to obtain optimum fits for the inner and outer bearing rings over the temperature range of 40°F to 180°F. A more detailed discussion on interference fits is included in Paragraph 2.1 below.

1.2.2 Ball Bearing Materials

The SR4HX88K and X88L bearings are both made from doubly vacuum melted stainless steel (vacuum induction followed by vacuum arc remelting), selected for freedom from non-metallic inclusions. The X88K bearings are 440C, conventionally hardened by a heat treatment aimed at maximum hardness ($\sim R_C 62$) consistent with the desired dimensional stability. The X88L bearings are 14-4-1 (Cr-Mo-V), a compositional variant that gives somewhat greater hardness and tempering resistance than 440C. The X88L steel was hardened by a thermo-mechanical process--ausforming--in which more than 50% reduction-in-area was introduced when the material was in the metastable austenitic stage during heat treatment. This resulted in higher hardness ($\sim R_C 65$) and other mechanical properties than conventional heat treatment. Conventional 440C balls were used in both types of bearings.

1.2.3 Ball Bearing Tolerances

In general the geometry of ball bearing parts was excellent and represented the best effort by the ball bearing manufacturer in the current manufacturing tech-



ITEM #	DESCRIPTION OF PART	MATERIAL
1	INERTIA RIM	GYROMET
2	HYSTERESIS RING	P-6 ALLOY
3	WHEEL HUB	TITANIUM (13V-11 Cr - 3 Al)
4	SPACER	440 STEEL
5	CAP	BERYLLIUM (BRUSH S-200)
6	CAP CLAMPING SCREW	303 STAINLESS
7	R-4 SEPARABLE BEARING ASSY	440 STEEL
8	SHAFT	BERYLLIUM (BRUSH S-200)

Fig. 1 Cross-sectional view of R-4 ball bearing Apollo I wheel assembly.

COMPARISON OF WHEEL DATA

PARAMETER DESCRIPTION	R-2 APOLLO WHEEL (ORIGINAL)	R-2 APOLLO WHEEL (081 CONFIGURATION)	R-4 APOLLO WHEEL
TYPE OF BEARING CONSTRUCTION	ANGULAR CONTACT INNER RACES INTEGRAL WITH SHAFT	ANGULAR CONTACT INNER RACES INTEGRAL WITH SHAFT	ANGULAR CONTACT SEPARABLE INNER AND OUTER RACES
BALL BEARING MATERIAL	52-100 STEEL	52-100 STEEL	(SEE PARA. 1.2.2)
CONTACT ANGLE AT 3/4 THRUST LOAD	31° - 32°	30° - 32°	29.5° - 30.5°
LUBRICANT	TERESSO V-78	SRG - 160	TERESSO V-78
RETAINER MATERIAL	SYNTHANE	NYLASINT	NYLASINT
TYPE OF RETAINER	OUTER RACE RIDING	INNER RACE RIDING	INNER RACE RIDING WITH STAGGERED POCKETS
INNER RACE CURVATURE	54 %	54 %	53 %
OUTER RACE CURVATURE	57.5 %	57.5 %	57 %
FRICTION TORQUE AT 137°F	800 - 1800 D. C.	500-1200 D. C.	~5300 D. C.
WINDAGE TORQUE AT 137°F (IN 1/2 ATMOSPHERE OF HELIUM)	1900 D. C.	1900 D. C.	1900 D. C.
PRELOAD AT ROOM TEMP.	2.5 [#] - 3.5 [#]	0.75 [#] - 1.25 [#]	1.9 [#] - 3.4 [#]
PRELOAD AT OPERATING TEMP (137°F)	2.5 [#] - 3.5 [#]	0.75 [#] - 1.25 [#]	5 [#] - 7 [#]
MEAN STRESS, INNER RACE	126,000 PSI	82,000 PSI	114,000 PSI
MAXIMUM STRESS, INNER RACE	189,000 PSI	123,000 PSI	171,000 PSI
AXIAL COMPLIANCE AT (MICROINCHES) ROOM TEMPERATURE (PER LB)	9.0 - 12.0	12.6 - 15.1	7.2 - 9.0
RADIAL COMPLIANCE AT (MICROINCHES) ROOM TEMPERATURE (PER LB)	9.0 - 12.0	12.6 - 15.1	7.2 - 9.0
WEIGHT OF ROTATING WHEEL PARTS	83.7 GRAMS	83.7 GRAMS	82.6 GRAMS
MOMENT OF INERTIA	183 GM CM ²	183 GM CM ²	161.3 GM CM ²
ANGULAR MOMENTUM AT 24000 RPM	0.459 x 10 ⁶ $\frac{\text{GM CM}^2}{\text{SEC}}$	0.459 x 10 ⁶ $\frac{\text{GM CM}^2}{\text{SEC}}$	0.405 x 10 ⁶ $\frac{\text{GM CM}^2}{\text{SEC}}$
RUN UP TIME AT 28 VOLTS IN FLOAT	82.5 SEC	70.2 SEC	39.4 SEC
COAST DOWN TIME IN FLOAT (2400 RPM TO 6000 RPM)	115.5 SEC	174.6 SEC	69.4 SEC

Fig. 2 Comparison of wheel data.

nology. Critical tolerances on the inner and outer rings are tabulated in Fig. 3. All roundness tolerances are radial. The bearing manufacturer was permitted an increase in any two of the 0.000020 tolerance limits by up to 100% with the exception of bore and O.D. roundness. The cross race curvature was held to within ± 0.000010 " maximum departure from true cross curvature. Some checks were made on roundness and cross race curvature (See "Teardown Analysis Reports" in Appendix A) and results showed that parts were well within tolerance limits.

1.2.4 Ball Bearing Retainer

Retainers were machined from nylasint which is manufactured by the Polymer Corp., Reading, Pa. Lot #MC26-6 and MC26-10 nylasint materials were used. Most of the retainers were machined from the MC26-6 material. The retainer was inner race riding and had seven staggered pockets. Spacing between adjacent ball pockets varied from a minimum of 45° to a maximum of 58° . This represented the maximum stagger permitted by the geometry of the part. Previous experimental work by E. Kingsbury of M.I.T.-IL has shown that staggering of the ball pockets will help assure retainer stability. The same result may be obtained by using retainers with equally spaced pockets but mismatching the balls in each complement. Either approach also results in increased hash width on differential milliwattmeter traces.

TOLERANCES	INNER RING	OUTER RING
Squareness	0.000020	0.000020
Eccentricity	0.000020	0.000050
Groove Wobble	0.000020	0.000040
*Groove Roundness	0.000020	0.000020
Bore Roundness	0.000020	
O.D. Roundness		0.000010

*Measured at Contact Angle

(NOTE: All Roundness Tolerances Are Radial)

Fig. 3 Tolerances on SR4HX88 bearing.

SECTION 2

WHEEL AND FLOAT DESIGN

2.1 Interference and Rotational Stresses

Materials for parts which mated with the inner and outer ball bearing rings was selected primarily on the basis of relative coefficients of thermal expansion. S-200 beryllium was used as a shaft material, and a titanium alloy containing 13% vanadium, 11% chromium and 3% aluminum was used to make the wheel hubs. A summary of maximum stresses resulting from interference fits and temperature changes from room temperature to + 40°F and + 180°F is shown in Fig. 4. Included in this figure is a listing of the linear thermal coefficients of expansion for the materials used. It may be observed that the inner ring has a lower coefficient than the shaft and also the hub has a lower coefficient than the outer ring. This relative matching of coefficients enabled mating parts to be selected with a minimum interference fit at room temperature, the interferences increasing at the operating temperature of 137°F. In all cases with the exception of the hysteresis ring, maximum stress occurs at the maximum temperature of 180°F. In the case of the hysteresis ring, maximum stress is at the minimum temperature of 40°F. In general, the maximum hoop stresses due to temperature variation are not excessive.

The hysteresis ring and inertia runs are subjected to rotational stresses in addition to interference stresses. The maximum operating stresses at 137°F due to interference fit and rotation at 24,000 r/min are summarized below.

	MATERIAL	INTERFERENCE STRESS	ROTATIONAL STRESS	TOTAL STRESS	MATERIAL U. T. S.
INERTIA RIM	GYROMET	20,700 PSI	4,070 PSI	24,770 PSI	130,000 PSI
HYSTERESIS RIM	P-6 ALLOY	8,830	1,980	10,810	150,000 PSI

An examination of the above data shows that there is an adequate factor of safety under operating conditions at 137°F and 24,000 r/min.

2.2 Effect of Temperature Change on Bearing Preload

The desired preload range at operating temperature of 137°F was 5 to 7 pounds. As a result of thermal mismatch between shaft, bearings and wheel hub, it was necessary to initially preload wheels in the range from 1.92 to 3.40 pounds at room temperature. The effect of elasto-hydrodynamic film thickness on preload was not considered. Axial and radial single bearing deflections due to increase in temperature from room temperature to 137°F are 27.3 and 9.7 microinches respectively. (See Fig. 5.)

To determine the initial required preload setting at room temperature, both axial and radial single bearing deflections due to temperature increase from room temperature to 137°F must be considered. Figures 6 and 7, which are axial and radial single bearing curves for the R-4 bearing, are used. Starting with Figure 6, the effect of the axial deflection of 27.3 microinches is determined. This effectively reduces the preload range from 5-7 lb to 3.2-4.9 lb. Figure 7 shows the effect of the radial deflection of 9.7 microinches. The preload range of 3.2-4.9 lb is further reduced to 1.92-3.40 lb, which is the initial required preload range at room temperature.

Figure 6 is an axial single bearing deflection curve vs preload for the R-4 bearing, plotted on log log paper. Knowing that the final preload range should be 5-7 lbs, and the axial deflection between room temperature and 137°F is 27.3 microinches; the graph shows that the initial required preload range setting at room temperature is 1.92 to 3.40 lbs.

An analogous procedure may be followed using the radial single bearing deflection curve vs preload shown in Fig. 7.

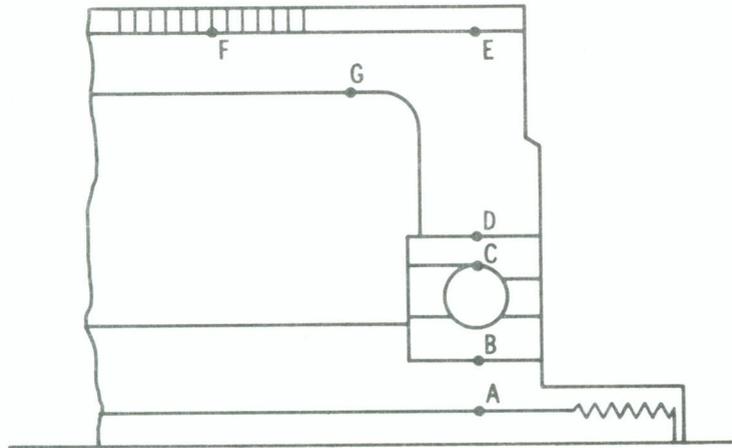
Also calculated was the axial force which would be induced in the shaft due to a change in temperature from room temperature to 180°F, and due to thermal mismatch between the S-200 beryllium shaft and the I-400 beryllium gimbal. To obtain the axial force, it was necessary to measure the compliance of the gimbal. Gimbal compliance was found to be 17.9 microinches per pound. Using a calculated compliance for the shaft of 0.394 microinches per pound, the induced axial force was found to be 4.83 lbs, which is negligible.

2.3 Isoelasticity of R-4 Wheel Assembly

Evaluation testing of the gyro included tests to determine the major and minor compliance terms for each gyro. Contract # NAS 9-3079 stated that "There will not be a specification on the magnitude of the compliance terms." However it was recognized that it would be desirable to select a contact angle which would result in an isoelastic wheel design.

Theoretical axial and radial compliance curves are shown in Fig. 8 and 9. These were calculated using a free contact angle of 30.2°. Figure 10 shows variation of axial-radial compliance difference with preload for $\beta_0 = 30.0, 30.2$ and 30.5°. Optimum theoretical elasticity is achieved using a free contact angle of 30.2°. It should be noted that the compliances include both bearing and shaft. Axial and radial compliances for the shaft are shown below:

$$C_{(\text{Axial shaft})} = 0.40 \mu\text{in/lb} \quad C_{(\text{Radial shaft})} = 0.54 \mu\text{in/lb}$$

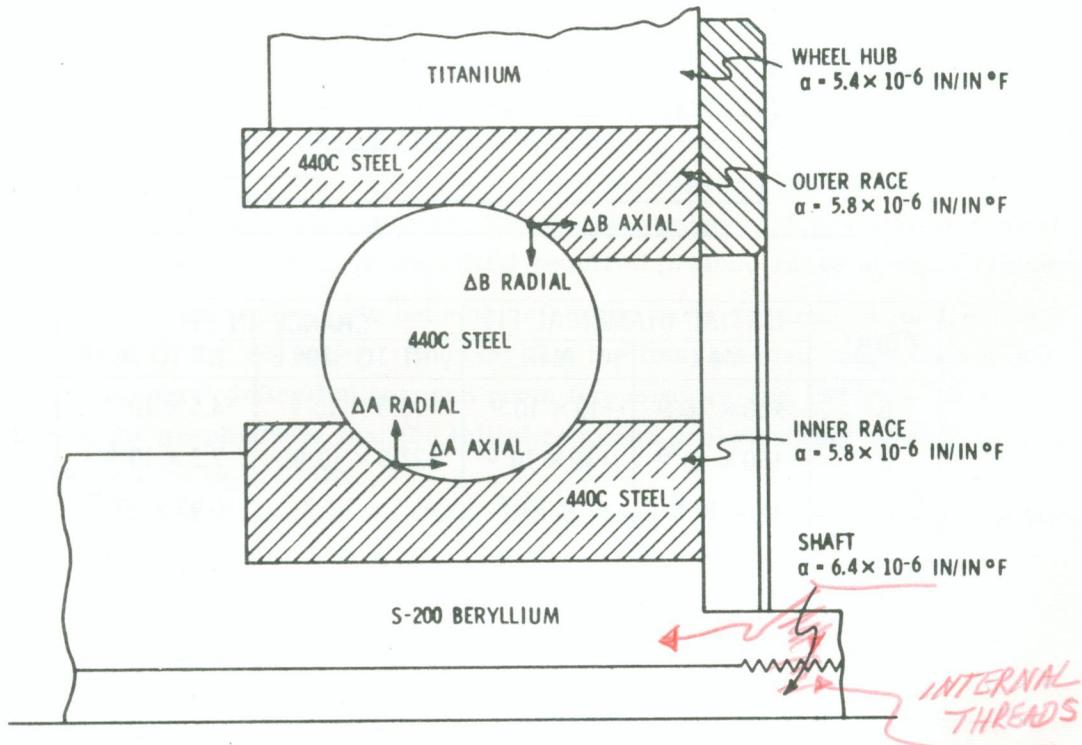


POINT	INITIAL DIAMETRAL FIT		CHANGE IN FIT	
	MAX	MIN	RT TO 180°F	RT TO 40°F
B	$+60 \times 10^{-6}$	-10×10^{-6}	$+16.5 \times 10^{-6}$	-4.5×10^{-6}
D	$+90 \times 10^{-6}$	$+10 \times 10^{-6}$	$+27.5 \times 10^{-6}$	-7.5×10^{-6}
E	$+6 \times 10^{-4}$	$+2 \times 10^{-4}$	$+3.5 \times 10^{-4}$	-0.95×10^{-4}
F	$+6 \times 10^{-4}$	$+2 \times 10^{-4}$	-1.1×10^{-4}	$+0.3 \times 10^{-4}$

(+) INTERFERENCE (-) CLEARANCE

PART	MATERIAL	α IN/IN/°F	MAX STRESS		
			PSI	POINT	TEMP °F
SHAFT	S-200 Be	6.4×10^{-6}	5,320	A	180
INNER RACE	440 C	5.8×10^{-6}	5,820	B	180
OUTER RACE	440 C	5.8×10^{-6}	1,610	C	180
HUB	T _i 13V-11CR-3AL	5.4×10^{-6}	9,450	G	180
INERTIA RIM	GYROMET	2.38×10^{-6}	30,500	E	180
HYSTERESIS RING	P-6 ALLOY	6.2×10^{-6}	10,900	F	40

Fig. 4 Interference fits and stresses in R-4 wheel.



$(\Delta A \text{ AXIAL} - \Delta B \text{ AXIAL}) = 27.3 \times 10^{-6}$ INCH
 $(\Delta A \text{ RADIAL} - \Delta B \text{ RADIAL}) = 9.7 \times 10^{-6}$ INCH

NOTE - BECAUSE OF ABOVE THERMAL BEARING DEFLECTIONS, INITIAL PRELOAD RANGE TO PRODUCE 5 TO 7 LBS AT 137 $^{\circ}$ F IS 1.92 TO 3.40 LBS AT R.T. (REFER TO FIGURES 6 AND 7)

Fig. 5 R-4 single bearing deflection due to increase in temperature from R. T. to 137 $^{\circ}$ F and corresponding increase in preload.

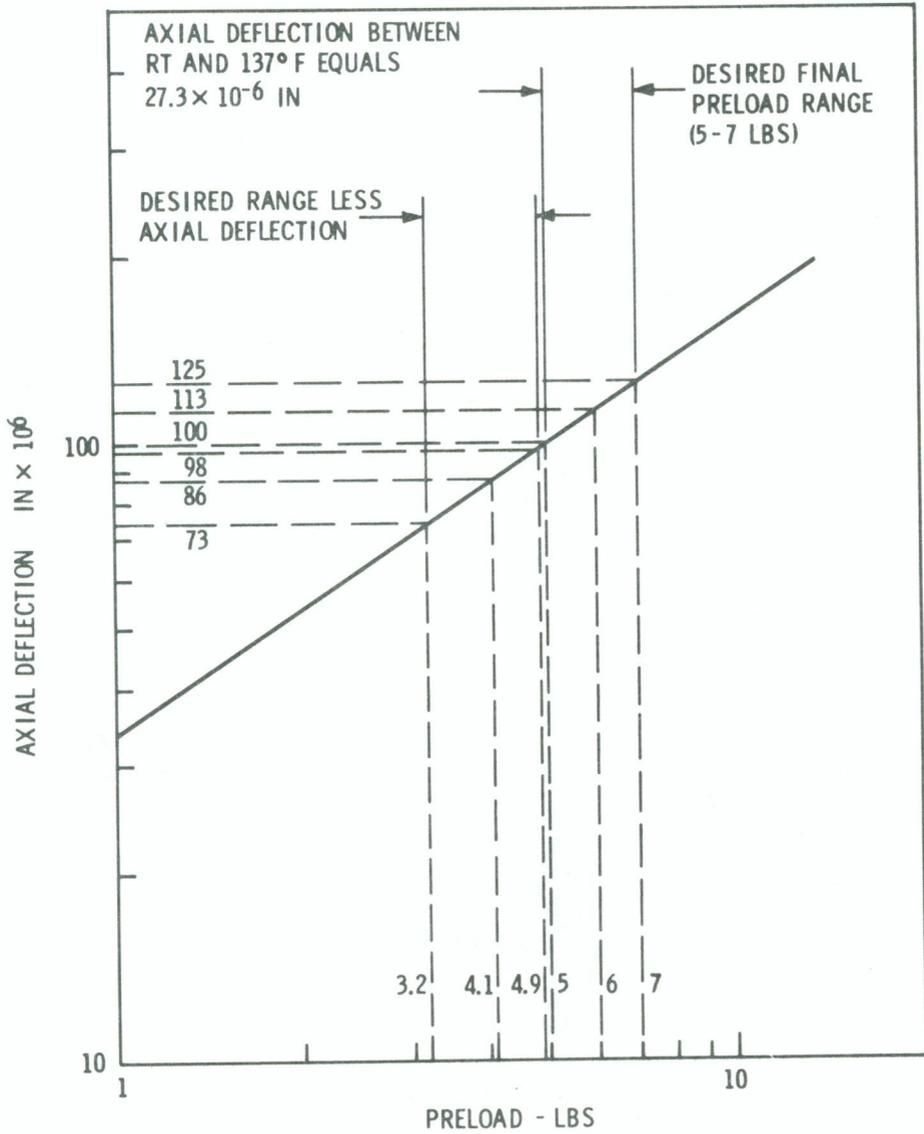


Fig. 6 Axial single bearing deflection vs preload, R-4 bearing.

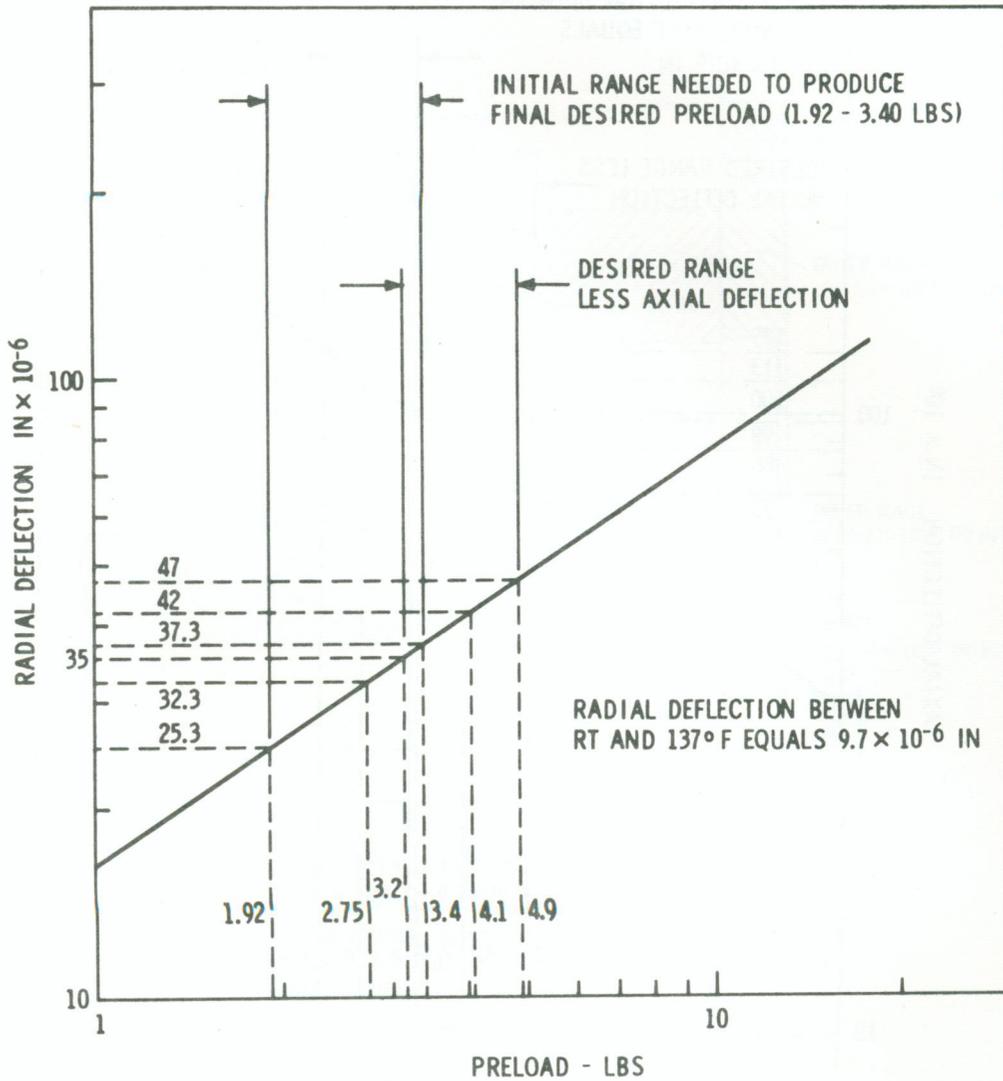


Fig. 7 Radial single bearing deflection vs preload, R-4 bearing.

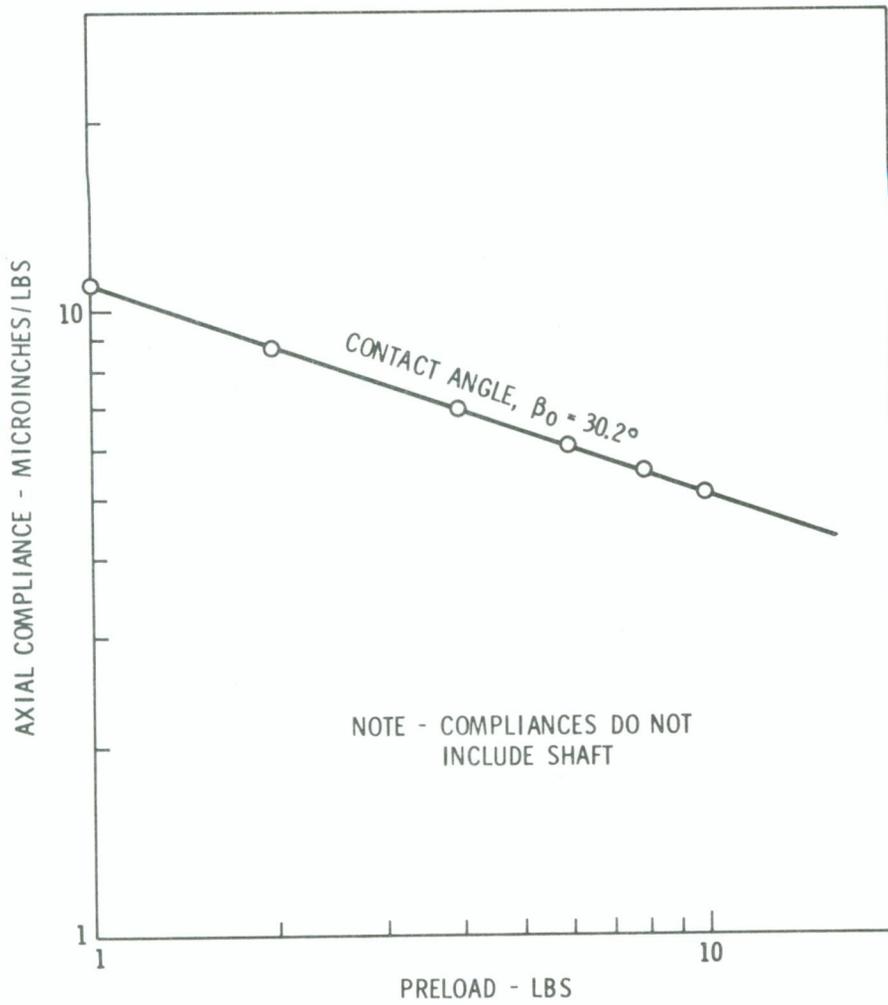


Fig. 8 R-4 bearing, Apollo I wheel, axial compliance vs preload.

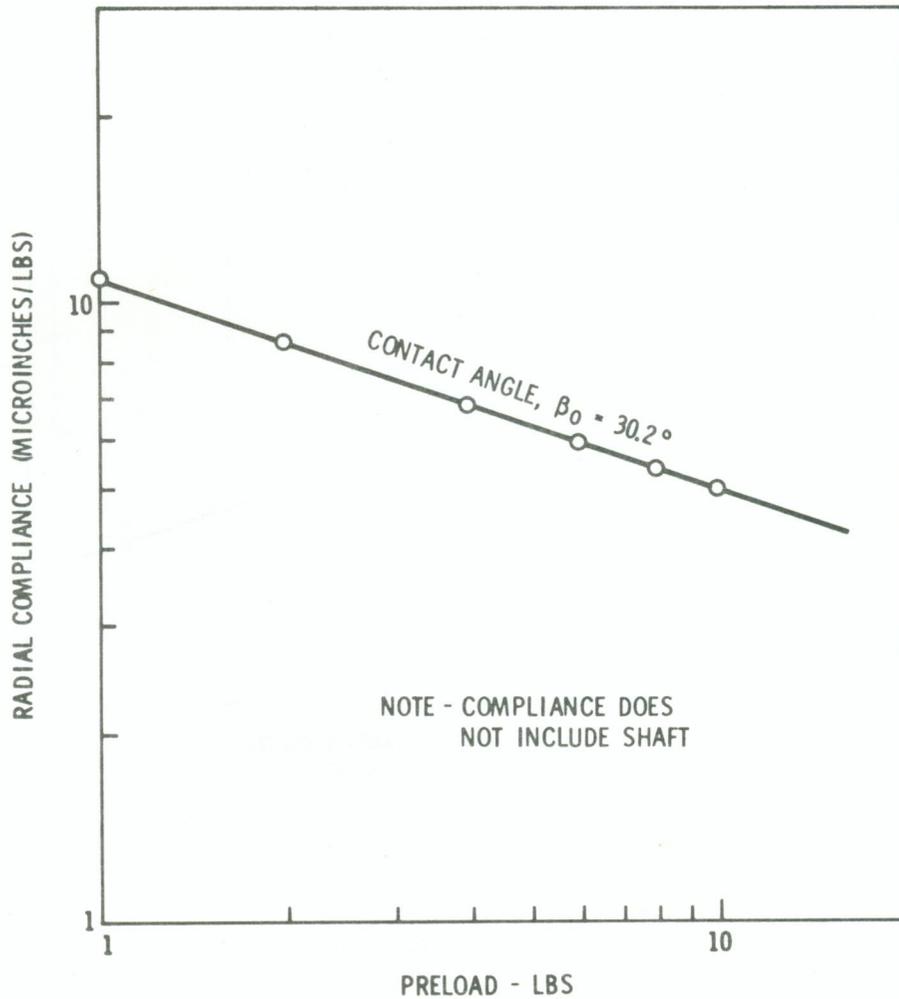


Fig. 9 R-4 bearing, Apollo I wheel, radial compliance vs preload.

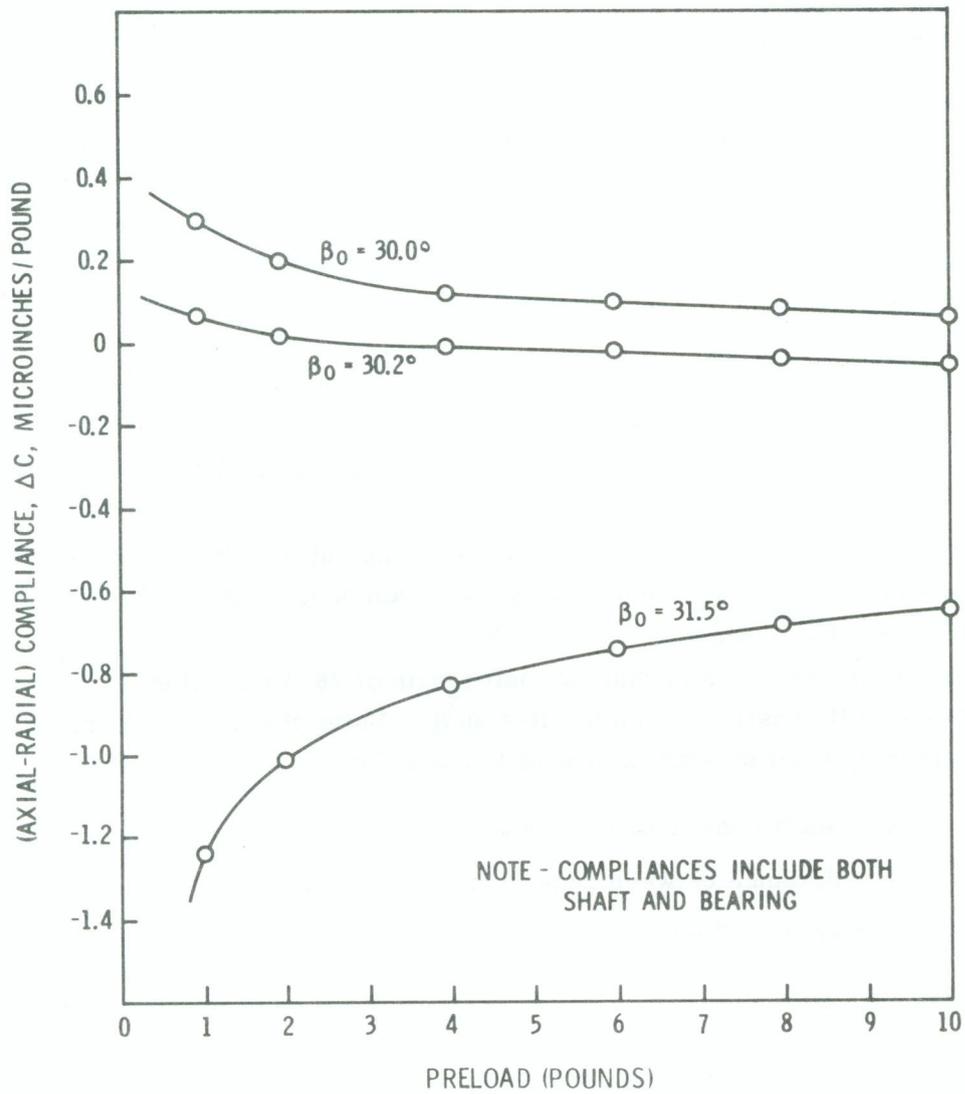


Fig. 10 Axial-radial compliance vs preload, R-4 bearing Apollo I wheel.

Float anisoelasticity was determined using a Vibrasonics VS-10 shaker to locate ball bearing resonant frequency. Figure 11 which is a graph of resonant frequency vs wheel compliance was used to obtain wheel compliance. Values for the five accepted wheels varied from 0.4 to 1.65 μ in/lb. (See Fig. 22).

It is to be noted that correlation between float anisoelasticity as determined on the VS-10 vibrator and during testing on the gyro level was not obtained. A discussion of this is included in Paragraph 4.2 below.

2.4 Closure Force Required for Float Assembly

The design of the Apollo I float requires the use of the wheel shaft to hold the float assembly together. Figure 12 shows the wheel assembled in the float. To assure a rigid and dimensionally stable float assembly, the shaft is stretched during assembly to obtain a 50 lb tensile force. In the float assembly the shaft performs two functions. It not only holds the float together but also imparts a portion of the preload to the bearings.

When the initial preload is set on the bearings during wheel assembly, the shaft is stretched to a tensile load of 50 lbs by the use of a special shaft stretch fixture (See Fig 13). Initially the preload of the bearings is partially dependent upon a spacer and the shaft stretch.

To determine the torque required by one of the nut adapters on the shaft stretch fixture, an R-4 shaft was instrumented with a strain gauge, and shaft strain vs torque was plotted. (See Fig. 14).

Calculations below show that, a shaft strain of 26.4 microinches/inch is equivalent to a 50 lb tensile load on the R-4 shaft. Using the curve in Fig. 14, torque required by shaft stretch fixture is 1.8 inch lbs.

$$C = \text{shaft compliance} = 0.4 \mu \text{ in/lb}$$

$$l = \text{distance between raceways} = 0.757 \text{ inch}$$

$$\delta = \text{shaft deflection, inches}$$

$$\epsilon = \frac{\delta}{l} = \text{shaft strain, microinches/inch}$$

To obtain a 50 lb tensile load, δ , shaft deflection is,

$$\delta = 50 C = 50 \times 0.4 = 20 \mu \text{ in.}$$

$$\epsilon = \frac{\delta}{l} = \frac{20}{0.757} = 26.4 \mu \text{ in/in}$$

From Fig. 14, corresponding torque required is 1.8 inch lbs.

A 50 lb tensile load will result in a 3,200 psi tensile stress in the shaft.

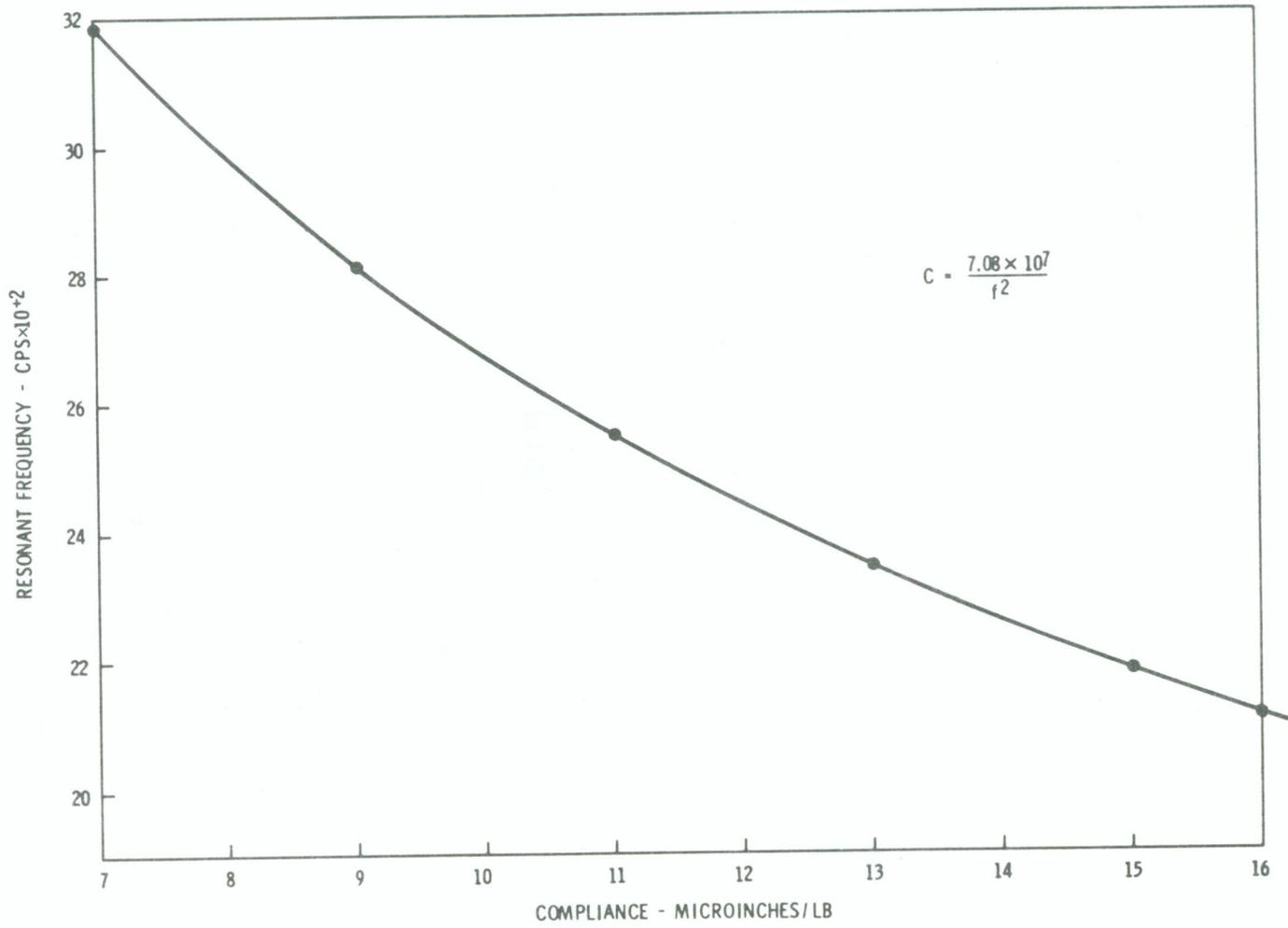


Fig. 11 Apollo R-4 wheel resonant frequency vs compliance.

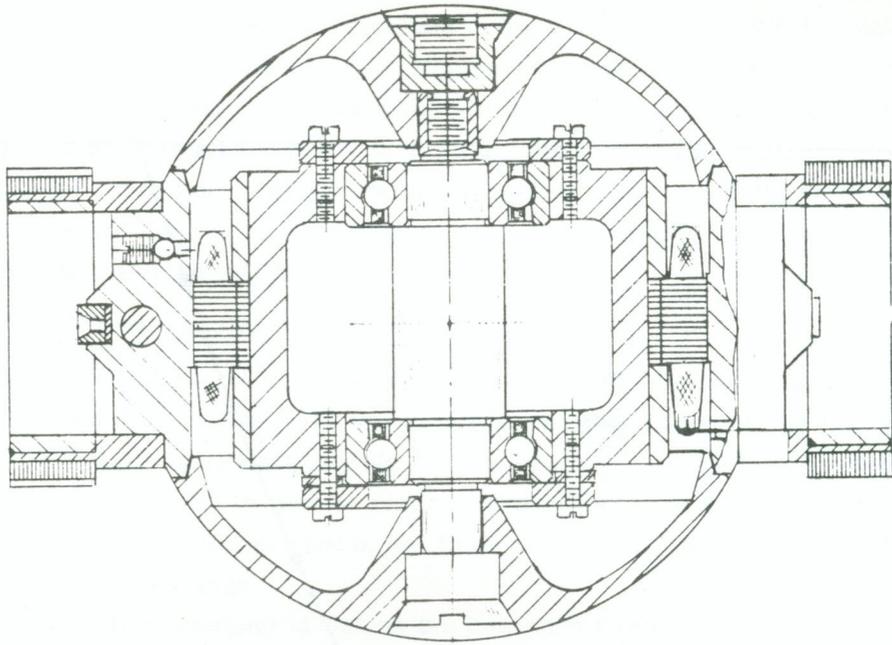


Fig. 12 Apollo I float assembly.

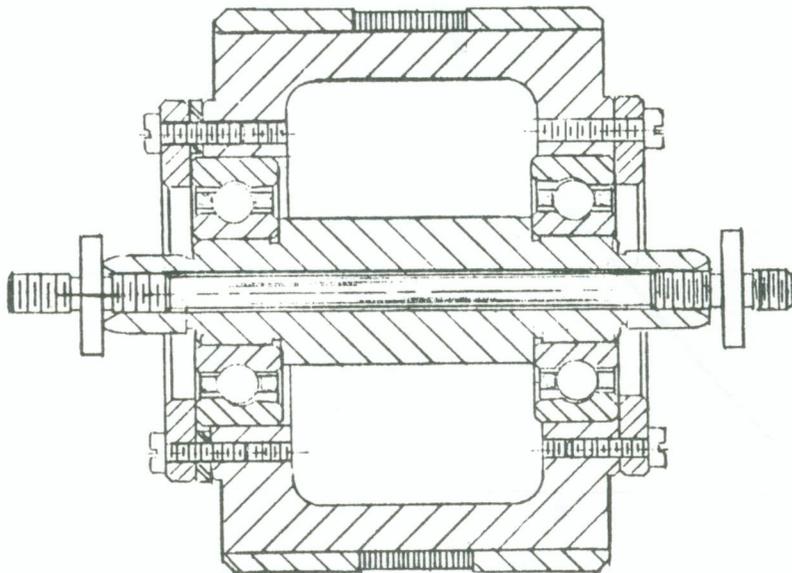


Fig. 13 Apollo I wheel assembled with shaft stretch fixture.

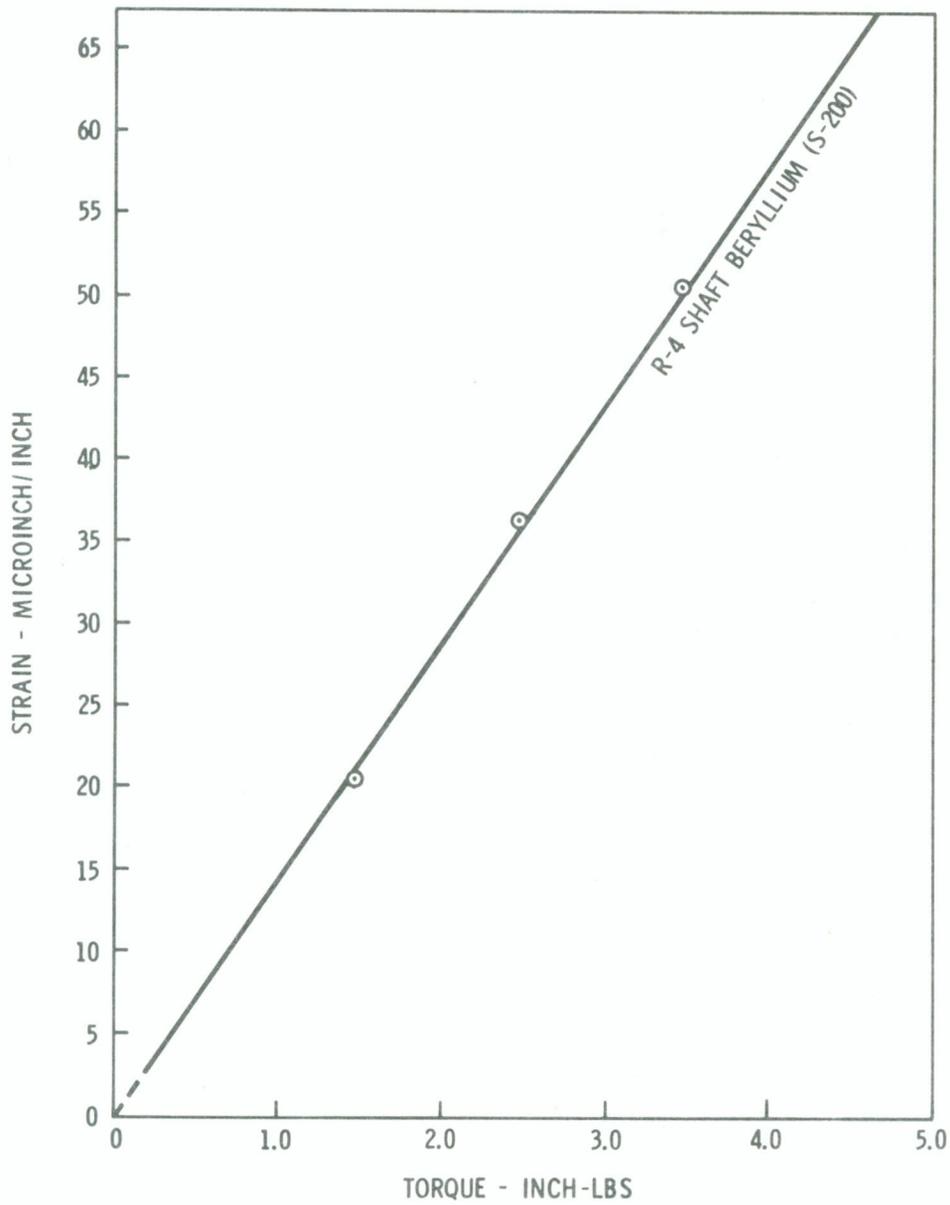


Fig. 14 Determination of elongation of R-4 beryllium (S-200) shaft at various torque levels.

Since the shaft was to be machined from S-200 beryllium, there was concern regarding the precision elastic limit of the beryllium. This problem was resolved by requesting the Brush Beryllium Co in Elmore, Ohio, to test three lots of S-200 beryllium for precision elastic limit. Results are shown below:

LOT NUMBER	PRECISION ELASTIC LIMIT (psi)
1	4,600 psi 5,600
2	2,300 2,600
3	1,800 2,600

Material from Lot #1 was used to machine shafts for this program; the precision elastic limit being higher than 3,200 psi.

2.5 R-4 Wheel Friction Torque at 24,000 RPM

Running torque of two R-4 wheels was calculated by timing the coast down from 24,000 RPM to 21,000 RPM. The speed of 21,000 RPM is determined by the appearance of the Lissajous pattern on an oscilloscope. Since the friction torque of ball bearing wheels is substantially constant over a small speed range, the method is a valid approach. However the assumption is also made that wheel deceleration is constant from 24,000 RPM to 21,000 RPM which is a close approximation. Total running torque is equal to the sum of windage and friction torque.

$$(1) \quad T_{TOTAL} = T_{WINDAGE} + T_{FRICTION}$$

Total torque is given by the following expression.

$$(2) \quad T_{TOTAL} = I \alpha$$

$$\text{Where } \alpha = \frac{d\omega}{dt} = \frac{\Delta\omega}{\Delta t} = \frac{\omega_o - \omega_i}{t_o - t_i}$$

$$I = \text{wheel moment of inertia} = 161.32 \text{ gram cm}^2$$

$$(3) \quad T_{TOTAL} = 161.32 \left(\frac{\omega_o - \omega_i}{t_o - t_i} \right)$$

A value of windage torque has previously been obtained from Apollo I wheels assembled with R-2 bearings and tested in dynamometers which measure and record running friction torque. The average windage so obtained is 1,900 dyne cm. Using this value Equation (1) becomes

$$161.32 \left(\frac{\omega_o - \omega_i}{t_o - t_i} \right) = 1,900 + T_{\text{FRICTION}}$$

$$(4) \quad T_{\text{FRICTION}} = 161.32 \left(\frac{\omega_o - \omega_i}{t_o - t_i} \right) - 1,900$$

where ω = angular velocity, rad/sec
 t = time in seconds

Friction torque of wheel number R-2A and number R-10 were measured using Eq (4). Results are compared below to Apollo I wheels assembled with R-2 bearings. It is to be noted that preload range at 137°F for R-2 bearings was 0.75 to 1.25 compared to 5 to 7 lbs for R-4 bearings.

FRICTION TORQUE AT 24,000 RPM

R-4 WHEELS	R-2 WHEELS
WHEEL #	DYNE-CM TORQUE RANGE
R-2A	500 to 1,500
R-10	4,500

2.6 Design of Motor Stator

Due to increased friction torque level of R-4 bearings, the design of the motor stator used for R-2 bearings was modified to increase its power capability. Friction and windage torque requirements of the Apollo wheel with R-4 bearings are than twice that with R-2 bearings. A comparison of drive motor data for R-2 and R-4 Apollo wheels is shown in Fig. 15.

P-6 alloy was used as hysteresis ring material on R-4 design instead of Simonds #73. The wheel was not operated over-excited, thus avoiding power drift changes. This is characteristic of a P-6 synchronous hysteresis motor operating in the over-excited mode, The R-4 motor stator was wound with less turns of a larger size aluminum wire. This resulted in an increase in nominal available power from 4.38 watts to 7.78 watts. The higher power requirement is a disadvantage in that this power is converted into heat in the center of the gyro and must be conducted to the outside case. The result, of course, is higher temperature gradients and the increased possibility of asymmetric temperature differences.

PARAMETER DESCRIPTION	R-2 APOLLO WHEEL	R-4 APOLLO WHEEL
VOLTS PER PHASE	28 VOLTS	28 VOLTS*
AMPERES PER PHASE	0.230 AMPS	0.224 AMPS*
TOTAL POWER (NOMINAL)	4.38 WATTS	7.78 WATTS*
FRICTION AND WINDAGE TORQUE	3000 D. C.	7200 D. C.
NUMBER OF POLES	4	4
NUMBER OF PHASES	2	2
FREQUENCY	800 CPS	800 CPS
NUMBER OF COILS PER POLE PER PHASE	3	3
URNS PER COIL	56	42
ALUMINUM WIRE SIZE	# 35 AWG	# 34 AWG
ANGULAR SPEED	24000 RPM	24000 RPM
HYSTERESIS RING MATERIAL	SIMONDS #73	P-6 ALLOY
STATOR LAMINATION MATERIAL	TRAN-COR T	TRAN-COR T
AIR GAP (RADIAL)	.004	.004

WHEEL POWER ANGLE

70°

51.7°

*MOTOR NOT OVER EXCITED.

Fig. 15 Synchronous hysteresis drive motor data.

$$P = VI \cos \theta$$

$$\cos \theta = \frac{P}{VI}$$

$$\theta = \cos^{-1} \left(\frac{P}{VI} \right)$$

SECTION 3

WHEEL ASSEMBLY AND EVALUATION

3.1 Assembly Procedure

The assembly of bearings to wheel was novel in that it was necessary to assemble both complete bearing assemblies in one operation. Wheel assembly consisted of three major steps. First, each bearing was prelubricated and assembled. Second, both bearing assemblies were assembled to the shaft. The last operation was to assemble the bearings and shaft as a cartridge assembly to the wheel hub.

In the assembly of the bearing sub-assemblies to the shaft, the fixture illustrated in Fig. 16 was used. Bearing assembly was placed on the fixture as shown. The fixture, with bearing assembly, was heated to 180^o F. This resulted in 0.0001" minimum clearance between I. D. of inner race and shaft O. D. Shaft was then assembled to bearing. Immediately after assembly, fixture with bearing and shaft was cooled on cold sink.

After removing shaft and bearing assembly from fixture, outer ring of the bearing was secured by assembling Parts 1, 2, 3, and 6, as illustrated in Fig. 17. Locking nut (Part 2) was tightened until it was just snug against stop ring (Part 3), to avoid excessive preloading of bearing.

With first bearing secured to shaft, second bearing was assembled using the same procedure and fixture shown in Fig. 16. The second bearing was then locked to shaft using tapered ring (Part 4), bottom guide (Part 5), locking nut (Part 2), and Part 7, which are shown in Fig. 17.

Bearing and shaft were then ready for assembly as a cartridge sub-assembly to the wheel hub. Referring to Fig. 17, procedure was to first place wheel hub on fixture (Part 8) and heat to 180^o F. Bearing cartridge was carefully positioned over hub and lowered firmly but gently into wheel hub bore until upper stop bottomed on the top of wheel hub. Wheel assembly was immediately removed from fixture and placed on cold sink to cool to room temperature. Fixture parts were removed. At this stage, the wheel assembly was ready for spacer selection and preloading procedure.

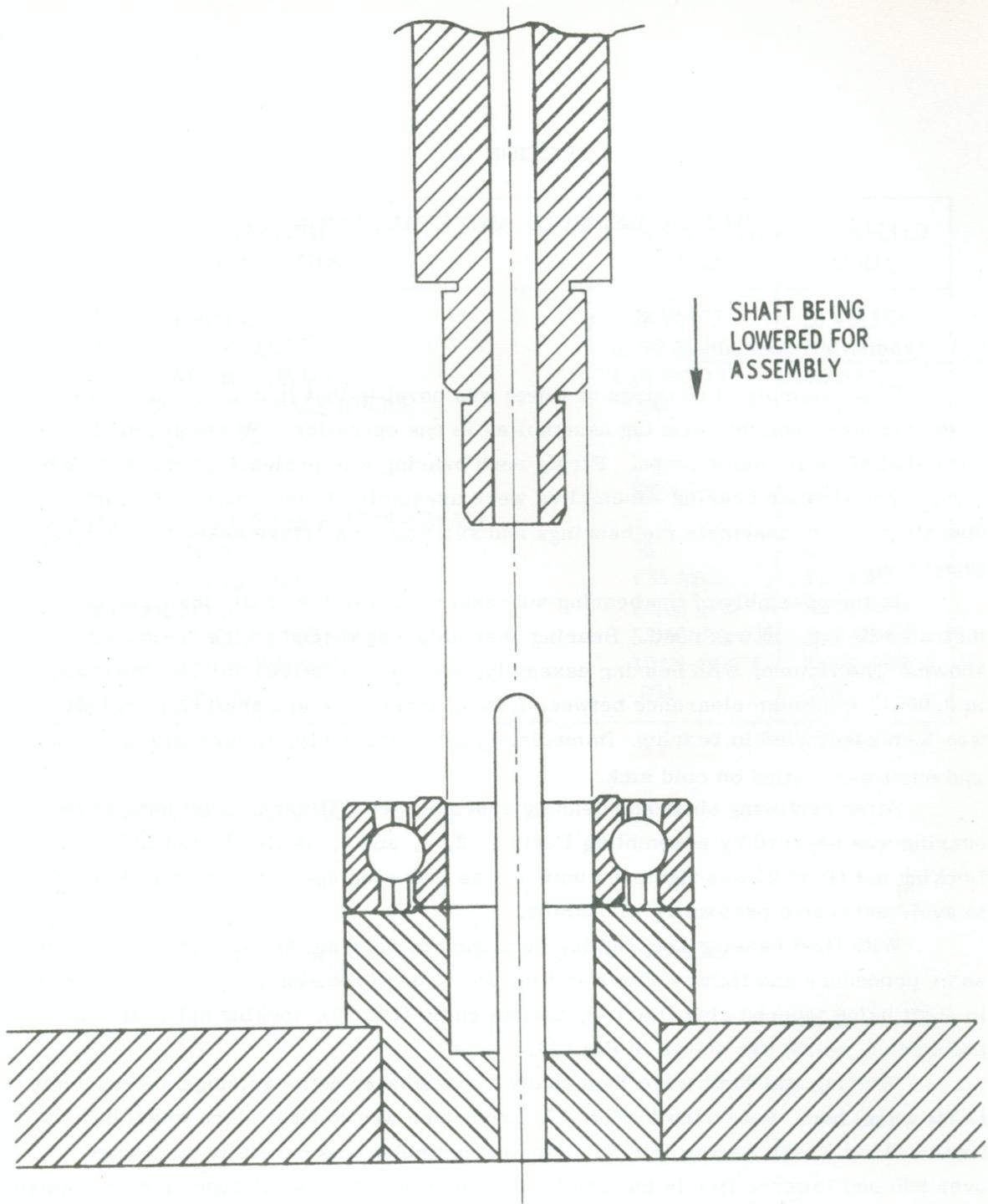


Fig. 16 Inner race assembly fixture.

3.2 Testing of Wheel Assembly

3.2.1 Retainer Stability Evaluation

Prior to evaluating the wheel using power monitoring and rundown time reporting as the critical parameters, retainer motion was observed to assure that the retainers were rotating in a stable mode. The wheel was assembled in a special milliwattmeter fixture which permitted visual observation of retainers during wheel operation. The wheel was operated in an ambient of one-half atmosphere helium at a temperature of 137° F. An American Optical binocular microscope was used with a stroboscopic light to observe retainers at 10X. Stability of motion was observed at 237 Hz when retainer appeared to stop and also with retainer slowly drifting. Severe erratic motion was cause for rejection.

During retainer evaluation, beat frequency was recorded using a crystal accelerometer (Columbia Accelerometer, Model #3025) mounted to milliwattmeter fixture base. Signal from accelerometer was fed into a cathode follower for amplification and then to a wave analyzer. Output of wave analyzer was recorded. In general visual observations of retainer stability were confirmed by beat frequency recordings. Figure 18 illustrates a stable and unstable beat frequency trace.

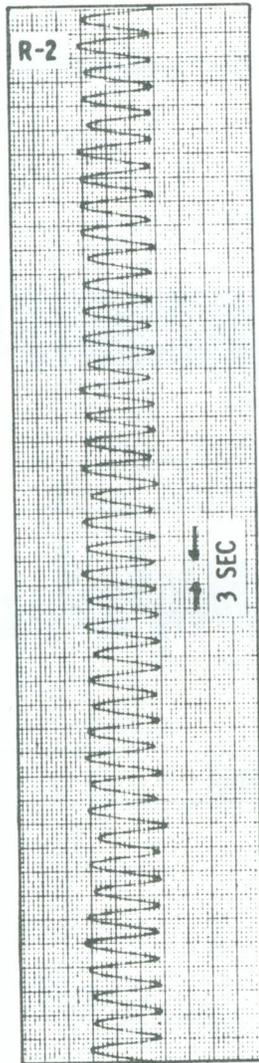
3.2.2 Evaluation of Wheel in Milliwattmeter Fixture

Wheel evaluation in the milliwattmeter fixture was made over a 200-hour qualification period using rundown time reporting and power monitoring as the critical parameters. The principal requirement for an acceptable wheel was performance during the power monitoring period that was stable and free of non-periodic or step power variations greater than 25 milliwatts. Oil jogs were considered to be acceptable. Rundown time results are discussed in Paragraph 3.2.4. Figure 19 shows sample traces of acceptable and non-acceptable milliwattmeter traces.

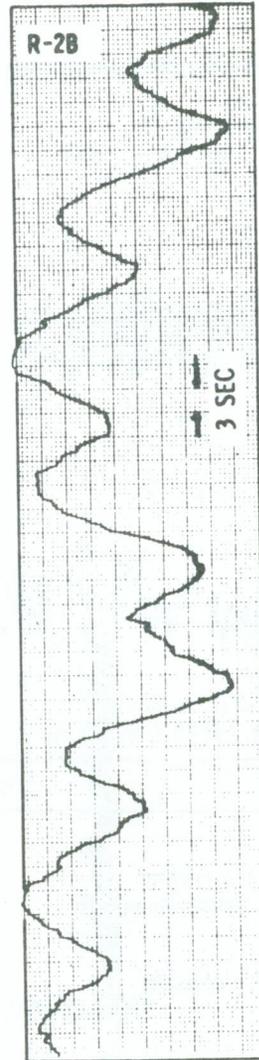
Retainer squeal was not acceptable and was a cause for wheel rejection. Retainer squeal occurs when the center of gravity of the retainer whirls about the inner race at a much higher angular rate than its solid body rotation.

The phenomenon can be caused when insufficient lubrication produces high frictional contact between retainer and race land on which the retainer is riding. The retainer then whirls at a high angular rate. There is a similarity to dry friction whirl which may occur with fluid film journal bearings. The motion is more complicated than in journal bearings since there is also an exchange of energy between the balls and the retainer.

Squeal incidence may be induced by reducing operating temperature, by lack of oil, and by relatively dry areas in retainer pockets. A large increase in bearing torque accompanies retainer squeal. This was particularly noted in the case of wheel #R-2, where the increase in bearing torque became excessive and caused the wheel to drop out of synchronism. Figure 20 shows milliwattmeter trace for wheel #R-4 which also exhibited retainer squeal.

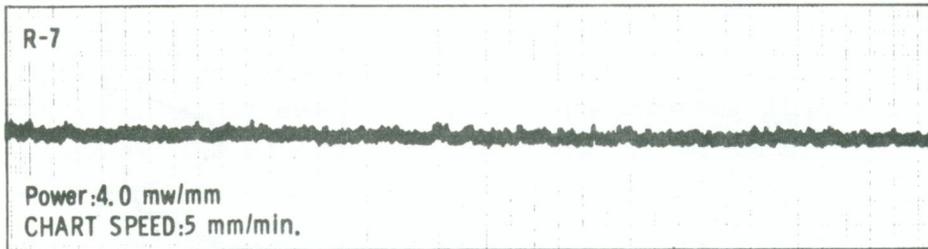


ACCEPTABLE

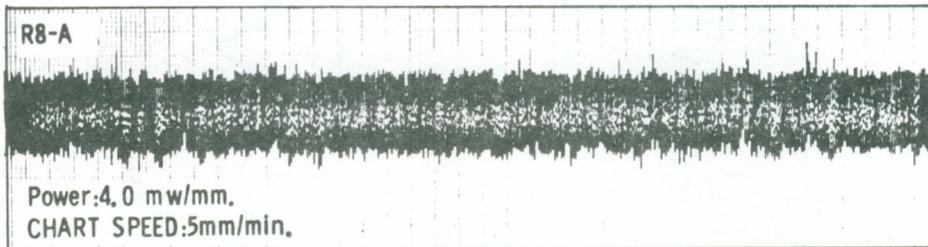


NON-ACCEPTABLE

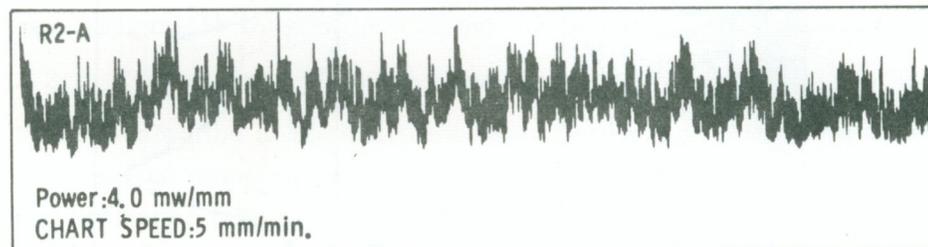
Fig. 18 R-4 retainer beat frequency traces (237 Hz).



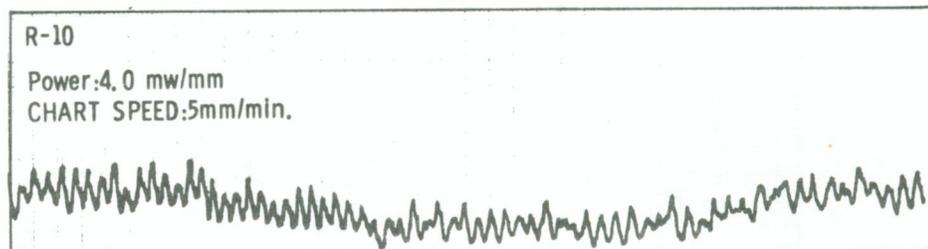
ACCEPTABLE TRACE



ACCEPTABLE TRACE



NON-ACCEPTABLE TRACE



NON-ACCEPTABLE TRACE

Fig. 19 Apollo I (R-4 bearings) differential milliwatt traces.

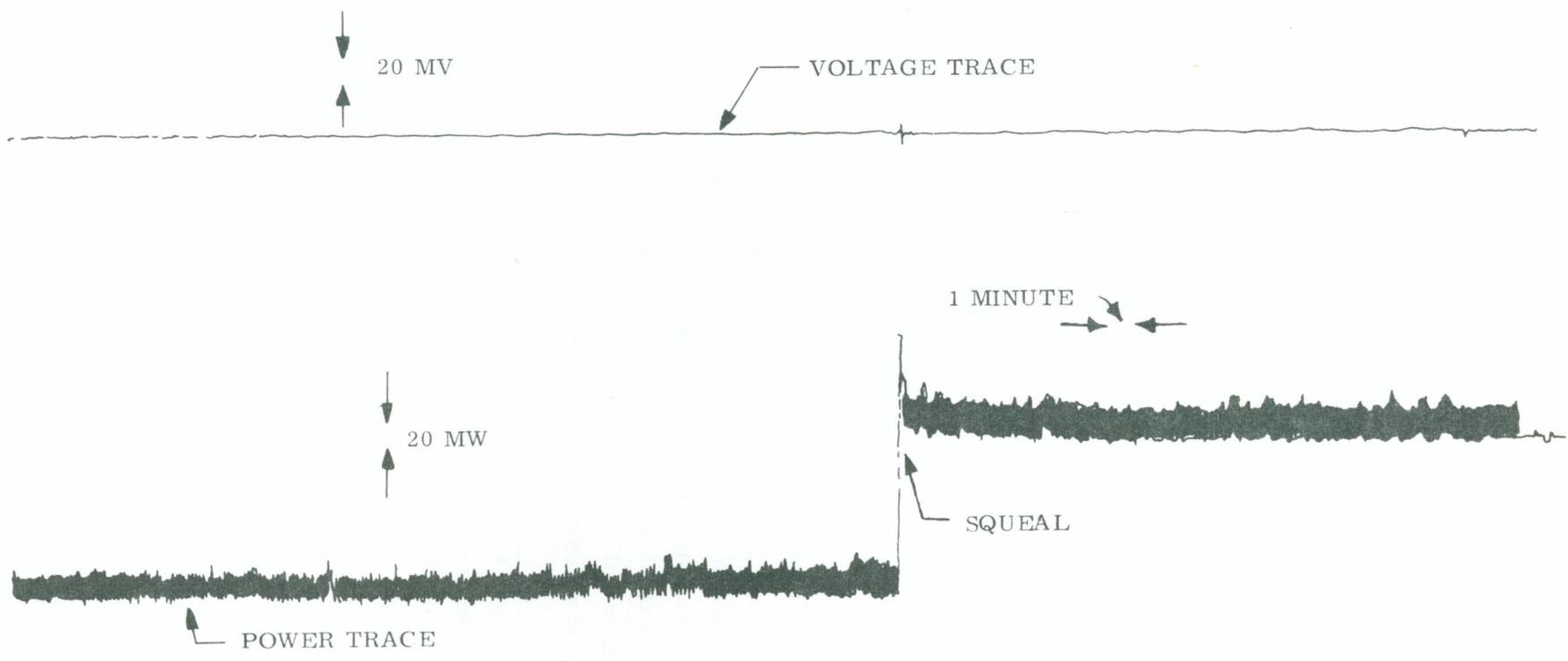


Fig. 20 Milliwattmeter trace, Float Unit 0610 (Wheel #R-4).

Before assembly of the wheel to the float, the bearings were visually examined for adequate oil lubrication and any evidence of contamination or incipient varnish build-up.

3.2.3 Evaluation of Wheel in Float

Wheel evaluation in the float was made over a 100-hour qualification period. The same criteria were used as for evaluation of wheel in milliwattmeter fixture. In addition, milliwattmeter and rundown time results in the float were compared with initial evaluation results in milliwattmeter fixture for any significant changes.

3.2.4 Discussion of Wheel Evaluation Results

Figure 21 contains a summary of wheel data for all of the wheels which were assembled and tested. There were a total of 14 wheels assembled. Six of these wheels successfully passed milliwattmeter evaluation and five were assembled into floats. There were a total of 8 wheels which failed. Four wheels failed retainer stability evaluation, and three wheels failed milliwattmeter evaluation. An additional wheel failed during dynamic balance because of retainer squeal. Failure analysis reports on all eight failures are included in Appendix A.

Wheel data in Fig. 22 were tabulated on accepted wheels primarily to compare wheel performance in milliwattmeter fixture to float. Small changes in beat frequency occurred between tests in milliwattmeter fixture and after float assembly with the exception of wheel #R-3. This wheel had an exceptionally long beat period of 47 seconds in milliwattmeter fixture. It also had the largest variation in beat period after float assembly. In all other testing, performance of wheel #R-3 was acceptable.

The stability and hash width of the power trace did not change after float assembly. If the wheel performance was good on initial evaluation in the milliwattmeter fixture, it did not deteriorate during float testing. There was good correlation between rundown times in milliwattmeter fixture and float. This is an indication that preload as adjusted by stretching shaft of wheel in float on Vibrasonics VS-10 vibrator is very close to initial wheel preload. The RMS of all wheel rundown times ranged from 0.99 to 5.12 seconds. This is greater than what is usually obtained with the R-2 bearing using V-78 oil. The RMS for the Apollo II wheel in float is less than 4 seconds. The difference can be attributed to the fact that the R-4 bearing is larger and has a much greater running friction level. This would contribute to more variation in rundown times.

Figure 23 is a flow chart showing percentage realization of wheel assembly builds through major wheel evaluation points. Overall process yield was 43%; retainer yield, 60%; and hardware yield, 54.5%. Comparing these yields to other past ball bearing programs, this performance is good. The major factor contributing to wheel failure was retainer instability.

WHEEL#	Bearing Material	Running Time, Hours		Beat Period, Sec.		Power Trace Width, MW		R. T. Pre-load	Float Anisoelast	Comments
		MW Meter Fixture	Float and Gyro	Wheel MW Meter Fixture	Float	Wheel MW Meter Fixture	Float		Microinches Per Pound	
R-1	Combo K	412	2054	4.8-5.8	8.9	18-40	20	3#	+0.75	Assembled in Gyro Unit # 0610
R-2	L	405	0	3.3	—	28-52	—	4	—	Rejected . Badly squealing
R-3	K	261	993	47	8.1-19.5	8	8-32	3.2	+0.4	Assembled in Gyro Unit # 0611
R-5	L	593	0	4.8-6.9	—	12-24	—	2.8	—	One retainer radially unstable
R-6	L —	242	0	7.0	—	8(Before float assembly) 84(After float disassembly)		2.4	—	Bearings overloaded during float disassembly
R-7	K	242	1254	3.9-4.2	3.7-4.0	8-20	12	2.4	+0.95	Assembled in Gyro Unit # 0612
R-8	K	2	0	7.8	—	92	—	3.3	—	Failed excessive MW trace width
R-9	L	—	0	Unstable 4.3-12.4	—	—	—	3.1	—	Retainers squealed during dynamic balance
R-2A	K	190	0	Unstable 4.3-12.4	—	20-64	—	3.15	—	Irregular MW trace failed
R-10	K	140	0	Very Unstable	—	15-84	—	3.0	—	Failed, irregular MW trace excessive trace
R-9A	L (Ball lapped)	509	1854	3.3	4.0-4.5	32-40	16-40	2.6	+1.50	Assembled in gyro Unit #0613
R-10A	K (Ball lapped)	42	0	4.7	—	40 (35 MW step changes)		2.4	—	Failed. Erratic retainer
R-2B	K	20	—	—	—	40	—	2.9	—	Failed. Retainer squealed
R-8A	L	292	895	—	4.5	50	40	2.6	1.65	Assembled in Gyro Unit #0614

Fig. 21 Summary of Apollo I R-4 wheel data.

GYRO #	WHEEL #	R. T. PRELOAD (lbs)	FLOAT ANISOELASTICITY (MICROINCHES PER POUND)	BEAT PERIOD (sec) AT 237 HZ		POWER TRACE WIDTH (MW)		AVE. R. D. T (sec)		R. M. S. (σ_F) (sec)	
				M. W. Fixture	Float	M. W. Fixture	Float	M. W. Fixture	Float	M. W. Fixture	Float
0610	R-4	3	0.75	4.8-5.8	8.9	18-40	20	81.7	72.4	2.63	5.08
0611	R-3	3.2	0.40	47	8.1 19.5	8	8-32	82.0	71.5	4.45	1.46
0612	R-7	2.4	0.95	3.9-4.2	3.7-4.0	8-20	12	77.3	64.9	2.66	1.24
0613	R-9A	2.6	1.50	3.3	4.0-4.5	32-40	16-40	74.8	84.5	5.12	0.99
0614	R-8A	2.6	1.65		4.5	50	40	64.3	68.8	4.52	4.7

Fig. 22 Summary of R-4 wheel and gyro float data.

BEARING CONFIGURATION - APOLLO I R-4 PROGRAM

$$\text{RETAINER YIELD} = \frac{\text{PAYROLL}}{\text{PAYROLL} + \text{SCRAP}} = \frac{12}{12 + 8} = 60\%$$

$$\text{PROCESS YIELD} = 43\% \quad \text{HARDWARE YIELD} = \frac{6}{6 + 5} = 54.5\%$$

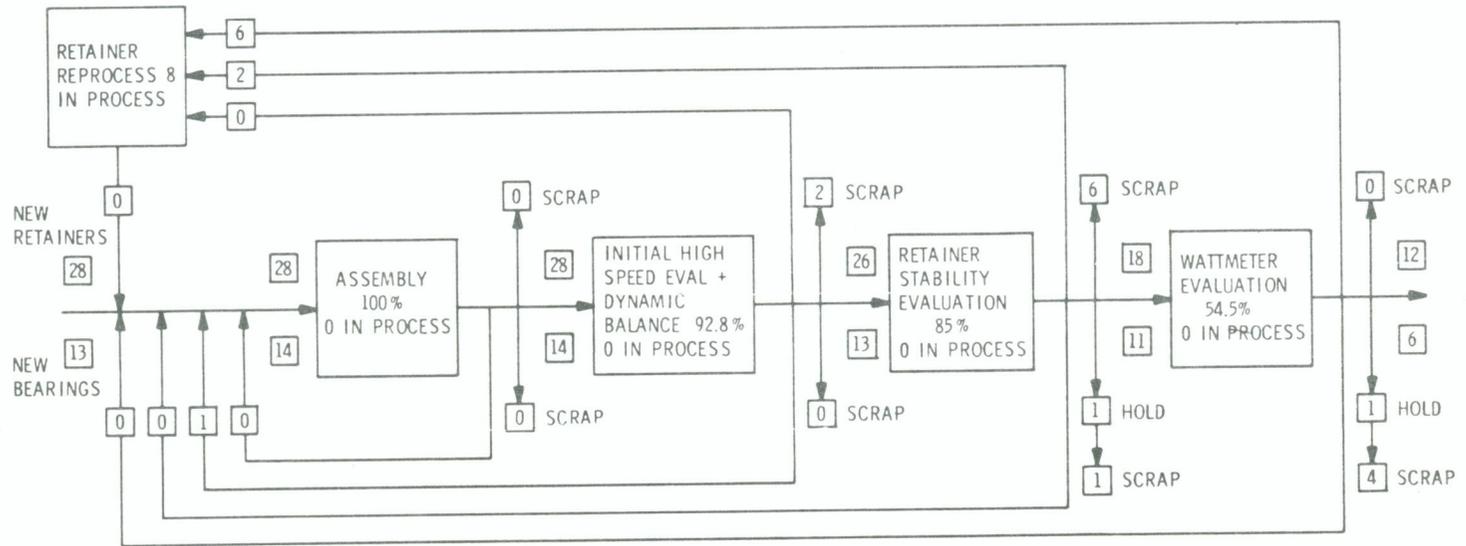


Fig. 23 Status report, Apollo ball bearing wheels.

SECTION 4

GYRO EVALUATION TEST PROGRAM

4.1 Description of Test Program

Testing was performed in accordance with the Schedule of R-348 Rev B, with no performance criteria. Extended testing was in the form of long term IA vertical tests. The major and minor compliance terms for each gyro were determined from four point tumbling tests. There was no specification on the magnitude of the compliance terms. One gyro (#0612) was submitted to a 15 g vibration test per the schedule of PS2021500.

4.2 Gyro Performance Results

4.2.1 Test Summary by Gyro Serial Number

Figures 24 through 29 contain summary information on all gyro performance parameters. Appendix B contains a reproduction of the computer printout of all gyro data from component and system tests. Outlined below are pertinent comments relative to the performance of each gyro.

Gyro #0610

(Test Period 9-29-67 to 1-3-68)

The gyro was received in test at the shrouded level of assembly. The initial ADSRA unbalance was (\sim) 290 meru - equivalent to eight (8) dy-cm. This unbalance was four times greater than anticipated on the basis of a measurement resolution of two (2) dy-cm obtained during flotation tank work. Subsequent tests indicated this problem to exist in some of the other R-4 bearing gyros tested. Calculations showed that, with a diametral clearance of 0.007 between I. D. of retainer and inner race land diameter, a maximum of 5.4 dy-cm unbalance could be contributed by both retainers.

From the float compliance test: $(K_{SS} - K_{II}) = 23 \text{ meru/g}^2$ and $K_{IO} = -28 \text{ meru/g}^2$.

During wheel power monitoring occasional step changes in wheel power were noted. These power changes, which were not present during initial wheel evaluation, occurred in a random fashion and varied in magnitude between 25 mw and 75 mw. No effect upon the gyro drift rate resulting from these power shifts was noted. Across

two cooldowns the mass unbalance shifts were < 1 meru.

Gyro #0611

(Test Period 12-14-67 to 2-16-68)

The gyro was received in test at the shrouded level of assembly. The initial ADSRA unbalance of 670 meru (19 dy-cm) exceeded the adjustment range (± 12.5 dy-cm) of the accessible balance capsule on the positive input axis. The shroud was removed to expose the (-) IA Capsule, and the gyro was then balanced. In view of the apparent uncertainty in tank work resulting from bearing retainer slop, it was decided that future gyros would be tested unshrouded thus making the four balance ports available if needed.

Moderate ADSRA shifts were noted across cooldowns; the largest being a Δ ADSRA = 6.3 meru.

Gyro #0612

(Test Period 1-25-68 to 3-27-68)

Gyro Unit #0612 was the first of the R-4 bearing gyros to undergo vibration. The vibration performance was in accordance with the schedule of PS2021500 with the following sequence:

- (a) 100 - 400 Hz @ 15 g's Peak
- (b) 400 - 2,000 Hz @ 3 1/2 g's Peak

Mass shifts resulting from vibration were equivalent to:

$$\Delta \text{ ADSRA} = + 7 \text{ meru}$$

$$\Delta \text{ ADIA} = + 9 \text{ meru}$$

During a final series of eight acceptance tests the performance parameters were stable within the following bandwidths:

$$\text{BD} = 4.5 \text{ meru}$$

$$\text{ADSRA} = 0.7 \text{ meru}$$

$$\text{ADIA} = 2.3 \text{ meru}$$

The $(K_{ss} - K_{ii})$ term was measured at 9 meru/g^2 and the K_{IO} at 2.4 meru/g^2 .

Gyro #0613

(Test Period 6-3-68 to 8-20-68)

The gyro was received in the test area unshrouded and showed excellent stability on all performance parameters during the initial servo testing. Following shrouding a pronounced degradation in performance, and uncertainties of 20 - 30 meru were recorded.

Eventually the gyro was deshrouded and the pin connectors were removed, revealing a thin sliver of solder between two of the gyro terminal pins (T.G. susp. leg 6-7 and the T (-) end of the torquer winding).

After removing the solder particle an additional series of twenty-one (21) acceptance tests were completed during which the bias and AD terms were stable within.

$$\Delta BD = 4 \text{ meru}$$

$$\Delta ADSRA = 3.8 \text{ meru}$$

$$\Delta ADIA = 2.1 \text{ meru}$$

Gyro #0614

(Test Period 12-17-68 to 3-14-69)

Gyro 0614 was initially unstable in the SRA up and SRA down positions. Level shifts between 20 - 30 meru were noted. In addition there was an ADIA ramp of approximately 0.2 meru/hr during 500 hours of testing. Subsequently the ramping effect disappeared, and the gyro showed greatly improved stability during IA horizontal testing.

Across a final series of six (6) acceptance tests the gyro's performance parameters were stable within the following bandwidths:

$$BD = 1.7 \text{ meru}$$

$$ADSRA = 2.0 \text{ meru}$$

$$ADIA = 1.9 \text{ meru}$$

The requirements for float compliance and vibration tests on gyro #0614 were waived per agreement with Mr. M. Jones on January 5, 1969.

4.2.2 Cooldown Sensitivity

All five gyros exhibited good stability across cooldowns to room temperature. A total of twenty (20) cooldowns were accomplished during the program - an average of four cooldowns per gyro. The maximum mass unbalance shifts occurred on gyro #0613 across cooldown #4 and was equivalent to:

$$\Delta\text{ADSRA} = -9 \text{ meru}$$

$$\Delta\text{ADIA} = +8 \text{ meru}$$

Figure 27 lists the mass unbalance shifts across cooldowns for each gyro and includes average and standard deviation of the shifts for the 5 gyros as a family.

4.2.3 Temperature Sensitivity

Figure 28 indicates the temperature sensitivity for the individual gyros. Note that with the exception of #0613 ($\text{ADSRA} = -2.2 \text{ meru}/^{\circ}\text{F}$) all gyros exhibit an unusually low sensitivity to temperature change.

4.2.4 Compliance Measurements

Compliances were obtained from a four point tumbling test in which the gyro O.A. was aligned parallel to E.A. and the input axis indexed through 90° increments. The results are compiled in Fig. 29. The presence of high anisoelastic terms is not completely understood. Results of VS-IO vibration tests (see Fig. A-22) show values within specification limits. Difference in results between gyro tumbling and VS-IO tests indicates that compliance measurements may be frequency sensitive. A discussion of this is included in MIT Report E-2417, entitled Gyro Compliance, by F.E. Cartwood, D.S. Nokes, and P.J. Palmer.

4.2.5 Retainer Beat Frequency and Gyro Drift Rates

For a wheel speed of 24,000 RPM the R-4 bearing retainer frequency is 237 Hz. Figure 33 shows the presence of this retainer frequency on the S. G. secondary output voltage. It appears as a 237 Hz sideband on the 3,200 Hz carrier frequency.

The test was performed using the S.G. secondary voltage as the input to a H.P. frequency analyzer. The analyzer was tuned to 3437 Hz (the upper 237 Hz sideband) and the indicated output voltage was recorded on Fig. 33. Note that this sideband voltage is modulated at the retainer beat frequency of ≈ 0.2 cycles/second.

Additional tests were run to determine:

- (a) Effect of gyro temperature upon retainer beat frequency.
- (b) If correlation exists between retainer beat frequency and gyro drift rate.

The tests, which were of the three position servo type, were performed at two temperatures. During the test, the retainer-beat frequency was continuously monitored.

Figures 30, 31, and 32 show the gyro drift and the measured-beat frequency for each of the three servo test positions. Only Fig. 31 shows the effect of temperature. The results of the above tests are not conclusive. The limited number of tests run do not show any consistent relationship between the retainer-beat frequency and gyro temperature or gyro drift rates.

4.2.6 Wheel Power

Differential wattmeter power traces for gyros #0610, 0613 and 0614 are shown on Fig. 34, 35, and 36, respectively. Figures 35 and 36 are typical of power measurements performed on gyros under this program.

Figure 34 illustrates a step change in wheel power seen occasionally on gyro #0610. No apparent effect upon the gyro drift rates was noted from these power shifts.

4.2.7 Gyro Performance vs Wheel Excitation Voltage

The effect of wheel voltage upon the gyro drift parameter was measured by varying the wheel voltage between the limits of 24 to 28 volts in 2-volt increments. At each voltage setting three-position servo tests were run to determine the magnitude of the bias and AD terms.

The wheel voltage appears to have a negligible effect upon the gravity sensitive terms. The slope of the bias term is -1.5 meru per volt for increasing wheel voltage. Refer to Fig. 37.

R-4 BEARING EVALUATION
PERFORMANCE PARAMETERS

Parameter	GYRO NUMBER							
	0610	0610	0611	0612	0612	0613	0614	0614
NBD-AVERAGE	-16	-15	2.9	-22.1	-23.1	4.8	-4.1	-4.4
DNBD	0.76	0.07	0.95	1.1	1.4	0.88	0.12	0.59
ADSRA-AVERAGE	9.9	4.7	-9.1	-2.6	5.5	7.0	2.7	13.7
DADSRA	1.6	0.07	2.2	8.1	0.23	0.48	0.22	0.75
ADIA-AVERAGE	9.6	26	-14.2	-18.4	-11.7	-27.6	-4.6	-7.95
DADIA	2.1	0.3	1.6	2.0	0.98	1.2	0.64	0.62

AFTER
PORT SEAL

BEFORE
VIBRATION

AFTER
VIBRATION

BEFORE
SHROUDING

AFTER
SHROUDING

Note: Where an appreciable mass shift occurred across vibration or shrouding the gyro performance is given before and after the operation.

Fig. 24

R-4 BEARING EVALUATION
FOURIER COEFFICIENTS - IA VERTICAL DRIFT RUNS

Gyro #	Run #	A_0	$A_1(\cos \theta)$	$B_1(\sin \theta)$	$A_2(\cos 2\theta)$	$B_2(\sin 2\theta)$	Rms: Residuals
0610	1	-3.61	-0.50	0.73	0.46	1.31	0.64
	2	-3.50	-0.59	0.22	0.11	1.35	0.57
	3	-3.30	-0.17	-0.28	0.43	1.00	1.56
0611	1	-4.56	1.04	1.0	0.33	-0.01	0.87
	2	-7.26	1.33	0.7	0.15	-0.55	0.67
0612	1	-26.7	-0.29	-1.23	-0.25	+0.17	0.58
0613	1	2.37	0.28	0.72	-0.04	0.55	0.44
	2	0.52	-0.17	0.40	0.00	0.32	0.32

All values are in meru.

where:

- θ = Table angle
- A_0 = Effect of bias and ADIA unbalance in meru
- A_1 } Effect of misalignment of gyro input axis to table axis -
- A_2 } peak value in meru.
- A_2 } Second harmonic terms - primarily measure
- B_2 } the drift rate resulting from compliance mismatch along the gyro principal axes.

Fig. 25

R-4 BEARING EVALUATION

GYRO STABILITY ACROSS SHROUDING AND PORT SEAL

GYRO NUMBER	Mass Unbalance Shifts in Meru			
	Across Shrouding		Across Port Seal	
	Δ ADSRA	Δ ADIA	Δ ADSRA	Δ ADIA
0610	--	--	-6	13
0611	3	1	-15	5
0612	0.5	-1	--	--
0613	1	0	0	-2
0614	11	-3	--	--

Gyro #0610 was received in test at the shrouded level.
 Gyros #0612 and #0614 were shrouded and port
 sealed in one operation.

Fig. 26

R-4 BEARING EVALUATION
GYRO COOLDOWN SENSITIVITY
MASS UNBALANCE SHIFTS IN MERU

	CD#1		CD#2		CD#3		CD#4		CD#5	
	Δ ADSRA	Δ ADIA								
0610	0.5	-0.6	0.4	0.7						
0611	3.0	1.1	6.3	0.9	3.1	-0.1	3.0	2.7	3.0	5.0
0612	-0.6	-0.7	-8.4	4.9	7.6	-8.0	1.0	1.0	-5.0	-4.0
0613	0.2	-0.4	0.0	0.3	1.0	-3.1	-9	8.0	-	-
0614	-1.9	1.6	2.5	-1.4	0.8	-1.0	-4	0.7	-	-

51

Δ ADSRA

Number of Values = 20
Arithmetic Mean = .175
Standard Deviation = 4.11

Δ ADIA

Number of Values = 20
Arithmetic Mean = .38
Standard Deviation = 3.29

Fig. 27

R-4 BEARING EVALUATION
FUNCTIONAL PARAMETERS

		TEMPERATURE SENSITIVITY		TRANSFER FUNCTION	TOTAL WHEEL POWER @28 VOLTS	WHEEL HOURS	AVERAGE WHEEL RUN DOWN TIMES" 24,000 6,000 RPM
GYRO NUMBER	FLOATATION TEMP °F	Meru/ °F		MV/M RAD.	WATTS	IN TEST	IN SECONDS
		ADSRA	ADIA				
0610	132.3	0.33	+0.35	13.4	7.8	1799	67
0611	132.5	0.14	0.6	11.67	7.66	816	67
0612	132.4	0.02	1.1	11.35	7.97	1154	68
0613	133.4	0.1	0.38	10.4	6.6	1716	71
0614	136.2	2.2	0.7	12.3	7.6	1233	62

TEMPERATURE SENSITIVITY	
ADSRA	
NUMBER OF VALUES	■ 5
ARITHMETIC MEAN	■ .51
STANDARD DEVIATION	■ .85
ADIA	
NUMBER OF VALUES	■ 5
ARITHMETIC MEAN	■ .094
STANDARD DEVIATION	■ .67

Fig. 28

R-4 BEARING EVALUATION

COMPLIANCE MEASUREMENT - FLOAT PACKAGE

GYRO NUMBER		#0610	#0611	#0612	#0613
$(K_{SS} - K_{II})$	Meru/g ²	23.	5.	9.	4.1
K_{IO}	Meru/g ²	-28.	-0.1	2.4	-

Fig. 29

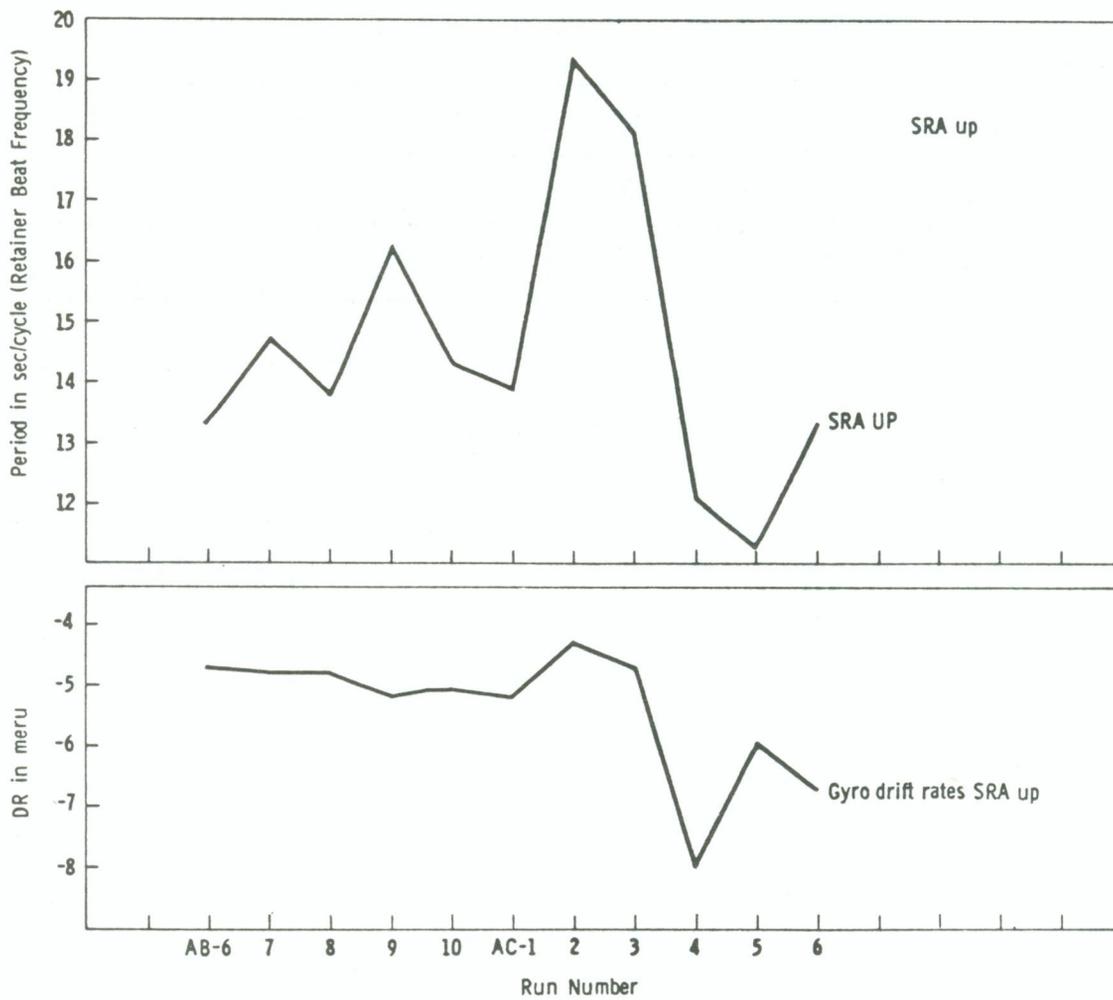


Fig. 30 Apollo I R-4 gyro drift rate vs retainer beat frequency (unit #0610) with SRA up.

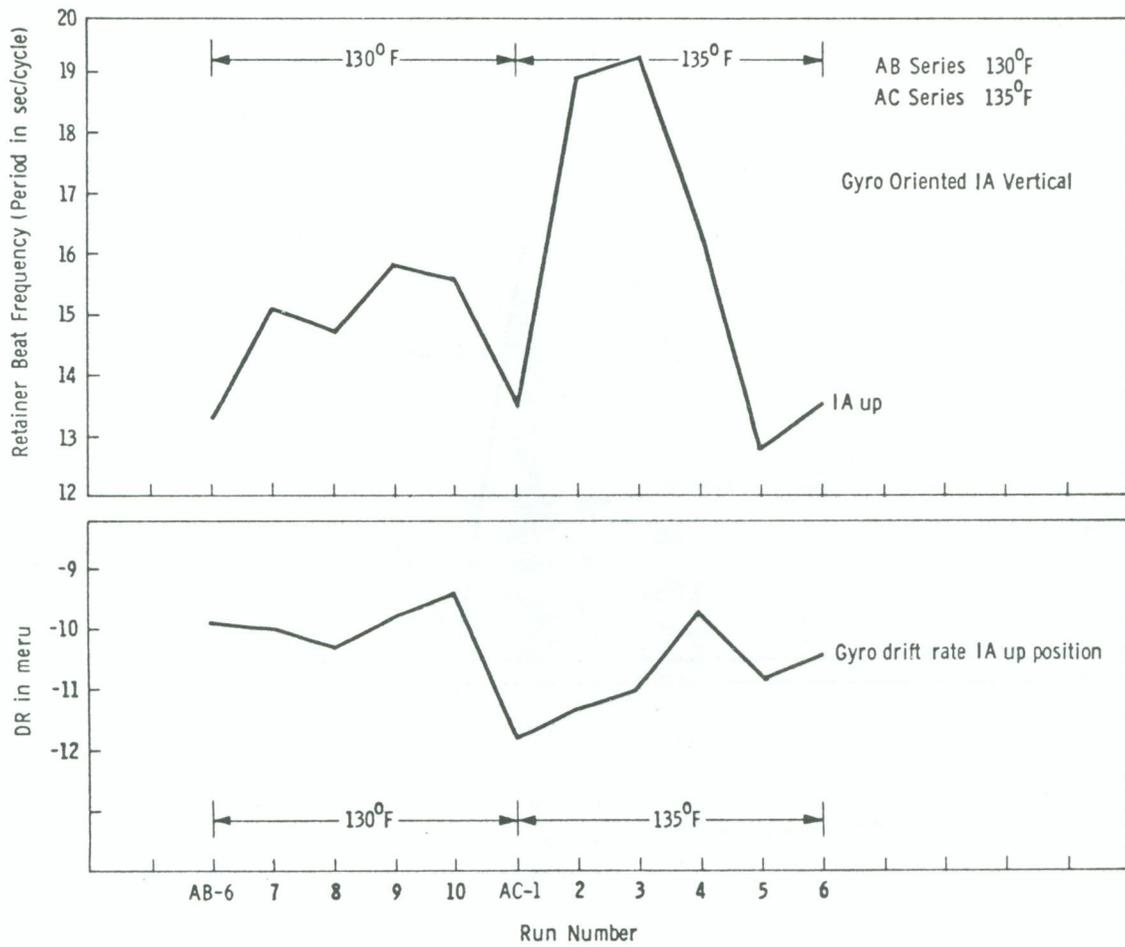


Fig. 31 Apollo I R-4 gyro drift rate vs retainer beat frequency (unit #0610) with IA vertical.

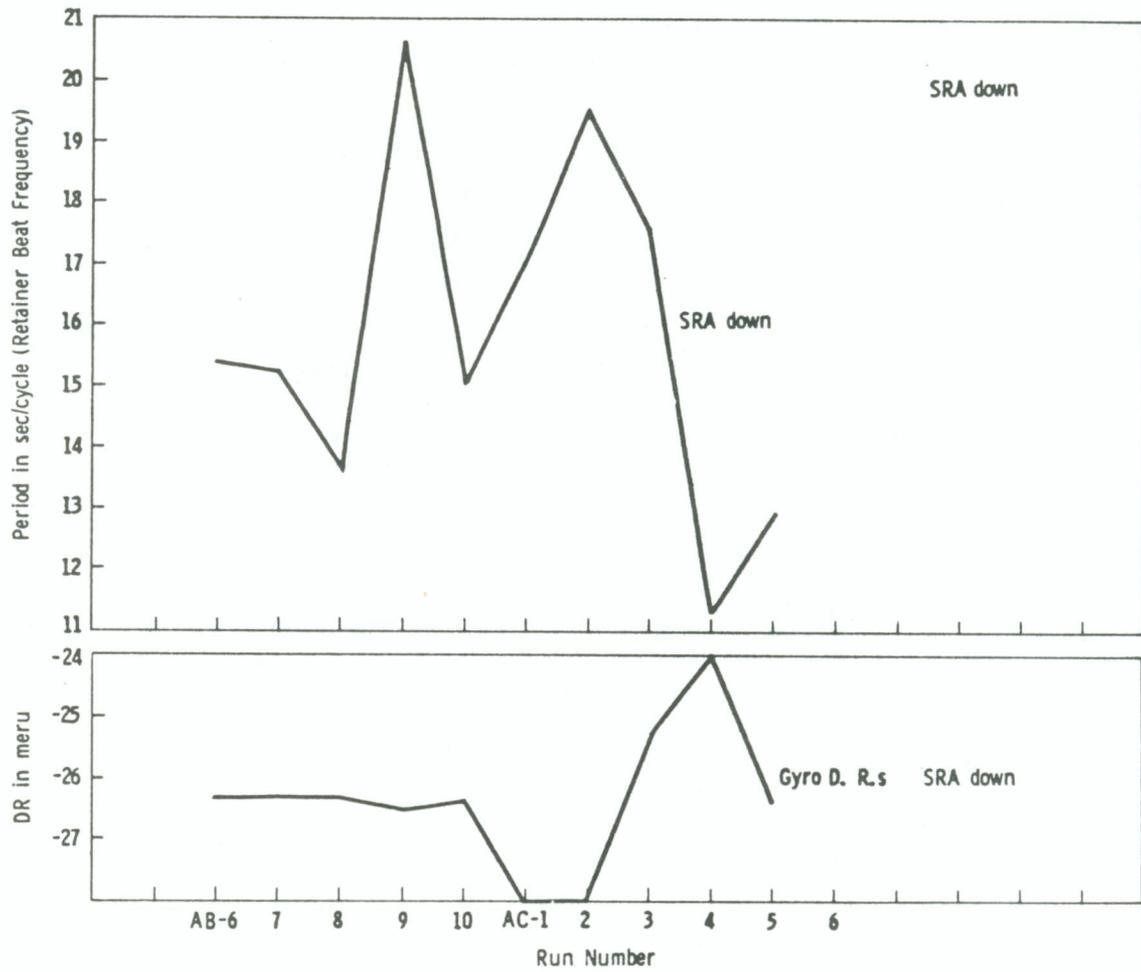


Fig. 32 Apollo I R-4 gyro drift rate vs retainer beat frequency (unit #0610) with SRA down.

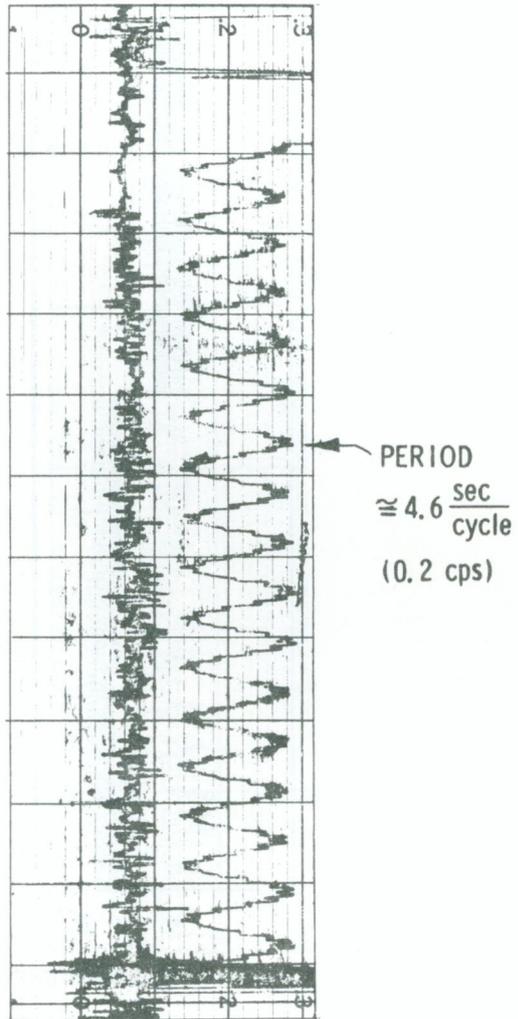
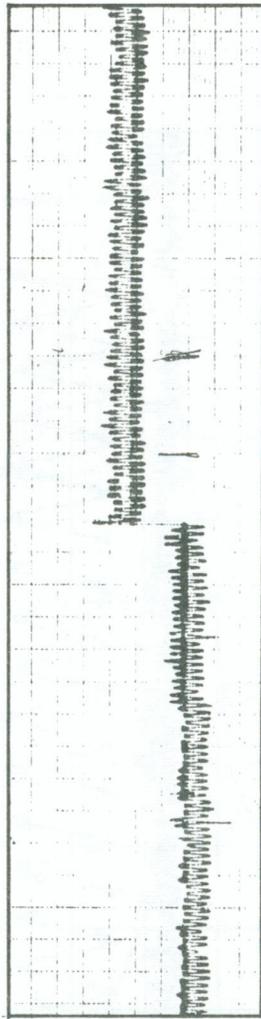


CHART SPEED: 4 in/min

Fig. 33 Retainer beat frequency for gyro #0614.



→ ← 25 mw

CHART SPEED: 5mm/min.

Fig. 34 Differential mw trace for gyro unit #0610.

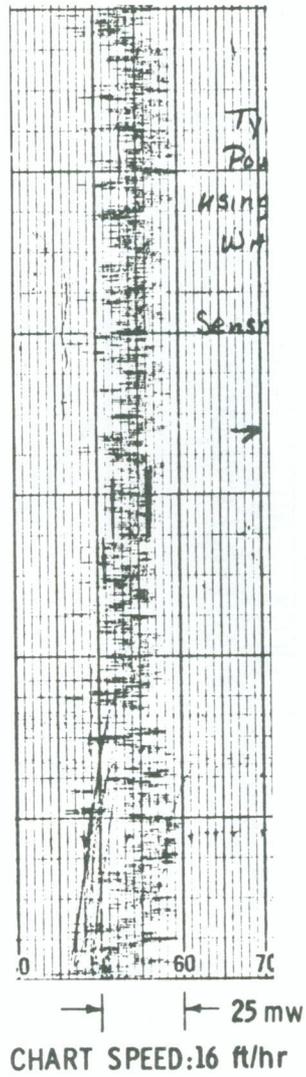


Fig. 35 Differential mw trace for gyro unit #0613.

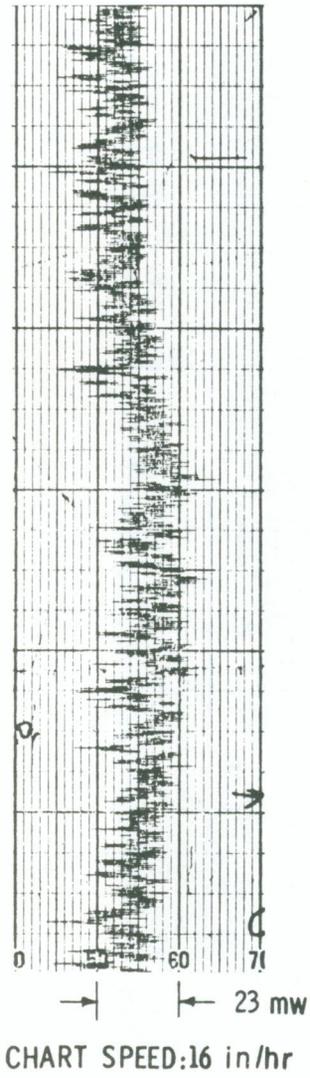


Fig. 36 Differential mw trace for gyro unit #0614.

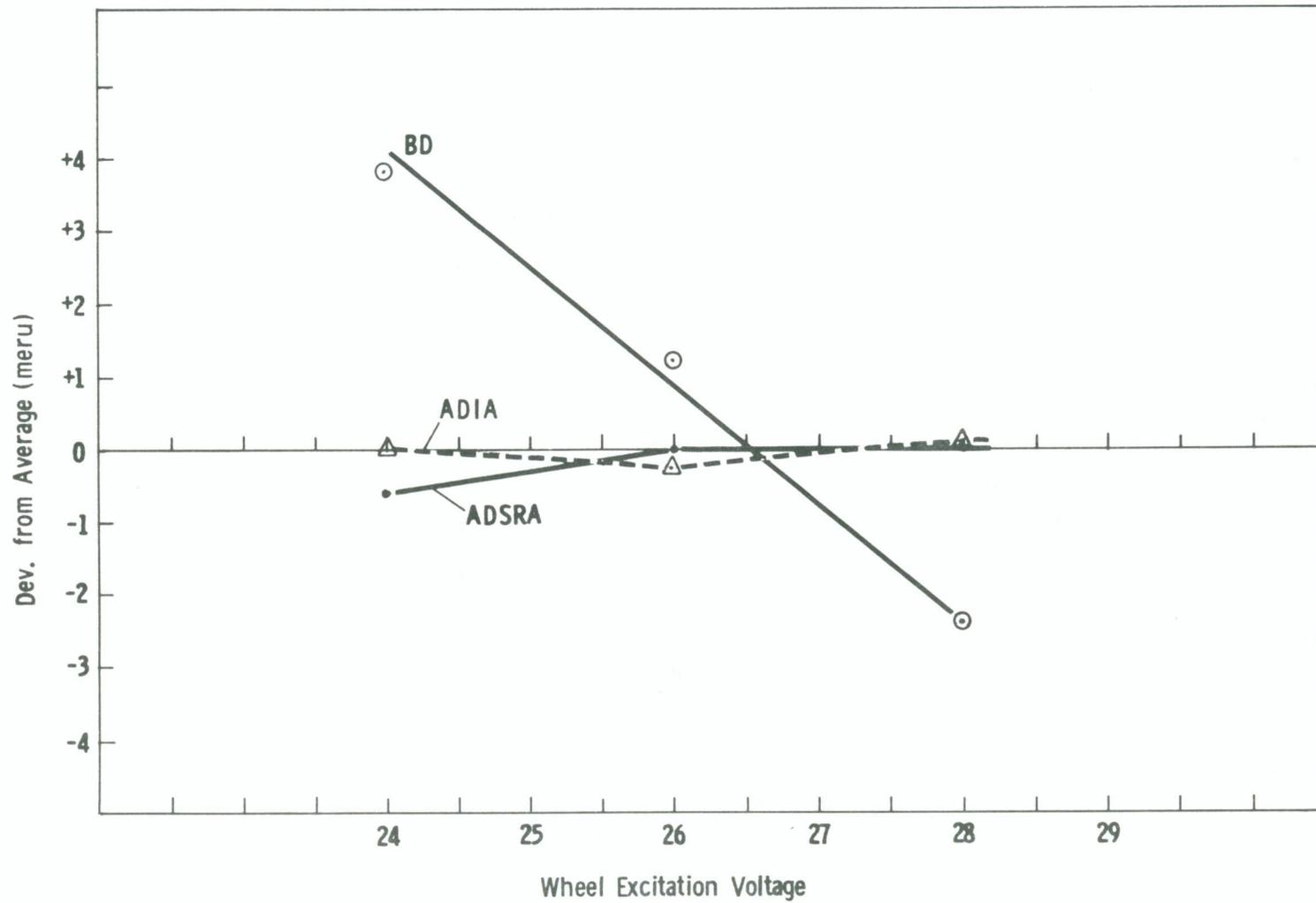


Fig. 37 Apollo I R-4 gyro drift vs wheel excitation voltage (unit #0610).

SECTION 5

DISCUSSION OF GYRO TEST RESULTS

5.1 Ball Beat

The pronounced amplitude of beat frequency in the signal generator output at the 3200-Hz sidebands can be detrimental to system servo performance. During system tests with the R-4 gyro, there was an instability problem and consequent difficulty in closing the servo loop. This problem might have been solved by design changes in the servo loop.

The reason for larger amplitude of retainer-beat frequency in the R-4 wheel compared to the R-2 is that the R-4 is a larger bearing. Also the R-4 retainer pockets were staggered to help assure retainer stability. Both of these factors contribute to greater mass unbalance in the retainer.

5.2 Compliance (Acceleration Squared Drift)

The large magnitude and range of the ΔK and K_{IO} terms leads to the conclusion that more work should be done in studying those parameters which affect g^2 sensitivity. This problem was previously discussed in Paragraph 4.2.4.

5.3 Unbalance Stability

The general uncertainty level and stability of the R-4 family is much the same as the R-2 equipped Apollo I family.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

The wheel assembly and evaluation phase of this program was successful. Wheels were assembled and tested with an overall process yield of 43%. The major reason for wheel failure was retainer instability. This situation might be improved by a study of the dynamics of retainer motion. The study should include a determination of the theoretical natural frequencies of component parts of the bearing. Although work has previously been done in the area of retainer dynamics, the fact that retainer instability is still a major problem indicates that further work is warranted.

Gyro test results showed the existence of a servo stability problem during system servo testing due to the pronounced ball beat component in the gyro signal generator output. In addition, there was the presence of large ΔK and K_{IO} compliance terms during tumbling tests. The tumbling test compliance results do not agree with those obtained during vibration tests. Consequently, if further use of the R-4 gyro configuration is to be made, it is recommended that the beat and g^2 sensitivity problems be resolved.

APPENDIX A

WHEEL FAILURE ANALYSIS REPORTS

I. FAILURE ANALYSIS REPORT FOR WHEEL #R-2

1. History

The subject Apollo I R-4 wheel was rejected because of audible "squealing" of the retainers.

2. Analysis

During initial wheel run-in, the retainer behavior was studied with a microscope and strobotac.

The #1 end of wheel retainer developed radial oscillations of varying intensity after 180 hours of operation. The #2 end of wheel retainer performed normally during observations. Beat frequency period of 3.3 seconds remained essentially the same throughout 405 hours of running time.

3. Wheel and Bearing Dissection

-SRA End I

A. Retainer

Light staining was noted on all but one pocket, covering an angle of approximately 300° surface of each pocket. No contamination was observed.

B. Inner Race

The raceway was in excellent condition with uniform oil distribution and wear track barely discernible.

C. Outer Race

The raceway contained a narrow discolored wear band, and the oil distribution was uniform.

D. Balls

There were no wear bands on dull finish of balls; however, the oil distribution was uniform.

+SRA End II

A. Retainer

Medium to heavy staining was observed on all seven pockets with the heaviest in the leading and trailing edges of pockets. Staining in one pocket was excessive enough to carry over on the O. D. of retainer. Approximately 300^o of surface of each pocket was covered with staining. There was no sign of internal or external contamination.

B. Inner Race

The race with a gray wear band approximately 0.0155 inches wide contained a light (tan and gold) residue of oil in the area between ball contact point and closest land diameter. Oil distribution was uniform on the rest of raceway.

C. Outer Race

A deep, wide, and severe discoloration band was observed. Wear band was severe enough to prohibit reusing outer race.

D. Balls

There were no wear bands on the dull finish of the balls. Oil distribution was uniform.

4. Special Checks

Roundness and cross race curvature were measured on the Talyrond. Results for inner and outer races which are shown in Figures A-1 and A-2 were acceptable.

Tabulated below are results of dimensional measurements made after wheel disassembly. Dimensional measurements in almost all cases were within drawing tolerances.

5. Bearing and Retainer Dimensions

No. 1 end of wheel containing bearing NA-57 type SR4H x 88L, retainer #6406

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>
width inner	0.195700	0.195695	0.1960	0.1955
width outer	0.195900	0.195895	0.1960	0.1955
bore	0.249980	0.249965	0.250000	0.249960
O. D.	0.624820	0.624810	0.624840	0.624800
Contact Angle	30° 5'		30° 30'	29° 30'
Ball Diam.	0.093500			

	<u>Retainer Dimensions</u>		<u>Tolerances</u>	
Pocket Diam.	0.097		0.098	0.097
I. D.	0.3845		0.386	0.382
O. D.	0.4782-0.4775		0.476	0.472
Width	0.1964		0.196	0.194
Oil Retention	13.9 %			

Bearing cleaning: Acetone extracted and re-passivated + re T.C.P. soaked. Three solution cleaned, wettability O.K.

No. 2 end of wheel containing bearing NA-59 type SR4H x 88L, retainer #6407.

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>
width inner	0.195795	0.195790	0.1960	0.1955
outer	0.195915	0.195910	0.1960	0.1955
bore	0.249975	0.249965	0.250000	0.249960
O. D.	0.624825	0.624820	0.624840	0.624800
Contact Angle	30° 30'		30° 30'	29° 30'
Ball Diam.	0.093350			

	<u>Retainer Dimensions</u>	<u>Tolerances</u>	
Pocket Diam.	0.097	0.098	0.097
I. D.	0.385	0.386	0.382
O. D.	0.4774-4766	0.476	0.472
Width	0.1967	0.196	0.194
Oil Retention	14.6 %		

Bearing cleaning: Acetone extracted and re-passivated re-T. C. P. soaked. Three solution cleaned, wettability O.K.

R-2 Retainer Teardown
Alignment Check

	End 1			End 2		
1	0.0471	0.0514		1	0.0474	0.0521
2	0.0465	0.0529		2	0.0470	0.0532
3	0.0469	0.0527		3	0.0465	0.0524
4	0.0470	0.0529		4	0.0464	0.0526
5	0.0466	0.0525		5	0.0464	0.0524
6	0.0462	0.0524		6	0.0467	0.0538
7	0.0468	0.0518		7	0.0464	0.0521
Maximum Misalignment	0.0009	0.0015		0.0010		0.0017

Note: Above dimensions represent distance of edge of hole from side surface of retainer.

6. Conclusions

Wheel #R-2 was originally rejected because of squealing retainers. Staining on ball pocket surfaces of each retainer confirmed this. The severe discoloration observed on the outer race surface of #2 end probably resulted from squealing phenomenon.



Fig. A-2 Roundness and cross race curvatures of outer races (Wheel R-2)

II. FAILURE ANALYSIS REPORT FOR WHEEL R-8

1. History

The subject Apollo I R-4 wheel was rejected due to large, irregular band width and power level changes on differential wattmeter.

2. Analysis

During first sixteen hours trace quality was acceptable with trace width of 36 milliwatts. Period of beat frequency was 7.8 seconds. Trace width slowly increased to approximately 80 milliwatts. This was accompanied by irregular changes in power level.

3. Wheel and Bearing Dissection

-SRA End I

A. Retainer

No staining noted anywhere on retainer. No internal or external contamination observed.

B. Inner Race

Wear trace visible, but very light. Oil distribution was uniform.

C. Outer Race

Very light wear trace with excellent oil uniformity.

D. Balls

No wear bands visible and oil distribution excellent.

+SRA End II

A. Retainer

Staining in front and back surfaces of retainer pockets.

B. Inner Race

Wear band barely discernible. Oil distribution was excellent.

C. Outer Race

Wear band was extremely light. Oil was uniformly distributed.

D. Balls

Uniform oil distribution was observed. There was no evidence

of wear bands.

General Comment

Upon cleaning of bearing for reuse in another build, staining occurred on #2 inner race and shaft body. After rubbing with nylon probe and lens paper dipped in eng sol failed, it was noted under microscope that film had been broken in three areas at the ball track. Acetone extraction and three solution cleaning failed to restore raceway to original condition.

4. Bearing and Retainer Dimensions

No. 1 end of wheel contained bearing NA-7 type SR 4 H x 88K retainer #6595.

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>
width inner	0.195705	0.195695	0.1960	0.1955
width outer	0.195750	0.195740	0.1960	0.1955
bore	0.249985	0.249975	0.250000	0.249960
O. D.	0.624825	0.624815	0.624840	0.624800
Contact Angle	30° 20'		30° 30'	29° 30'
Ball Diam.	0.093500			

	<u>Retainer Dimensions</u>		<u>Tolerances</u>	
Pocket Diam.	(3) 0.0965 (2) 0.096	(2) 0.0955	0.098	0.097
I. D.	0.3840		0.386	0.382
O. D.	0.4763-.4770		0.476	0.472
width	0.1942		0.196	0.194
oil retention	12.3 %			
stock	MC 26-6-83			

Bearing cleaning: Acetone extracted. Normal solution sodium hydroxide and hot tapwater. Trichloroethylene extracted. Wettability O.K.

No. 2 end of wheel contained bearing NA-10 type SR 4 H x 88K retainer #6594.

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>
width inner	0.195705	0.195695	0.1960	0.1955
width outer	0.195750	0.195745	0.1960	0.1955
bore	0.24998	0.249965	0.250000	0.249960
O. D.	0.624825	0.624815	0.624840	0.624800
Contact Angle	30° 10'		30° 30'	29° 30'
Ball Diam.	0.093650			

	<u>Retainer Dimensions</u>	<u>Tolerances</u>	
Pocket Diam.	(6 - 0.096)(1 - 0.0955)	0.098	0.097
I. D.	0.3840	0.386	0.382
O. D.	0.4754 - .4777	0.476	0.472
width	0.1938	0.196	0.194
oil retention	16.5 %		
stock	MC 26-6-83		

Bearing cleaning: Acetone extracted. TCP soaked. Wettability O.K.

R-8 Retainer Hole Alignment Check

1	0.0471	0.0517	1	0.051	0.0472
2	0.0463	0.0511	2	0.051	0.0474
3	0.0477	0.0509	3	0.0493	0.0465
4	0.0475	0.0513	4	0.0505	0.0477
5	0.0478	0.0520	5	0.0503	0.0487
6	0.0470	0.0514	6	0.0496	0.0483
7	0.0473	0.0506	7	0.0505	0.0479
Maximum Misalignment	0.0015	0.0014		0.0017	0.0022

Note: Above dimensions represent distance of edge of hole from side surface of retainer.

5. Special Checks

Roundness and cross race curvatures were measured on the Talyrond and the results were found to be acceptable. (See Fig. A-3 and A-4.) In Fig. A-4, on the shaft raceway roundness measurement, the small blip in the trace was the result of surface damage during cleaning operation.

6. Conclusions

Wheel #R-8 was originally rejected because of irregular milliwatt-meter trace width. While the wheel was running, motion of retainer in #2 end was unstable. After teardown slight staining was observed in forward and back surfaces of #2 retainer only. It appears that #2 retainer contributed to irregular milliwattmeter trace.

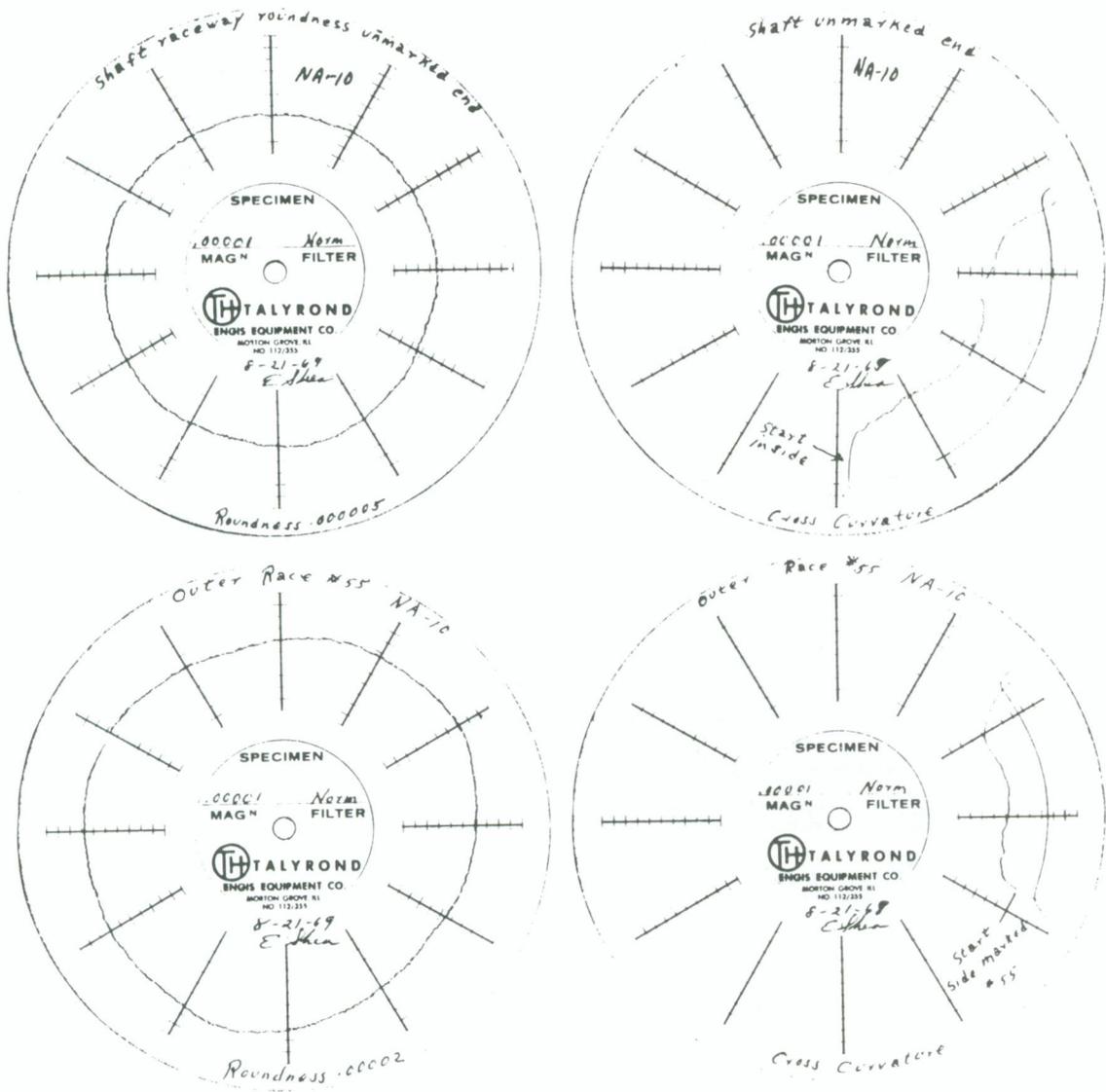


Fig. A-3 Roundness and cross race curvatures of inner and outer races on side #2 (Wheel R-8).

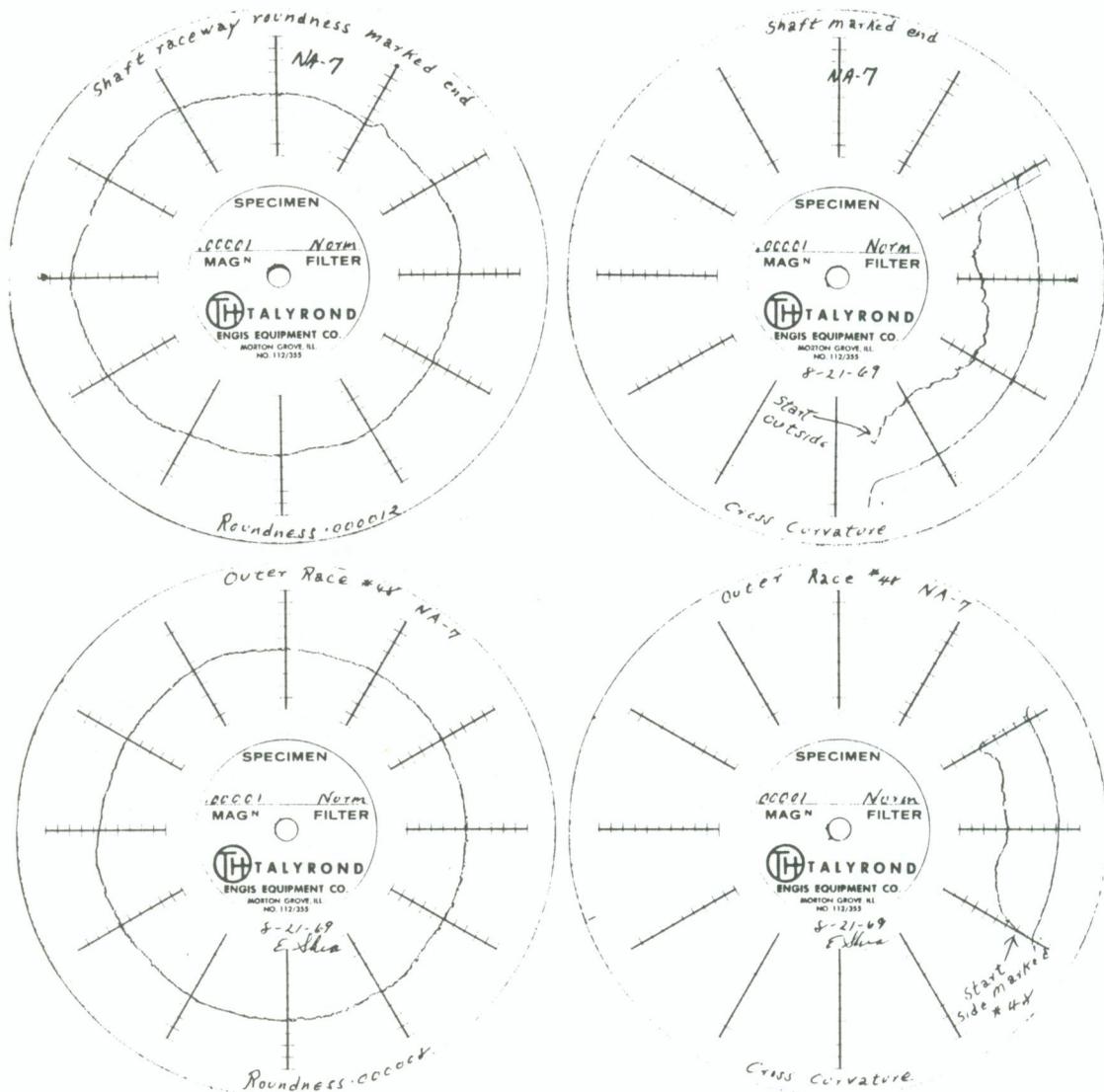


Fig. A-4 Roundness and cross race curvatures of inner and outer races on side #1 (Wheel R-8).

III. FAILURE ANALYSIS REPORT FOR WHEEL R-9

1. History

The subject Apollo I R-4 wheel was rejected because of audible squealing of the retainers while in dynamic balancer.

2. Analysis

No analysis was taken. Wheel did not reach differential wattmeter fixture.

3. Wheel and Bearing Dissection

-SRA End I

A. Retainer

No staining was noted in pockets. Retainer was free externally and internally of foreign contaminants.

B. Inner Race

There were two pronounced gray ball tracks. Background of ball tracks was a matte finish. Oil uniformity was very poor. Oil was concentrated close to ball track.

C. Outer Race

Only one ball track was observed on outer race. The ball track was pronounced. No discoloration was noted. Oil uniformity was good.

D. Balls

Two of the seven balls showed very light banding. Oil uniformity was good.

+SRA End II

A. Retainer

No staining was noted in pockets and retainer was free from contamination.

B. Inner Race

The ball track was barely discernable. Oil uniformity was excellent. No foreign material was evident on raceway.

C. Outer Race

The ball track had a very fine, light band. Oil uniformity was very good throughout raceway.

D. Balls

No banding was noted on balls. Balls had a uniform distribution of oil.

4. Bearing and Retainer Dimensions

No. 1 end of wheel contained bearing NA A-64 type SR 4 H x 88L retainer #6596.

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>
width inner	0.195920	0.195910	0.1960	0.1955
width outer	0.195910	0.195905	0.1960	0.1955
bore	0.249980	0.249965	0.250000	0.249960
O. D.	0.624830	0.624815	0.624840	0.624800
Contact Angle	30° 5'		30° 30'	29° 30'
Ball Diam.	0.093350			

	<u>Retainer Dimensions</u>		<u>Tolerances</u>	
Pocket Diam.	See retainer alignment check		0.098	0.097
I. D.	0.3840		0.386	0.382
O. D.	0.4760 - .4764		0.476	0.472
Width	See retainer alignment check		0.196	0.194
Oil Retention	18.8 %			

Bearing cleaning: Acetone extracted and re-passivated and re-T. C. P soaked. Wettability O.K.

No. 2 end of wheel contained bearing NA-58 type SR 4 H x 88L retainer #6491.

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>
width inner	0.195925	0.195920	0.1960	0.1955
width outer	0.195915	0.195910	0.1960	0.1955
bore	0.249980	0.249965	0.250000	0.249960
O. D.	0.624825	0.624815	0.624840	0.624800
Contact Angle	30° 25'		30° 30'	29° 30'
Ball Diam.	0.093450			

	<u>Bearing Dimensions</u>	<u>Tolerances</u>	
Pocket Diam.	See retainer alignment check	0.098	0.097
I. D.	0.3845	0.386	0.382
O. D.	0.4767	0.476	0.472
Width	See retainer alignment check	0.196	0.194
Oil Retention	13.4 %		

Bearing cleaning: Acetone extracted and re-passivated and re-T. C. P. soaked. Wettability OK.

R-2 Retainer Teardown Alignment
Check

	<u>End #1</u>					<u>End #2</u>			
Hole #	Distance to Edge	Hole Diameter	Distance to Edge	Total Width		Distance to Edge	Hole Diameter	Distance to Edge	Total Width
1	0.0507	0.0967	0.0473	0.1947		0.0510	0.0975	0.0464	0.1949
2	0.0507	0.0949	0.0485	0.1941		0.0504	0.0962	0.0483	0.1949
3	0.0512	0.0944	0.0484	0.1940		0.0506	0.0984	0.0474	0.1964
4	0.0501	0.0964	0.0472	0.1937		0.0519	0.0976	0.0474	0.1969
5	0.0507	0.0967	0.0458	0.1932		0.0520	0.0974	0.0456	0.1950
6	0.0502	0.0960	0.0468	0.1930		0.0521	0.0963	0.0464	0.1948
7	0.0498	0.0967	0.0462	0.1927		0.0510	0.0972	0.0469	0.1951
Max. Misalignment	0.0014		0.0017			0.0017		0.0027	

Note: Above measurements were made using a toolmaker's microscope. Accuracy of each measurement is $\pm 0.0001''$.

Conclusions:

Wheel #R-9 was rejected because of squealing retainers. Wheel was not run long enough to cause any staining in retainer pockets. Squealing may have been caused by a combination of a small ball to retainer pocket clearance of $0.00105''$ and retainer ball pocket misalignment of $0.0014''$ in #1 end. Squealing could cause the balls to skid in #1 end resulting in double ball track on inner race. Inner race is more heavily stressed than other race. This may account for only one ball track being visible on outer race. After cleaning the bearing races were examined and found to be reusable.

IV FAILURE ANALYSIS REPORT FOR WHEEL #R-10

1. History

The subject Apollo I R-4 wheel was rejected because of erratic trace. Band width on differential wattmeter was 64 mw with spikes to 84 mw.

2. Analysis

Beat period was not recorded because of instability of trace. Both retainers were unstable.

3. Wheel and Bearing Dissection

-SRA End I

A. Retainer

Light tan colored staining was noted on all ball pockets on forward and trailing edges. No internal or external contamination was noted.

B. Inner Race

Wear track was light with oil residue on one side. No frostiness or discoloration was noted. Oil distribution was excellent throughout raceway.

C. Outer Race

There was a medium wear track with large oil residue and breakdown deposits on each side. Residue was removable. Underneath residue there was a fine frosty track.

D. Balls

Finish of balls was dull with no evidence of wear bands. There were light traces of brown varnish.

+ SRA End II

A. Retainer

Very light spotted staining was observed in all pockets. There was no evidence of contamination.

B. Inner Race

Wear track was very light with oil residue on one side. Oil distribution was excellent.

C. Outer Race

There was a light wear track with oil residue deposit concentrated on one side.

D. Balls

One heavy shiny band was noted on all seven balls. Oil distribution was good.

4. Bearing and Retainer Dimensions

No. 1 end of wheel contained bearing NA-11 type
SR 4 H x 88 K retainer #6710

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>
Width inner	0.195690	0.195680	0.1960	0.1955
Width outer	0.195810	0.195800	0.1960	0.1955
Bore	0.249985	0.249970	0.250000	0.249960
O.D.	0.624815	0.624810	0.624840	0.624800
Contact Angle	29 ^o 50'		30 ^o 30'	29 ^o 30'
Ball Dia	0.093500			

	<u>Retainer Dimensions</u>		<u>Tolerances</u>	
	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>
Pocket Dia	See retainer alignment check		0.098	0.097
I.D.	0.3855		0.386	0.382
O.D.	0.4764		0.476	0.472
Width	See retainer alignment check		0.196	0.194
Oil Retention	12.6%			

Bearing cleaning: Acetone extracted, passivated, T.C.P. coated. Re-acetone extracted, water scrub acetone ultrasonic. Repassivated, re T.C.P. coated. Acetone ultrasonic, trichloroethylene extracted.

No. 2 end of wheel containing bearing NA-12 type
SR 4 H x 88 K retainer #6714

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>
Width inner	0.195630	0.195615	0.1960	0.1955
Width outer	0.195805	0.195795	0.1960	0.1955
Bore	0.249990	0.249975	0.250000	0.249960
O.D.	0.624805	0.624800	0.624840	0.624800
Contact angle	30°15'		30°30'	29°30'
Ball diam	0.093500			

	<u>Retainer Dimensions</u>		<u>Tolerances</u>	
Pocket diam	See retainer alignment check		0.098	0.097
I.D.	0.3855		0.386	0.382
O.D.	0.4752		0.476	0.472
Width	See retainer alignment check		0.196	0.194
Oil Retention	16.7%			

Bearing cleaning: Acetone extracted, passivated, and T.C.P. coated.
Re-acetone extracted, water scrub and acetone ultrasonic.
Trichloroethylene extracted, repassivated, re T.C.P. coated.

R-10 Retainer Teardown Alignment Check							
<u>End 1</u>				<u>End 2</u>			
Distance to Edge	Pocket O.D.	Distance to Edge	Total Width	Distance to Edge	Pocket O.D.	Distance to Edge	Total Width
1. 0.046	0.0994	0.0498	0.1952	1 0.0492	0.0988	0.0479	0.1959
2. 0.0455	0.0997	0.0496	0.1948	2 0.0493	0.0987	0.0471	0.1951
3. 0.0461	0.0995	0.0505	0.1961	3 0.0491	0.0986	0.0474	0.1951
4. 0.0459	0.0992	0.0501	0.1952	4 0.0483	0.0991	0.0476	0.1950
5. 0.0464	0.0978	0.0508	0.1950	5 0.0498	0.0980	0.0469	0.1947
6. 0.0462	0.0978	0.0510	0.1950	6 0.0511	0.0966	0.0478	0.1955
7. 0.0453	0.0991	0.0507	0.1951	7 0.0487	0.0988	0.0483	0.1958
MAXIMUM MISALIGNMENT							
0.0011		0.0014		0.0028		0.0014	

Retainer O.D.	0°	0.478	Retainer	O.D.	0°	0.4783
	O.D.	180°		O.D.	180°	0.4760
Retainer I.D.	0°	0.3855	Retainer	I.D.	0°	0.3864
	I.D.	180°		I.D.	180°	0.3858

Note: Above dimensions represent distance of edge of hole from side surface of retainer. Readings taken with a Unitron toolmaker's microscope. Accuracy of each measurement is $\pm 0.0001''$.

5. Special Checks

Roundness and cross race curvature were measured on the Taly-rond. Results for inner and outer races which are shown in Figures A-5 and A-6 were acceptable.

6. Conclusions

Wheel #R-10 was rejected because of an excessively wide erratic milliwattmeter trace. Oil breakdown resulted in oil residue and sludge deposits on both outer races. This condition was more pronounced in the #1 end of the wheel. This end of the wheel also had a much heavier wear track. Associated with these observations is the fact that the retainer in the #1 end had 12.6% oil retention compared to 16.7% in the #2 end. Frosty track on #1 outer race prevented reuse of this bearing.

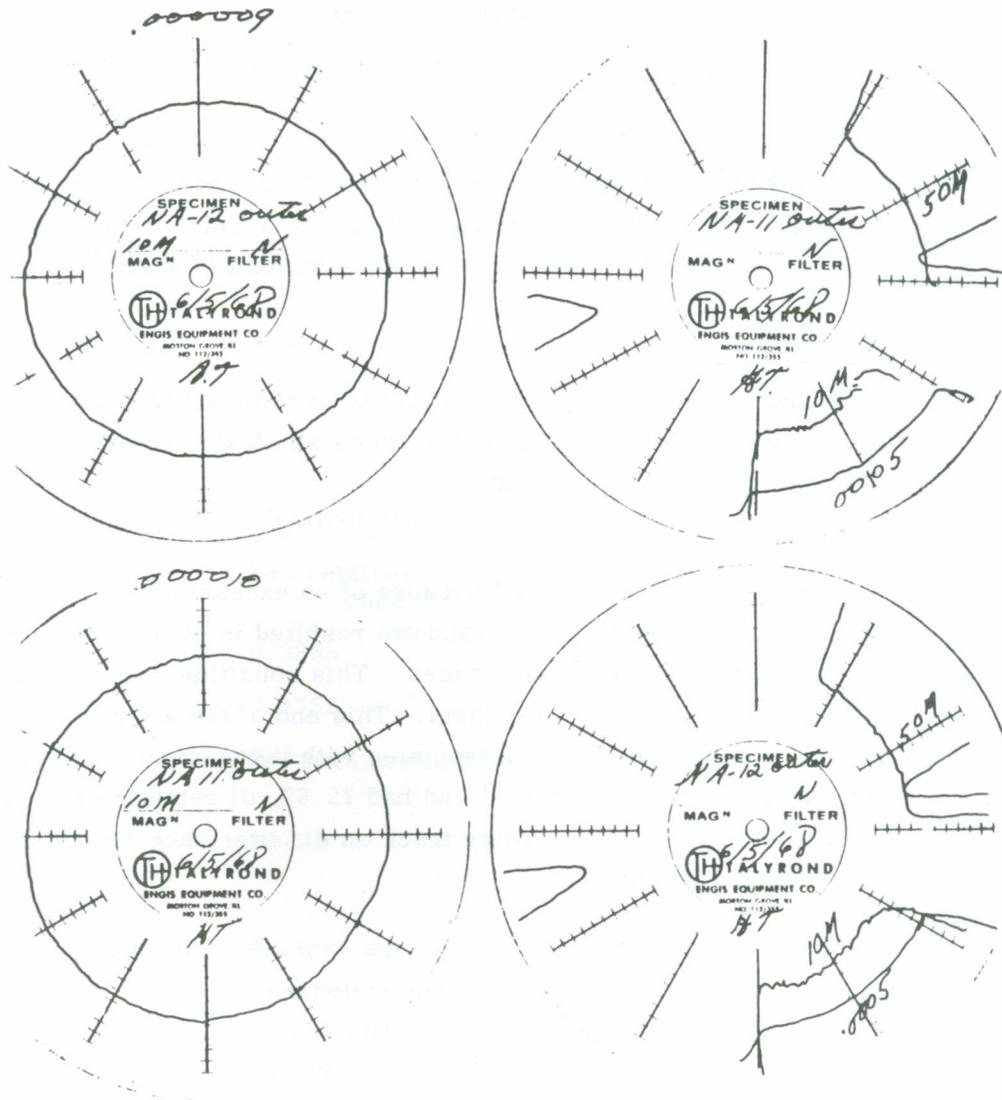


Fig. A-5 Roundness and cross race curvatures of outer races (Wheel R-10).

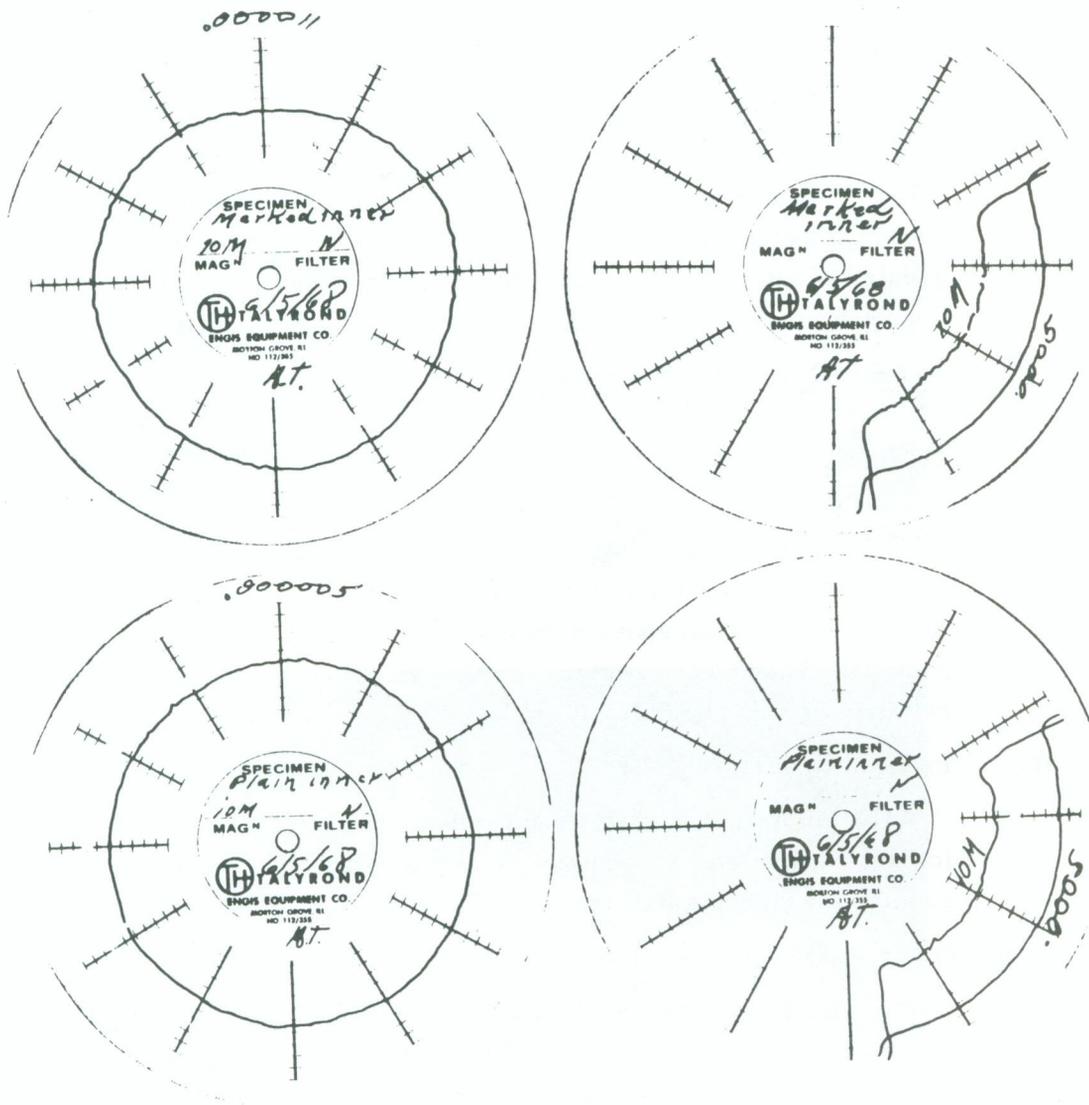


Fig. A-6 Roundness and cross race curvatures of inner races assembled to shaft (Wheel R-10).

V FAILURE ANALYSIS REPORT FOR WHEEL #R-2A

1. History

The subject Apollo I R-4 wheel was rejected because of unstable retainers which caused a hashy erratic differential power trace of approximately 55 mw. in width.

2. Analysis

Microscope-stroboscope study of the retainer behavior showed both retainers to be unstable. The No. 1 retainer displayed the greater erratic motion. This instability resulted in an irregular beat frequency period which ranged from 4.3 seconds to 12.4 seconds.

3. Wheel and Bearing Dissection

-SRA End 1

A. Retainer

Uneven dark brown stains were observed on forward wall of pockets. Occasional light tan spots were also observed on opposite wall of pockets. There were several varnish streaks & spots on I.D. of retainer around one ball pocket.

B. Inner Race (Figure A-7)

Oil film distribution was good. Residue margins were noted flank- ing debris spotted ball track. There was also a light discolor line running through the ball track.

C. Outer Race (Figure A-8)

Oil film distribution was good. Photograph shows heaviest oil concentration as white areas. There was an uneven stain in ball track area flanked by debris. The cleaned bearing showed no discoloration.

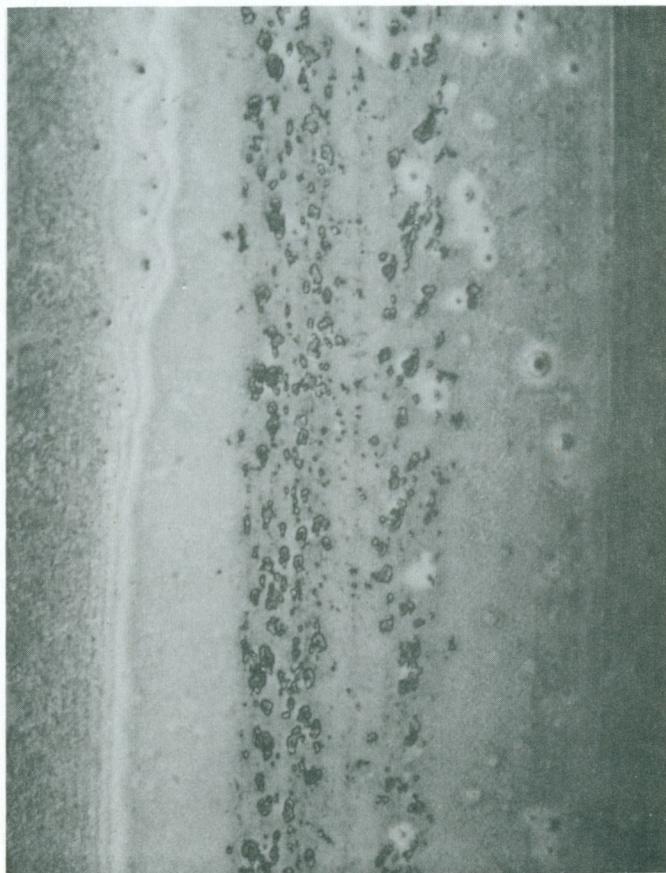
D. Balls (Figure A-9)

There was an unusually wide wear band covering each ball. Oil stains on balls were normal.

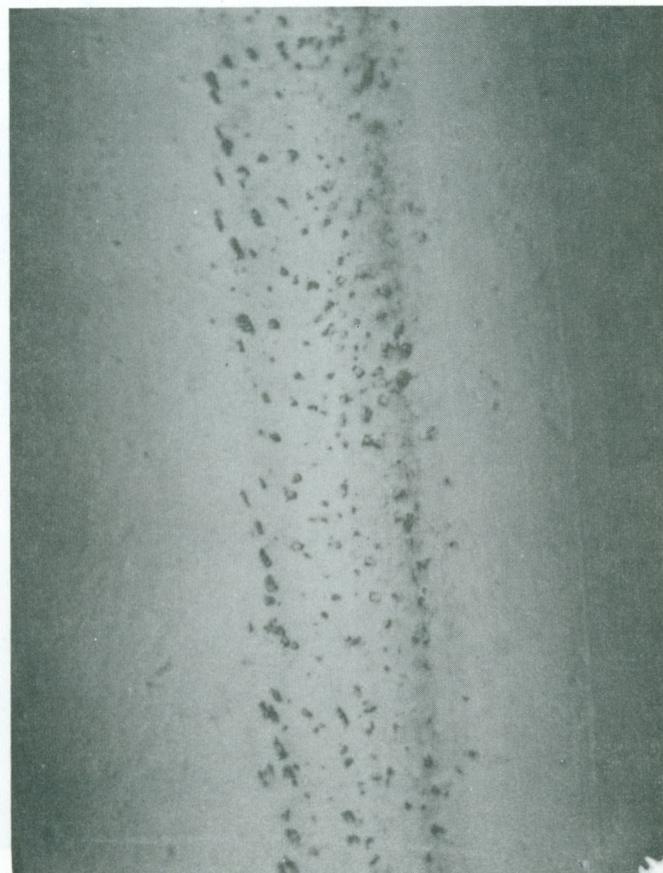
+ SRA End 2

A. Retainers

One small brown stain was observed on forward wall of four pockets.

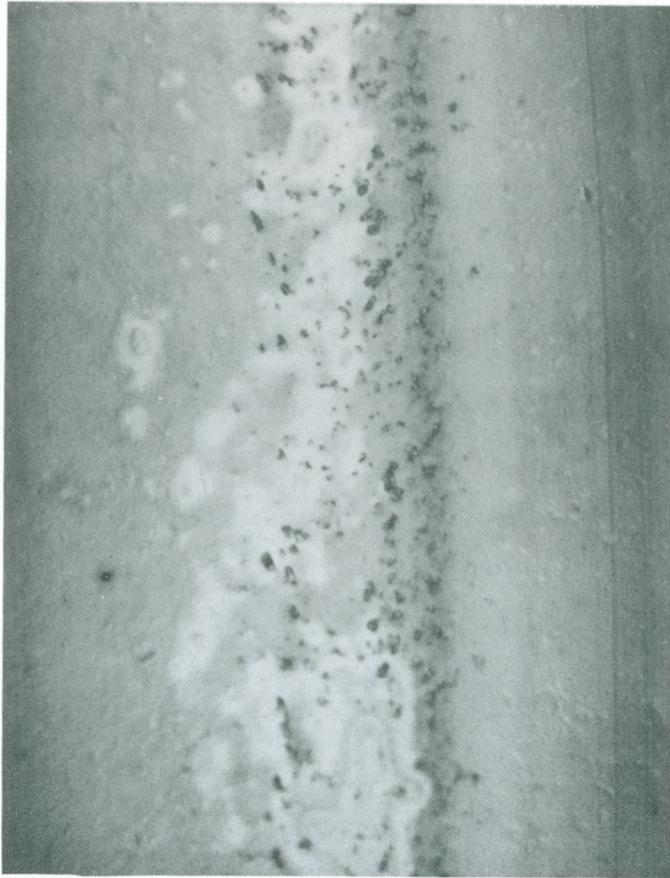


Uncleaned

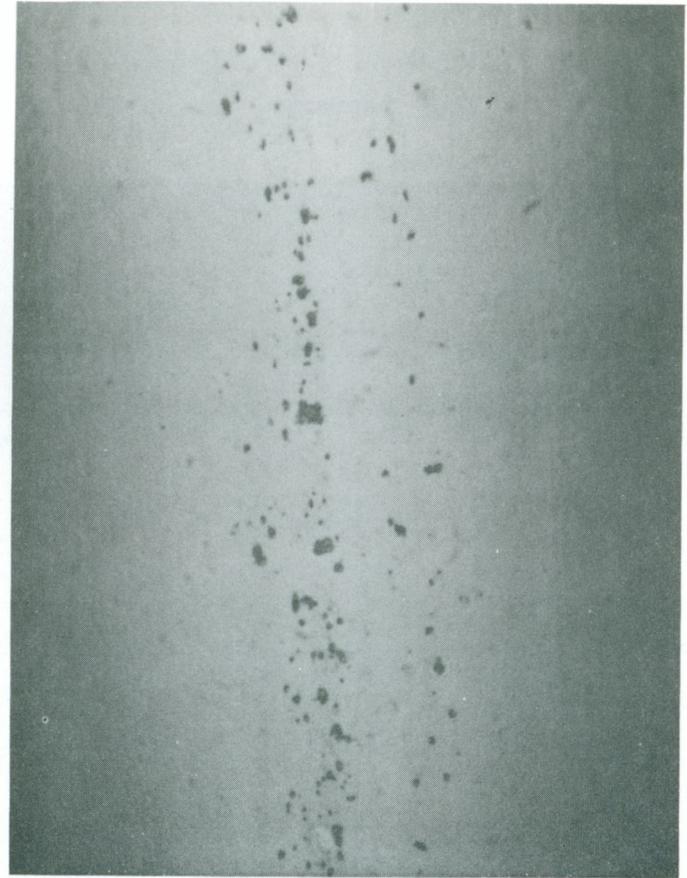


Cleaned

Fig. A-7 R-2A Inner Race 1, (160X).



Uncleaned



Cleaned

Fig. A-8 R-2A Outer Race 1, (160X).

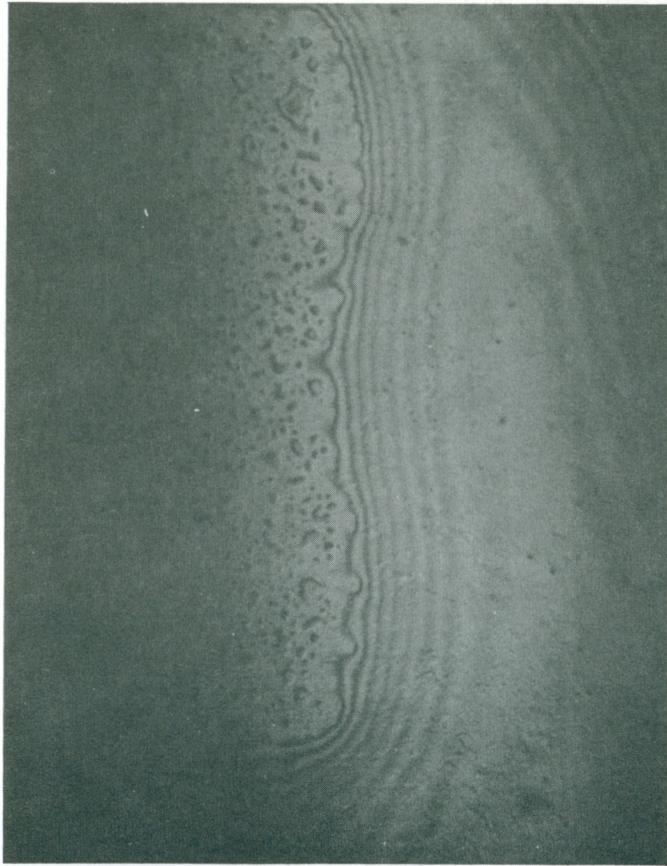


Uncleaned

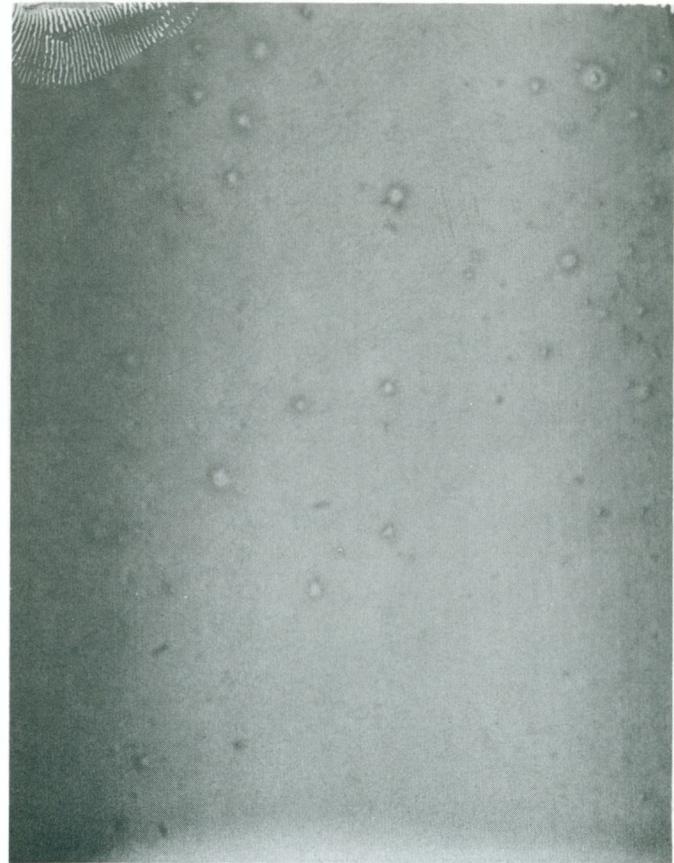


Cleaned

Fig. A-9 R-2A Ball, End 1, (160X).



Inner



Outer

Fig. A-10 R-2A Races 2, Uncleaned, (160X).

The other pockets contained a few light tan spots scattered on forward wall of retainer pockets.

B. Inner Race (Figure A-10)

Oil film distribution was good. Photograph shows oil retraction. There was a normal light gray ball track with no evidence of debris or residue deposits. Photograph shows dewetting.

C. Outer Race (Figure A-10)

Oil film distribution was good. There was a normal light gray ball track, with no evidence of debris or residue deposits. Specks in photograph are due to contamination after disassembly.

D. Balls

The balls had normal oil staining.

4. Bearing and Retainer Dimensions

No. 1 end of wheel contained bearing NA-15 type SR4 H x 88K retainer #6406.

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>
Width inner	0.195660	0.195650	0.1960	0.1955
Width outer	0.195740	0.195735	0.1960	0.1955
Bore	0.249980	0.249965	0.250000	0.249960
O.D.	0.624805	0.624800	0.624840	0.624800
Contact Angle	29°50'		30°30'	29°30'
Ball Diameter	0.09375 Inner Race Land O.D.		0.3776	
	<u>Retainer Dimensions</u>		<u>Tolerances</u>	
Pocket Diam	See retainer pocket alignment check		0.098	0.097
I.D.	0.3860		0.386	0.382
O.D.	0.4768		0.476	0.472
Width	See retainer alignment check		0.196	0.194
Oil Retention:	16.6%		Material: MC-26-6	

Bearing cleaning for Wettability: Acetone extracted, passivated, TCP treated, re-acetone extracted; non-wett-able. Bearing was aged in V-78 oil at 180°F. Alkaline cleaned, acetone extrac-
ted: passed wettability.

No. 2 end of wheel contained bearing NA-14 type SR 4 H x 88 K Retainer # 6712.

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>
Width inner	0.195645	0.195635	0.1960	0.1955
Width outer	0.195810	0.195805	0.1960	0.1955
Bore	0.249985	0.249965	0.250000	0.249960
O.D.	0.624820	0.624815	0.624840	0.624800
Contact Angle	30°10'		30°30'	29°30'
Ball Diameter	0.09345	Inner Race Land O.D.:		0.3777

	<u>Retainer Dimensions</u>	<u>Tolerances</u>	
Pocket Diam	See retainer pocket alignment check	0.098	0.097
I.D.	0.3845	0.386	0.382
O.D.	0.4757	0.476	0.472
Width	See retainer alignment check	0.196	0.194
Oil Retention:	17.1%	Material: MC-26-6	

Bearing cleaning for Wettability: Acetone extracted, passivated, TCP treated, re-acetone extracted; non wett-able. Bearing was aged in V-78 oil at 180°F. Alkaline cleaned, acetone extrac-
ted: Wettability O.K.

RETAINER POCKET ALIGNMENT CHECK

<u>END #1</u>					<u>END #2</u>				
1.	0.0450	0.1004	0.0501	0.1955	1.	0.0465	0.0996	0.0502	0.1963
2.	0.0458	0.0998	0.0502	0.1958	2.	0.0468	0.1001	0.0500	0.1969
3.	0.0457	0.0997	0.0504	0.1955	3.	0.0472	0.0991	0.0501	0.1964
4.	0.0455	0.1002	0.0500	0.1957	4.	0.0462	0.0996	0.0505	0.1963
5.	0.0451	0.1000	0.0503	0.1954	5.	0.0463	0.0998	0.0506	0.1967
6.	0.0450	0.1000	0.0500	0.1950	6.	0.0464	0.0995	0.0506	0.1965
7.	0.0445	0.1004	0.0492	0.1941	7.	0.0466	0.0993	0.0504	0.1963
Max. Misalignment									
0.0013		0.0012			0.001		0.0006		

Note: Above dimensions represent distance from side surface of retainer to edge of hole; from edge of hole to edge of hole; from edge of hole to opposite side surface of retainer. Readings taken with a Unitron toolmaker's microscope. Accuracy of each measurement is $\pm 0.0001''$.

5. Special Checks

Roundness and cross race curvature were measured on the Taly-ron. Results for inner and outer races which are shown in Figures A-11 and A-12 are within accepted limits, however, the outer race (NA-15) at the #1 end was marginal in the roundness check. Diametral roundness was 36 micro-inches.

6. Conclusions

Wheel # R-2A was rejected because of erratic differential power trace with a hash level of 20 to 64 mw. Retainer instability was observed under stroboscopic light before wheel disassembly. The more active of the retainers was in the #1 end. The appearance of retainer, balls and races on this end corroborate the greater amount of energy that was expended. Bearing on #1 end of the wheel was considered to be a hardware failure. # 2 end was reusable.

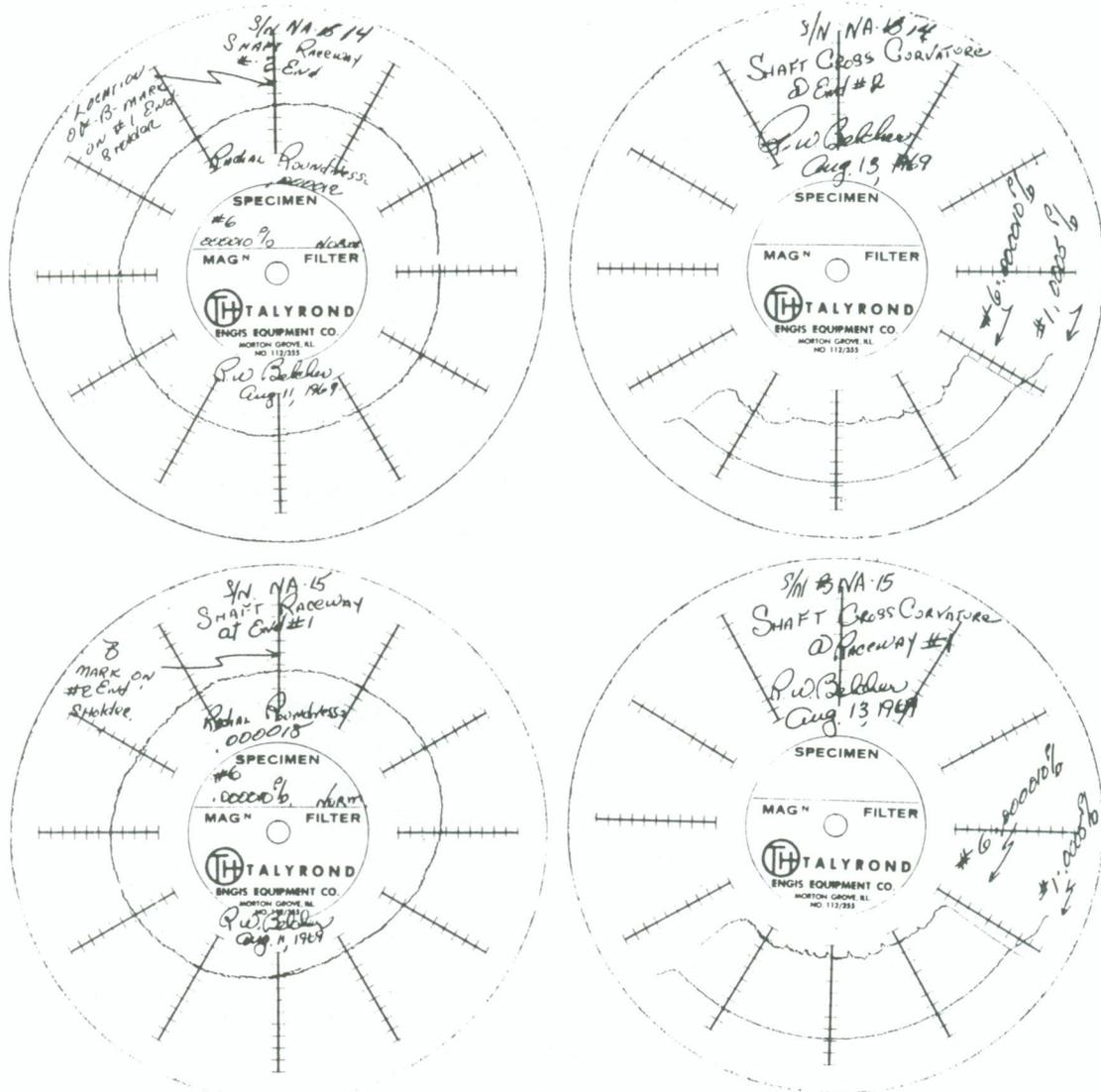


Fig. A-11 Roundness and cross race curvatures of inner races assembled to shaft (Wheel R-2A).



Fig. A-12 Roundness and cross race curvatures of outer races (Wheel R-2A).

VI FAILURE ANALYSIS REPORT FOR WHEEL #R-2B

1. History

The subject Apollo I R-4 wheel was rejected because of erratic milliwatt trace and retainer squealing. Band Width of differential wattmeter trace was 40 mw plus spikes.

2. Analysis

Beat period was not measured because of instability of trace due to an unstable retainer.

3. Wheel and Bearing Dissection

-SRA End I

A. Retainer

All surfaces, including pockets, were free of stain and contamination.

B. Inner Race (Figure A-13)

There was good oil film distribution. White areas on photograph indicate a heavier concentration of oil. Normal gray ball track was observed. This was not visible on photograph due to lighting. There was no evidence of debris or residue deposits. Surface irregularities may be seen in photograph.

C. Outer Race (Figure A-14)

There was good oil film distribution. Under 250X microscope some oil retraction was noted. Photograph of cleaned bearing shows a wide light straw color ball track with a narrow shiny path running along the center of it. Lightly scattered retainer debris may be observed in photograph of uncleaned bearing.

D. Balls

The balls had normal oil staining.

+ SRA End II

A. Retainers

All surfaces, including pockets, were free of stain and contamination.



Uncleaned

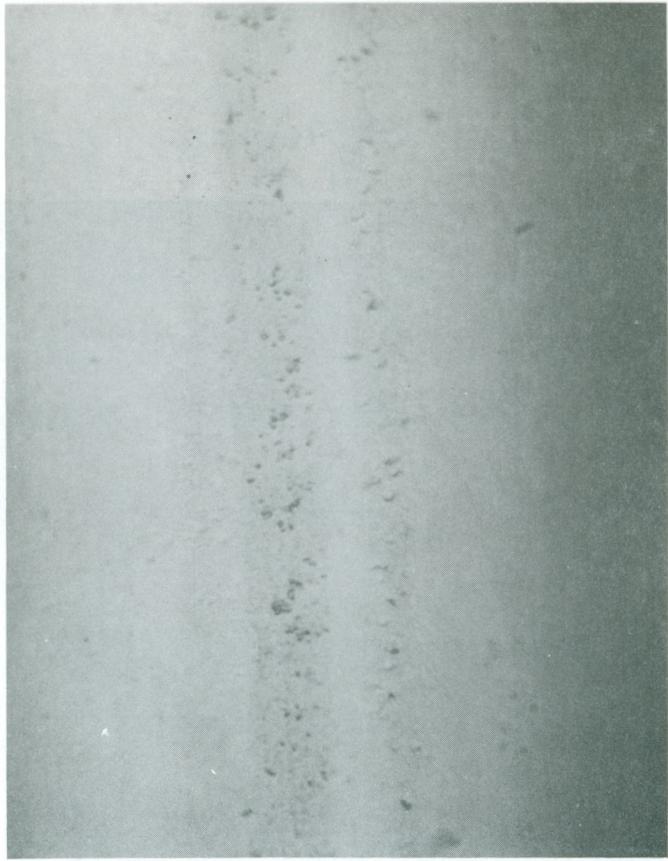


Cleaned

Fig. A-13 R-2B Inner Race 1, (250X).



Uncleaned



Cleaned

Fig. A-14 R-2B Outer Race 1, (250X).

B. Inner Race (Figure A-15)

Good oil distribution was observed. A light oil/debris mixture was deposited on load side of raceway. There was normal wear in ball track.

C. Outer Race (Figure A-15)

There was good oil distribution. However, under 250X microscope some oil retraction was noted. A light oil/debris mixture was deposited on load side of raceway. Normal wear was noted in ball track.

D. Balls

The balls had normal oil staining.

4. Bearing and Retainer Dimensions

No. 1 End of Wheel contained bearing NA-1 type
SR 4 H x 88 K with retainer #6773.

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>
Width inner	0.195650	0.195640	0.1960	0.1955
Width outer	0.195785	0.195780	0.1960	0.1955
Bore	0.249995	0.249980	0.250000	0.249960
O.D.	0.624825	0.624815	0.624840	0.624800
Contact Angle	29°50'		30°30'	29°30'
Ball Diam	0.09365			
Inner Race Land O.D.	0.3777			

	<u>Retainer Dimensions</u>		<u>Tolerances</u>	
Pocket Diam	See retainer pocket alignment check		0.098	0.097
I.D.	0.3855		0.386	0.382
O.D.	0.4772		0.476	0.472
Width	See retainer alignment check		0.196	0.194
Oil Retention	13.2%			
Material	MC-26-10			



Inner



Outer

Fig. A-15 R-2B Races 2, Uncleaned, (250X).

Bearing cleaning for oil wettability: Acetone extracted; T.C.P. soak.
Wettability check, O.K.

No. 2 End of wheel contained bearing NA-5 type
SR 4 H x 88 K with retainer #6774

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>
Width inner	0.195645	0.195630	0.1960	0.1955
Width outer	0.195820	0.195815	0.1960	0.1955
Bore	0.249985	0.249970	0.250000	0.249960
O.D.	0.624825	0.624815	0.624840	0.624800
Contact Angle	30 ⁰ 0'		30 ⁰ 30'	29 ⁰ 30'
Ball Diameter	0.09340			
Inner Race Land O.D.	0.3776			

	<u>Retainer Dimensions</u>		<u>Tolerances</u>	
Pocket Dia	See retainer pocket alignment check		0.098	0.097
I.D.	0.3860		0.386	0.382
O.D.	0.4778		0.476	0.472
Width	See retainer alignment check		0.196	0.194
Oil Retention:	15.5%	Material: MC-26-10		

Bearing cleaning for wettability: Acetone extracted, wettability check,
T.C.P. soak, wettability check, special 3
Freon cleaning, oil ageing in V-78 oil at
180⁰F for one week. Wettability check. O.K.

RETAINER POCKET ALIGNMENT CHECK

<u>End 1</u>				<u>End 2</u>				
0.0501	0.1001	0.0455	0.1957	1.	0.0470	0.1035	0.0438	0.1943
0.0499	0.1000	0.0468	0.1967	2.	0.0478	0.1019	0.0448	0.1945
0.0500	0.1001	0.0456	0.1957	3.	0.0469	0.1034	0.0438	0.1941
0.0496	0.1033	0.0449	0.1978	4.	0.0479	0.1030	0.0437	0.1946
0.0480	0.1025	0.0435	0.1940	5.	0.0480	0.1010	0.0445	0.1935
0.0482	0.1015	0.0452	0.1949	6.	0.0490	0.1024	0.0441	0.1955
0.0498	0.1011	0.0433	0.1942	7.	0.0456	0.1060	0.0419	0.1935
<u>Max. Misalignment</u>								
0.0021		0.0035			0.0034		0.0029	

Note: Above dimensions represent distance from side surface of retainer to edge of hole; from edge of hole to edge of hole; from edge of hole to side surface of retainer. Readings taken with a Unitron tool-maker's microscope. Accuracy of each measurement is $\pm 0.0001''$.

5. Special Checks

Roundness and cross race curvature were measured on the Taly-rond. Results for inner and outer races which are shown in Figures A-16 and A-17 were within specified limits with the exception of the out of roundness condition of #1 inner race (NA-1) which had a diametrical run-out of 50 micro-inches.

6. Conclusions

Wheel #R-2B was rejected after a brief run because of an erratic differential power trace which often went off scale followed by a return. This behavior is typical of an unstable retainer. Erratic retainer motion was observed using microscope and stroboscope. End 1 bearing outer race and balls sustained damage as a result of this instability. The hardware on this end was not reusable. Bearings on #2 end were reusable. The wheel was run for only 20 hours. The brevity of this run is the reason for the good appearance of retainers.



Fig. A-16 Roundness and cross race curvatures of inner races assembled to shaft (Wheel R-2B).

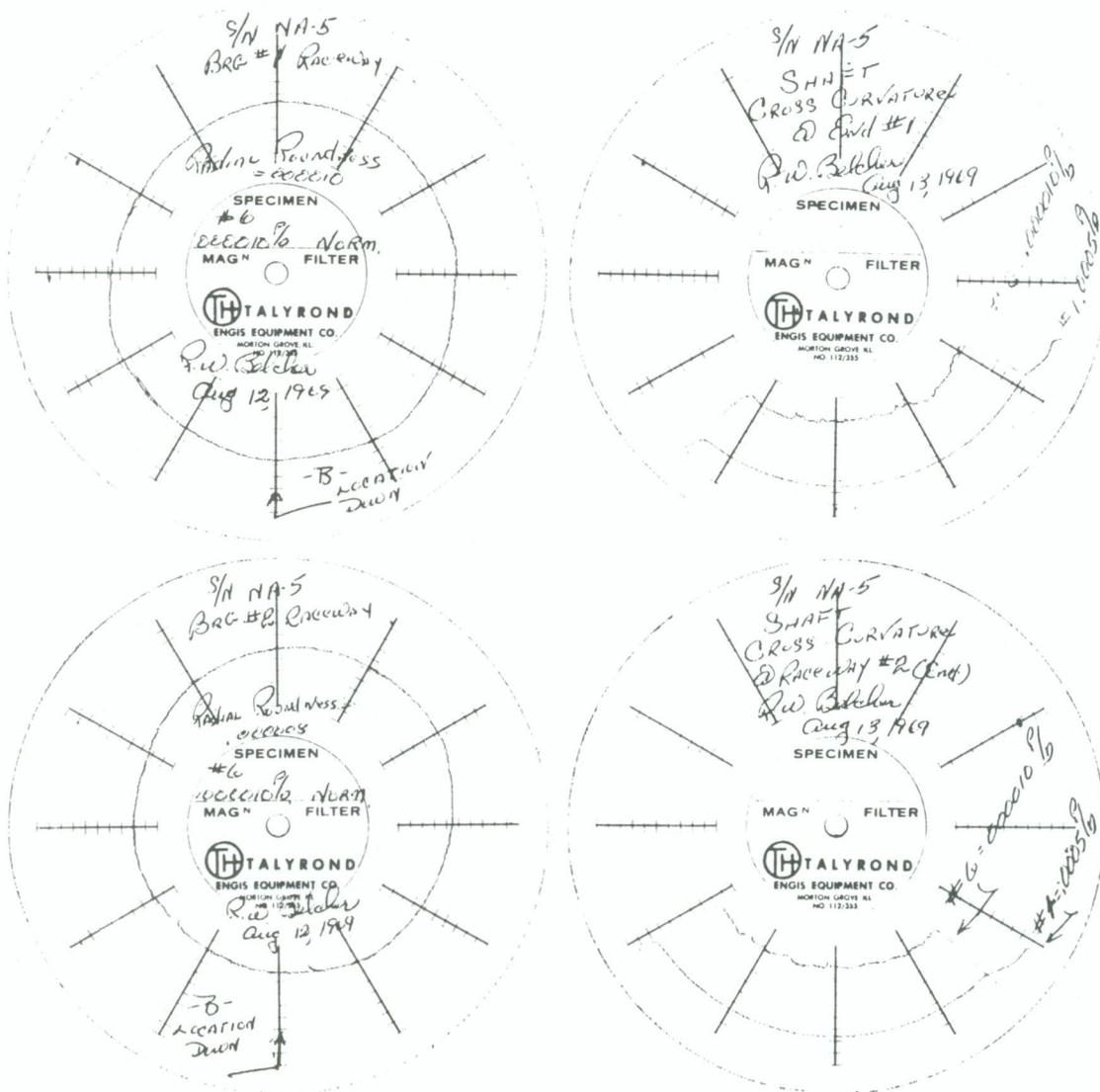


Fig. A-17 Roundness and cross race curvatures of outer races (Wheel R-2B).

VII FAILURE ANALYSIS REPORT FOR WHEEL # R-5

1. History

The subject Apollo I R-4 wheel was rejected because of retainer instability in the # 2 end.

2. Analysis

A microscope-stroboscope study revealed that the # 2 retainer was radially unstable. Although the mean power level was fairly constant the differential wattmeter trace quality was poor and the retainer beat period varied from 4.8 to 6.9 seconds.

3. Wheel and Bearing Dissection

- SRA End I

A. Retainer

Surfaces were clean and unstained except for three pockets which had approximately 180 degree medium brown stain in a spotty accumulation midway on the forward walls.

B. Inner Race (Figure A-18)

Ball trace was normal in appearance with varying shades of gray. Two small parallel scratches may be seen on photograph. No perceptible oil film was present on raceway except for dark blotch of oil shown in photograph. No discolor, debris or residue deposits were observed.

C. Outer Race (Figure A-18)

Ball track was normal appearing with varying shades of gray. Photo shows scratch on raceway. No perceptible oil film on raceway (except for blob in photo). No discolor, debris or residue deposits were observed.

D. Balls

All balls had a dry dull appearance and were unmarked except in two instances. One ball had a very faint gray band encircling it. The other had a fine shiny hairline about its circumference.

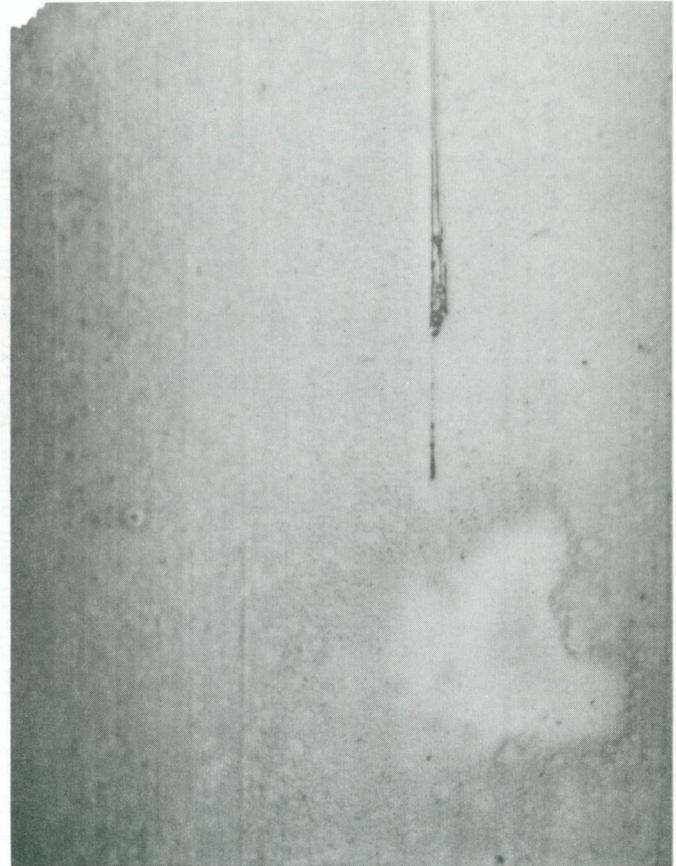
+ SRA End 2

A Retainer

Surfaces were clean and free of stain except for a few pockets



Inner



Outer

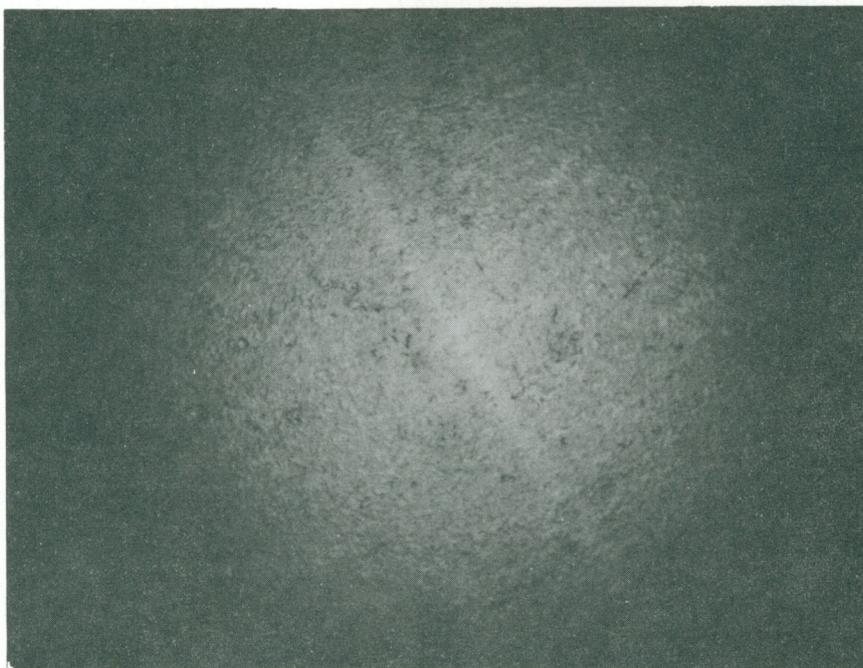
Fig. A-18 R-5 Races 1, Uncleaned, (160X).



Inner Race



Outer Race



Ball End

Fig. A-19 R-5 Bearing Parts 2, Uncleaned, (160X).

which had very light tan spots sprinkled about a small area.

B. Inner Race (Figure A-19)

No perceptible oil film was on raceway. Ball track was grey with light discoloration running along center of it (see photograph). There were no debris or residue deposits.

C. Outer Race (Figure A-19)

No detectable oil film was found on raceway. Two small white blobs in photo may be oil drops. Normal gray ball track was noted but no evidence of debris, discoloration or residue.

D. Balls (Figure A-19)

Two balls had one fine shiny hairline circumscribing them. Three balls had one light wide wear band around their circumference (see photograph) the remaining two balls were unmarked.

4. Bearing and Retainer Dimensions

No. 1 end of wheel contained bearing NA-56 type SR 4 H x 88 L Retainer #6448

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>
Width inner	0.195940	0.195925	0.1960	0.1955
Width outer	0.195925	0.195920	0.1960	0.1955
Bore	0.249980	0.249935	0.250000	0.249960
O.D.	0.624820	0.624810	0.624840	0.624800
Inner Race Land O.D.	0.3776			
Contact Angle	29 ⁰ 45'		30 ⁰ 30'	29 ⁰ 30'
Ball Diam	0.09335			

	<u>Retainer Dimensions</u>		<u>Tolerances</u>	
Pocket Diam	See retainer pocket alignment check		0.098	0.097
I.D.	0.3845		0.386	0.382
O.D.	0.4777		0.476	0.472
Width	See retainer alignment check		0.196	0.194

Material: MC-26-10

Oil Retention: 14.4%

Bearing Cleaning for oil wettability: Acetone extraction and passivation.
Re-TCP soak, 3 solution cleaned.
Wettability O.K.

No. 2 End of wheel contained bearing NA-62
Type SR 4 H x 88 L Retainer # 6449

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
	<u>Max</u>	<u>Min</u>	<u>Max</u>	<u>Min</u>
Width inner	0.195930	0.195925	0.1960	0.1955
Width outer	0.195945	0.195940	0.1960	0.1955
Bore	0.249990	0.249975	0.250000	0.249960
O.D.	0.624835	0.624825	0.624840	0.624800
Inner Race Land O.D.	0.3776			
Contact Angle	30° 20'		30° 30'	29° 30'
Ball Diameter:	0.09345			

	<u>Retainer Dimensions</u>		<u>Tolerances</u>	
Pocket Diam	See retainer pocket alignment check		0.098	0.097
I.D.	0.3840		0.386	0.382
O.D.	0.4779		0.476	0.472
Width	See retainer alignment check		0.196	0.194
Material:	MC-26-10			

Oil Retention: 15.3%

Bearing cleaning for oil wettability: Acetone extracted, re-passivated,
Re-TCP soak, wettability check, O.K.

RETAINER ALIGNMENT CHECK

<u>END #1</u>				<u>TOTAL</u>				<u>END #2</u>				<u>TOTAL</u>			
1.	0.0527	0.0963	0.0471	0.1961	1.	0.0472	0.0970	0.0529	0.1971						
2.	0.0523	0.0960	0.0466	0.1949	2.	0.0468	0.0968	0.0526	0.1963						
3.	0.0519	0.0970	0.0471	0.1960	3.	0.0468	0.0956	0.0520	0.1944						
4.	0.0528	0.0972	0.0468	0.1968	4.	0.0478	0.0971	0.0528	0.1977						
5.	0.0526	0.0968	0.0472	0.1966	5.	0.0477	0.0975	0.0524	0.1966						
6.	0.0528	0.0968	0.0472	0.1968	6.	0.0472	0.0963	0.0524	0.1959						
7.	0.0524	0.0967	0.0474	0.1965	7.	0.0481	0.0980	0.0528	0.1989						

(TOLERANCE RANGE: 0.0480 to 0.0495)

Maximum
Misalignment

0.0009

0.0008

0.0013

0.0009

Note: Above dimensions represent distance from side surface of retainer to edge of hole; from edge of hole to edge of hole; from edge of hole to side surface of retainer. Readings taken with a Unitron toolmaker's microscope. Accuracy of each measurement is $\pm 0.0001''$.

5. Special Checks

Roundness and cross race curvature was measured on the Talyrond. Results for inner and outer races which are shown in Figures A-20 and A-21 were within acceptable limits.

6. Conclusions:

The rejection of wheel # R-5 after 593 hours of running time was due to the instability of the retainer in the # 2 end. Scratch on # 1, outer raceway precluded it from being reused. Lack of detectable oil film on raceway surfaces after disassembly is a matter of concern. The data parameters pointed to unreliability in performance and a prognosis for bearing deterioration with continued running.

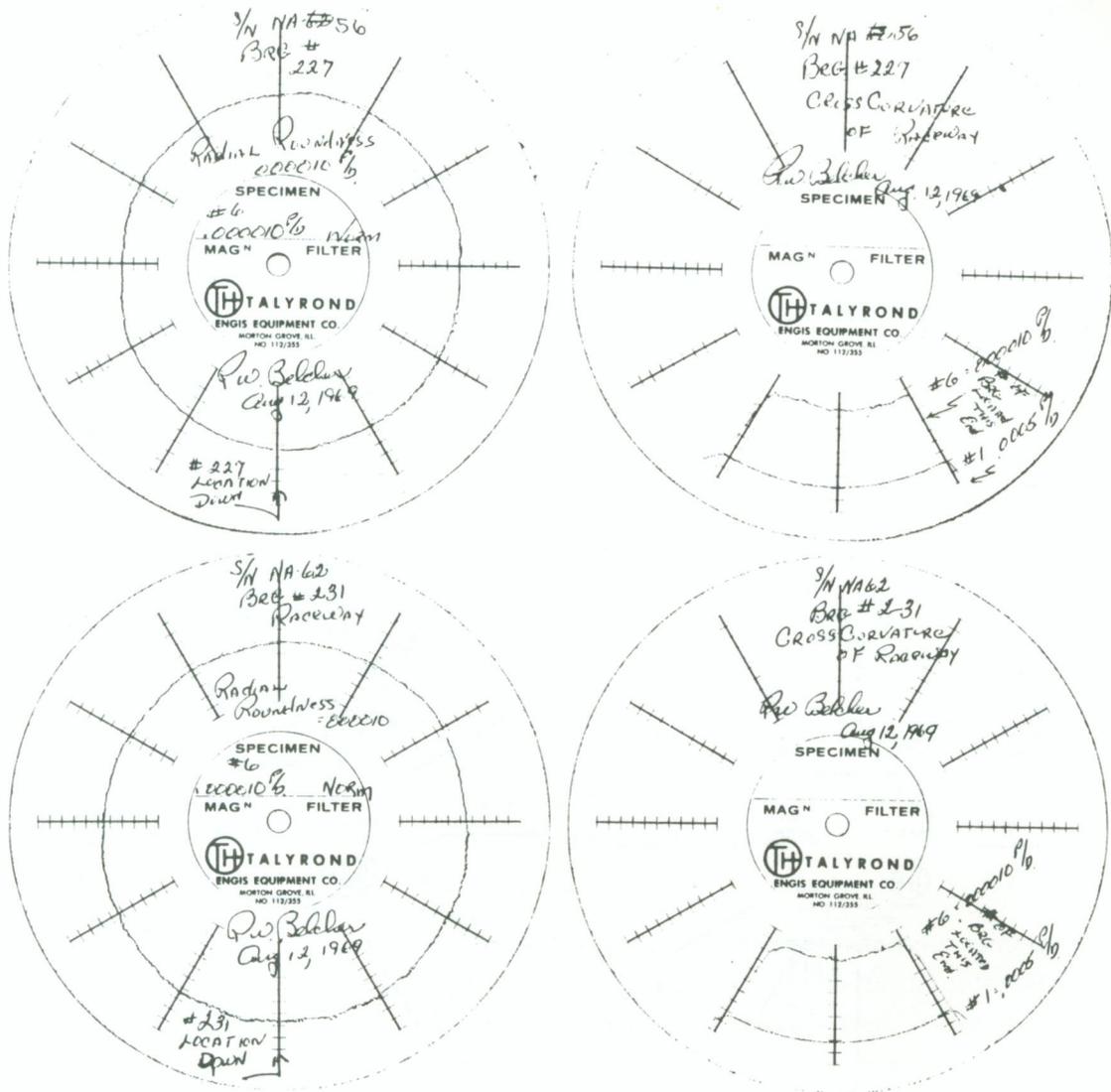


Fig. A-20 Roundness and cross race curvatures of outer races (Wheel R-5).

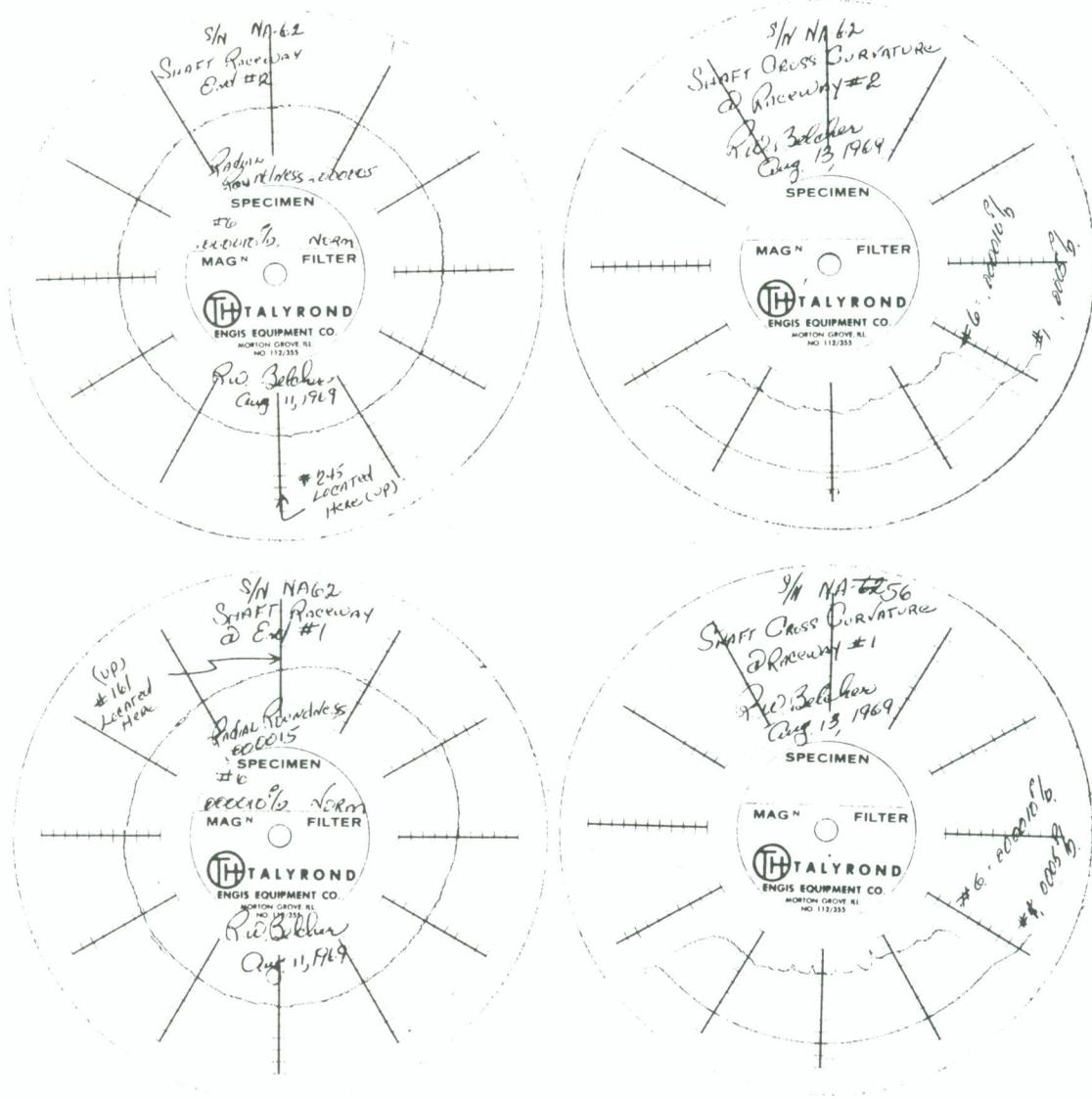


Fig. A-21 Roundness and cross race curvatures of inner races assembled to shaft (Wheel R-5).

VIII. FAILURE ANALYSIS REPORT FOR WHEEL #R-10A

1. History

The subject Apollo I R-4 wheel was rejected because of an erratic differential power trace with a hash level of approximately 40 milliwatts, superimposed with spikes. There were also power step level changes of about 35 milliwatts.

2. Analysis

The wheel was stopped after 42 hours of running time. Retainer motion study showed no abatement of retainer instability.

3. Wheel and Bearing Dissection

-SRA End I

A. Retainer

Surfaces were free of metal and varnish contamination. Ball pockets showed very light brown spots of stain on the forward and trailing walls of a few pockets. The remainder were lightly speckled on just one wall.

B. Inner Race (Figure A-22)

The surface had a matte-like finish typical of ball-lapped bearings. A light oil film was evident on the shiny ball track. There was no residue, discoloration, or debris. Photograph shows inner raceway surface was unmarked after cleaning.

C. Outer Race (Figure A-22)

Race surface had light oil film distributed over a matte finish. There was a shiny ball track with a narrow line of discoloration running along it. No debris or residue accumulations were observed. Outer raceway surface was unmarked after cleaning.

D. Balls (Figure A-22)

Balls had a matte finish covered with light oil stain. Four balls had two parallel shiny bands. Three balls had the two parallel shiny bands plus a narrow discolored band.

+SRA End II

A. Retainer

Surfaces were free of metal and varnish contamination. There were a few very light spots of stain in some of the ball pockets.

B. Inner Race (Figure A-23)

Surface had a matte finish and light oil film. There was a normal shiny ball track with no discoloration, debris, or residue deposits. Raceway was unmarked after cleaning.

C. Outer Race (Figure A-23)

Surface had a matte finish and light oil film. There was a normal shiny ball track with no discoloration, debris, or residue deposits. Raceway was unmarked after cleaning.

D. Balls

Balls had a matte finish covered with light oil stain. Each ball had one shiny wear band.

4. Bearing and Retainer Dimensions

No. 1 end of wheel contained bearing NA-21R type
S R 4 H x 303 (88K Rework) Retainer #6765

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
Width Inner	0.195705	0.195695	0.1960	0.1955
Width Outer	0.195840	0.195830	0.1960	0.1955
Bore	0.249980	0.249975	0.250000	0.249960
O. D.	0.625835	0.625825	0.624840	0.624800
Contact Angle	30° 25'		30° 30'	29° 30'
Ball Diameter	0.09340			
Inner Race Land O. D.	0.3776			

	<u>Retainer Dimensions</u>		<u>Tolerances</u>	
Pocket Diam.	See retainer alignment check		0.098	0.097
I. D.	0.3845		0.386	0.382
O. D.	0.4785		0.476	0.472
Width	See retainer alignment check		0.196	0.194
Oil Retention	18.3 %			
Material	MC-26-6			

Bearing cleaning for wettability: 3 solution cleaning in ultrasonic--rinsed in solution--wettability O.K.

No. 2 end of wheel contined bearing NA-22R type S R 4 H x 303
 (88K rework), retainer # 6766.

	<u>Bearing Dimensions</u>		<u>Tolerances</u>	
Width Inner	0.195560	0.195540	0.1960	0.1955
Width Outer	0.195815	0.195805	0.1960	0.1955
Bore	0.249985	0.249965	0.250000	0.249960
O. D.	0.624825	0.624820	0.624840	0.624800
Contact Angle	30 ⁰ 25'		30 ⁰ 30'	29 ⁰ 30'
Ball Diameter	0.09340			
Inner Race Land OD	0.3776			

Bearing cleaning for wettability: 3 solution cleaning in ultrasonic--rinsed
 in solution--wettability O.K.

	<u>Retainer Dimensions</u>	<u>Tolerances</u>	
Pocket Diam	See retainer alignment check	0.098	0.097
I. D.	0.3845	0.386	0.382
O. D.	0.4783	0.476	0.472
Width	See retainer alignment check	0.196	0.194
Oil Retention	21.1 %		
Material	MC-26-6		

RETAINER ALIGNMENT CHECK

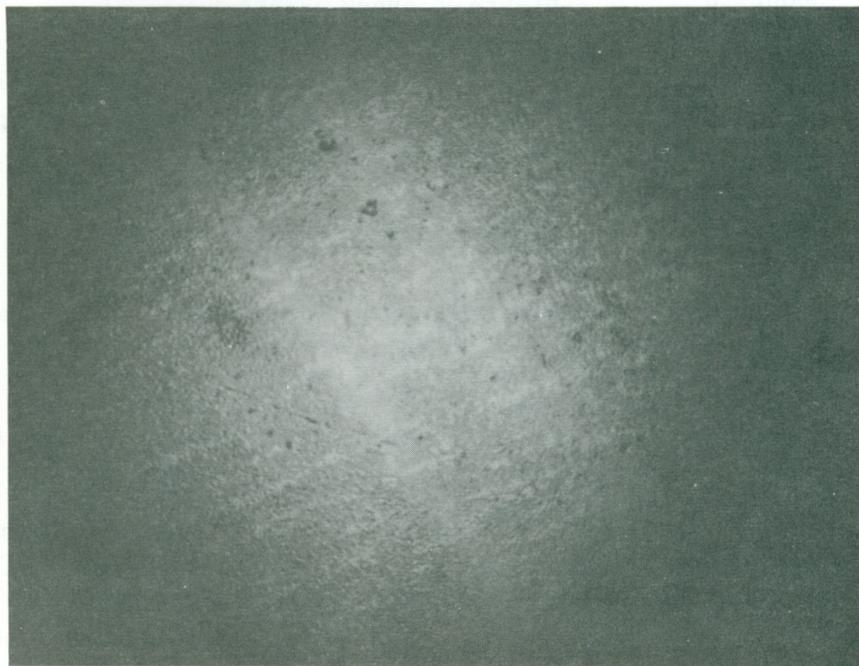
	<u>End 1</u>					<u>End 2</u>			
				Total					Total
1.	0.0454	0.0961	0.0511	0.1926	1.	0.0460	0.0964	0.0509	0.1933
2.	0.0450	0.0956	0.0512	0.1918	2.	0.0470	0.0965	0.0510	0.1945
3.	0.0449	0.0958	0.0515	0.1920	3.	0.0469	0.0972	0.0513	0.1954
4.	0.0448	0.0955	0.0509	0.1932	4.	0.0465	0.0962	0.0511	0.1938
5.	0.0454	0.0956	0.0513	0.1923	5.	0.0460	0.0965	0.0512	0.1937
6.	0.0442	0.0963	0.0511	0.1916	6.	0.0455	0.0960	0.0503	0.1918
7.	0.0453	0.0952	0.0506	0.1911	7.	0.0461	0.0954	0.0502	0.1917
Max. Misalignment									
	0.0012		0.0009			0.0015		0.0011	



Inner Race

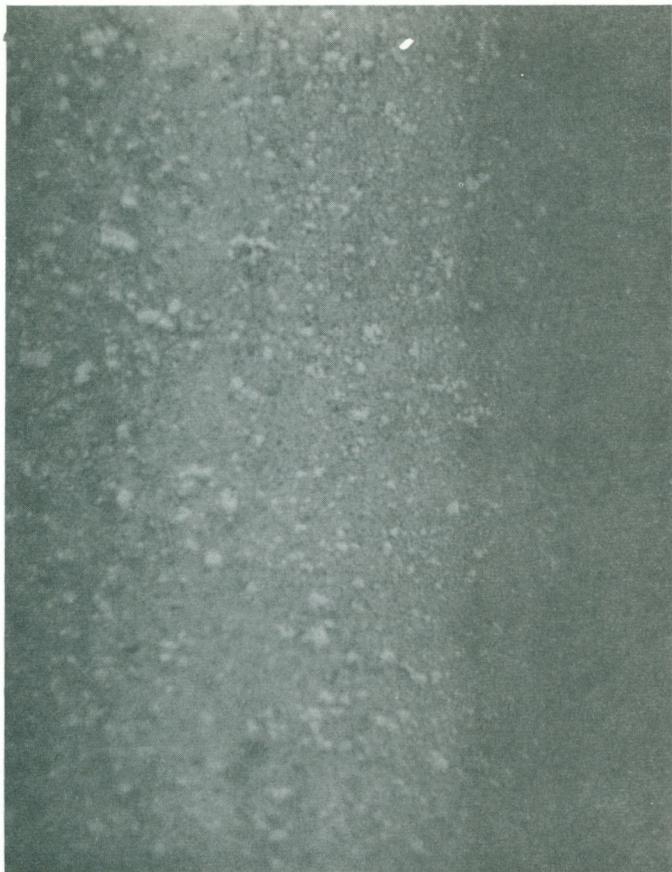


Outer Race



Ball End

Fig. A-22 R-10 Bearing Parts 1, Uncleaned, (160X).



Inner Race Area 1
Uncleaned



Inner Race Area 2
Uncleaned



Outer Race
Cleaned

Fig. A-23 R-10 Bearing parts 2, (160X)

Note: Above dimensions represent distance from side surface of retainer to edge of hole; edge of hole to edge of hole; edge of hole to side surface of retainer. Readings taken with a Unitron tool-maker's microscope. Accuracy of each measurement is $\pm 0.0001''$

5. Special Checks

Roundness and cross race curvature was measured on the Taly-rond. Results for inner and outer races are shown in Figures A-24 and A-25. The # 2 end of the shaft showed a diametral out of roundness condition of 68 micro-inches.

6. Conclusions

The rejection of R-10A was the result of retainer instability which caused an erratic differential power trace and power step level changes on an order not conducive to good performance. Evidence of the effects of this unstable mode was seen in its incipient stage on the #1 retainer, outer race and balls. Bearing hardware was found to be reusable after cleaning.

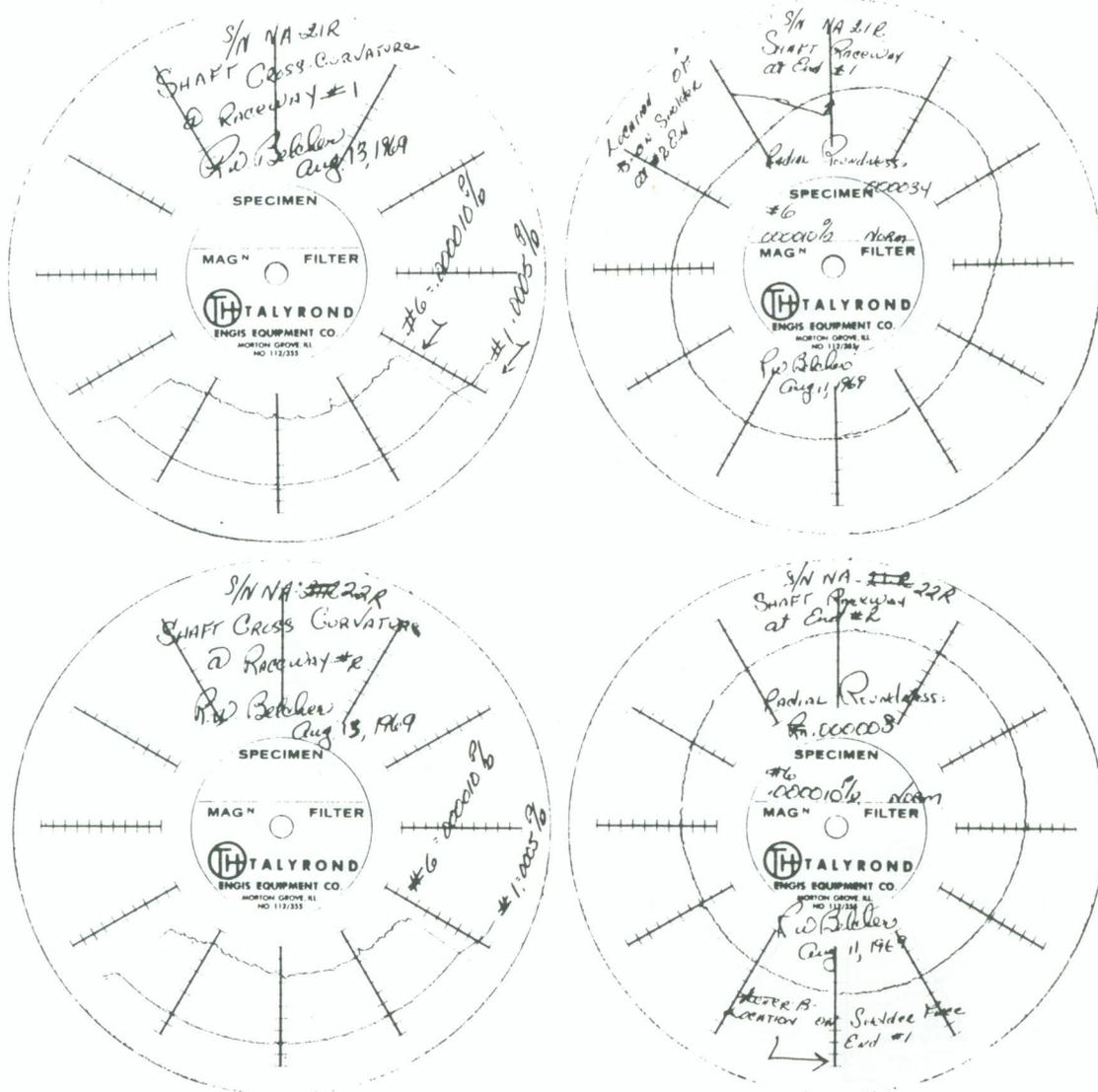


Fig. A-24 Roundness and cross race curvatures of inner races assembled to shaft (Wheel R-10A).

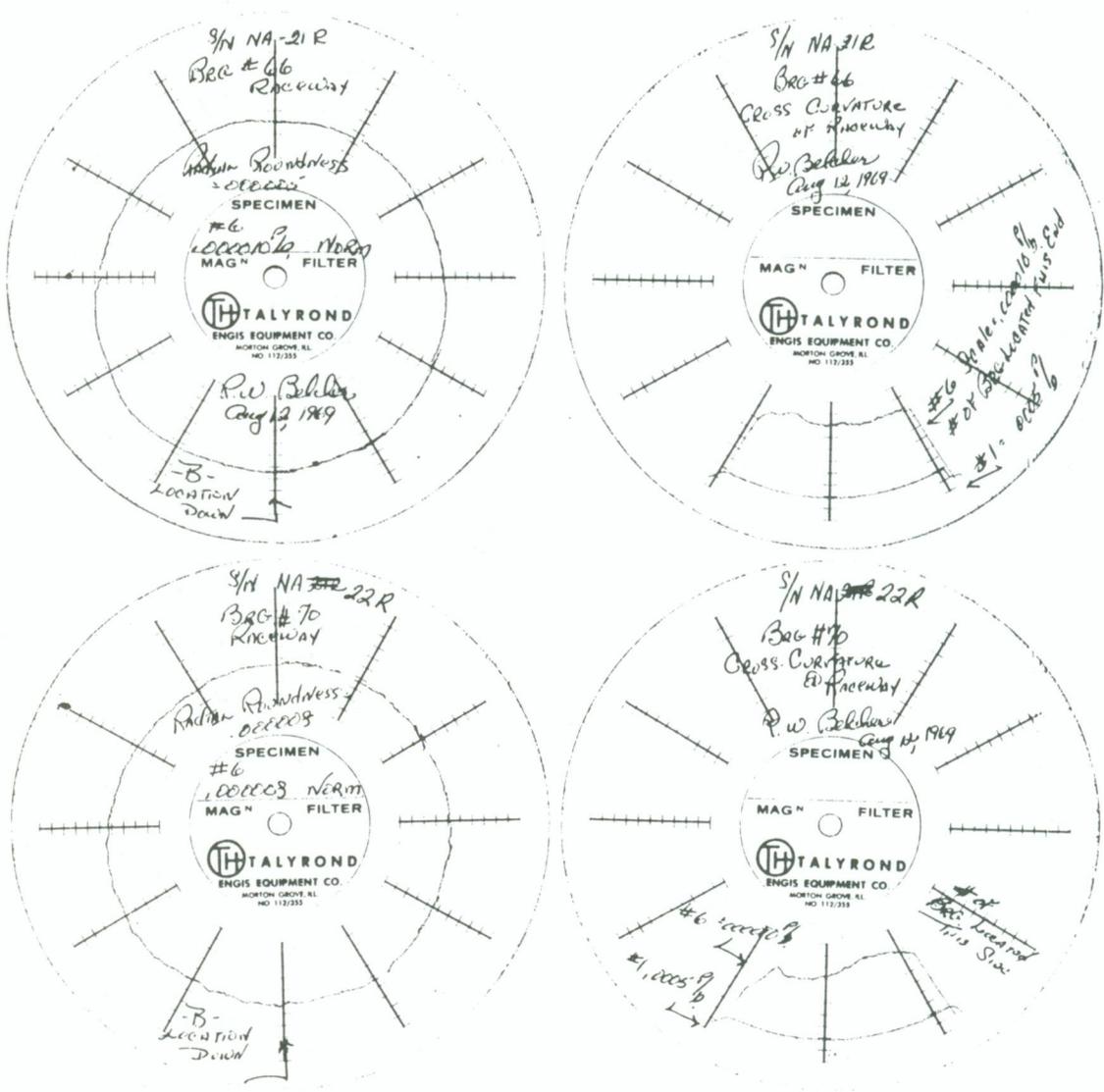


Fig. A-25 | Roundness and cross race curvatures of outer races (Wheel R-10A).

APPENDIX B

COMPUTER PRINTOUT OF GYRO DATA
FROM COMPONENT AND SYSTEM TESTS

R46100

APOLLO RA BEARING - HIP S/N 610

DA/MO/YR	LOC	FYP	NBD	ADPSRA	ADIA	ID	ROT	SDT	WBZEL	ADGA	IAVERT	SRA UP	SRADN2	SDADN1	SRA RDN	POSIT	
									HGURS		SD	SD	SD	SD	UP	DOWN	HORZ
29 SE 67	M63	C1A	-19.6	(-289.2)	-12.2						1.70	0.50	0.90				
BALANCED																	
29 SE 67	M63	C1C	-20.1	-5.0	-5.2						0.70	3.70	0.70				
30 SE 67	M63	C2C	-20.9	-6.1	-4.6						0.80	0.60	1.50				
30 SE 67	M63	C3C	-21.6	-6.8	-6.5	-24.					0.60	0.90	0.60	0.80			
30 SE 67	M63	C4C	-20.8	-7.0	-5.9						0.60	0.80	1.00				
30 SE 67	M63	C5C	-20.7	-7.1	-6.0						0.70	0.60	0.80				
30 SE 67	M63	C6C	-19.5	-7.0	-6.8						0.70	0.60	1.00				
IA VERTICAL, STORAGE, 6 HOURS, EXCITATION ON.																	
1 OC 67	M63	C1D	-20.8	-7.5	-6.2						0.70	0.50	0.70				
1 OC 67	M63	C2D	-20.7	-7.6	-5.3						0.60	0.70	1.50				
WHEEL OVEREXCITED, NEXT RUN REFRAN SRA UP.																	
1 OC 67	M63	C3D	-21.4	-7.2	-4.7	-26.					0.70	0.50	1.00	0.80			
1 OC 67	M63	C4D	-20.6	-6.5	-5.8						0.60	2.40	0.90				
2 OC 67	M63	C5D	-20.9	-7.2	-5.5						0.70	0.70	1.00				
NEXT RUN BE OVEREXCITED WHEEL, SRALED TEMP.																	
2 OC 67	M63	C6D	-18.1	-8.6	-8.2						0.90	2.30	1.10				
WHEEL SYNC, & RUN AT 28V. PHASE A 4.1 WATT, PHASE B 3.7 WATT																	
RADIAL CENTERING SX 1.0, SY 1.0, TX 1.7, TY 2.2																	
2 OC 67	M63	C1G	-22.3	-7.8	-7.0						0.60	0.70	1.10				
2 OC 67	M63	C2G	-21.9	-7.9	-7.4						1.50	0.70	1.50				
2 OC 67	M63	C3G	-21.8	-7.8	-7.0	-22.					1.20	0.70	1.20	0.80			
3 OC 67	M63	C4G									0.90						
FLUTATION SG 132.6F, TG 132.2F.																	
3 OC 67	M63	C1I	-18.5	-9.1	-7.7						0.70	0.80	0.70				
3 OC 67	M63	C2I	-18.5	-9.2	-8.3						0.70	0.70	0.80				
4 OC 67	M63	C3I	-18.3	-9.6	-7.4	-22.					0.60	0.60	0.70	0.90			
4 OC 67	M63	C4I	-20.1	-2.8	-6.2						0.60	0.80	0.90				
NEXT THREE TESTS UNIT TEMP. 140 DEG F																	
4 OC 67	M63	C1J	-12.6	-8.3	-14.3						0.70	10.40	1.50				
4 OC 67	M63	C2J	-17.2	-15.5	-6.7						0.60	0.60	0.70				
4 OC 67	M63	C3J	-18.2	-17.0	-5.1	-21.					0.60	0.80	0.70	0.70			
5 OC 67	M63	C1K	-17.1	-17.4	-4.6						0.60	0.80	1.00				
NEXT RUN REFRAN SRA DOWN, BLOW FUSE IN WHEEL SUPPLY																	
5 OC 67	M63	C2K	-25.3	-5.3	-6.7						0.70	0.70	0.90				
5 OC 67	M63	C3K	-17.2	-8.1	-3.3						0.70	0.70	0.70				
WHEEL SUPPLY REPAIRED. ADJUSTED PHOTOCELL AMP																	
5 OC 67	M63	C1L	-17.7	-7.9	-2.9						0.70	1.20	0.60				
5 OC 67	M63	C2L	-17.7	-8.0	-3.3						0.50	0.70	0.70				
5 OC 67	M63	C3L	-17.0	-7.7	-2.2	-21.											
NEXT TEST UNIT TEMP. 130 DEG F																	
6 OC 67	M63	C1M									0.50	1.00	1.10	0.80			
											0.50	4.10					
6 OC 67	M63	C1N	-16.7	-8.8	-1.8						0.40	0.80	1.10				
6 OC 67	M63	C2N	-17.3	-8.7	-2.7						0.50	0.70	0.80				
7 OC 67	M63	C3N	-17.2	-8.7	-3.0	-21.					0.50	1.00	0.90	0.90			
COOLDOSE#4, 17 HOURS, NEXT RUN IA VERT.																	
7 OC 67	M63	C1O	-16.8	-9.2	-2.5						0.50	1.10	0.90				
8 OC 67	M63	C2O	-17.2	-9.2	-2.8						0.70	0.70	0.80				
8 OC 67	M63	C3O	-17.3	-9.3	-3.3	-21.					0.60	0.80	0.90	0.80			

DI/NO/TP	LOC	TYP	NBD	ADSEA	ADIA	ID	RUT	RDT	WHEEL HOURS	ADOA	IAVERT SD	SRA UP SD	SRADN2 SD	SDADN1 SD	SRA RNDM UP	POSIT DOWN	HORZ
COOLDOWN #2, 6 HOURS, NEXT RUN IN VERT.																	
8	OC	67	H63	C1P	-15.8				9.4	-	1.8	0.60	1.00	1.10			
9	OC	67	H63	C2P	-15.8				9.7	-	2.1	0.50	0.70	0.80			
9	OC	67	H63	C3P	-15.8			20.	9.7	-	2.6	0.50	0.80	0.70	0.70		
9	OC	67	H63	C4P								0.50					
CHANGED WHEEL SUPPLY																	
9	OC	67	H63	C1Q	-17.6				9.7	-	5.0	0.70	0.80	0.50			
9	OC	67	H63	C2Q	-17.5				9.9	-	4.4	0.60	0.80	0.50			
16	OC	67	H63	C3Q	-17.8			22.	9.8	-	4.1	0.60	1.00	1.00	0.80		
10	OC	67	H63	C4Q	-17.8				10.1	-	4.2	0.60	1.00	0.50			
WHEEL RUN DOWN, NEXT DATA 5 DEGREES PER POSITION																	
17	OC	67	H63	C1R	-16.3				10.5	-	5.2	0.60	0.60	1.20			
NEXT THREE TESTS UNIT TEMP. 140 DEG F																	
14	OC	67	H63	C1S	-16.2				10.7	-	6.4	0.50	0.70	1.00			
10	OC	67	H63	C2S	-16.1				10.8	-	6.6	0.60	0.70	1.00			
10	OC	67	H63	C3S	-16.1			19.	10.9	-	6.9	0.60	0.80	1.00	0.90		
11	OC	67	H63	C1T	-15.6				10.3	-	5.1	0.50	0.90	0.90			
11	OC	67	H63	C2T	-15.8				10.6	-	5.0	0.60	1.00	0.90			
NEXT RUN WHEEL RAN AT 24V, NOT OVEREXCITED																	
11	OC	67	H63	C1U	-11.5				10.2	-	1.1	0.60	1.00	0.80			
11	OC	67	H63	C2U	-11.4				10.3	-	2.1	0.60	0.90	0.90			
11	OC	67	H63	C3U	-11.6			16.	10.3	-	1.6	0.60	1.30	1.10	1.00		
NEXT RUN WHEEL RAN AT 26V, NOT OVEREXCITED																	
12	OC	67	H63	C1V	-13.4				11.1	-	6.9	0.60	0.70	0.90			
12	OC	67	H63	C2V	-14.3				10.5	-	2.0	0.70	0.80	0.90			
12	OC	67	H63	C3V	-14.3			18.	10.7	-	2.8	0.60	1.10	1.00	1.20		
NEXT RUN WHEEL RAN AT 28V, NOT OVEREXCITED																	
12	OC	67	H63	C1W	-17.7				10.7	-	1.7	0.60	1.10	1.10			
12	OC	67	H63	C2W	-17.6				10.7	-	1.6	0.70	1.10	0.90			
12	OC	67	H63	C3W	-17.6			22.	10.8	-	1.5	0.60	1.00	1.00	0.80		
NEXT RUN WHEEL RAN AT 30V, NOT OVEREXCITED																	
13	OC	67	H63	C1X	-17.9				11.2	-	2.0	0.60	0.90	0.90			
13	OC	67	H63	C2X	-17.7				11.1	-	3.0	0.70	0.80	1.60			
13	OC	67	H63	C3X	-17.9				11.6	-	2.8	0.60	0.50	1.50			
NEXT RUN WHEEL START & RAN AT 28V																	
12	OC	67	H63	C1Y	-14.9				11.4	-	2.5	0.70	1.10	1.40			
LONG TEST IN VERT.																	
16	OC	67	H63	C1A	-12.3				11.7	-	0.2	0.60	11.00	3.20			
16	OC	67	H63	C2A	-14.6				11.0	-	2.8	1.20	1.50	0.90			
17	OC	67	H63	C3A	-14.6			19.	11.1	-	2.8	0.70	1.50	0.70	1.00		
17	OC	67	H63	C4A	-14.8				11.1	-	3.0	0.70	1.70	0.80			
17	OC	67	H63	C5A	-15.3				11.6	-	3.1	0.60	1.20	1.40			
NEXT TEN TESTS UNIT TEMP. 130 DEG F																	
17	OC	67	H63	C1B	-15.0				11.0	-	4.0	0.50	1.50	0.90			
17	OC	67	H63	C2B	-15.0				10.7	-	4.5	0.50	1.30	1.40			
17	OC	67	H63	C3B	-15.2			20.	10.7	-	4.8	0.60	1.20	1.20	0.80		
18	OC	67	H63	C4B	-15.2				10.6	-	5.1	0.60	1.30	1.30			
18	OC	67	H63	C5B	-15.5				10.7	-	5.8	0.60	1.40	0.80			
18	OC	67	H63	C6B	-15.5			20.	10.8	-	5.6	0.60	1.70	0.90	1.00		
18	OC	67	H63	C7B	-15.6				10.7	-	5.6	0.60	1.30	0.90			
18	OC	67	H63	C8B	-15.5				10.8	-	5.2	0.50	1.60	0.90			
19	OC	67	H63	C9B	-15.8			20.	10.7	-	6.1	0.60	1.30	1.00	0.80		
19	OC	67	H63	C0B	-15.8				10.7	-	6.3	0.70	1.30	1.00			
18	OC	67	H63	C1C	-16.7				11.4	-	4.0	0.50	1.40	1.40			

DA/MO/YR	LOC	TYP	RBD	ADSPA	ADIA	ID	RUT	RDT	WHEEL HOURS	ADDA	IAVERT SD	SRA UP SD	SRADN2 SD	SDADM1 SD	SRA RMDN UP DOWN	POSIT HORZ
19	OC	67	M53	C2C	-16.3	12.7	5.0				3.60	1.20	1.40			
19	OC	67	M53	C3C	-15.0	10.3	4.1	-17.			0.50	0.80	1.30	0.50		
19	OC	67	M53	C4C	-16.0	8.0	6.3				0.60	1.70	1.10			
20	OC	67	M53	C5C	-16.2	10.2	5.4				0.60	0.70	0.60			
20	OC	67	M53	C6C							0.50	1.90				
20	OC	67	M53	C1D	-9.3	8.7	4.6				4.00	1.90	5.60			
20	OC	67	M52	C2D	-9.4	6.5	6.5				3.30	2.00	3.90			
20	OC	67	M52	C3D	-9.0	8.3	5.5				1.50	4.20	10.60			
LONG TERM IA VERT. FOR ACCEPTANCE E, F, G, H,																
27	OC	67	M62	C1I	-16.7	7.8	8.8				0.50	0.20	1.40			
30	OC	67	M62	C2I	-16.5	7.6	8.3				1.20	1.10	0.70			
30	OC	67	M62	C3I	-16.8	7.4	9.0				0.60	0.40	0.70			
30	OC	67	M62	C1J	-17.6	7.2	9.3				0.50	0.90	1.50			
30	OC	67	M62	C2J	-15.2	10.0	7.0				0.40	0.70	1.70			
1/2 EXCITATION WAS RUN SRA UP																
30	OC	67	M62	C3J	-17.2	12.0	11.3	-20.			0.60	0.80	0.40	0.90		
31	OC	67	M62	C4J	-17.6	12.3	12.1				0.80	0.90	1.00			
31	OC	67	M62	C5J							0.40		1.70			
LONG TERM IA VERT. COUNTER CHANGED																
2	NO	67	M62	C1L	-15.2	10.1	7.9				0.40	0.90	1.50			
2	NO	67	M62	C2L	-15.2	11.3	8.8				0.40	4.80	2.20			
3	NO	67	M62	C3L	-16.4	10.3	11.4	-19.			0.40	0.60	0.50	0.50		
3	NO	67	M62	C4L	-15.8	10.9	11.8				0.50	0.60	1.10			
3	NO	67	M62	C5L	-15.9	11.0	11.0				0.80	0.60	0.60			
3	NO	67	M62	C6L	-15.7	10.8	11.2	-19.			0.50	0.70	0.80	0.50		
3	NO	67	M62	C7L	-15.5	10.8	11.9				0.50	0.60	1.40			
3	NO	67	M62	C8L	-15.5	10.7	11.0		65		0.70	0.60	0.50			
LONG TERM IA VERT. HORIZ. AND COMPLIANCE TESTS.																
NEXT RUN SHROUD PORTS SEALED.																
LONG TERM IA VERT. NEXT RUN SHROUD PORTS SEALED.																
2	JA	68	M64	C1C	-14.9	4.6	25.5				0.30	2.30	1.40			
2	JA	68	M64	C2C	-15.1	4.8	26.1				0.10	1.30	1.20			
3	JA	68	M64	C3C	-15.1	4.6	26.3	-19.9			0.10	1.40	1.50	1.40		
3	JA	68	M64	C4C					2199		0.80	1.20				16
SJA68 DELIVERED TO MIT/IL APOLLO GROUP.																
UNIT REALIGNED AS A MOD.3 CYAO RUN AT 9600CPS EXCITATION & SUSP.																
PRIMARY RESISTOR ADJUSTS TRANSFER FUNCTION TO 15 MV/50.																
29	FE	68	M51	C5D	-21.1	5.3	23.7				0.16	1.15	2.62			
IA HORIZ. SERVO RUN 2 1/3 REVOLUTIONS 1-48R58.																
5	MR	68	M51	C5D	-23.0	6.5	25.6				0.16	1.41	1.62			
6	MR	68	M51	C5D	-22.6	6.9	25.3				0.17	2.01	1.74			
IA VERT. SERVO RUN 1 1/6 REVOLUTIONS 8-11MR58.																
IA VERT. SERVO RUN 1 REVOLUTION 15-16MR58.																
13	MR	68	M51	C5D	-19.1	14.2	24.2									
NEXT RUN SAME TIME AS PREVIOUS. THIS RUN ON UP DOWN.																
19	MR	68	M51	C5D	-17.9					0.3						
19	MR	68	M51	C5D	-25.9	15.4			2761							
IA VERT. SERVO RUN 1/2 REVOLUTION 21-22MR68.																
13	MR	68	M51						67							
CHECKED AS "I" ON PROD. MOD. PREAMP.																
UNIT68 INSTALLED INTO Y AXIS OF GNSIP.																
14	CC	68							3011							21
180C68 REMOVED FROM Y AXIS OF GNSIP.																

DA/MO/YR	LOC	TYP	MBD	ADSR	ADIA	ID	RUT	RDT	WHEEL	IAVERT	SRA	UP	SRADN2	SDADM1	SRA	RBDW	POSIT
150C68	UNIT	DELIVERED	TO	IL-7	COMPONENT	AREA.			HOURS	ADDA	SD	SD	SD	SD	UP	DOWN	HORZ

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DA/MO/YR	LOC	TYP	NBD	ADSPA	ADIA	ID	RUT	EDT	WHEEL HOURS	ADOA	I/VERT SD	SRA UP SD	SRADN2 SD	SDADN1 SD	SRA-RNDN UP DOWN	POSIT HORZ
14 DE 67	H63	C1A	4.4	(-671.2)	(110.4)						1.30	3.50	0.43			
14 DE 67	H63	C2A	4.3	(-670.9)	(110.3)						0.60	2.00				
14 DE 67	H63	C3A	4.7	(-671.0)	(109.0)						0.70	1.80				
BALANCED. NEXT RUN 3 DEG. DATA PER POSITION. DESHROUDED.																
15 DE 67	H63	C1C	6.8	(-378.4)	45.5						0.90	1.50	0.50			
BALANCED.																
15 DE 67	H63	C1E	5.9	2.0	52.8						0.60	0.70	0.80			
15 DE 67	H63	C2E	5.9	1.5	51.4						0.60	0.70	0.80			
16 DE 67	H63	C3E	6.2	1.3	50.4	11.8					0.60	0.60	0.80	0.80		
16 DE 67	H63	C1F	6.9	0.8	51.5						0.70	0.70	1.00			
16 DE 67	H63	C2F	5.9	0.8	51.6						0.60	0.80	1.00			
16 DE 67	H63	C3F	5.7	0.8	51.3	11.7					0.90	0.80	0.90	0.80		
NEXT 3 RUNS, UNIT TEMP. 135F.																
16 DE 67	H63	C1G	6.3	0.7	50.2						0.50	0.60	0.90			
17 DE 67	H63	C2G	7.3	1.1	46.9						0.50	0.70	0.80			
17 DE 67	H63	C3G	6.9	0.5	49.2	11.6					0.60	0.70	0.90	0.70		
NEXT 3 RUNS, UNIT TEMP. 140F.																
17 DE 67	H63	C1H	5.6	2.2	47.2						0.60	0.70	0.90			
17 DE 67	H63	C2H	5.0	1.7	45.8						0.50	0.70	1.00			
17 DE 67	H63	C3H	5.3	1.5	45.6	11.0					0.60	0.70	1.00	0.80		
NEXT 3 RUNS, UNIT TEMP. 135F.																
18 DE 67	H63	C1I	6.5	0.8	44.6						0.50	0.70	0.90			
18 DE 67	H63	C2I	5.7	1.4	44.4						0.60	0.70	0.90			
18 DE 67	H63	C3I									0.90	0.80				
BALANCED.																
18 DE 67	H63	C1K	5.6	16.0	1.0						0.60	0.70	0.90			
18 DE 67	H63	C2K	5.7	16.2	0.7						0.60	0.60	0.60			
18 DE 67	H63	C3K	6.4	16.6	0.4	11.6					0.60	0.70	0.70	0.90		
COOLDOWN #1, 8 HOURS, IA VERT. 5 DEG. DATA PER POSITION.																
19 DE 67	H63	C1L	6.2	19.5	2.4						0.60	0.80	0.90			
BALANCED.																
19 DE 67	H63	C1N	6.8	7.2	6.9						0.80	0.80	0.90			
19 DE 67	H63	C2N	7.2	7.3	1.3						0.60	0.70	0.90			
19 DE 67	H63	C3N	6.8	6.4	2.4	30.2					0.60	0.90	0.90	0.90		
DESHROUDED. 5 DEG. DATA PER POSITION.																
21 DE 67	H63	C1O	6.0	9.4	0.2						0.60	0.70	0.70			
5 DEG. TAKEN AT 45 DEG. INTERVALS. IA HORIZ. COMPLIANCE.																
RADIAL CENTERING SX 1.4, SY 2.3, TX 2.7, TY 1.3																
TRANSP. FUNCTION 11.67 HV/HR LOGAR *15.25HR - 15.38 HR.																
28 DE 67	H63	C1T	3.0	9.0	0.3						0.60	0.60	0.80			
28 DE 67	H63	C2T	4.1	9.2	1.6						0.50	0.60	0.80			
29 DE 67	H63	C3T	4.1	8.6	0.8	11.0					0.70	0.80	1.00	0.80		
29 DE 67	H63	C4T	4.6	8.0	0.5						1.00	0.80	0.90			
FLOTATION SG 132.5 DEG. F TG 132.5 DEG. F.																
29 DE 67	H63	C1V	3.9	8.5	1.9						1.40	0.90	1.20			
29 DE 67	H63	C2V	4.3	8.6	1.4						0.60	0.50	1.20			
COOLDOWN #2, 72 HOURS, IA VERT.																
2 JA 68	H63	C1W	2.7	13.4	0.1						0.90	0.80	1.50			
2 JA 68	H63	C2W	4.1	15.4	3.6						1.10	0.70	0.80			

DA/MO/YR	LOC	TYP	WBD	ABSRA	ADIA	ID	RUT	RDT	WHEEL HOURS	ADDA	IAVERT SD	SRA UP SD	SHADN2 SD	SDADN1 SD	SEA HNDL POSIT UP DOWN HORE
2 JA 68	H63	C3W	4.4	15.9	1.6	11.1					0.70	0.70	0.90	0.70	
2 JA 68	H63	C4W	4.8	15.8	1.1						0.70	0.70	0.90		
2 JA 68	H63	C5W	4.2	16.5	0.5						0.60	0.70	1.70		
2 JA 68	H63	C6W	4.4	16.1	0.2	11.1					0.70	0.70	0.90	0.90	
3 JA 68	H63	C7W	4.9	15.8	1.3						0.70	0.80	1.20		
3 JA 68	H63	C8W	3.3	17.3	4.2						0.70	0.70	0.60		
NEXT RUN WHEEL RUN UP AT 22V.															
3 JA 68	H63	C1X	6.0	13.5	1.6						0.50	0.60	0.70		
3 JA 68	H63	C2X	7.1	14.4	3.9						0.60	0.70	0.70		
4 JA 68	H63	C3X	7.4	13.9	4.2	11.7					0.60	0.70	0.80	0.70	
NEXT RUN WHEEL RUN UP AT 24V.															
4 JA 68	H63	C1Y	6.8	13.3	2.8	16.4					0.60	0.60	0.80	0.70	
4 JA 68	H63	C2Y	7.6	13.6	4.0						0.80	0.60	0.70		
NEXT RUN INTERRUPTED WHEEL, BEHAF SRA DOWN.															
4 JA 68	H63	C3Y	7.4	12.8	3.6	13.1					0.60	0.70	0.70	0.50	
NEXT RUN WHEEL RUN AT 26V.															
4 JA 68	H63	C1Z	5.2	13.9	1.3	11.6					0.80	0.70	0.80	0.70	
4 JA 68	H63	C2Z	5.5	13.9	2.9	12.4					0.70	0.60	1.00	0.80	
NEXT RUN WHEEL INTERRUPTED AT 179 DEG.															
5 JA 68	H63	C3Z	7.3	13.0	3.1	14.2					0.70	0.80	1.10	0.80	
5 JA 68	H63	C4Z									0.70				
NEXT RUN WHEEL RUN AT 28V, INTERRUPTED WHEEL PRIOR TO SRA UP POS.															
5 JA 68	H63	C1A	4.6	12.6	2.3	11.2					0.90	1.20	1.10	0.70	
5 JA 68	H63	C2A	5.2	13.2	3.1	11.8					0.60	0.80	0.90	0.70	
6 JA 68	H63	C3A	4.6	13.6	2.9	11.5					0.60	0.70	0.80	0.70	
NEXT RUN WHEEL RUN AT 30V.															
6 JA 68	H63	C1B	6.2	12.1	5.6	13.1					0.70	0.60	0.80	13.30	
06 JA 68	H63	C2B	6.1	12.2	5.8	12.9					0.70	0.70	0.70	0.80	
06 JA 68	H63	C3B	5.8	12.5	5.6	11.7					1.20	4.40	0.70	0.70	
WHEEL RUN AT 28V FOR LONG TERM IA VERT.															
10 JA 68	H62	C1D	4.1	8.1	9.4						0.40	0.40	0.70		
10 JA 68	H62	C2D	6.1	7.5	19.1						0.50	0.60	0.60		
11 JA 68	H62	C3D	4.7	9.4	18.5	14.2					0.40	0.50	0.30	0.80	
11 JA 68	H62	C4D	6.0	9.6	19.6						1.50	1.00	0.60		
11 JA 68	H62	C5D	6.0	7.7	19.5						0.30	0.60	0.30		
LONG TERM IA HORIZ.															
15 JA 68	H62	C1F	6.4	19.7	22.9						0.70	0.20	0.80		
15 JA 68	H62	C2F	6.2	20.2	21.7						1.10	0.80	0.50		
16 JA 68	H62	C3F	6.7	20.3	22.5	15.0					0.60	0.70	0.40	0.80	
16 JA 68	H62	C4F	8.8	18.9	22.4						7.00	1.20	2.20		
NEXT RUN READ OUT ADJUSTED.															
16 JA 68	H62	C1G	6.6	18.0	24.3						1.00	0.70	0.90		
16 JA 68	H62	C2G	7.7	18.7	28.2						0.70	1.40	1.20		
16 JA 68	H62	C3G	6.5	18.5	23.5	15.8					1.40	1.10	0.90	1.00	
16 JA 68	H62	C4G	6.8	18.1	24.0						1.30	1.20	0.60		
WHEEL POWER CHECKS, COOLDOWN 82, 8 HOURS, IA VERT.															
18 JA 68	H62	C1I	4.6	21.1	23.1						1.00	0.50	0.80		
18 JA 68	H62	C2I	5.8	21.3	26.0						1.00	1.50	0.80		
18 JA 68	H62	C3I	4.0	22.2	23.7						1.30	0.80	2.70		
NEXT RUN 3 TO 10 DEG. DATA PER POSITION. REBALANCED.															
18 JA 68	H62	C1J	6.3	0.8	6.2						2.30	0.20	1.20		
SHROUD PORTS SEALED.															
19 JA 68	H62	C1K	5.8	6.8	18.5						1.10	1.90	1.80		
19 JA 68	H62	C2K	5.1	6.5	18.6						1.40	1.00	1.90		

DA/MO/YR	LOC	TYP	NBD	ADSRA	ADIA	ID	RUT	PDT	WHEEL HOURS	ADOA	IAVERT' SD	SRA UP SD	SRADN2 SD	SDADN1 SD	SRA-BNDW POSIT UP-DOWN HORE
19 JA 68	M62	C3K	5.8	6.5	10.1	15.1					0.86	0.80	1.60	0.29	
COOLDOWN #4, 14 HOURS, IA VERT. IA REALIGNED.															
20 JA 68	M62	C1L	4.5	9.4	16.4						0.40	0.70	1.70		
20 JA 68	M62	C2L	5.4	9.2	14.9						1.16	0.50	1.50		
20 JA 68	M62	C3L	5.7	8.8	15.3	14.4					0.50	0.90	1.10	1.20	
COOLDOWN #5, 20 HOURS, IA VERT.															
22 JA 68	M62	C1M	2.9	11.9	10.7						0.40	0.90	1.90		
NEXT RUN SRA UP, NULL DRIFTING. SRA DN, TABLE GOING BACKWARDS.															
22 JA 68	M61	C2M									0.60	0.70			
ADJUSTED SERVO LOOP.															
22 JA 68	M62	C1M	55.1	60.9	65.5						0.10	1.40	1.10		
27 JA 68	M62	C2M	6.3	11.3	16.4						0.80	0.90	1.60		
NEXT RUN NO 1/2 EXC. LOOP WOULD NOT REMAIN CLOSED.															
23 JA 68	M62	C3M	5.5	9.6	14.9						0.50	0.50	0.70		
23 JA 68	M62	C4M	7.2	9.2	16.1						1.40	0.90	0.80		
23 JA 68	M62	C5M						66			1.16				
23 JA 68	M61	C10									0.40		0.90		
TABLE STORAGE, 6 HOURS, IA VERT. NEXT RUN TABLE GOING BACKWARD.															
24 JA 68	M61	C1P (-558.1)									0.70	0.40	15.60		
24 JA 68	M61	C2P	6.7	7.9	8.7						0.56	0.50	0.70		
NEXT RUN LOOP OPENED AT SRA DN POS. WILL NOT CLOSE AGAIN AT ANY POS.															
24 JA 68	M61	C3P	7.6	7.5	8.7						0.90	1.00	1.10		
CL. DN. #6, 4 DAYS, IA VERT. TABLE ELEC. CHECKED. LONG TERM IA VERT.															
COOLDOWN #7, 11 DAYS, 11 DAYS, IA VERT. ONE SUSPENSION LEG OFF.															
12 FE 68	M63	C1E	77.9	26.9	132.1						2.90	9.00	11.90		
12 FE 68	M63	C2E	90.4	10.6	30.0						16.70	8.50	7.10		
13 FE 68	M63	C3E	71.1	6.4	15.6						3.00	4.20	6.30		
OVER STORAGE, 2 HOURS, IA VERT. AFTER REPAIRING CONNECTOR.															
13 FE 68	M63	C1E	1.5	6.0	15.9						0.70	1.10	1.70		
13 FE 68	M63	C2E	3.2	6.3	15.2						0.60	1.10	2.20		
13 FE 68	M63	C3E	3.7	8.2	14.5						0.70	1.00	2.40	0.60	
14 FE 68	M63	C4E	4.1	6.5	12.1						1.10	1.60	2.20		
14 FE 68	M63	C5E	3.4	7.8	12.8						1.10	1.20	2.40		
14 FE 68	M63	C6E	2.5	7.4	12.7						0.80	1.10	1.50	0.90	
NEXT RUN OA UP DOWN.															
14 FE 68	M63	C6E	4.6					1.6							
14 FE 68	M63	C7E	3.1	10.3	11.5						0.80	1.10	1.00		
NEXT RUN OA UP DOWN.															
14 FE 68	M63	C7E	4.8					1.6							
NEXT RUN WHEEL SRA UP, TC RADIAL SHORTED.															
14 FE 68	M63	C8E	2.4	10.4	14.0						0.60	0.90	1.50		
NEXT RUN OA UP DOWN.															
14 FE 68	M63	C8E	4.2					1.4							
15 FE 68	M6C	9E	1.3	12.2	13.9						0.60	1.00	1.80	0.80	
NEXT RUN OA UP DOWN.															
15 FE 68	M63	C9E	4.9					2.1							
15 FE 68	M63	C0E	4.1	11.3	16.1						0.80	0.90	1.10		
NEXT RUN OA UP DOWN.															
15 FE 68	M63	C0E	5.5					3.2							
15 FE 68	M63	C1E	3.8	10.6	15.9						0.70	1.50	1.70		
NEXT RUN OA UP DOWN.															
15 FE 68	M63	C1E	2.6					3.8							
16 FE 68	M63	C2E	1.8	12.2	16.1	12.4					0.60	0.80	1.50	1.30	
NEXT RUN OA UP DOWN.															

DA/MO/YR	LOC	TYP	MBD	ADSRA	ADIA	ID	RUT	EDT	WHEEL HOURS	ADDA	INVERT SD	SRA UP SD	GRADE2 SD	SDAD#1 SD	SRA RNDM UP DOWN	POSIT HORZ
16	FE	68	M62	C25					1303	1.2						21
19FB68 DELIVERED TO MIT/IL APOLLO GROUP.																
UNIT REALIGNED AS A MOD.3 GYRO RUN AT 9600CPS EXCITATION & SUSP.																
PRIMARY RESISTOR ADJUSTS TRANSFER FUNCTION TO 15 NV/HR.																
22HR68 IN VERT. SERVO RUN 2 REVOLUTIONS 22-25HR68.																
25	HR	68	M51	CSD												
25	HR	68	M51	CSD												
28	29HR68	IN	VERT.	SERVO	RUN	1/2	REVOLUTION.									
29	HR	68	M51	CIV												22
12HR68 INSTALLED INTO Y AXIS OF GUSIP.																
14	OC	68														
14	OC	68							1744							
14OC68 REMOVED FROM Y AXIS OF GUSIP.																
14OC68 UNIT DELIVERED TO IL-7 COMPOSBUT AREA.																

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LONG TRPM IA VERT.

DA/MO/YR	LOC TYP	NBD	ADSEA	ADIA	ID	RUP	RPT	WHEEL HOSES	ADOA	IAVERT SD	SRA UP SD	SRADN2 SD	SDALN1 SD	SEA RNDW POSIT UP-DOWN HGRZ
26 JA 68	M52 C1B	-18.4	(-185.4)	(-52.5)						0.40	0.40	0.60		
BALANCE														
5 JA 68	M52 C1D	-17.5	-2.6	-8.2						0.80	0.90	0.40		
26 JA 68	M52 C2D	-17.4	-3.4	-9.3						0.60	0.40	0.80		
TABLE STORAGE, 34 HRS, IA VERT. EXCITATION ON.														
25 JA 68	M52 C1E	-22.1	-4.1	-10.9						0.50	0.50	0.60		
28 JA 68	M52 C2E	-21.0	-4.6	-10.6						0.70	0.60	1.90		
28 JA 68	M52 C3E	-20.8	-4.9	-11.3	11.6					0.60	0.30	2.40	0.90	
UNIT TEMP 130 DEG.F.														
29 JA 68	M52 C1F	-20.9	-7.2	-12.4						0.80	0.50	3.00		
29 JA 68	M52 C2F	-20.3	-7.5	-12.9						0.80	0.30	0.90		
UNIT TEMP 135 DEG.F.														
29 JA 68	M52 C1G	-19.6	-6.3	-19.5						0.40	0.60	0.50		
29 JA 68	M52 C2G	-19.1	-7.0	-20.3	8.4					1.00	0.40	0.50	0.50	
COOLDOWN #1, 8 HRS, IA VERT. IA REALIGNED.														
30 JA 68	M52 C1H	-21.2	-6.5	-20.4						2.20	0.80	0.40		
30 JA 68	M52 C2H	-21.9	-5.7	-20.7						0.50	0.70	0.50		
RADIAL-CENTERING SX 2.6, SY 1.1, IZ 4.5, TX 1.0														
30 JA 68	M52 C1J	-22.3	-5.6	-23.5						1.60	0.60	0.60		
30 JA 68	M52 C2J	-21.9	-6.2	-24.0						0.60	0.40	1.10		
31 JA 68	M52 C3J	-21.7	-6.0	-24.4						0.70	0.60	5.10		
31 JA 68	M52 C4J	-21.6	-6.2	-25.2						0.70	0.80	0.90		
31 JA 68	M52 C5J	-21.2	-6.7	-25.2						0.80	0.80	0.90		
31 JA 68	M52 C6J									1.00				
31 JA 68	M52 C1K								63					
TRANSFER FUNCTION 11.35 MV/MR, LOBAR 15.9 MR-16.6 MR.														
COOLDOWN #2, 8 HRS, IA VERT.														
31 JA 68	M52 C1L	-20.9	-16.2	-18.4						0.30	0.30	0.50		
1 FE 68	M52 C2L	-20.4	-14.2	-19.4						0.30	0.40	0.40		
1 FE 68	M52 C3L	-20.2	-15.1	-20.6						0.20	0.40	0.20		
FLOTATION SG 132.6 DEG.F. TG 132.0 DEG.F.														
1 FE 68	M52 C1M	-21.3	-14.8	-17.6						0.40	0.30	0.60		
1 FE 68	M52 C2M	-20.6	-14.7	-20.4						0.40	1.20	0.40		
2 FE 68	M52 C3M	-20.3	-14.8	-20.9	7.8					0.50	0.40	3.10	0.60	
2 FE 68	M52 C4M	-19.8	-15.4	-22.5						0.20	0.50	0.30		
BALANCE														
2 FE 68	M52 C1P	-20.0	-0.7	-0.5						0.30	0.50	2.90		
2 FE 68	M52 C2P	-19.0	-0.3	-3.8						0.40	0.80	0.50		
2 FE 68	M52 C3P	-18.9	-0.1	-4.2	7.3				65	0.20	0.40	0.40	0.40	
COOLDOWN #3, 18 HRS, IA VERT. UNIT TEMP 135 DEG.F.														
3 FE 68	M52 C1Q	-18.1	-7.8	-8.6						0.50	0.30	1.90		
3 FE 68	M52 C2Q	-17.9	-8.0	-9.8						1.70	0.50	0.50		
4 FE 68	M52 C3Q	-17.8	-7.8	-8.4	7.8				61	0.90	0.60	1.30	0.60	
UNIT TEMP 135 DEG.F.														
4 FE 68	M52 C1R	-17.8	-7.5	-3.7						1.20	0.70	0.90		
4 FE 68	M52 C2R	-17.9	-7.1	-5.6						0.70	0.70	0.60		
4 FE 68	M52 C3R	-17.7	-7.1	-6.5						0.50	0.50	1.00	0.50	
UNIT TEMP 135 DEG.F.														
4 FE 68	M52 C1S	-17.6	-7.3	-10.3						1.50	1.70	1.40		

DA/MO/YR	LOC	TYP	NBD	ADSRA	ADIA	ID	RUT	RDT	WHEEL HOURS	ADOA	I/VERT SD	SRA UP SD	SRADN2 SD	SDADN1 SD	SRA RNDM POSIT UP DOWN HORZ
4 FE 68	H62	C2S	17.4	7.1	11.2						0.60	0.40	0.40		
5 FE 68	H62	C3S	17.5	7.1	10.8	9.2					1.80	0.60	0.20	0.70	
SHROUDED.															
7 FE 68	H62	C1T	16.2	7.4	10.5						0.50	0.30	0.60		
7 FE 68	H62	C2T	15.6	7.5	11.5						0.80	0.80	0.80		
7 FE 68	H62	C3T	15.4	7.4	11.6	7.7		64			0.90	2.30	0.40	0.20	
7 FE 68	H62	C4T	15.2	7.3	12.7						0.80	0.50	1.10		
8 FE 68	H62	C5T	15.1	7.4	12.8						0.90	1.10	0.30		
8 FE 68	H62	C6T									0.70	0.70			
LONG TERM IA HORIS. LONG TERM IA PARAL.															
14 FE 68	H62	C1H	16.2	6.0	19.1						0.70	1.80	0.50		
14 FE 68	H62	C2H	16.1	6.1	19.4						0.60	1.10	0.40		
15 FE 68	H62	C3H	16.0	6.3	19.4	7.4					0.40	0.30	3.10	0.50	
15 FE 68	H62	C4H	16.0	6.7	19.4			63			0.60	0.70	0.50		
CHANGED WHEEL SUPPLY.															
15 FE 68	H62	C1H	16.3	8.0	20.5						0.60	0.40	0.30		
15 FE 68	H62	C2H	16.2	8.2	20.3						0.50	0.70	2.40		
16 FE 68	H62	C3H	16.1	7.9	20.1	7.4					0.50	0.50	1.10	0.50	
16 FE 68	H62	C4H	16.2	6.1	18.7						2.80	0.20	0.70		
16 FE 68	H62	C5H									1.00				
COMPLIANCE. COOLDOWN #4, 51 HRS. IA VERT.															
28 FE 68	H63	C1A	21.3	6.7	19.2						0.80	0.60	1.20		
28 FE 68	H63	C2A	21.1	6.8	17.1						1.00	0.80	0.70		
28 FE 68	H63	C3A	20.6	7.0	16.7	11.9					1.20	0.70	1.00	0.60	
29 FE 68	H63	C4A	20.3	4.7	18.7						0.70	0.60	0.80		
29 FE 68	H63	C5A	21.6	2.8	18.3						3.40	0.70	0.80		
NEXT RUN WHEEL CURRENT INCREASED SRA POSITION DOWN.															
29 FE 68	H63	C6A	21.8	1.5	16.5	6.4					0.60	0.80	0.90	1.90	
29 FE 68	H63	C7A	23.9	1.1	16.2						0.90	0.60	0.80		
29 FE 68	H63	C8A	23.5	1.1	16.7						0.80	4.30	2.30		
29 FE 68	H63	C9A	23.2	0.3	16.6	8.4					1.50	0.70	0.80	0.60	
1 RR 68	H63	C0A	23.4	0.3	17.2						1.10	0.60	0.90		
1 RR 68	H63	C1A	22.8	0.9	18.3						1.50	0.70	5.50		
1 RR 68	H63	C2A	23.2	4.4	15.9	8.7					0.70	0.80	0.70	0.60	
1 RR 68	H63	C3A	20.8	3.5	16.3						0.70	0.60	1.40		
1 RR 68	H63	C4A	21.0	1.7	16.4			68			0.60	0.80	0.70		
COOLDOWN #6, 44 HRS. IA VERT.															
3 RR 68	H63	C1B	22.8	2.2	19.4						0.80	12.90	2.50		
3 RR 68	H63	C2B	21.2	6.0	20.4						0.60	0.70	2.20		
4 RR 68	H63	C3B	22.7	13.9	19.7	8.1					0.70	0.80	0.80	0.70	
4 RR 68	H63	C4B	22.4	14.1	20.3						0.70	0.60	0.50		
WHEEL POWER MEASUREMENTS.															
4 RR 68	H63	C1D	23.9	14.7	21.9						0.80	0.60	0.70		
4 RR 68	H63	C2D	22.8	15.8	22.9						0.70	0.70	0.80		
NEXT RUN WHEEL CURRENTS CHANGED INTERRUPTED WHEEL SRA POSITION UP.															
4 RR 68	H63	C3D	23.6	15.8	20.9	8.9					0.80	0.50	0.60	0.70	
5 RR 68	H63	C4D	21.8	14.9	19.7						1.00	0.80	0.70		
VIBRATION.															
18 RR 68	H63	C1F									0.30				
TABLE STORAGE, 16 HRS. IA VERT.															
19 RR 68	H63	C1C	14.3	5.5	14.8						0.60	3.70	1.00		
19 RR 68	H63	C2C	14.6	10.5	6.5	5.1					0.10	1.10	3.50	0.60	
19 RR 68	H63	C1H						76							
LONG TERM IA VERT. COOLDOWN #7, 60 HRS. IA VERT.															

DA/MO/YF	LOC-TYP	NBD	ADSRA	ADIA	ID	RJT	PDT	WHEEL HOURS	ADOA	IAVERT SD	SEA UP SD	SRADN2 SD	SDADM1 SD	SEA RNDN UP DOWN	POSIT HORZ
26 NR 68	M53 C1I	26.4	5.6	9.6						0.80	0.80	0.80			
26 NR 68	M53 C2I	23.4	5.9	12.2						0.70	0.70	0.70			
26 NR 68	M53 C3I	23.2	5.7	12.4	10.8					0.70	0.70	0.70	0.60		
26 NR 68	M53 C4I	22.9	5.4	12.3						0.70	0.70	0.60			
26 NR 68	M53 C5I	23.0	5.3	12.1						0.60	0.60	0.70			
26 NR 68	M53 C6I	22.2	5.3	12.9	10.5					0.70	0.70	1.00	0.70		
27 NR 68	M53 C7I	21.9	5.2	11.0				1134		0.60	0.80	0.70			16
27 NR 68	M53 C8I	21.9	5.3	11.3				67		0.70	0.60	0.70			
28AP68 DELIVERED TO MIT/IL APOLLO GROUP.															
UNIT PREALIGNED AS A MOD.3 GYRO RUN AT 9660CPS EXCITATION & SUSP.															
PRIMARY RESISTOR ADJUSTS TRANSFER FUNCTION TO 15 MV/ME.															
29 AP 68	M51 CIV														
1A VERT. SERVO RUN 1 REVOLUTION.															
2 NY 68	M51 CIV														
1A VERT. SERVO RUN 1/2 REVOLUTION.															
3 NY 68	M51 CSD	2.6	4.2	2.7						0.46	1.38	0.11			19
1A HORIZ. SERVO RUN 3 REVOLUTIONS.															
7MY68 1A VERT. SERVO RUN 1 1/4 REVOLUTION															
9 NY 68	M51														
13MY68 INSTALLED INTO Z AXIS OF GNSIP.															
14 OC 68															
14OC68 REMOVED FROM Z AXIS OF GNSIP.															
15OC68 UNIT DELIVERED TO IL-7 COMPONENT AREA.															
30 JA 69	M51 CSD														20

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PRE-BALANCE.

DA/NO/YR	LOC TYP	NBD	ADSEA	ADIA	ID	RUT	RDT	WHEEL HOURS	ADOA	IAVERT SD	SRA UP SD	SRADN2 SD	SDADN1 SD	SRA RNDM POSIT UP DOWN HORIZ
3 JB 68	H64 C1A	7.9	(-226.1)	(51.6)						0.20	0.30	0.40		
3 JB 68	H64 C2A	7.6	(-226.3)	(50.7)						0.10	0.30	0.40		
4 JB 68	H64 C3A	7.6	(-226.6)	(50.5)	6.8					0.10	0.30	0.20	0.30	
4 JB 68	H64 C4A									0.10	0.30			
BALANCED.														
4 JB 68	H64 C1C	7.6	9.9	4.1						0.05	0.03	0.10		
RADIAL CENTERING SX 1.0, SY 1.4, TX 1.7, TY 1.3														
TC CH 2-3 +.01 NFD.														
4 JB 68	H64 C1B	16.1	7.5	2.1						0.10	0.10	0.04		
4 JB 68	H64 C2B	16.2	7.7	2.0						0.20	0.10	0.03		
5 JB 68	H64 C3B	16.3	7.6	2.2	6.8					0.10	0.10	0.10	0.10	
5 JB 68	H64 C4B	16.3	7.7	1.6						0.10	0.10	0.10		
SUSPENSION NORMAL.														
5 JB 68	H64 C1F	7.2	9.3	2.8						0.10	0.10	0.10		
5 JB 68	H64 C2F	7.2	9.3	3.1						0.10	0.10	0.10		
5 JB 68	H64 C3F	7.2	9.4	3.1	6.7					0.10	0.10	0.10	0.10	
NEXT RUN UNIT TEMP. 140 DEG. F.														
6 JB 68	H64 C1G	6.7	8.5	5.7						0.20	0.10	0.05		
6 JB 68	H64 C2G	6.9	7.8	5.9						0.10	0.10	0.20		
6 JB 68	H64 C3G	6.8	7.6	5.6	6.8					0.10	0.10	0.10	0.10	
NEXT RUN UNIT TEMP. 125 DEG. F.														
6 JB 68	H64 C1H	7.0	8.2	2.5						0.20	0.10	0.10		
6 JB 68	H64 C2H	7.0	8.0	1.9						0.10	0.10	0.10		
6 JB 68	H64 C3H	7.1	8.1	1.3	6.7					0.10	0.10	0.10	0.10	
NEXT RUN UNIT TEMP. 130 DEG. F.														
7 JB 68	H64 C1I	7.3	6.9	1.9						0.30	0.10	0.10		
7 JB 68	H64 C2I	7.4	6.3	1.6						0.20	0.10	0.10		
7 JB 68	H64 C3I	7.4	6.9	2.3						0.10	0.10	0.10		
NEXT RUN UNIT TEMP. 135 DEG. F.														
7 JB 68	H64 C1J	7.1	6.1	0.5						0.20	0.10	0.20		
7 JB 68	H64 C2J	7.3	6.1	0.9						0.20	0.10	0.10		
8 JB 68	H64 C3J	7.3	6.2	1.5	7.0					0.10	0.10	0.10	0.20	
COOLDOWN #1, 3 HRS. 1A VERT.														
8 JB 68	H64 C1K	6.8	6.2	1.4						0.20	0.10	0.10		
8 JB 68	H64 C2K	6.8	6.3	1.1						0.10	0.10	0.10		
9 JB 68	H64 C3K	6.8	6.3	1.0	6.4					0.10	0.10	0.10	0.10	
COOLDOWN #2, 3 HRS. 1A VERT.														
9 JB 68	H64 C1L	6.7	6.4	0.7						0.40	0.10	0.10		
9 JB 68	H64 C2L	6.5	6.1	1.1						0.10	0.20	0.10		
9 JB 68	H64 C3L	6.5	6.2	1.1	6.1					0.03	0.10	0.10	0.10	
10 JB 68	H64 C4L	6.6	6.3	0.3						0.10	0.10	0.10		
10 JB 68	H64 C5L	6.7	6.3	0.6						1.20	0.10	0.10		
INSTALLED WATT METER.														
10 JB 68	H64 C1M	5.6	6.6	3.0						0.10	0.10	0.10		
10 JB 68	H64 C2M	5.9	6.7	2.5						0.10	0.10	0.10		
10 JB 68	H64 C3M	5.9	6.8	2.3	5.3					0.10	0.10	0.10	0.10	
11 JB 68	H64 C4M	5.9	6.9	1.8						0.10	0.10	0.10		
11 JB 68	H64 C5M	5.9	6.9	1.3						0.10	0.10	0.20		
11 JB 68	H64 C6M	5.9	6.9	1.0	5.3					0.20	0.10	0.10	0.20	

DA/MO/YR	LOC	TYP	NBD	ADSRA	ADIA	ID	RUT	RDT	WHEEL HOURS	ADOA	IAVERT SD	SEA UP SD	SRADN2 SD	SDADM1 SD	SEA RNDM UP DOWN	POSIT HORE
WHEEL POWER MEASUREMENTS. WATT METER IN NEXT RUN.																
11	JB	68	H64	C10	6.2	6.6	-	1.0			0.10	0.10	0.10			
11	JB	68	H64	C20	6.6	6.6	-	1.5	73	170	0.10	0.10	0.10			
12	JB	68	H64	C30	6.5	6.7	-	1.4		6.0	0.10	0.10	0.10	0.10		
12	JB	68	H64	C40							0.50	0.10				
NEXT RUN AFTER SHROOD.																
13	JB	68	H64	C1P	6.6	7.7	-	0.2			0.10	0.10	0.20			
13	JB	68	H64	C2P	6.4	7.6	-	1.4			0.10	0.10	0.30			
14	JB	68	H64	C3P	6.3	7.6	-	1.3	5.8		0.10	0.20	0.40	0.20		
14	JB	68	H64	C4P	5.6	7.0	-	1.1			0.10	0.10	0.40			
14	JB	68	H64	C5P							0.20					
IA VERT. FOUR QUADRANT.																
14	JB	68	H64	C1Q							0.10	0.10	0.10			
LONG TERM IA VERT.																
18	JB	68	H64	C1S	7.5	5.7	-	9.5			0.10	0.10	0.30			
19	JB	68	H64	C2S	5.5	3.7	-	9.1			0.20	0.10	0.30			
19	JB	68	H64	C3S	5.5	3.8	-	10.1	5.3		0.20	0.10	0.30	0.10		
LONG TERM IA PARALLEL.																
LONG TERM IA HORIZONTAL.																
24	JB	68	H64	C1V	5.5	6.5	-	19.1		68	0.10	0.10	0.10			
COMPLIANCE. TRANSFER FUNCTION 10.40 MV/HR. LOEAR +14.4HR - 14.4 HR.																
COOLDOWN 43, 11 DAYS, IA VERT.																
28	JB	68	H64							414						
9	JL	68	H64	C1Y	3.0	8.1	-	16.9			0.20	0.30	0.10			
9	JL	68	H64	C2Y	6.4	11.4	-	26.7			0.70	0.10	0.20			
10	JL	68	H64	C3Y	3.1	7.2	-	23.1	0.2		0.10	0.10	0.40	1.20		
10	JL	68	H64	C4Y	8.6	4.0	-	30.4			0.10	0.30	0.40			
10	JL	68	H64	C5Y	5.1	6.2	-	15.4			0.20	0.20	2.40			
10	JL	68	H64	C6Y	0.7	15.1	-	16.6	10.0		0.20	0.40	0.20	0.20		
10	JL	68	H64	C7Y	7.7	9.7	-	14.9			0.50	0.30	0.20			
11	JL	68	H64	C8Y	6.8	7.1	-	7.4			1.30	0.30	0.20			
11	JL	68	H64	C9Y	2.5	10.0	-	19.6	3.5		0.20	0.20	0.10	0.10		
NEXT RUN WATT METER IN.																
11	JL	68	H64	C1B	4.6	16.4	-	10.7			0.20	0.20	0.10			
LONG TERM IA VERT.																
13	JL	68	H64	C1B	9.6	12.6	-	18.7			0.10	0.20	0.10			
13	JL	68	H64	C2B	3.3	1.6	-	18.0			2.60	0.30	0.10			
13	JL	68	H64	C3B	2.6	0.4	-	11.5	23.1	71	0.20	0.20	0.10	0.20		
COOLDOWN 44, 8 HRS.																
14	JL	68	H64	C1C	16.6	4.2	-	11.8			0.20	0.50	0.20			
14	JL	68	H64	C2C	17.6	7.1	-	20.9			0.10	0.20	0.10			
14	JL	68	H64	C3C	2.3	14.2	-	14.9	7.7	73	0.10	0.50	0.30	0.20		
COOLDOWN 45, 9 HRS.																
15	JL	68	H64	C1D	5.2	17.1	-	12.2			0.10	0.50	0.30			
15	JL	68	H64	C2D	14.2	9.4	-	22.1			0.10	0.20	0.20			
15	JL	68	H64	C3D	10.9	10.6	-	12.8	25.7		0.10	0.40	0.30	0.30		
WHEEL MONITORED ON SANBORN.																
15	JL	68	H64	C1E	7.8	3.7	-	19.0			0.10	0.40	0.20			
15	JL	68	H64	C2E	1.2	9.3	-	8.5			0.10	0.30	0.20			
15	JL	68	H64	C3E	2.1	3.0	-	7.3	8.1		0.10	0.30	0.20	0.20		
16	JL	68	H64	C4E	4.3	16.4	-	3.7			0.10	0.20	0.20			
16	JL	68	H64	C5E	1.7	14.4	-	5.6			0.30	0.30	0.30			
NEXT RUN UNIT AT FLOTATION TEMP.																
16	JL	68	H64	C1F	6.7	26.3	-	20.8			0.20	0.30	0.40			

DL/NO/YR	LOC TYP	MBD	ADSRA	ADIA	ID	RGT	RDT	WHEEL HOURS	ADDA	INVERT SD	SRA UP SD	SRADW2 SD	SRADW1 SD	SRA RNDW POSIT UP DOWN MORE
16	JL 68	H64 C2F	12.1	17.6	25.2					1.20	0.20	0.10		
16	JL 68	H64 C3F	19.5	11.8	14.9	11.7				0.70	0.20	0.20	0.20	
17	JL 68	H64 C4F	17.9	11.6	43.4					0.10	0.20	0.20		
SUSPENSION OFF.														
17	JL 68	H64 C1C	4.5	7.0	29.5					2.40	0.30	0.20		
17	JL 68	H64 C2C	1.4	4.5	15.3					0.20	0.10	0.30		
17	JL 68	H64 C3C	3.8	2.9	17.8					0.30	0.30	0.20		
17	JL 68	H64 C4C	2.3	12.2	17.6	2.3				0.10	0.30	0.20	0.20	
17	JL 68	H64 C5C	4.5	8.5	19.7					0.10	0.20	0.20		
18	JL 68	H64 C6C	4.7	9.2	19.8					0.10	0.30	0.20		
18	JL 68	H64 C7C	1.5	12.1	16.7	1.6				0.10	0.80	0.40	0.20	
18	JL 68	H64 C8C	1.7	12.2	16.9					0.10	0.30	0.30		
SHEET RUN WITH AT FLOATION TRUP. PDB BOWARDG + IA.														
18	JL 68	H64 C1E	5.6	3.0	18.1					0.20	0.20	0.20		
18	JL 68	H64 C2E	4.3	2.4	17.6					0.10	0.50	0.30		
18	JL 68	H64 C3E	5.4	4.0	17.6	8.3				0.20	0.40	0.30	0.20	
18	JL 68	H64 C4E	4.8	3.4	15.7					0.20	0.40	0.20		
19	JL 68	H64 C5E	3.7	2.6	18.4					0.60	0.40	0.30		
19	JL 68	H64 C6E	5.2	2.9	20.5					0.20	0.30	0.30		
19	JL 68	H64 C7E	4.5	3.7	18.7					0.20	0.40	0.20		
19	JL 68	H64 C8E	4.2	3.4	18.0					0.10	0.30	0.30		
19	JL 68	H64 C9E	4.7	3.9	15.5	6.3				0.40	0.50	0.40	0.20	
20	JL 68	H64 C0E	4.3	3.9	16.2					0.20	0.40	0.30		
TABLE STORAGE, 14 HRS.														
20	JL 68	H64 C1I	4.6	3.4	18.8					0.20	0.40	0.20		
21	JL 68	H64 C2I	3.9	3.7	16.8					0.20	0.50	0.30		
21	JL 68	H64 C3I	4.0	3.8	17.0	4.0				0.20	0.50	0.40	0.20	
21	JL 68	H64 C4I	3.8	3.6	18.9					0.10	0.60	0.40		
21	JL 68	H64 C5I	4.9	4.3	20.6					0.10	0.70	0.30		
21	JL 68	H64 C6I	5.0	3.5	20.8	4.2				0.10	0.50	0.30	0.20	
22	JL 68	H64 C7I	3.4	3.8	14.7					0.10	0.40	0.30		
22	JL 68	H64 C8I	4.1	3.5	19.5					0.10	0.40	0.20		
22	JL 68	H64 C9I	4.0	3.2	21.5	3.3				0.10	0.60	0.20	0.20	
22	JL 68	H64 C0I								0.20				
SHEET RUN AFTER SHROUD REMOVAL.														
22	JL 68	H64 C1J	3.6	10.2	17.4					0.20	0.80	0.40		
22	JL 68	H64 C2J	11.2	3.4	11.5		74			0.40	0.70	0.30		
23	JL 68	H64 C3J	5.8	7.8	21.4	17.5				0.20	0.30	0.20	0.20	
23	JL 68	H64 C4J								0.40	0.80			
BALANCE PADDLE PICKLED.														
23	JL 68	H64 C1K	3.4	8.4	14.0					0.20	0.80	0.50		
23	JL 68	H64 C2K								0.60	0.80			
BALANCE PADDLE CHANGED.														
23	JL 68	H64 C1L	5.3	0.7	10.2					0.10	0.50	0.40		
23	JL 68	H64 C2L	15.0	11.6	26.3					0.20	0.70	0.40		
24	JL 68	H64 C3L	10.2	4.3	8.5	12.3				0.80	0.70	0.40	0.20	
24	JL 68	H64 C4L	12.8	16.6	26.0					0.20	0.70	0.50		
BALANCE PADDLE RETICKLED.														
24	JL 68	H64 C1M	10.7	14.7	21.6					0.10	0.60	0.40		
24	JL 68	H64 C2M	3.0	4.8	1.8					0.10	0.50	0.30		
SHEET RUN PDB BOWARDG + IA.														
24	JL 68	H64 C1N	4.2	3.4	14.8					0.20	0.70	0.40		
24	JL 68	H64 C2N	3.4	3.6	14.2					0.40	0.60	0.40		
25	JL 68	H64 C3N	3.4	2.0	12.1	3.5				0.10	0.90	0.30	0.20	

DA/MO/YR	LOC	TYP	NBD	ADSRA	ADIA	ID	RUT	RDT	WHEEL HOURS	ADOA	IAVERT SD	SRA UP SD	SRADN2 SD	SDADM1 SD	SPA-RWDN-POSIT UP-DOWN-HORZ
NEXT RUN PRD TOWARDS - IA .006.															
25	JL	68	M64	C10	- 51.0	59.2	- 33.9				3.10	5.50	7.30		
25	JL	68	M64	C20							4.00	8.10			
NEXT RUN PRD TOWARDS - IA .004.															
25	JL	68	M64	C1P	- 5.7	5.4	- 11.1				0.10	0.10	0.50		
25	JL	68	M64	C2P	- 1.8	12.9	- 16.3				0.30	1.00	0.50		
26	JL	68	M64	C3P	- 2.2	13.0	- 17.7	3.5			0.20	1.00	0.50	0.50	
26	JL	68	M64	C4P							0.20				
LONG TERM - IA HORIZ. NEXT RUN PRD TOWARD + IA .003.															
29	JL	68	M64	C1R	- 3.6	2.8	- 10.2				0.10	1.00	0.40		
29	JL	68	M64	C2R	- 10.4	3.5	- 34.8				0.10	0.80	0.40		
29	JL	68	M64	C3R	- 4.8	4.1	- 22.0	4.8			0.20	1.20	0.40	0.50	
30	JL	68	M64	C4R	- 4.2	3.2	- 17.2				0.10	0.90	0.40		
30	JL	68	M64	C5R	- 5.6	12.0	- 26.5				0.10	1.00	0.40		
30	JL	68	M64	C6R	- 3.5	4.7	- 0.8	0.7	795		0.20	0.90	0.30	0.50	
NEXT RUN PRD TOWARDS + IA .005.															
30	JL	68	M64	C1S	- 8.1	3.6	- 28.1				0.20	1.10	0.50		
30	JL	68	M64	C2S	- 8.9	4.0	- 26.6				0.20	0.90	0.50		
30	JL	68	M64	C3S	- 4.2	0.4	- 20.7	4.3			0.10	1.10	0.50	0.30	
31	JL	68	M64	C4S	- 2.3	- 2.5	- 23.1				0.10	0.20	0.50		
31	JL	68	M64	C5S	- 9.8	- 1.8	- 29.0				0.10	0.80	0.40		
31	JL	68	M64	C6S	- 6.8	1.6	- 23.1				0.20	1.00	0.40		
NEXT RUN PRD TOWARDS + IA .005.															
31	JL	68	M64	C1T	- 12.3	14.9	- 14.6				0.20	0.90	0.30		
31	JL	68	M64	C2T	- 4.1	24.2	- 40.3				0.10	1.10	0.60		
1	AU	68	M64	C3T	- 11.4	- 1.8	- 33.6	3.5			0.10	1.00	0.40	0.50	
1	AU	68	M64	C4T							0.20	1.20			
FLOAT FREEDOM TEST. COOLDOWN #6, 4 DAYS.															
12	AU	68	M63	C1Z	- 5.4	9.4	- 25.1				0.20	1.10	0.90		
12	AU	68	M63	C2Z	- 6.9	10.1	- 26.3				0.20	1.30	2.50		
13	AU	68	M63	C3Z	- 5.6	8.7	- 24.7	6.4			0.10	1.30	0.60	0.40	
13	AU	68	M63	C4Z	- 5.4	8.5	- 24.5				0.10	1.30	0.60		
NEXT RUN WATT METER IN.															
13	AU	68	M63	C1A	- 3.8	7.5	- 25.2				0.30	1.00	0.60		
13	AU	68	M63	C2A	- 4.2	7.5	- 24.7				0.40	1.10	0.60		
14	AU	68	M63	C3B	- 4.0	7.4	- 24.5	6.3			0.20	1.00	0.90	0.50	
14	AU	68	M63	C4B	- 4.7	6.9	- 25.4				0.20	0.90	0.70		
14	AU	68	M63	C5A	- 4.6	8.5	- 25.0				0.30	1.30	0.70		
14	AU	68	M63	C6A	- 4.8	6.7	- 25.8	6.2			0.30	1.00	0.70	0.30	
14	AU	68	M63	C7A	- 3.6	5.3	- 24.6				0.20	0.90	1.40		
15	AU	68	M63	C8A	- 4.2	7.3	- 24.7				0.20	1.30	0.90		
15	AU	68	M63	C9A	- 3.9	7.7	- 24.7	6.0			0.30	0.90	0.80	0.60	
15	AU	68	M63	C0A							0.20				
NEXT RUN AFTER RE-SHROUD.															
16	AU	68	M63	C1B	- 5.4	7.2	- 25.9				0.10	1.10	0.70		
16	AU	68	M63	C2B	- 5.3	7.3	- 26.9				0.20	1.20	0.90		
17	AU	68	M63	C3B	- 4.0	7.8	- 26.5	6.2			0.20	0.90	1.10	0.70	
17	AU	68	M63	C4B	- 5.2	7.4	- 27.1				0.30	1.20	0.90		
17	AU	68	M63	C5B	- 5.4	7.4	- 27.3				0.20	1.20	0.60		
17	AU	68	M63	C6B	- 6.4	6.4	- 28.5	5.3			0.30	1.00	0.60	0.70	
17	AU	68	M63	C7B	- 5.4	7.4	- 27.4				0.50	1.00	0.50		
17	AU	68	M63	C8B	- 5.7	7.6	- 28.1				0.20	1.10	0.70		
18	AU	68	M63	C9B	- 5.4	7.4	- 26.8	6.9			0.40	1.20	0.50	0.40	
18	AU	68	M63	C0B	- 5.2	7.0	- 26.9				0.30	1.20	0.80		

DA/MO/YR	LOC	TYP	WDD	ADSHA	ADIA	ID	RUT	RDT	WHEEL HOURS	ADOA	IAVVRT SD	SRA UP SD	SRADW2 SD	SDADW1 SD	SRA RWDE-POSIT UP DOWN HOURS
18	10	68	H63	C1B	4.8	6.9	25.2				0.20	1.40	0.70		
18	10	68	H63	C2B	5.4	7.3	28.1	6.3			0.30	1.20	0.50	0.40	
18	10	68	H63	C3B	4.9	6.8	26.9				0.40	1.20	0.60		
19	10	68	H63	C4B	5.2	6.2	27.2				0.30	1.30	0.70		
19	10	68	H63	C5B	4.8	5.7	26.9	5.6			0.30	1.30	0.60	0.30	
19	10	68	H63	C6B							0.10				
BALLING PORTS.															
19	10	68	H63	C1B	2.4	7.0	28.6				0.20	1.20	0.70		
19	10	68	H63	C2B	3.6	7.2	29.4				0.30	1.10	0.70		
19	10	68	H63	C3B	3.7	6.9	29.4	3.0		70	0.40	1.20	0.80	0.70	
20	10	68	H63	C4B	3.9	6.6	29.7				0.40	1.00	0.60		
20	10	68	H63	C5B	3.8	7.0	29.1				0.30	1.30	0.50		
20	10	68	H63	C6B	4.4	6.8	29.5	4.4		68	1224				
60 SECONDARY CHECKS.															
21	10	68	H63												
23	10	68	H63												
27	10	68	H63												

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APOLLO R4 BEARING - MIT S/N 614

PRE-BALANCE.

DA/NO/TA	LOC	TYP	WDD	ADSR	ADIA	ID	RUT	RDT	WHEEL HOURS	ADDA	IAVERT SD	SRA UP SD	SRADN2 SD	SDADM1 SD	SRA RNDM POSIT UP DOWN	HORS
17 DE 68	M65	C1A	-12.9	-327.9	87.4						0.40	8.50				
17 DE 68	M65	C2A	-29.8	-308.5	95.2						0.40	5.80	8.20			
18 DE 68	M65	C3A	-5.9	-282.7	77.0						0.20	0.30	0.40			
CHANGE.																
18 DE 68	M65	C1C	-21.4	-9.1	15.6						0.50	10.30	14.60			
RADIAL CENTERING, SX 2.13, SY 1.04, TX 2.02, TY 1.34.																
18 DE 68	M65	C1E	-6.7	3.9	2.5						0.30	1.90	0.20			
18 DE 68	M65	C2E	-5.4	2.1	5.4						0.20	0.30	0.80			
18 DE 68	M65	C3E	-4.7	-5.6	-9.7	-11.6					0.50	1.40	0.50	0.40		
19 DE 68	M65	C4E	-6.6	-8.8	-10.5						0.40	0.20	0.20			
19 DE 68	M65	C5E									0.20	0.50				
NEXT RUN AFTER TABLE STORAGE 4 HRS. IA VERT.																
19 DE 68	M65	C1F	-6.7	-10.0	-12.0						0.30	0.20	0.20			
19 DE 68	M65	C2F	-5.6	-11.0	-12.7						0.40	2.00	0.30			
19 DE 68	M65	C3F	-6.7	-11.1	-13.6	-14.6					0.90	0.20	0.20	0.30		
20 DE 68	M65	C4F	-6.5	-7.6	-11.3						0.30	0.30	0.20			
20 DE 68	M65	C5F	-6.5	-7.5	-13.1						0.20	0.30	0.20			
20 DE 68	M65	C6F	-7.6	-12.3	-13.4	-16.4					0.20	0.20	0.20	0.20		
NEXT RUN UNIT TEMP. 130 DEG.F.																
20 DE 68	M65	C1G	-7.7	-3.7	-16.9						0.20	0.40	0.20			
20 DE 68	M65	C2G	-10.9	0.3	-14.4						0.30	0.60	4.10			
20 DE 68	M65	C3G	-7.9	-2.2	-17.8	-16.8					0.40	0.30	0.20	0.40		
H,I,J SERIES FLOATATION. SC 136.23 DEG.F. TC 136.25 DEG.F.																
NEXT RUN UNIT TEMP. 135 DEG.F.																
21 DE 68	M65	C1H	-7.6	-15.7	-19.3						0.40	0.70	0.30			
21 DE 68	M65	C2H	-8.7	-16.0	-20.3						0.30	0.50	0.50			
21 DE 68	M65	C3H	-7.6	-16.7	-24.2	15.6					0.80	0.40	0.20	0.20		
NEXT RUN UNIT TEMP. 140 DEG.F.																
21 DE 68	M65	C1I	-5.4	-24.5	-24.7						0.20	1.60	0.30			
21 DE 68	M65	C2I	-7.6	-25.4	-24.3						0.20	0.20	0.30			
21 DE 68	M65	C3I	-7.7	-24.4	-24.6	15.6					0.10	0.20	0.20	0.30		
NEXT RUN UNIT TEMP. 135 DEG.F.																
22 DE 68	M65	C1J	-7.7	-22.5	-25.6						0.60	0.30	0.20			
22 DE 68	M65	C2J	-7.6	-23.4	-26.5						0.30	0.20	0.30			
22 DE 68	M65	C3J	-7.6	-23.2	-27.4	-15.8					0.30	0.20	0.20	0.20		
22 DE 68	M65	C4J	-14.3	-16.3	-21.3						0.30	0.30	6.80			
22 DE 68	M65	C5J	-11.9	-14.4	-24.6						0.40	0.70	4.80			
22 DE 68	M65	C6J	-10.9	-4.5	-25.9						0.30	0.50	5.30			
RELIEF FUNCTION 12.2 HV/MR + 150 HV - 140 HV.																
23 DE 68	M65	C1L	-6.0	-8.5	-30.1						0.30	0.40	0.40			
23 DE 68	M65	C2L	-6.5	-8.7	-40.4						2.60	0.50	0.20			
23 DE 68	M65	C3L	-12.1	-12.9	-26.4	-21.0					2.80	3.20	0.50	0.80		
24 DE 68	M65	C4L	-7.7	-6.3	-30.5						0.70	0.50	0.50			
24 DE 68	M65	C5L	-8.9	-6.6	-31.7			37			0.30	0.50	0.70			
NEXT RUN AFTER COOLDOWN 41, 40 HRS. IA VERT.																
26 DE 68	M65	C1M	-8.7	-5.4	-31.3						0.20	0.80	0.30			
26 DE 68	M65	C2M	-8.7	-4.9	-33.0						0.30	0.60	0.70			
26 DE 68	M65	C3M	-8.9	-4.6	-29.9	-17.2					1.20	0.30	0.60	0.50		
FOUR QUADRAN CHECKS. IA VERT. LONG TERM DRIFT RUN.																

DA/MO/YR	LOG TYP	NBD	ADSR	ADIA	ID	RUT	WHEEL HOURS	ADOA	INVERT SD	SRA UP SD	SRADW2 SD	SDADW1 SD	SRA-BWDM UP-DOWN	POSIT HORZ
NEXT RUN AFTER IA HORIZ. LONG TERM DRIFT RUN.														
1 JA 69	H65 C1Q	8.8	0.9	68.7					0.40	0.40	0.50			
1 JA 69	H65 C2Q	8.3	0.1	68.0					0.40	0.30	0.30			
1 JA 69	H65 C3Q	8.4	0.7	67.8	17.3				0.30	0.30	0.50	0.40		
2 JA 69	H65 C4Q	8.5	1.9	67.6					0.30	0.50	0.50			
2 JA 69	H65 C5Q								0.20					
NEXT RUN AFTER LONG TERM RUNS.														
3 JA 69	H61 C1B	6.1	5.4	66.7					0.40	0.40	0.80			
3 JA 69	H61 C1B	6.3					65	-1.6						
3 JA 69	H61 C2B	5.2	2.1	69.7					0.30	0.50	0.30			
3 JA 69	H61 C2B	6.6						-1.6						
3 JA 69	H61 C3B	6.5	1.8	68.7	15.0				0.30	0.80	0.70	0.50		
3 JA 69	H61 C3B	6.5						-1.1						
3 JA 69	H61 C4B	6.3	1.7	70.5					0.30	0.60	0.80			
3 JA 69	H61 C4B	6.7						-0.8						
NEXT RUN AFTER TABLE STORAGE 23 HRS. IA VERT. EXCITATION ON.														
4 JA 69	H61 C1B	6.9	5.7	76.9					0.50	0.50	1.40			
5 JA 69	H61 C2B	7.2	5.4	76.3					0.30	0.60	0.60			
5 JA 69	H61 C2B	7.3						-1.1						
5 JA 69	H61 C3B	6.5	4.1	78.0	13.6				0.40	0.40	0.30	0.30		
5 JA 69	H61 C3B	6.9						-1.4						
5 JA 69	H61 C4B	6.6	4.0	79.7					0.30	0.20	0.30			
5 JA 69	H61 C4B	7.5						-0.5						
5 JA 69	H61 C5B	6.4	3.8	81.3					0.30	0.40	0.40			
5 JA 69	H61 C5B	6.9						-1.1						
6 JA 69	H61 C6S	7.0	4.6	82.4					0.30	0.40	0.50			
6 JA 69	H61 C6S	6.8						-1.2						
NEXT RUN AFTER TABLE CHECK OUT.														
8 JA 69	H61 C1T	7.2	11.7	89.2					0.30	0.20	0.30			
8 JA 69	H61 C2T	7.1	11.9	90.1					0.30	0.10	0.20			
9 JA 69	H61 C3T	7.0	11.8	90.9	13.9				0.20	0.20	0.40	0.30		
9 JA 69	H61 C4T	6.9	11.9	91.5					0.20	0.20	0.20			
9 JA 69	H61 C5T								0.20					
9 JA 69	H61 C1U						70		0.60	0.40				
10 JA 69	H61 C						63							
10 JA 69	H61 C						62							
10 JA 69	H61 C						63							
10 JA 69	H61 C						62							
10 JA 69	H61 C						63							
10 JA 69	H61 C						64							
NEXT RUN AFTER IA VERT. LONG TERM DRIFT RUN.														
11 JA 69	H62 C1W	7.8	19.2	106.2					0.50	0.50	0.40			
11 JA 69	H62 C2W	7.9	18.7	107.0					0.20	0.60	0.50			
15 JA 69	H62 C3W	7.7	20.6	106.9	13.7				0.40	0.50	0.60	0.40		
15 JA 69	H62 C4W	7.5	20.2	107.4					0.40	0.30	0.20			
15 JA 69	H62 C5W	7.8	20.4	108.5					0.40	0.40	0.40			
15 JA 69	H62 C6W								0.40					
NEXT RUN AFTER REBALANCE.														
15 JA 69	H62 C1Y	6.6	0.3	4.5					0.40	0.40	0.60			
15 JA 69	H62 C2Y	6.6	0.2	5.2					0.20	0.40	0.70			
15 JA 69	H62 C3Y	6.6	0.0	6.1	12.9				0.40	0.50	0.50	0.30		
15 JA 69	H62 C													
15 JA 69	H62 C													
15 JA 69	H62 C													
15 JA 69	H62 C													
16 JA 69	H62 C4Y	7.6	1.2	5.1					0.30	0.40	0.40			

DA/MO/YR	LOC TYP	NBD	ADSEA	ADIA	ID	RUT	RDT	WHEEL HOURS	ADOA	IAVERT SD	SEA UP SD	SRADN2 SD	SDADN1 SD	SEA RNDM UP DOWN	POSIT HORZ
16 JA 69	H62 C5Y	6.7	2.4	7.3						0.30	0.40	0.50			
NEXT RUN AFTER WHEEL CHECKS.															
16 JA 69	H62 C1E	5.3	2.4	12.6						0.40	0.60	0.50			
16 JA 69	H62 C2E	5.4	2.7	12.7						0.60	0.40	0.30			
17 JA 69	H62 C3E	5.7	3.3	12.3	12.2					0.60	0.30	0.30	0.70		
17 JA 69	H62 C4E	5.6	3.5	12.2				1130		0.60	1.00	0.70			37
NEXT RUN AFTER COOLDOWN #2, 8 HRS. IA VERT.															
17 JA 69	H62 C1A	6.8	6.7	12.6						0.60	1.00	0.50			
17 JA 69	H62 C2A	6.7	6.8	14.3			61			0.50	0.40	0.80			
18 JA 69	H62 C3A	7.9	7.3	14.7	13.6					0.40	0.40	0.50	0.30		
NEXT RUN AFTER COOLDOWN #3, 8 HRS. IA VERT.															
18 JA 69	H62 C1B	6.5	7.7	15.4						0.30	0.60	0.30			
18 JA 69	H62 C2B	6.9	7.8	15.5			60			0.40	0.30	0.50			
19 JA 69	H62 C3B									0.40	1.30				
NEXT RUN AFTER COOLDOWN #4, 8 HRS. IA VERT.															
19 JA 69	H62 C1C	6.7	8.0	19.5						0.50	0.70	0.20			
19 JA 69	H62 C2C	6.6	8.2	16.5						0.30	0.60	0.30			
19 JA 69	H62 C3C	6.9	8.4	15.4	13.3					0.30	0.40	0.40	0.70		
12 FE 69	H62 C														59
20 FE 69	H62 C														63
28 FE 69	H62 C														68
13 BE 69	H62 C														60
14 BE 69	H62 C														67 1667

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