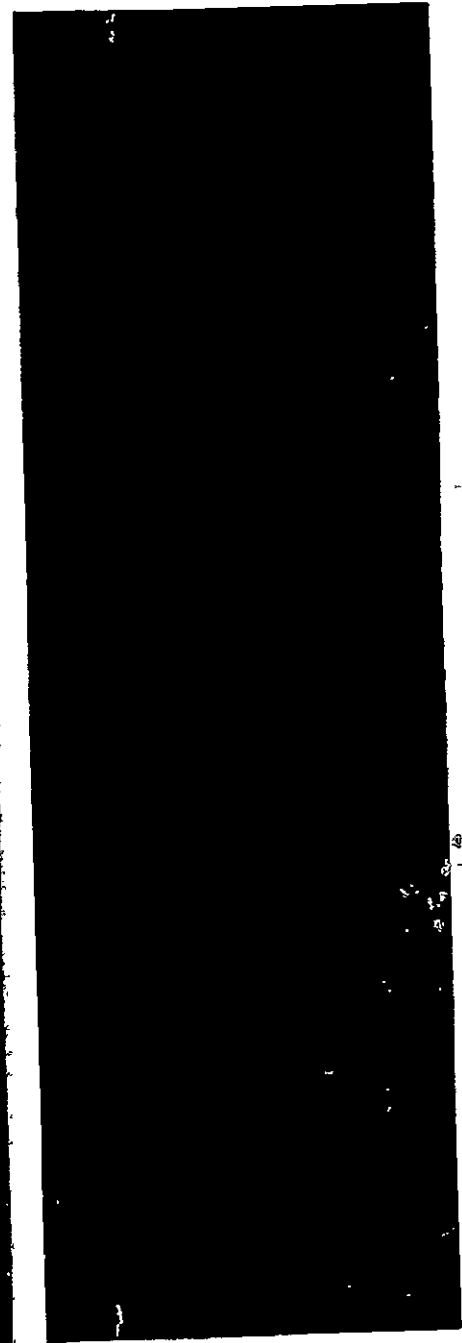
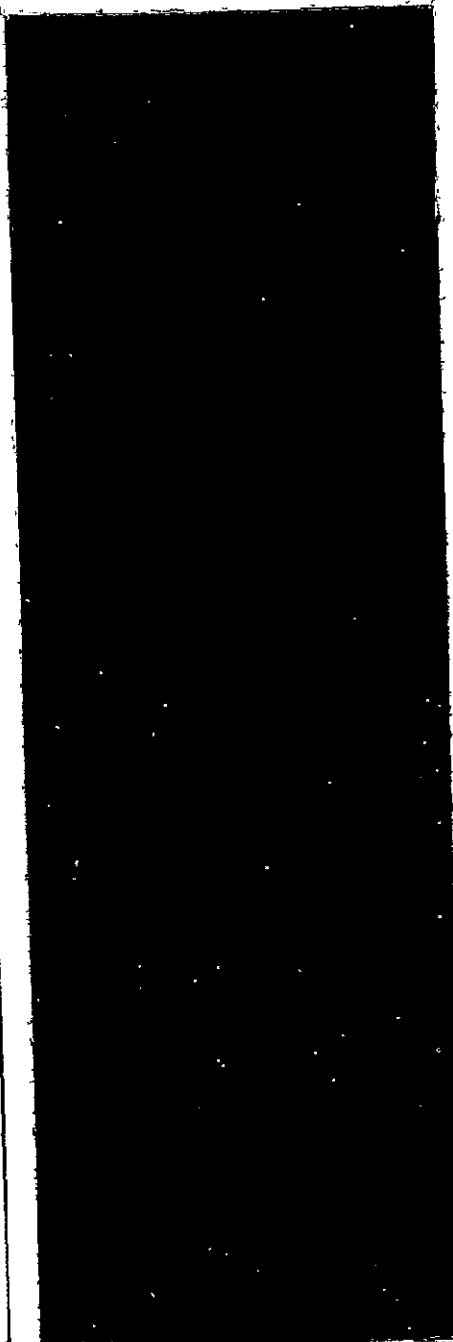
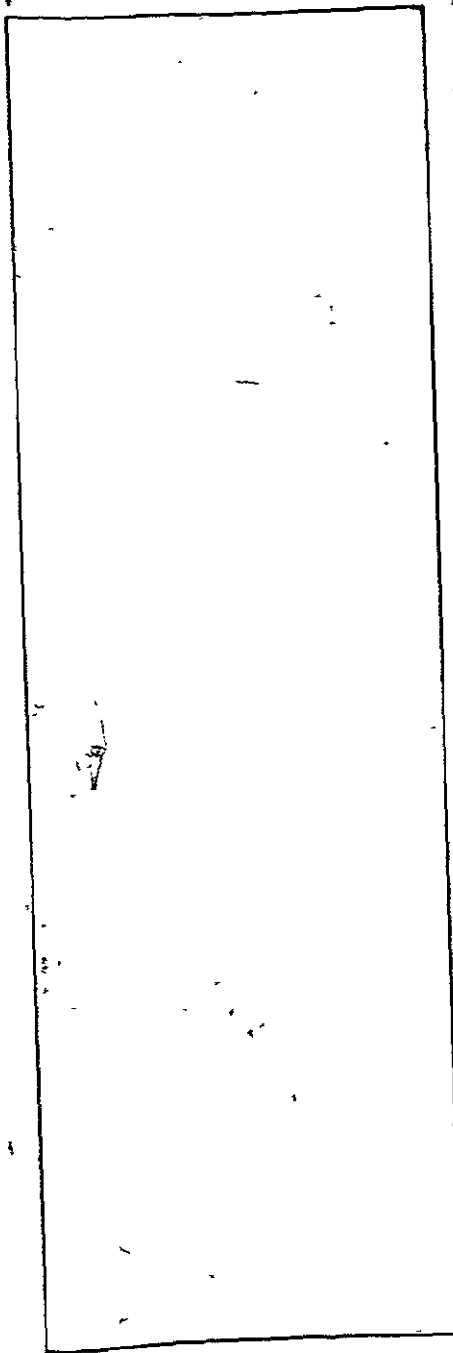


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HYDROSTATIC FLUID
BEARING GYRO

CONTRACT NO.
NAS 8-24414

FINAL REPORT

SEPTEMBER 1970

VOLUME I

HYDROSTATIC FLUID BEARING GYRO
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SEPTEMBER 1970

VOLUME I

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NAVIGATION AND CONTROL DIVISION
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SECTION 1
SCOPE OF WORK

A. Program Goals

The objective of this program was to design, fabricate, assemble, test and deliver three Prototype Hydrostatic Liquid Bearing Gyro assemblies. These units were built by reworking standard AB5-K8 gas bearing parts (sleeves, end-plates, and cylinders) for the hydrostatic liquid bearing. The liquid in the unit is recirculated by means of a spiral groove pump located within the sealed, self-contained system. The pump was designed for minimum size and power consumption, consistent with the pressure and flow requirements of the bearing. The program goals were to meet the interface, environmental and flight qualification requirements of the AB5-K8 gyro.

B. Program Requirements

The specific requirements of this program were as follows:

- (1) Build two Liquid Bearing Gyros (LB5 #1 and LB5 #2) using standard AB5-K8 ball bearing gyro motors, ball bearing Spiral Groove pumps and Freon 113 in the hydrostatic bearing.
- (2) Build one Liquid Bearing Gyro (LB5 #3) using a hydrodynamic gyro motor, a journal bearing Spiral Groove pump and Freon E2 in the fluid bearing.
- (3) Unit Performance Goals (Absolute Values)
 - ≤ 0.100 °/hr Bias
 - ≤ 0.250 °/hr/g Mass Unbalance
- (4) Determine the run-to-run repeatability and long-term stability of the constant and g sensitive drift coefficients of the LB5.
- (5) Determine optimum Spiral Groove pump configuration for the LB5.

SECTION 2

SUMMARY OF PROGRAM ACCOMPLISHMENTS

All three Liquid Bearing Gyros have been delivered to NASA Marshall Space Flight Center at Huntsville, Alabama:

LB5 #1 Delivered March 19, 1970

LB5 #2 Delivered July 20, 1970

LB5 #3 Delivered September 3, 1970

Gyro Test Summary

Figure 2-1 is a summary of the constant and g-sensitive sidereal drift data taken at Navigation & Control Division for all three units. The stability of the bias and end plate terms is seen to be superior to typical Saturn AB5-K8 gas bearing gyros. LB5 #1 and LB5 #2 meet the performance goals as outlined in the program requirements, but Mc and Muia for LB5 #3 slightly exceed the desired values. These terms were originally adjusted within the desired range without the Mu-Metal covers in place. After the covers were put on (providing magnetic shielding for the gyro), the absolute value of Mc and Muia went out of the desired range. It was decided to ship the unit rather than delay by re-adjusting it, since repeatability was even better than before. This brings up an interesting point --- that is, the repeatability of LB5 #3 is basically the same as for LB5 #1 and LB5 #2, even though it has only one-fourth the angular momentum. Thus, it seems that test stand repeatability is actually being determined rather than gyro repeatability, which may be significantly better.

Figures 2-2 and 2-3 present a comparison between the gas bearing performance and the liquid bearing performance of LB #1 and LB5 #2. (There is no comparison for LB5 #3 because it has a hydrodynamic cylinder with no gas bearing

test history). In both cases, repeatability improved after conversion to liquid bearing operation. Figures 2-4 and 2-5 represent some of the performance of LB5 #1 and LB5 #2 at NASA MSFC. (No NASA test data of this type was available on LB5 #3 at the time this report was written, but conversation with NASA personnel indicated that its performance is as good as the first two units.) The units were run in a torque-balance mode with the output axis vertical & input axis east-west. Each day they were run up from room temperature & drift readings taken at 100 second intervals starting immediately after wheel sync. Initial drift is the first reading for each day and steady state drift is an average of the last 72 readings. Day-to-day repeatability (A) for both units is very good, reading-to-reading repeatability (B) is excellent and temperature sensitivity is low. Long-term stability for LB5 #1 is excellent, while there is insufficient data on LB5 #2 to make a similar evaluation.

Pump Test Summary

Figure 2-6 is a summary of the test data taken on three optimum pump designs: (1) MOD I pump - Lucalox rotor and thrust pads, beryllium housing; (2) MOD II pump - all beryllium design; (3) Journal Bearing pump-journal bearing instead of ball bearing, all beryllium design. Each of the pumps are basically the same as far as groove and gap geometry are concerned, with the principle differences among them being material and/or radial support. All data was taken in a fixture utilizing a restrictor which simulates the LB5 gyro; the test liquid was Freon 113.

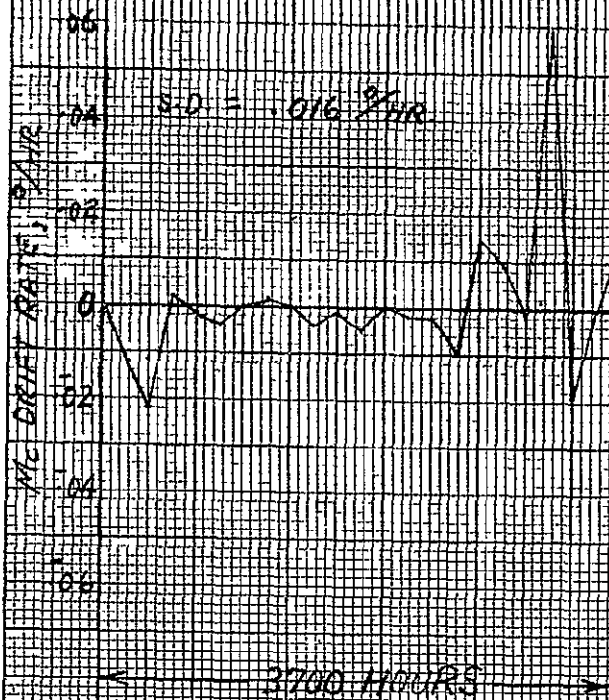
LB5 CONSTANT AND G-SENSITIVE SIDEREAL DATA SUMMARY

UNIT SERIAL NO.	1	2	3
LIQUID	Freon 113	Freon 113	Freon E2
PUMP	Ball Brg	Ball Brg	Hydrodynamic
GYRO MOTOR	Ball Brg	Ball Brg	Hydrodynamic
ANGULAR MOMENTUM (gm-cm ² /sec)	2.4x10 ⁶	2.4x10 ⁶	0.54x10 ⁶
Mc: Average	+ .063	- .019	+ .120
Standard Deviation	.004	.004	.003
Musra: Average	+ .056	- .077	- .163
Standard Deviation	.035	.027	.013
Muia: Average	- .212	+ .054	+ .265
Standard Deviation	.020	.022	.008
Mep: Average	+ .004	- .001	+ .014
Standard Deviation	.003	.007	.006
Number of Test Runs	23	17	16

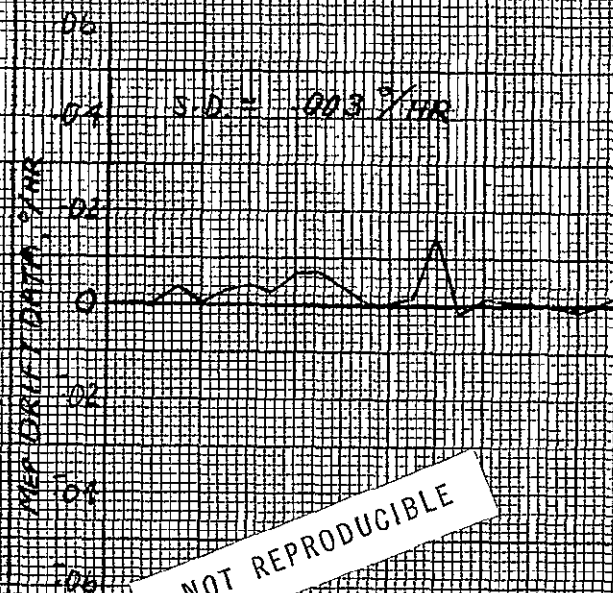
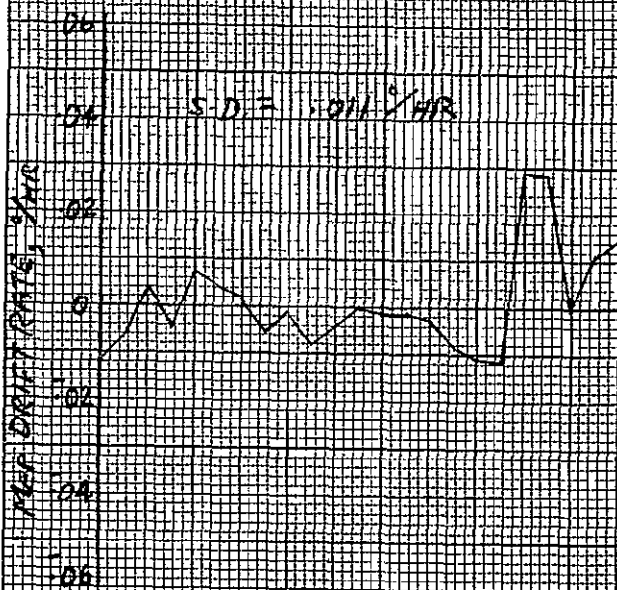
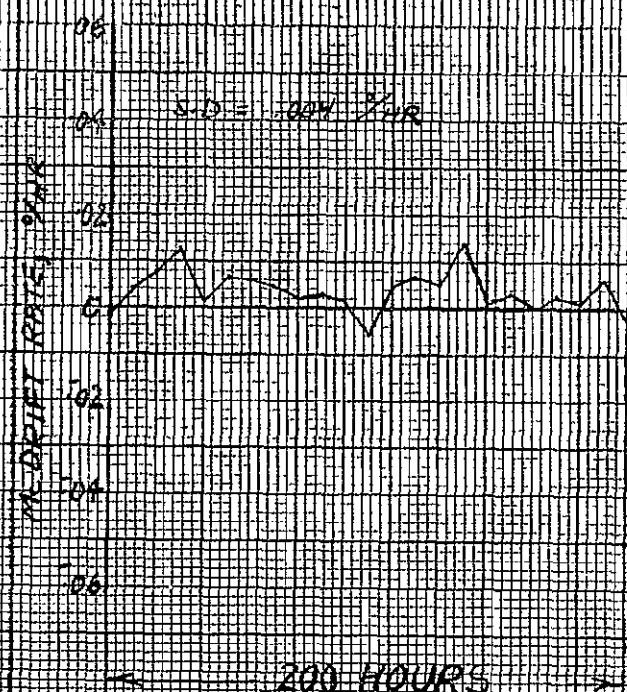
FIGURE 2-1

LIBS*1 GAS AND LIQUID BEARING SIDERIAL DATA COMPARISON

GAS BEARING DATA*



LIQUID BEARING DATA*



* NORMALIZED

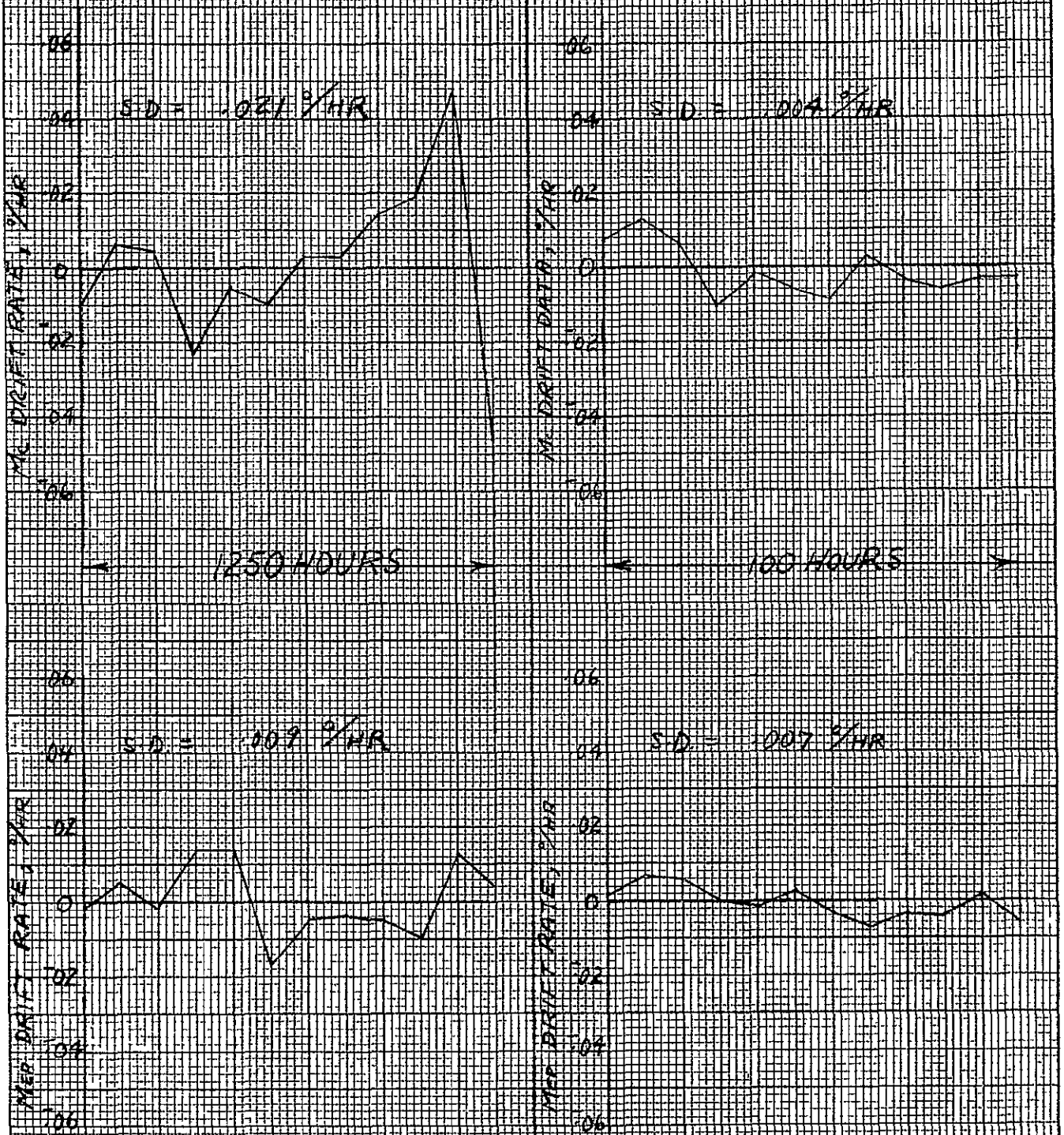
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FIGURE 2.2

LBS*2 GAS AND LIQUID BEARING SIDERAL DATA COMPARISON

GAS BEARING DATA *

LIQUID BEARING DATA *



* NORMALIZED

FIGURE 2-3

LB5#1 DRIFT - NORTH SEEKING, TORQUE-BALANCE MODE*

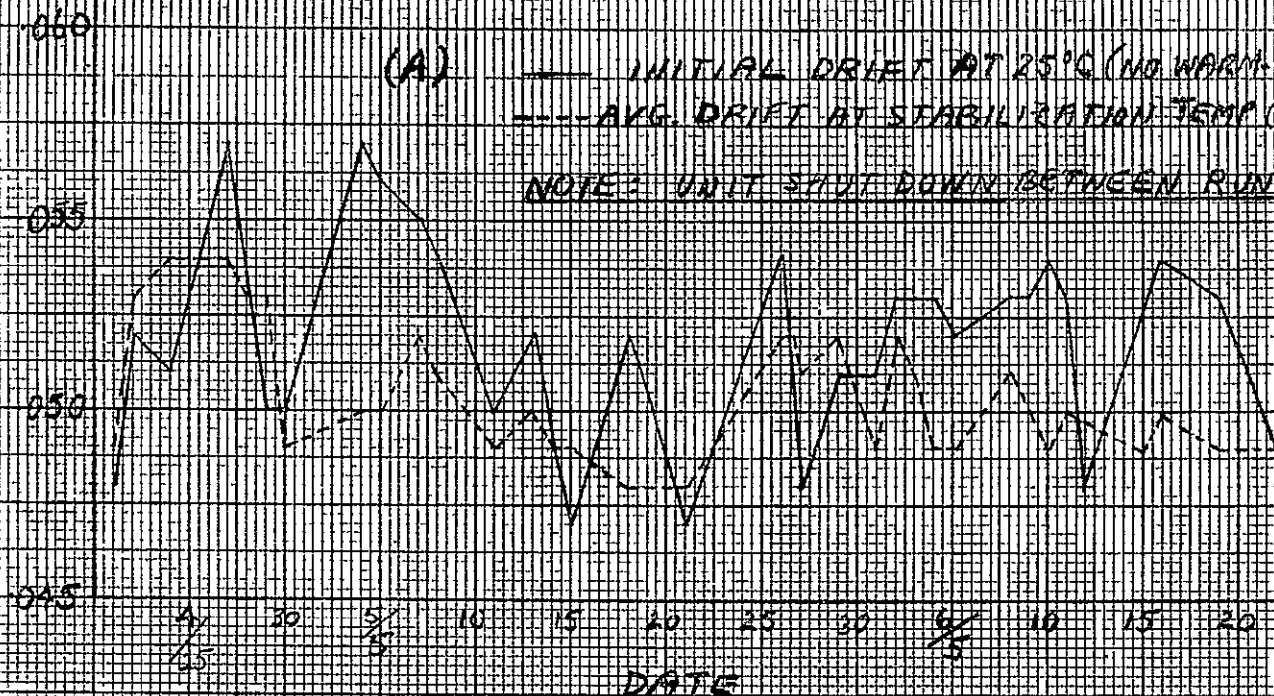
* AT NASA M.S.F.C.

DEGREES/HOUR

(A)

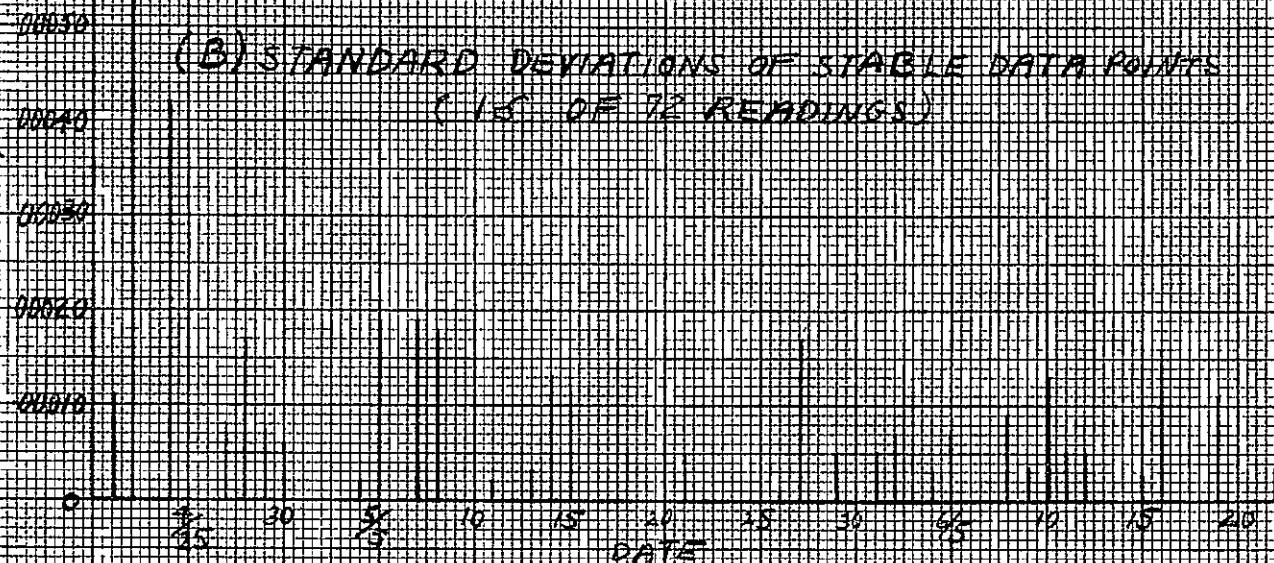
— INITIAL DRIFT AT 25°C (NO WARM-UP)
 ---- AVG. DRIFT AT STABILIZATION TEMP (45°C)

NOTE: UNIT SHUT DOWN BETWEEN RUNS



DEGREES/HOUR

(B) STANDARD DEVIATIONS OF STABLE DATA POINTS
 (15 OF 72 READINGS)



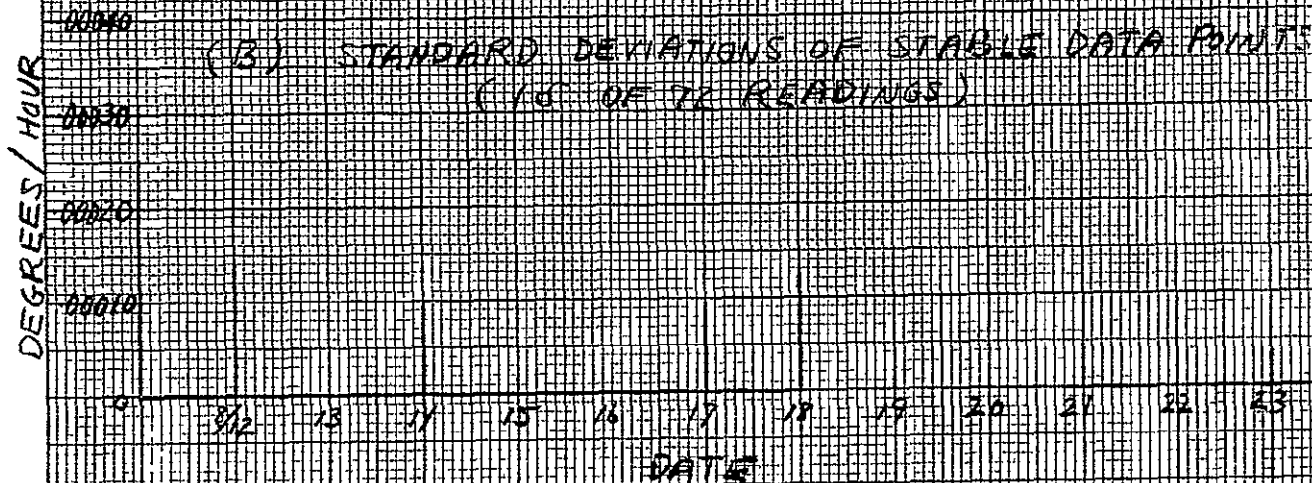
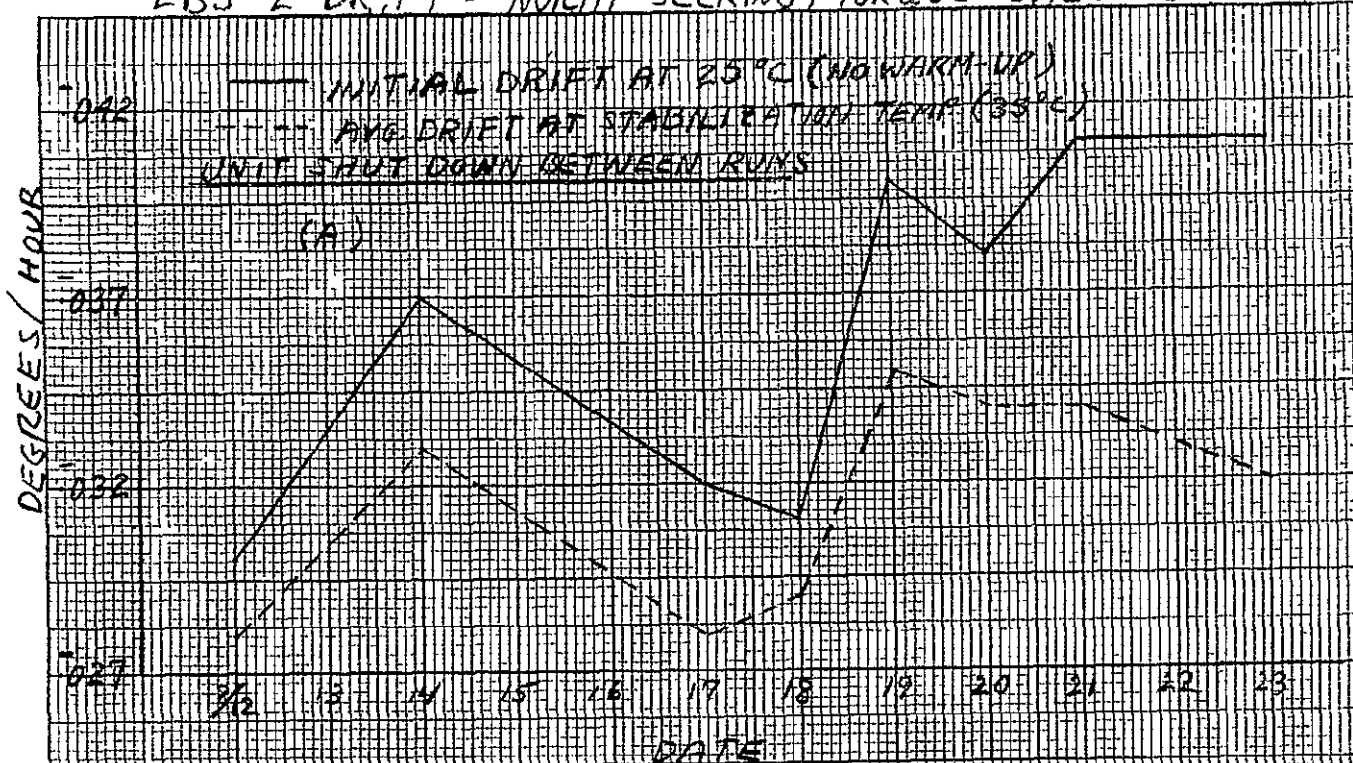
INITIAL DRIFT: AVERAGE = 0.516°/HR
 STD DEV. = 0.027°/HR
 SLOPE OF LEAST SQUARES STRAIGHT LINE = -0.00005°/HR/DAY

DRIFT AFTER TEMP. STABILIZATION: AVERAGE = 0.504°/HR
 STD DEV. = 0.017°/HR
 SLOPE OF LEAST SQUARES STRAIGHT LINE = -0.00044°/HR/DAY

AVERAGE TEMP. SENSITIVITY: -0.00012°/HR/°C = (25°C → 45°C)

FIGURE 2-4

LBS#2 DRIFT - NORTH SEEKING, TORQUE-BALANCE MODE*



INITIAL DRIFT: AVERAGE = -0.0362 °/HR
 STD DEV. = -0.0042 °/HR
 SLOPE OF LEAST SQUARES STRAIGHT LINE = -0.000913 °/HR/°C

DRIFT AFTER TEMP. STABILIZATION: AVERAGE = -0.0316 °/HR
 STD DEV. = -0.0026 °/HR

AVERAGE TEMP SENSITIVITY = -0.00046 °/HR/°C (25°C → 35°C)

*AT NASA M.S.F.C.

FIGURE 2-5

SPIRAL GROOVE PUMP OPTIMUM DESIGNS-TEST SUMMARY

<u>TYPE</u>	<u>MOD I</u>	<u>MOD II</u>	<u>JOURNAL BRG</u>
Rotor Material	Al ₂ O ₃	Be	Be
Thrust Pad Material	Al ₂ O ₃	Anodized Be	Anodized Be
Housing Material	Be	Be	Be
Radial Support	Ball Brg	Ball Brg	Journal Brg
Serial Number	SQ4	SQ2B	SQ1BJ
Number of Grooves	12	12	12
Groove O.D. (in)	1.10	1.10	1.10
Groove I.D. (in)	0.67	0.67	0.67
Groove Depth (in)	.0012	.0012	.0012
Radial Seal (in)	.005	.005	.005
Gap/Side (in)	.0001	.0001	.0001
Test Liquid	Freon 113	Freon 113	Freon 113
Ambient Temperature (°F)	125	125	110
Ambient Pressure (psig)	15.5	17.4	21.4
psi*/rpm	2.77x10 ⁻³	2.43x10 ⁻³	2.33x10 ⁻³
Drag Torque (in-oz/rpm)	1.68x10 ⁻⁴	1.61x10 ⁻⁴	2.0x10 ⁻⁴
Performance Index (psi*/in-oz)	16.5	15.1	11.7
Axial g cap. at 2000 rpm (g's)	>30	>30	>30
Radial g cap. at 2000 rpm (g's)	-	-	>30
Slew Rate cap. at 2000 rpm (rad/sec)	>20	>20	>20
ΔP* at 300~, 36v(psi)	7.4	6.5	6.1
Speed at 300~, 36v(rpm)	2665	2675	2600
Input Power at 300~, 36v (watts)	3.1	2.6	2.9
Efficiency at 300~, 36v(psi/watt)	2.38	2.50	2.10

* Across LB5 Simulator

FIGURE 2-6

SECTION 3
TECHNICAL DISCUSSION

A. Design

1) General

The LB5 gyro, as shown in Figure 3-1 and 3-20, is built around modified Saturn AB5-K8 hardware, with two separate housings enclosing the electrical and balance ends of the gyro (Part Nos. 1957021 and 1957088, respectively), Viton o-ring sealed to the modified AB5-K8 sleeve (1957091). The unit contains a Spiral Groove pump (1923307) located at the balance end. The liquid enters the pump at the rotor I.D., is forced radially outward along the spiral grooves due to viscous shear and exits the pump through two outlet ports located at the periphery. The liquid flows through two Millipore outlet filters into the sleeve, through the two rows of radially directed orifices (containing Millipore restrictors), into the bearing gaps (between the sleeve and cylinder 1869499) and past the stepped end plates (1957034 and 1957035), providing radial and axial support for the inner cylinder. It exhausts from both ends and is returned to the inlet side of the pump (through the same type of Millipore filters), where it is recycled. The hydrostatic bearing operation is exactly the same as in a standard AB5-K8 gas bearing gyro except that the working fluid is a liquid.

The liquid bearing gyro concept was proven feasible with a concept model as described in MT 3945 ("Development of a Gyro with a Liquid Hydrostatic Bearing), included in the Appendix of this report. Tests showed bearing torque,

repeatability, g-capability, vibration response and fluid power requirements to be satisfactory. On the basis of these encouraging results, the LB5 program was begun.

2) Spiral Groove Pump

The Spiral Groove pump is an adaptation of the spiral groove thrust bearing. The groove pattern is shown schematically in Figure 3-2. If the grooved disk is rotated as shown relative to the smooth disk, the fluid between them will have an angular velocity imparted to it due to viscous shear. The fluid has a linear velocity V (relative to the rotor) at the radius shown, which makes an angle B with the tangent to the trailing groove wall. Thus the velocity has a component normal to the groove wall which creates a pressure build up in the groove from the leading wall to the trailing wall. There is also a component along the groove, and the fluid flows in this direction. The groove walls converge outwardly, thus wedging the fluid flowing between them, causing an increase in pressure from the inner to the outer diameter of the disk. The rotation of the grooved disk also adds a centrifugal effect to the pressure build-up. A schematic representation of the pressure distribution is shown in Figure 3-3.

Pressure, Flow Requirements

Tests performed on a Saturn AB5-K8 gyro (described in MT 3959, "G-Capability of an AB5-K8 Gyro Converted to Liquid Bearing Operation", in the Appendix) indicated that a Freon 113 pressure differential of about 8 psi would be required to achieve a load capacity of 18 g's in the LB5

gyro. At 125°F this would mean a flow rate of 16 cm³/min. Preliminary evaluation of a prototype Spiral Groove pump (See MT 3958, "Preliminary Spiral Groove Pump Design" and MT 3960, "Experimental Evaluation of Spiral Patterns for a Liquid Viscous Shear Pump" in the Appendix) demonstrated the ability of this type of pump to meet the bearing requirements of the gyro at reasonable power consumption. Subsequent tests showed that the addition of a radial seal to the rotor (i.e.: dead-ending the grooves, followed by a sealing land area, rather than cutting them thru to the O.D.) would give the pump intrinsic g-capability of more than 30g's. The output was somewhat reduced, however, requiring a corresponding increase in pump speed.

Configuration

The following design parameters were decided upon for the LB5 pump (shown in Figure 3-4):

GROOVE PROFILE	OUTWARDLY CONVERGING WHIPPLE
NUMBER OF GROOVES	12
GROOVE O.D.	1.100
GROOVE I.D.	0.67
GROOVE DEPTH	.0012
GAP/SIDE	.0000 → .0005 (in)
RADIAL SEAL	.020 → .000 (in)
SPEED	2000 → 3000 rpm
OUTLINE DIMENSIONS	2.32 in. O.D. x 1.03 in. High

The groove profile (See Figure 3-5) chosen was the same as in the prototype pump. This configuration had proven to be the most efficient of those tested (MT 3958 and MT 3960 in the Appendix). The number of grooves (12) is the maximum

which would fit on the rotor, as dictated by analytical studies (MT 13947, "Analysis of the Spiral Groove Friction Pump", Appendix) which showed that an infinite number of grooves would theoretically yield the highest efficiency. The groove O.D. is the same as in the test pump, so that the speed would not be radically different, since for a given output, speed varies inversely with O.D. squared (See MT 13947). The groove I.D. was a compromise between optimum O.D. to I.D. ratio and required ball bearing diameter. The pump was designed so that the gaps and radial seal could be varied by machining in order to trim output and g-capability to the necessary values. Consequently the operating speed could not be more closely predicted. The pump outline dimensions were chosen as the largest that could fit inside the bellows housings (See Figure 3-1) which, in turn, were dimensioned for minimum overall unit size.

Fabrication

The basic material of construction for the pumps is beryllium, chosen because of its: (1) coefficient of expansion that matches the beryllium end plate to which it is fastened; (2) good thermal conductivity (3) light weight; (4) non-magnetic properties. The MOD II pump (shown in Figure 3-6) is made entirely of beryllium. However, concern over the bearing characteristics of a beryllium rotor on beryllium thrust pads prompted an alternate design (The MOD I pump, Figure 3-4) which utilizes Lucalox* rotor and thrust pads.

* G.E. trade name for aluminum oxide ceramic

Perhaps the single most important practical consideration in the manufacture of these pumps was holding parallelism between rotor and stator surfaces. The pumps were designed so that the thrust pads are parallel to each other within .000050 in. and each face of the rotor parallel to the other within .000025 in. The overall tolerance build-up, therefore, does not exceed .000075 in. as shown in Figure 3-7. Since the average finished gap per side is .0001 in., interference is avoided. Flatness and surface finish are also critical, being held to .000025 and 4 micro-inches, respectively.

Ball Bearing

The MOD I and MOD II pumps have ball bearing radial support. The bearing chosen was Barden #SR 188 W4C11; its characteristics are tabulated in Figure 3-8. The maximum running torque of .07 in-oz was sufficiently small compared to the expected value of .50 in-oz for the overall pump. Another significant feature of this bearing is its relatively high axial play (.004 in. p-p) this, in conjunction with suitable pump dimensions and tolerances, allows the rotor to center itself hydrodynamically in the axial direction when running (See Figure 3-4 or 3-6), and to rest on either thrust pad when stationary. The low radial play, (.0003 to .0005 in.) on the other hand, effectively achieves radial centering for the rotor under all conditions. The total radial eccentricity build-up, including bearing radial play, inner and outer race runout, bearing fit and pump geometry does not exceed .0008 inch in the absolute worst condition (as tabulated in Figure 3-9). This compares favorably with the minimum magnetic flux radial gap of .002 in. for the pump motor.

A very important reason for using this particular ball bearing in the Spiral Groove pump was the excellent life test performance in Freon 113. Two of these bearings were immersed at 125°F and run for over 7000 hours at 2000 rpm, with no significant increase in torque throughout the test.

Journal Bearing

The MOD IV pump (Figure 3-12) has a Rayleigh Step journal bearing for radial support. Basically it is a straight journal design with unique pads, or Rayleigh Steps (See Figure 3-13), added for increased stability at slightly lower load capacity. A description of this bearing and the design procedures followed are presented in ER 70-09-239, "Design of the Hydrodynamic Journal for the Liquid Bearing Pump", and ER 70-09-243, "Design and Analysis of the Rayleigh Step Bearing for Incompressible Flow". in the Appendix. The most important practical consideration for this design was maintaining orthogonality between the journal bearing and the thrust bearing (which is inherent in the spiral groove pump) so that neither would run in a skewed condition. This was accomplished by holding .000050 in. parallelism between the journal seat and bottom thrust pad (Figure 3-14), .000025 in. perpendicularity between the journal seat and O.D. (Figure 3-15), and .000050 in. perpendicularity between the rotor bore and bottom surface (Figure 3-16). Eccentricity considerations for the stationary rotor were identical to the ball bearing except that the radial clearance between the journal and rotor (.0003 in. maximum, Figure 3-16) replaced half the radial play of the ball bearing (.00025 in. maximum,

Figure 3-8). In the running pump, the journal centers the rotor radially and even at the maximum eccentricity ratio of the bearing (0.7 from ER 70-09-243), the offset is less than in the stationary pump. Starting torque was expected to be higher than in the ball bearing pump, but good surface finish for the rotor I.D. and journal O.D. (4 micro-inch) was expected to keep the contribution from the journal small as compared to the rotor thrust pad interface. Running torque as calculated from ER-70-09-243 was satisfactory at .068 in-oz (compared to .07 in-oz for the ball bearing).

3) Pump Motor

As previously indicated, the speed range requirement was 2000 to 3000 rpm. The predicted running torque (From MT 3958 and MT 3960 in the Appendix) was 0.5 in-oz and the estimated starting torque was not expected to exceed 1.0 in-oz. The maximum allowable motor volume (From MT 3957, "Tentative Motor Requirements for a Spiral Groove Pump", in the Appendix) was controlled by the pump rotor O.D. and the bellows I.D. and by the inside height of the pump.

A maximum power consumption of 3 watts was added as a further restriction. With these requirements in mind, the parameters in Figure 3-17 evolved. The design approach, procedures and calculations are described in ER 70-09-253, "Spiral Groove Pump Motor Design", in the Appendix. The characteristic curves are shown in Figure 3-18, and an outline drawing presented in Figure 3-19.

4) Bellows

The function of the bellows is to allow for thermal expansion of the fill fluid, while maintaining total system pressure above the vapor pressure of the liquid and below a safe upper limit. The first step in the LB5 design, of course, was a concept layout showing the pump size and location, flow paths, end housing configuration, seals, fill port and electrical feed-thru. The prime objective was to maintain the Saturn AB5-K8 configuration, minimum outline dimensions (See the Final outline, Figure 3-20) and minimum interior volume to reduce the expansion requirement. Study of the design concept yielded an interior volume estimate of 100 cm^3 (6.1 in^3). The temperature extremes for the LB5 are 75°F to 125°F operating, and from 32°F to 175°F storage. The coefficient of expansion of Freon 113 is $9.1 \times 10^{-4} \text{ in}^3/\text{in}^3$ $^\circ\text{F}$. On the basis of this information, the bellows design described below was carried out.

It was assumed that the unit would be filled and sealed at atmospheric pressure (15 psia) and room temperature (75°F); the bellows is at free length under these conditions. The expansion capability required when the unit is heated from 75°F to 175°F is:

$\Delta V = V_o C_v \Delta T$, where

ΔV = increase in fluid volume (in^3)

V_o = initial fluid volume = $6.1 (\text{in}^3)$

C_v = coeff. of volumetric expansion = $9.1 \times 10^{-4} \text{ in}^3/\text{in}^3 \text{ } ^\circ\text{F}$

ΔT = temperature change = $175^\circ\text{F} - 75^\circ\text{F} = 100^\circ\text{F}$

$\Delta V = (6.1) (9.1 \times 10^{-4}) (100) = .56 \text{ in}^3$

The outline dimensions of the bellows (from the concept layout) were 3.0 in. O.D., 2.5 in. I.D. and .7 in. high. The allowable bellows area, then was given by:

$$A_e = \text{effective bellows area} = \frac{\pi}{4} \left\{ \frac{\text{I.D.} + \text{O.D.}}{2} \right\}^2$$

$$A_e = \frac{\pi}{4} \left(\frac{2.5 + 3.0}{2} \right)^2 = 5.9 \text{ in}^2$$

The required stroke is then obtained:

$$S = \text{Stroke} = \Delta V / A_e = .56 / 5.9 = .095 \text{ in}$$

The spring rate of the bellows was calculated by first determining the desired temperature-pressure curve for the unit. Figure 3-21 shows the vapor pressure of Freon 113 vs temperature. In order to prevent boiling, the system pressure must always be greater than the vapor pressure. Thus the second curve, LB5 internal pressure (at 1 atmosphere ambient pressure) was drawn in Figure 3-21. The spring rate was computed as follows:

$$\text{From } 75^{\circ}\text{F to } 175^{\circ}\text{F, } \Delta P = 40 \text{ psi}$$

$$F = \Delta P A_e = (40)(5.9) = 236 \text{ lbs.}$$

$$K = \text{spring rate} = F / S = 236 / .095 = 2500 \text{ lbs/in}$$

This spring rate keeps the maximum system pressure below 60 psia during high temperature storage, but well above the Freon 113 vapor pressure throughout the gyro operating temperature range. Figure 3-22 is a listing of the design parameters which were used as purchase specifications for the LB5 bellows, and Figures 3-23 and 3-24 are the resulting detail and assembly drawings.

Internal Pressure as a Function of Temperature

Note that at the intersection of the bellows characteristic curve and the Freon 113 vapor pressure curve in Figure 3-21, the system pressure follows the vapor curve. This can be better understood by examining the schematic representation in Figure 3-25. When the unit is filled (at 75°F, 1 atmosphere ambient) the bellows is at equilibrium position, and

$$P_{\text{sys}} = P_{\text{amb}} = 15 \text{ psia (See Figure 3-25a)}$$

As the temperature is reduced (<75°F) the liquid contracts, atmospheric pressure on the cap deflects the bellows inward (See Figure 3-25c) and the system pressure is given by:

$$P_{\text{sys}} = P_{\text{amb}} - KS/A_e$$

$$P_{\text{sys}} = 15 - 2500/5.9 S = 15-424S$$

But S (bellows deflection or stroke) is a function of temperature; from before, for $\Delta T = 100^\circ\text{F}$, $S = .095 \text{ in}$

$$\therefore S/\Delta T = .095/100 = .00095 \text{ in}/^\circ\text{F}$$

$$\therefore P_{\text{sys}} = 15-424 (.00095) \Delta T$$

$$\text{when } T = 46^\circ\text{F, or } \Delta T = 75-46 = 29^\circ\text{F}$$

$$P_{\text{sys}} = 15-424(.00095)(29) = 3.2 \text{ psia} \\ (S = .028 \text{ in})$$

This is the vapor pressure of Freon 113 at 46°F (as shown in Figure 3-21), and the system pressure is now* given by $P_{\text{sys}} = P_{\text{v.p.}}$ (for $P_{\text{amb}} - KS/A_e = P_{\text{v.p.}}$; Figure 3-25d),

since a liquid at a specified temperature must exhibit a certain vapor pressure. From 46°F down to 32°F , the system pressure is merely the vapor pressure of Freon 113 at that particular temperature.

Internal Pressure as a Function of Ambient Pressure

It is also necessary to know the effect of ambient pressure on LB5 internal pressure; Figure 3-26 shows the effect at various temperatures. Once again Figure 3-21 can be useful in understanding what is taking place. For example, take the case of Figure 3-25b, assume that the temperature is 125°F and initially $P_{\text{amb}} = 15 \text{ psia}$. From Figure 3-21, $P_{\text{sys}} = 35 \text{ psia}$ and the following relationship is true:

$$P_{\text{sys}} = P_{\text{amb}} + KS/A_e$$

since, the temperature is fixed, the liquid volume is fixed and therefore the bellows deflection is constant. Hence, the second term on the right side of the equation is constant:

$$P_{\text{sys}} = P_{\text{amb}} + \text{Constant}$$

*NOTE: If the bellows is mechanically constrained so that an inward deflection of .028 in cannot be attained, the system pressure will prematurely drop to the vapor pressure at that point.

Thus, as P_{amb} is reduced, P_{sys} decreases at the same rate, until total vacuum is reached, when $P_{sys} = 20$ psia, the bellows deflection remains unchanged.

Another case would be when the temperature is 75°F (Figure 3-25a). The same analysis applies: from Figure 3-21, at 1 atmosphere, $P_{sys} = 15$ psia; as P_{amb} is reduced, P_{sys} decreases at the same rate. However, when P_{sys} reaches the vapor pressure of Freon 113 at 75°F (3.2 psia), it remains fixed regardless of further reduction of P_{atm} . At this point, the following equation holds:

$$P_{sys} = \text{Constant} = P_{amb} + KS/A_e$$

Thus as P_{amb} continues to decrease, the bellows deflection increases.

The curve for $T = 104^{\circ}\text{F}$ was included in Figure 3-25, because it represents the lowest temperature at which the LB5 can theoretically be run in vacuum environment without vaporization occurring. This was determined by applying the following relationship:

$$P_T - 15 = V.P._T$$

P_T = LB5 internal pressure at temp T and 1 atm

$V.P._T$ = vapor pressure of fill liquid at temp T

T = lowest temperature at which LB5 can be run in total vacuum ambient.

For this case: $P_T = 26.5$ psia from Figure 3-21

$V.P._T = 11.5$ psia at $T = 104^{\circ}\text{F}$

$$26.5 - 15 = 11.5$$

$$11.5 = 11.5$$

Effect of Freon E2 on Bellows Design

The bellows was primarily designed for Freon 113. However, substitution with Freon E2 can be made without any problems. The coefficient of expansion for both liquids is approximately the same, so the system pressure rise vs temperature is unchanged. The vapor pressure of Freon E2 is much lower, hence a greater safety factor against boiling is achieved. Figure 3-27 shows this quite clearly. The effect of ambient pressure on the LB5-E2 system pressure is seen in Figure 3-28. It is identical to the original case except that the minimum temperature for vacuum operation is reduced to 77°F, due to the lower vapor pressure.

5) Filters

An important practical aspect of the LB5 design is cleanliness. For the liquid bearing to exhibit the high degree of repeatability necessary to match Saturn AB5 K8 gas bearing performance, it must be free of contamination. Likewise, the Spiral Groove pump must also be clean in order to run properly. The first step, of course, was to build the unit clean initially. This was accomplished by careful cleaning, handling and assembly of parts under the controlled white room conditions normally used for precision inertial components. The second, and equally important step, was to make sure the unit stayed clean. In the LB5 gyro, this was done by taking advantage of the inherent cleaning characteristics of the fill fluid (Freon 113 or Freon E2).

As previously described, the liquid is forced out of the Spiral Groove pump, through the hydrostatic bearing and recirculated back to the pump. Millipore filters are placed at the inlet and outlet ports to maintain cleanliness within the unit.

Configuration

The filters were designed for retention of the smallest possible particles while maintaining reasonable flow restriction. The restriction of membrane filters is inversely proportional to total filter area, thus the LB5 design layout was examined to determine the maximum area that was practically attainable. The end plate to which the pump mounts was found to accommodate two outlet and two inlet filters whose outline dimensions are .438 O.D. x .162 thick (See Figure 3-29). Using a configuration similar to that used for the bearing orifice restrictors, the filters were made of a Millipore filter disk bounded on each side by a stainless steel mesh screen for rigidity (See Figure 3-30). In addition, there are sealing washers on each side, used in conjunction with an o-ring to make sure the liquid goes through the filter and not around it (See Figure 3-1). The assembly is bounded together by cement wafers between each component piece. The largest flow diameter attainable within this configuration was .30 in.

Pore Size

To determine what membrane pore size would be best suited for this application, it was first necessary to examine the flow pattern more closely. Figure 3-31 is a schematic representation of the flow paths in the LB5 gyro. It is seen that the loss due to the filters is

$$\Delta P_f = Q \frac{3R}{4}$$

Q = total flow through LB5 (ccm)
 R = restriction/filter (psi/ccm)

The design limit placed on ΔP_f was that it not exceed 20% of the pressure drop through the bearing. Thus

$$Q \frac{3R}{4} \leq .2 \Delta P_{brg} \text{ or } R \leq .266 \frac{\Delta P_{brg}}{Q}$$

For Freon 113 at 125°F,

$$R \leq .266 \frac{(8)}{(16)} = .133 \text{ psi/ccm}$$

Published data* on MF-Millipore filter membrane revealed the following information

<u>PORE SIZE</u>	<u>FLUID</u>	<u>FLOW DIA.</u>	<u>RESTRICTION</u>
0.45μ	Freon 113 at 125°F	.300 in.	.246 psi/ccm
0.67	"	"	.118 psi/ccm
0.80	"	"	.084 psi/ccm

Ideally, it was desirable to use the 0.45μ (or smaller) Millipore in the filters, since the orifice restrictors in the gyro sleeve (which the filters are supposed to

* Reference: Catalog MF-68, Millipore Corporation

protect against contamination) are this size. However, the restriction was too high, so the next larger pore size (0.67μ) was selected. The corresponding loss across the filters is then:

$$\Delta P_f = Q \frac{3R}{4} = (16) \frac{3(.118)}{4} = 1.42 \text{ psi}$$

It should be noted at this time that all pump test data given in this report was taken in a fixture which contained these same filters, in addition to a gyro restriction simulator. Thus the pump was subject to actual operating conditions, and pressure differential readings taken across the gyro simulator are true indications of the bearing pressure in the LB5.

Filter Restriction With Freon E2

The filters and the gyro itself are linear restrictors. Thus predicting the effect of substituting Freon E2 for Freon 113 was straight-forward. The density of both liquids is about the same. The effective inner cylinder weight was therefore unchanged and the pressure differential required for 18g's load capacity remained at 8 psi (See Section 3.A.2). Thus, since the entire flow path is linear, and flow rate is inversely proportional to viscosity, the new flow rate was computed as follows:

$$Q_{E2} = Q_{113} \frac{M_{113}}{M_{E2}}$$

The restriction per filter is directly proportional to viscosity, and the new value is given by:

$$R_{E2} = R_{113} \frac{M_{E2}}{M_{113}}$$

The loss through the filters with Freon E2 is then

$$\Delta P_f = 3/4 QR = 3/4 Q_{113} \frac{M_{113}}{M_{E2}} \times R_{113} \frac{M_{E2}}{M_{113}}$$

$$\Delta P_f = 3/4 Q_{113} R_{113} \quad \underline{\text{UNCHANGED}}$$

6) Fluids

Freon 113 was chosen as the fill fluid for the LB5 gyro on the basis of the bearing performance, g-capability, and compatibility tests described in MF 3945 (Appendix); its characteristics are tabulated in Figure 3-32. The self-cleaning property of the liquid makes it ideal for this application since removal of fill fluid from parts is automatic upon disassembly of the unit. Its solvent characteristic tends to remove contaminants from the hydrostatic bearing and keep it clean. It is non-toxic, inexpensive and extremely easy to handle.

Freon E2 was chosen for LB5 #3 primarily because its lower freezing point (-190°F as opposed to -30°F) greatly increases the storage temperature range and its lower vapor pressure increases the allowable temperature at which the LB5 can be run in a vacuum environment. It also has a viscosity close enough to Freon 113 that the Spiral Groove pump performance was not drastically different. The lower vapor pressure, however, makes it necessary to subject the unit to rough vacuum (at room temperature) in order for it to be self-cleaning. Freon E2 is quite similar to Freon 113 in all other aspects, including compatibility, and the two are interchangeable in the LB5.

B. Evaluation

1) Spiral Groove Pump Tests

Test Fixture

The pump test fixture is shown in Figure 3-33. It consists of: a mounting pad for the pump, inlet and outlet filters identical to those found in the LB5 gyro; a 3.0 μ Millipore restrictor which has the same pressure-flow characteristics as the gyro; two pressure gages (or transducers) located immediately before and after the gyro simulator; an o-ring sealed cover which has a window through which the pump speed-port can be viewed; a safety valve set to open automatically above 50 psig; two 150-watt cartridge heaters; a thermistor probe used in conjunction with the heaters, and an external proportional temperature-control circuit; two toggle valves used for evacuation and filling. Schematically the fixture is represented in Figure 3-34.

Approach

As outlined in the program requirements, it was necessary to determine the optimum Spiral Groove pump design. As previously discussed, the number of grooves, the groove profile O.D., I.D., and depth had already been determined by prior analysis and test; the gaps and radial seal were made variable. The pumps were built with different combinations of gaps and seals, tested, re-machined, re-built and tested again, until the most efficient configuration was found. The design with the highest Performance Index*

*Performance Index = ΔP across LB5 gyro (psi)/rotor drag torque
(in-oz)

while meeting axial and radial g-capability requirements of 18 g's (making the pump compatible with the gyro in terms of load capacity) was considered to be the best. The optimum pump geometry and corresponding test data are summarized in Figure 2-6, while data summaries for all configurations tested are shown in Figures 3-35 through 3-39.

Selection of Pump Excitation

Figure 3-40 shows a typical set of performance vs excitation data for the spiral groove pump. The frequencies were chosen on the basis of the motor design curves presented in ER 70-09-253 (Appendix). The voltage at each frequency was chosen so that the running speed would be 10% to 15% lower than the no-load speed, at which point the electrical efficiency (for the induction motor) is highest. The last column, overall efficiency, is defined as output pressure per input watts. Notice that this parameter is highest at 250 cps, and decreases with decreasing or increasing frequency. 300 cps, 36 volts was chosen as the most suitable excitation because it yielded the highest output pressure while remaining within the design goal of 3 watts power input.

Effect of the Radial Seal on Performance Index

The effect of the radial seal on Performance Index can be seen in Figures 3-35 and 3-36.

MOD I pump configurations 2, 3, and 4 differ only in this respect: when the seal was decreased from .020 to .005, the P.I. increased from 12.3 to 16.5 (in/oz rpm). However, elimination of the seal caused the P.I. to decrease back down to 6.1. Configuration 5 also had no seal, but the gaps were increased to .00025. The performance index was further reduced to 4.19. Thus it was learned that the pump output was highest with as small a radial seal as practically possible (.005 in, due to eccentricity build-up) without eliminating it completely.

Effect of Shear Gap on Performance Index

Examination of the MOD II pump data (Figure 3-37) reveals the effect of shear gap size on the performance index. All three configurations were built with .005 in. radial seals but with different gaps. The performance index increases with decreasing gap, from 7.8 at .00033 in. to 15.1 at .0001 in, which is the closest fit possible due to non-parallelism build up in the pump assembly (See Figure 3-7). From MT 13947 (Appendix) the relationship between shear gap size and performance index is as follows:

$$P/w = k/h^2 \text{ where } P = \text{pump output pressure}$$

$$w = \text{rotor speed}$$

$$k = \text{constant when all parameters (except gap) are held constant}$$

$$h = \text{shear gap}$$

$$M/w = k^1/h$$

$$M = \text{rotor drag torque}$$

$$k^1 = \text{constant}$$

$$\text{Perf Index} = P/M = P/w \cdot w/M = k/h^2 \cdot h/k^1$$

$$\text{P.I.} = K/K^1 \text{ l/h}$$

Thus P.I. is inversely proportional to shear gap. The data points obtained from Figure 3-37 for the Mod II pump are plotted in Figure 3-41, along with data points from Figure 3-39 for the journal bearing pump.

Journal Bearing Torque

The only basic difference between the journal bearing pump and the MOD II pump is the radial bearing. (The optimum design for both pumps is achieved at .0001 in. gaps and .005 in. radial seal).

Thus, the journal bearing torque can be determined by comparison of the total torque levels as follows:

For the optimum MOD II pump (Figure 3-37, Configuration#3):

$$M_T = (1.61 \times 10^{-4}) (2675) = .43 \text{ in-oz}$$

For the optimum journal bearing pump (Figure 3-38, configuration#3):

$$M_T = (2.0 \times 10^{-4}) (2600) = .52 \text{ in-oz}$$

The total torque for the MOD II pump is the sum of the pumping (shear) torque and the ball bearing torque:

$$M_T = .43 = M_p + M_{bb}$$

but $M_{bb} = .065 \text{ in-oz}$ (from Figure 3-8)

$$\therefore M_p = .430 - .065 = .365 \text{ in-oz}$$

The same relationship is true for the journal bearing pump.

$$M_T = .52 = M_p + M_{jb}$$

$$M_{jb} = .52 - M_p = .520 - .365$$

$$M_{jb} = .155 \text{ in-oz (at 2000 rpm with Freon 113 at } 125^{\circ}\text{F)}$$

The journal bearing torque is directly proportional to liquid viscosity(ER70-09-239 Appendix) so that the torque with Freon E2 is calculated as follows:

$$(M_{jb})_{E2} = (M_{jb})_{113} \frac{M_{E2}}{M_{113}}$$

$$(M_{jb})_{E2} = .16 \frac{.68}{.48} = .23 \text{ in-oz}$$

Centrifuge Tests

The g-capability and slew rate capacity of the pumps were determined by centrifuge testing. Figure 3-42 is a schematic representation of the test set up. Figure a shows the orientation of the pump during radial g-capability testing. Figure b shows the pump placement during axial g-capability and slew rate capacity tests. Note that the pump is subjected to the combined effects of axial g-loading and slewing simultaneously thereby imposing more severe conditions than indicated on the data summary sheets (Figure 3-35 through 3-39). The g-capability (slew rate capacity) of the spiral groove pump was defined as that g-level (slew rate) at which it stopped running, as indicated by a zero pressure differential*across the LB5 simulator. All pump configurations

*NOTE: The pressure differential was indicated by two Kistler Model 408 strain-gage transducers whose output signals(along with all other electrical requirements of the test fixture) are fed through the centrifuge slip rings.

(except the MOD I no-seal pump, Figure 3-36) exceeded 30 g's axial and radial load capacity and 20 rad/sec slew rate capacity (at 2000 rpm pump speed) without stopping. The centrifuge was not run much above 30 g's (20 rad/sec) as a safety precaution, hence the exact values were not determined. Since the desired levels of performance were 18 g's and 6 rad/sec, this was not deemed necessary.

Stop-Start Tests

A MOD II pump was inspected, assembled and tested for starting voltage and running speed at fixed excitation. It was placed in a +lg (axial) orientation so that when the rotor was stationary, it rested on the bottom thrust pad (See Figure 3-6). The pump was connected to an automatic on-off timer which ran it for 50 seconds and then shut it off for 70 seconds. The pump went thru 20,000 stop-start cycles (over a period of about a month) and periodic starting voltage and running speed checks revealed no change in either parameter. The pump was disassembled and inspected for wear, but the only noticeable difference in the parts was a slight polishing of the bottom thrust pad and the adjacent rotor surface. Microscopic examination of the pump outlet filters revealed no significant wear particle contamination, and flow-rate tests indicated no increase in filter restriction.

A journal bearing pump was also subjected to stop-start testing, in both lg-radial and lg-axial positions. It went through 6000 cycles in each orientation, and like the MOD II pump, exhibited no significant changes in performance or appearance.

2) Pump Motor Tests

The Spiral Groove pump motor was tested as a separate sub-assembly before it was used in the pump. The test fixture, procedures and results are discussed in ER 70-09-253 (Appendix). The speed-torque curves are presented in Figure 3-18 and show good agreement with the performance characteristics predicted by the design calculations (See Figure 3-17).

3) Bellows Tests

Upon receipt from the vendor, each bellows assembly (Figure 3-24) was initially checked for leaks (helium leak rate not to exceed 4×10^{-8} cm³/min) bellows free length, and inner to outer housing concentricity. Then each one was built into an LB5 assembly for spring rate, expansion capability and hysteresis testing. The test set-up is shown in Figure 3-43. The unit was subjected to 10, 20, 30, and 40 psig and then back to 0 psig, while dimension H was measured at each pressure level. The data appears in Figure 3-44, and is plotted in Figure 3-45. The spring rates are somewhat higher than the 2500 lbs/in design specification, (See Section 3.A.4); but the maximum internal pressure (at high temp. storage) is still acceptable:

$$(P_{\max})_{\text{actual}} = (P_{\max})_{\text{design}} \frac{K_{\text{actual}}}{K_{\text{design}}}$$

$$P_{\max} = 40 \text{ psig} \frac{3470}{2500}$$

$$P_{\max} = 55 \text{ psig}$$

There was no measurable hysteresis encountered during the tests as indicated by comparison of the 0 psig readings before and after 40 psig pressurization. The initial H dimension varies quite a bit from one bellows assembly to another, but this is caused by variations in the bellows free height, which is independent of spring rate and expansion capability.

4) Filter Tests

Filter assemblies (See Figure 3-30) were made using .22, .45, and .67 micron Millipore, based on the design effort presented in Section 3.A.5. Flow rate tests yielded the following information:

<u>PORE SIZE</u>	<u>FLUID</u>	<u>PRESS DROP</u>	<u>FLOW</u>	<u>RES. AT 75°F</u>	<u>RES. at 125°F*</u>
.22μ	Freon 113 at 75°F	8.0 psi	8.0ccm	1.0 psi/ccm	.75 psi/ccm
.45μ	"	2.5 psi	8.0ccm	.31 psi/ccm	.23 psi/ccm
.67μ	"	2.5 psi	21.0ccm	.12 psi/ccm	.09 psi/ccm

.67 microns is the smallest pore size which can be used without exceeding the allowable flow restriction of .133 psi/ccm. Thus, the LB5 filters were made of this material and the resultant pressure drop thru the filtering system is

$$\Delta P_F = 3/4 QR = 3/4(16) (.09) = 1.08 \text{ psi}$$

* The flow restriction at 125°F was calculated by multiplying the measured value at 75°F by M_{125}/M_{75} .

5) LB5 Gyro Tests

Gas Bearing Tests

The LB5 gyro is built into gas bearing configuration in essentially the same manner as the AB5 K8: The sleeve orifices are flow rate tested; the sleeve, endplate and cylinder geometry are checked; the gas bearing is assembled and a preliminary (mechanical) decay curve taken; the electrical plate assembly is added and an electrical decay curve is taken along with flotation pressure tests; the float is static balanced, and the spin motor de-magnetized. The flex leads are placed on the unit and set to null out any gas bearing torque present. The gyro is then sent to calibration where it is run on a sidereal stand and dynamic balanced, the flex-leads fine adjusted and pressure and g^2 sensitivity tests run. The unit is then put through a series of Saturn AB5 K8 six-position sidereal final tests (described in GTSP 1853135) to determine the level and repeatability of its constant and g-sensitive drift. When all these tests are performed and the results compare favorably with Saturn specifications, the unit is further assembled into liquid bearing configuration (i.e.: addition of the spiral groove pump, the flow filters, the electrical end housing, the bellows assembly and the fill port) and filled.

Liquid Bearing Tests

Immediately after liquid bearing assembly, the LB5 is static checked on a torque-balance test stand for pump performance, proper fill and bearing repeatability. It

then goes to sidereal test (same stand as for gas bearing test) where the mass unbalance terms are measured and reduced. The unit, initially balanced in air, can be as high as 10 to 12⁰/hr out of balance (due to non-coincidence of the centers of mass and buoyancy) in liquid bearing operation. Since there are no provisions for external balance in the LB5, the procedure is basically cut and try. A technique aimed at eliminating a large part of the uncertainty is described in detail in NCER 70-09-248 "Balancing the LB5 Gyro" (Appendix). Typically, three balance cuts are required to bring the mass unbalance to within the .250⁰/hr/g design goal (See Section 1.B), after which the unit is once again subjected to the six-position sidereal tests described above. Summaries of the resulting g-sensitive and constant drift data for LB5 #1, 2, and 3 appear in Figure 2-1. The complete sets of data are chronologically tabulated in Figures 3-46 thru 3-64. Included for LB5 #3 is the test data taken in three different configurations: (1) Freon 113, ball bearing pump, no mu-metal covers; (2) Freon E2, journal bearing pump, no mu-metal covers; (3) Freon E2, journal bearing pump, mu-metal covers. The unit was rebalanced between the first and second configurations due to the difference in liquid density; It was shipped in the third configuration (data summarized in Figure 2-1). The magnitude of certain drift coefficients (M_{cy} , M_{ep} , M_{uia} , M_{usra}) for the third configuration are different from the second configuration because the mu-metal covers provided magnetic shielding for the gyro during third configuration tests; repeatability was also affected, showing significant improvement. This effect is shown in Figure 3-65. In addition to the sidereal evaluation of the gyros at Navigation and

Control, north-seeking tests were run at NASA Marshall Space Flight Center. The units were positioned with output axis vertical and input axis east-west, in a torque-balance mode. Thus, any bias torque was indicated by torquer variable phase current which could be converted directly into effective drift rate in degrees per hour. Each day the units were run up from room temperature and drift readings taken at 100 second intervals starting immediately after wheel sync. The data for LB5 #1 and LB5 #2 appears in Figures 3-66 thru 3-69, and is summarized in Figures 2-4 and 2-5. (No NASA data of this type is presently available on LB5 #3). Initial drift is the first reading for each day and steady-state drift is an average of the last 72 readings for each day. The 45°C case temperature (for LB5 #1) was attained by using external heaters, while the 35°C case temperature (for LB5 #2) was reached without ambient heat.

C) Conclusions and Recommendations

This study has shown that precision inertial components, utilizing liquid hydrostatic inner gimbal support, can be built. The LB5 gyro built from modified Saturn AB5 K8 hardware performs as well or better than its gas bearing counterpart (See Figure 2-1 thru 2-5) with only about a 2 watt increase in power and slightly larger outline dimensions. A unit of this type combines the desirable characteristics of both gas bearing and floated components. It is a sealed self-contained package requiring no gas supply system and is impervious to external contamination once it is closed up. A significant feature is its optimum thermal design. The use of liquid instead of gas provides immediate reduction of thermal gradients because of the higher liquid conductivity. The smaller bearing gaps and the liquid flow yield lower inherent thermal gradients than are found in floated gyros. Improved heat conduction thru the unit results in a shorter reaction time than for typical floated units. The reduced thermal sensitivity eliminates temperature storage problems.

The inherent liquid damping is not found in gas bearing units, nor is the added support provided by the liquid buoyant force. The hydrostatic bearing, as opposed to the floated concept, is self-centering, requires no magnetic suspension or centering jewel and allows a much larger selection of fluids due to the non-critical fluid density. The absence of a magnetic suspension eliminates the need for elaborate electrical trimming networks, resulting in gyro performance being principally dependent on mechanical design. Problems associated with magnetic torques within the suspension system are eliminated and costs are lower. The

non-critical float density also allows the use of self-cleaning fluids, thereby reducing the build-up and teardown problems associated with floated components. Fluids can also be chosen so that air solubility improves with increasing internal temperature & pressure, thereby eliminating the possibility of bubble formation and, with it, the need for preliminary degasing. The stratification problems common to floated units are eliminated due to the use of homogeneous fluids. The dry metal-to-metal contact between the inner cylinder and sleeve that occurs during shutdown of gas bearing components is also avoided. The lack of ambient, pressure sensitivity (due to heavier allowable float construction) eliminates the need for external shrouding found in floated designs.

On the basis of the excellent test results described in this report and the extremely desirable characteristics outlined above, it is recommended that liquid bearing inertial components be considered for use in any application where gas bearing or floated components seem suitable. Liquid bearing components combine the relative ease of fabrication, assembly and system integration of the gas bearing component with the sealed, self-contained aspect of the floated unit. Performance is comparable to that of the gas bearing configuration which has proven so successful in the Pershing and Saturn programs, but the cumbersome gas supply system and its associated plumbing are eliminated.

It should be noted that the LB5 gyro is a prototype built around existing (modified) hardware to prove the concept, and that significant reductions in size and input power can be realized by designing a completely new unit specifically for liquid operation. A new unit could also include such advantageous mechanisms as built in balance adjust which would eliminate the fill required with each cut. It is also recommended that further studies be made on the LB5, aimed at centrifuge and vibration testing with capacitance pickoffs to determine g-capability of the hydrodynamic bearing, both with a journal bearing Spiral Groove pump and with a solenoidal piston pump. This information could be useful in optimizing the bearing geometry for liquid operation. The piston pump unit should also be built to compare its drift characteristics with the standard LB5.

A separate program involving conversion of the Saturn AMAB3-K8 accelerometer to liquid operation would also be valuable at this time, in order to determine the performance of the instrument and any significant problems which might be encountered in the effort. As in the case of the LB5, the Liquid Bearing Accelerometer (AMLB-3) would be designed to meet the interface, environmental and flight qualification requirements of its gas bearing counterpart. This would make possible, if so desired at some future date, insertion of both the LB5 and the AMLB3 into a (slightly modified) Saturn ST124 inertial system.



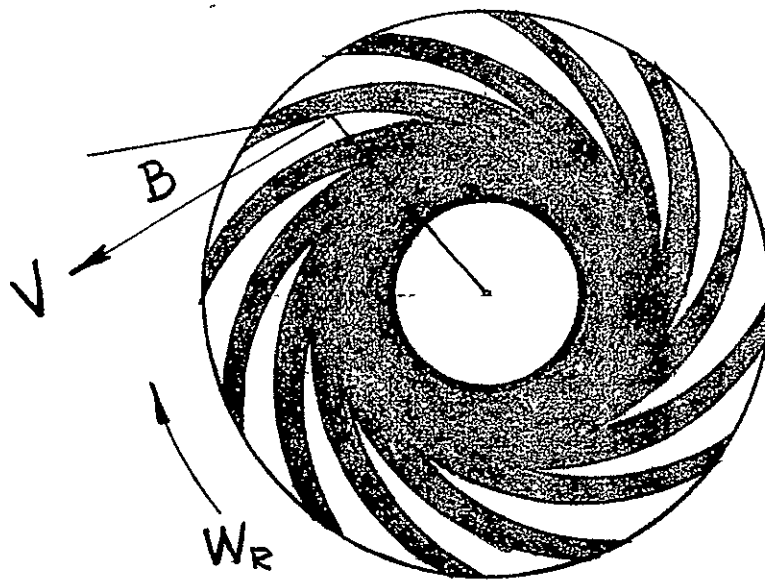
NOTES:-

- 1 ASSEMBLE PER ENGINEERING DEPT INSTRUCTIONS
- 2 FOR SCHEMATIC DIAGRAM SEE - - - - -
- 3 FOR WIRING DIAGRAM SEE - - - - -
- 4 FOR OUTLINE SEE 1957065
- 5 SOFT SOLDER CONNECTIONS MIL STD 454 REFS PER 1919035 (P2)
USING COMP SWSO, FORM W, TYPE RA, C26 P3, ST6C QR-S-571
- 6 APPLY IDENTIFICATION PLATE PER - - -

FIG. 3-1

(1) THIS DOCUMENT IS UNCLASSIFIED (2) EXEMPT FROM GDS SERVICE CONTROL (3) NO DISSEMINATION CONTROL, JMWAVE		(1) DATE OF ACCEPTANCE FOR SERVICE (2) BY WHOM (3) DATE OF ACCEPTANCE FOR SERVICE (4) BY WHOM		(1) DATE OF ACCEPTANCE FOR SERVICE (2) BY WHOM (3) DATE OF ACCEPTANCE FOR SERVICE (4) BY WHOM		THE BARCLAY GORDON "CN" NAVIGATION & COMM. - "S" REPAIRS, NEW YORK 10111 - "S"	
MAINTENANCE (1) DATE OF ACCEPTANCE FOR SERVICE (2) BY WHOM (3) DATE OF ACCEPTANCE FOR SERVICE (4) BY WHOM		(1) DATE OF ACCEPTANCE FOR SERVICE (2) BY WHOM (3) DATE OF ACCEPTANCE FOR SERVICE (4) BY WHOM		(1) DATE OF ACCEPTANCE FOR SERVICE (2) BY WHOM (3) DATE OF ACCEPTANCE FOR SERVICE (4) BY WHOM		LIQUID BEARING ST-311 GYRO ASSEMBLY L ⁵ E ⁵	
PART REF (1) DATE OF ACCEPTANCE FOR SERVICE (2) BY WHOM (3) DATE OF ACCEPTANCE FOR SERVICE (4) BY WHOM		(1) DATE OF ACCEPTANCE FOR SERVICE (2) BY WHOM (3) DATE OF ACCEPTANCE FOR SERVICE (4) BY WHOM		(1) DATE OF ACCEPTANCE FOR SERVICE (2) BY WHOM (3) DATE OF ACCEPTANCE FOR SERVICE (4) BY WHOM		SEE GDS RELAT NO. F 19315 SCALE 3/11 95704C	
ORIGINAL GDS-REF-1 (1) DATE OF ACCEPTANCE FOR SERVICE (2) BY WHOM (3) DATE OF ACCEPTANCE FOR SERVICE (4) BY WHOM		(1) DATE OF ACCEPTANCE FOR SERVICE (2) BY WHOM (3) DATE OF ACCEPTANCE FOR SERVICE (4) BY WHOM		(1) DATE OF ACCEPTANCE FOR SERVICE (2) BY WHOM (3) DATE OF ACCEPTANCE FOR SERVICE (4) BY WHOM		OFFICIAL OFFICIAL OFFICIAL OFFICIAL	

SPIRAL GROOVE PUMP SCHEMATIC



VIEW A-A

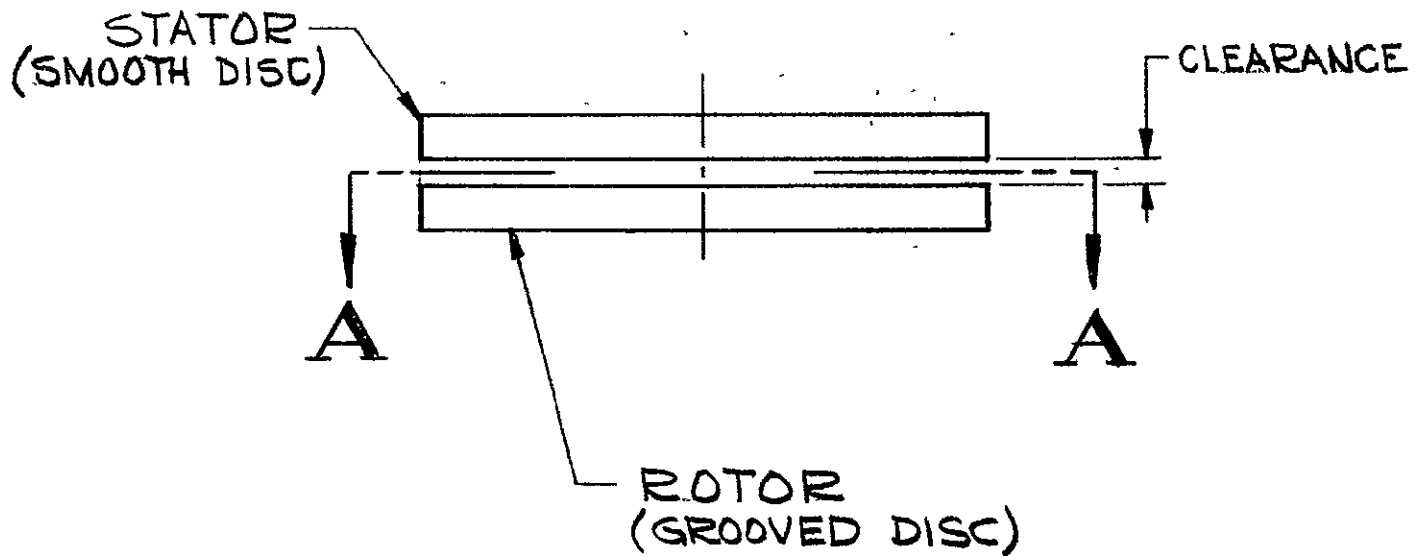


FIGURE 3-2

PRESSURE DISTRIBUTION IN THE SPIRAL GROOVE PUMP

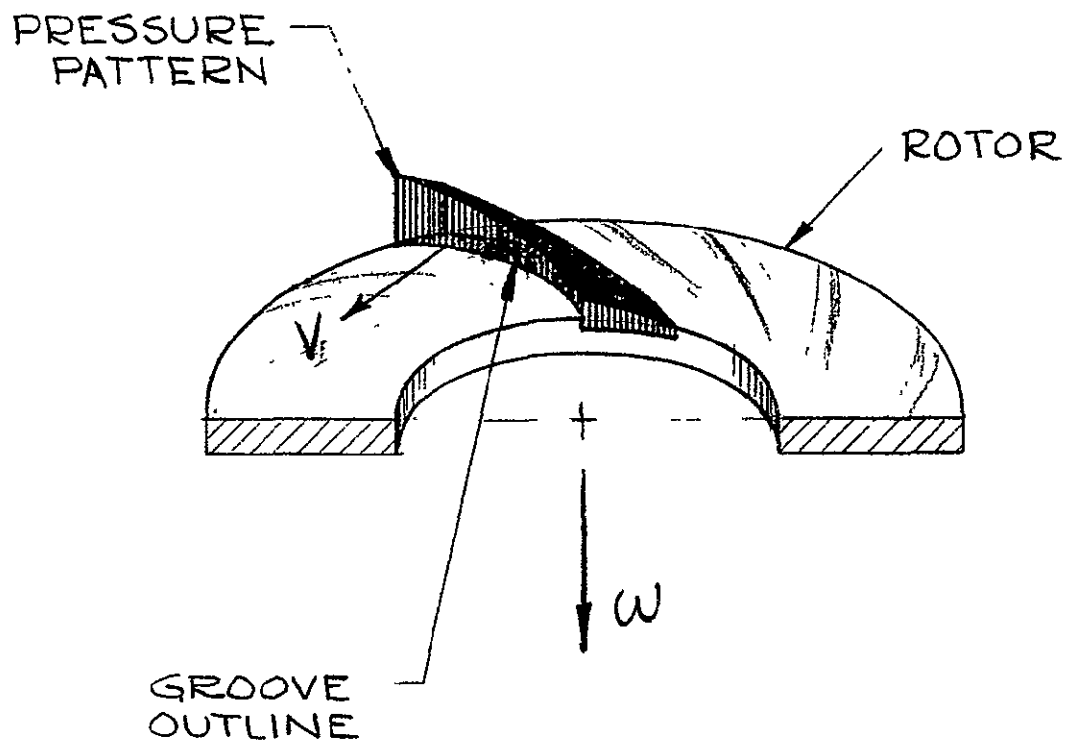


FIGURE 3-3

PART NO	REVISIONS	DATE	APPROVED				
MF	ZONE LTR	DESCRIPTION					
1923307-1 MS 9241-03E *1923308-1 *1923318-1 92704-1000 1937760-28 *1923316-1 SECTION A-A							
FIG. 3-4							
NOTE - 1 ASSEMBLE PER ENG INSTR.							
FIG. 3-4							
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 25%;"> *=INDICATES SUBASSEMBLY + =VENDOR ITEM - SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING HARDNESS FINISH THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION AND SUCH INFORMATION MAY NOT BE DISCLOSED TO OTHERS FOR ANY PURPOSE NOR USED FOR MANUFACTURING PURPOSES WITHOUT WRITTEN PERMISSION FROM THE BENDIX CORPORATION </td> <td style="width: 25%;"> — LIMITS OF ACCEPTABLE WORKMANSHIP ARE DEFINED IN NAVIGATION & CONTROL STANDARDS DS-103 PART REF ORIGINALLY DESIGNED FOR LIQUID BEARING GYRO 19570-10-1 </td> <td style="width: 25%;"> UNLESS OTHERWISE SPECIFIED — DIMENSIONS ARE IN INCHES — TOLERANCES ON DECIMALS 2 PLACE 3 PLACE 4 PLACE ± .03 ± .005 ± .0005 MATERIAL CONTRACT NO APPROVAL APPROVAL </td> <td style="width: 25%;"> DR 1923307-1 3 REQ'D CHK ENGR Y D MET REL APPD THE BENDIX CORPORATION NAVIGATION & CONTROL DIVISION TETERBORD, NEW JERSEY, U S A PUMP ASSEMBLY MOD I (SPIRAL GROOVE) SIZE CODE IDENT NO C 19315 1923307 SCALE 2/1 SHEET 1 OF 1 </td> </tr> </table>				*=INDICATES SUBASSEMBLY + =VENDOR ITEM - SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING HARDNESS FINISH THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION AND SUCH INFORMATION MAY NOT BE DISCLOSED TO OTHERS FOR ANY PURPOSE NOR USED FOR MANUFACTURING PURPOSES WITHOUT WRITTEN PERMISSION FROM THE BENDIX CORPORATION	— LIMITS OF ACCEPTABLE WORKMANSHIP ARE DEFINED IN NAVIGATION & CONTROL STANDARDS DS-103 PART REF ORIGINALLY DESIGNED FOR LIQUID BEARING GYRO 19570-10-1	UNLESS OTHERWISE SPECIFIED — DIMENSIONS ARE IN INCHES — TOLERANCES ON DECIMALS 2 PLACE 3 PLACE 4 PLACE ± .03 ± .005 ± .0005 MATERIAL CONTRACT NO APPROVAL APPROVAL	DR 1923307-1 3 REQ'D CHK ENGR Y D MET REL APPD THE BENDIX CORPORATION NAVIGATION & CONTROL DIVISION TETERBORD, NEW JERSEY, U S A PUMP ASSEMBLY MOD I (SPIRAL GROOVE) SIZE CODE IDENT NO C 19315 1923307 SCALE 2/1 SHEET 1 OF 1
*=INDICATES SUBASSEMBLY + =VENDOR ITEM - SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING HARDNESS FINISH THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION AND SUCH INFORMATION MAY NOT BE DISCLOSED TO OTHERS FOR ANY PURPOSE NOR USED FOR MANUFACTURING PURPOSES WITHOUT WRITTEN PERMISSION FROM THE BENDIX CORPORATION	— LIMITS OF ACCEPTABLE WORKMANSHIP ARE DEFINED IN NAVIGATION & CONTROL STANDARDS DS-103 PART REF ORIGINALLY DESIGNED FOR LIQUID BEARING GYRO 19570-10-1	UNLESS OTHERWISE SPECIFIED — DIMENSIONS ARE IN INCHES — TOLERANCES ON DECIMALS 2 PLACE 3 PLACE 4 PLACE ± .03 ± .005 ± .0005 MATERIAL CONTRACT NO APPROVAL APPROVAL	DR 1923307-1 3 REQ'D CHK ENGR Y D MET REL APPD THE BENDIX CORPORATION NAVIGATION & CONTROL DIVISION TETERBORD, NEW JERSEY, U S A PUMP ASSEMBLY MOD I (SPIRAL GROOVE) SIZE CODE IDENT NO C 19315 1923307 SCALE 2/1 SHEET 1 OF 1				

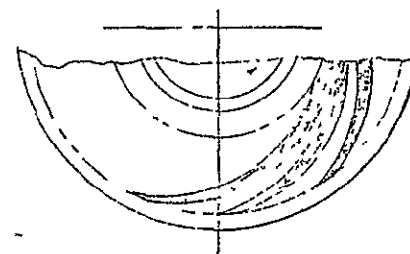
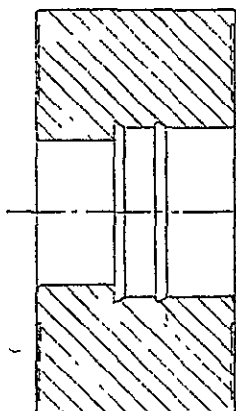
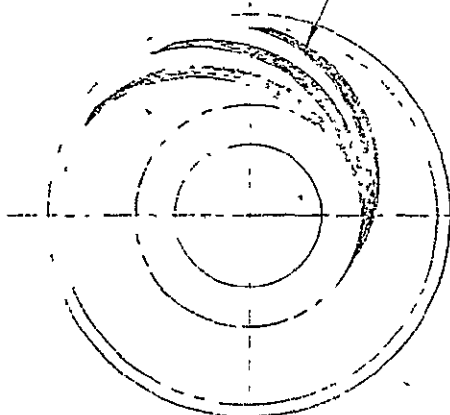
NOT REPRODUCIBLE

3-35

PART NO
1923321-1

MF			REVISIONS			DATE	APPROVED
ZONE	LTR		DESCRIPTION				

AIR ABRASE SPIRAL GROOVES
.0013 DEEP, USING STENCILS & FIXTURE
PROVIDED BY ENGINEERING,
ON BOTH SIDES.

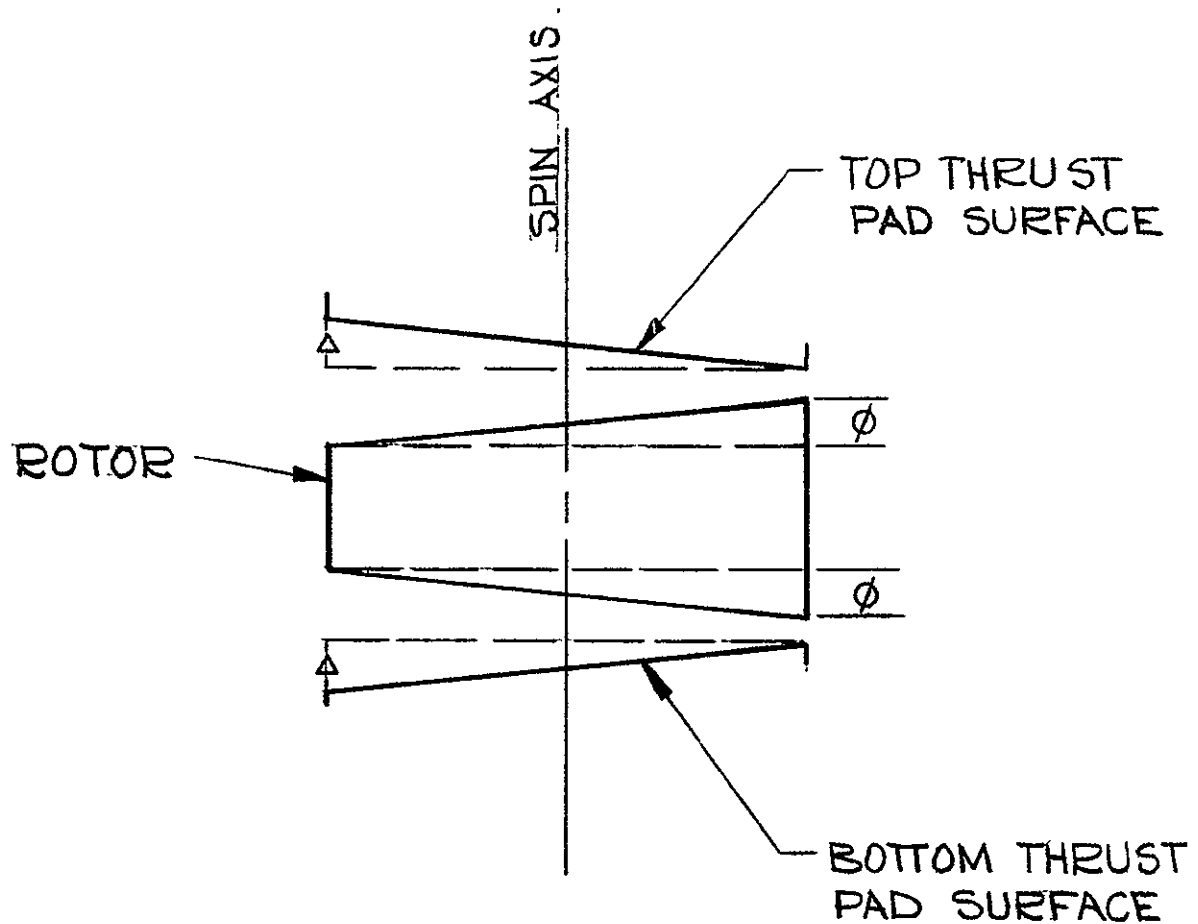


1923322-1

FIG. 3-5

* INDICATES SUBASSEMBLY † VENDOR ITEM - SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING		LIMITS OF ACCEPTABLE WORKMANSHIP ARE DEFINED IN NAVIGATION & CONTROL STANDARDS DS-103		UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS 2 PLACE 3 PLACE 4 PLACE $\pm .03$ $\pm .005$ $\pm .0005$		OR <i>FLAUSED</i> 18 JUN 69 CHK _____ ENGR _____ T D _____ MET _____ REL _____ APPD _____		THE BENDIX CORPORATION NAVIGATION & CONTROL DIVISION TETERBORO NEW JERSEY, U.S.A.	
HARDNESS		MATERIAL		CONTRACT NO		ROTOR, PUMP (GROOVE ABRADING)			
FINISH		PART REF		APPROVAL		SIZE	CODE	IDENT NO	
THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION AND SUCH INFORMATION MAY NOT BE DISCLOSED TO OTHERS FOR ANY PURPOSE, NOR USED FOR MANUFACTURING PURPOSES WITHOUT WRITTEN PERMISSION FROM THE BENDIX CORPORATION		ORIGINALLY DESIGNED FOR SPIRAL GROOVE PUMP 1923307-1		APPROVAL		C	19315	1923321	
□ DO NOT MARK PART NO. □ MARK PART NO AS SPECIFIED						SCALE	1/1		SHEET 1 OF 1

PARALLELISM IN THE SPIRAL GROOVE PUMP



$$2\Delta \leq 50 \times 10^{-6}$$

$$2\phi \leq 25 \times 10^{-6}$$

$$2\Delta + 2\phi \leq 75 \times 10^{-6}$$

FIGURE 3-7

SPIRAL GROOVE PUMP BALL BEARING CHARACTERISTICS*

Manufacturer:	Barden
Type:	Deep groove, Medium speed, Low torque, Open design, W-type retainer
Outer Diameter:	.5000 - .0001 (in)
Inner Diameter:	.2500 - .0001 (in)
Width:	.1250 $\pm$ $\begin{smallmatrix} .000 \\ .001 \end{smallmatrix}$ (in)
Material:	Inner race, Outer race, Balls, and Retainer-Hardened 440C Stainless Steel
Radial Play:	.0003 - .0005 (in)
Axial Play:	.004 (in)
Angular Misalignment:	1/2° (Allowable, running)
Inner Race Radial Run Out:	.000075 (in)
Outer Race Radial Run Out:	.0001 (in)
Maximum Running Torque with 5 lb. Radial and Axial load:	.065 (in-oz)
Number of Balls:	11

*REFERENCE: Engineering Catalog G-3, Barden Corp.

FIGURE 3-8

RADIAL ECCENTRICITY IN THE BALL BEARING SPIRAL GROOVE PUMP

A. Eccentricity Introduced Into Rotor Assembly by Ball Bearing:

1. Bearing I.D.:	.2500-.0001 (in)
Housing Post O.D.:	2497 + .0001
Clearance Fit:	.0001 - .0003

2. Inner Race Radial Run Out: .000075 $\approx$.0001

3. Outer Race Radial Run Out: .0001

4. Radial Play: .0003 - .0005

5. Bearing O.D.:	.5000 - .0001
Pump Rotor I.D.:	.5001 + .0001
Clearance Fit:	.0001 - .0003

(Total) A: .0012 in. T.I.R. worst case (.0006 in. radial)

B. Eccentricity Between Rotor I.D. and Rotor O.D.:

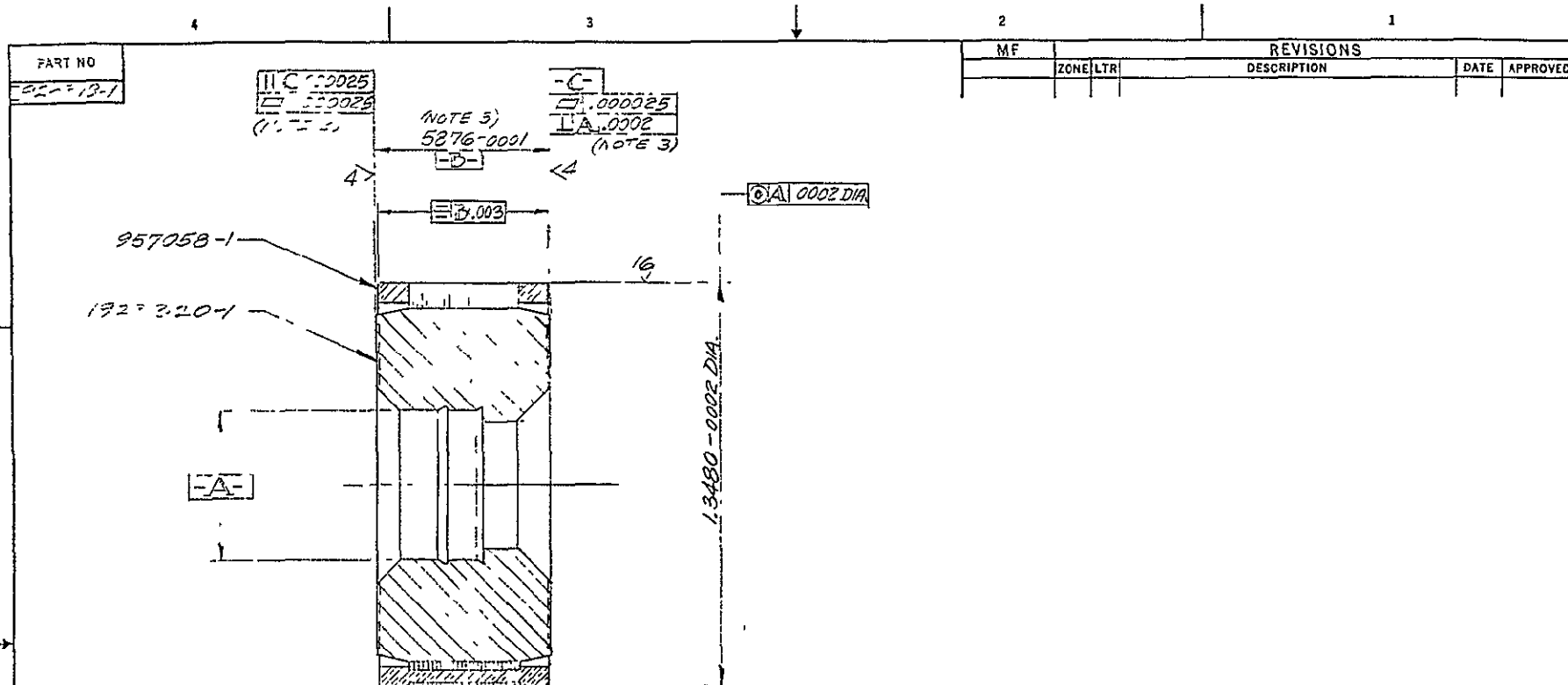
Ground Concentric to .0001 radial (See Figure 3-10)

C. Eccentricity Between Stator I.D. and Bearing Post O.D.:

Ground Concentric to .0001 radial (See Figure 3-11)

A + B + C = .0008 in.

FIGURE 3-9



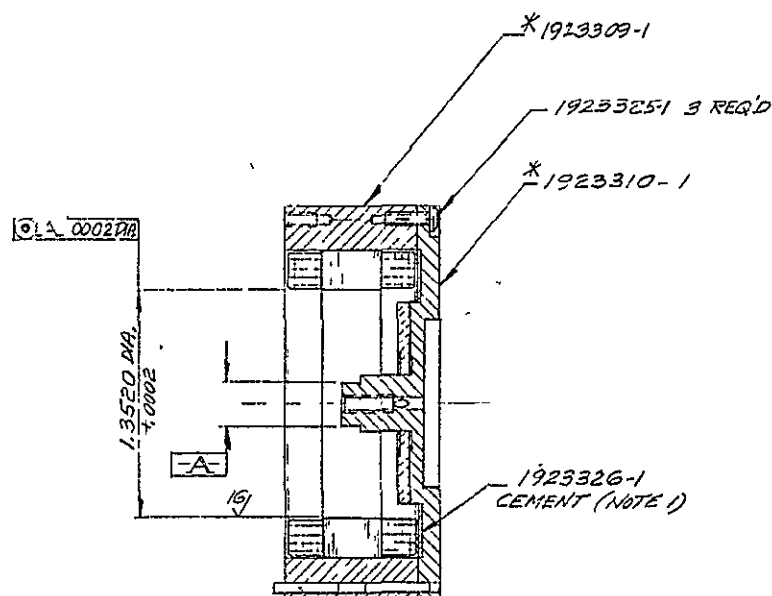
NOTE:

1. CELENT 1957058-1 ON 1923320-1 PER 1919269(P5)
2. MACHINE OD TO DIMENSION DV
3. REMOVE EQUAL AMOUNTS OF BOTH SIDES TO OBTAIN "B" DIMENSION, & ATTEND TO PARALLELISM

FIG. 3-10

*INDICATES SUBASSEMBLY †=VENDOR ITEM - SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING		- LIMITS OF ACCEPTABLE WORKMANSHIP ARE DEFINED IN NAVIGATION & CONTROL STANDARDS DS-103		UNLESS OTHERWISE SPECIFIED - DIMENSIONS ARE IN INCHES - TOLERANCES ON DECIMALS 2 PLACE 3 PLACE 4 PLACE $\pm .03$ $\pm .005$ $\pm .0005$		DR 1 2 3 4 5 6 7 8 9 10 11 12 ENGR T D MET REL APPD		THE BENDIX CORPORATION NAVIGATION & CONTROL DIVISION TETERBORO NEW JERSEY U.S.A.	
HARDNESS				MATERIAL				ROTOR ASSY. PUMP & MOTOR, MECHANICAL	
FINISH						CONTRACT NO			
THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION AND SUCH INFORMATION MAY NOT BE DISCLOSED TO OTHERS FOR ANY PURPOSE NOR USED FOR MANUFACTURING PURPOSES WITHOUT WRITTEN PERMISSION FROM THE BENDIX CORPORATION		PART REF ORIGINALLY DESIGNED FOR SP. 2. 62215 P.M.P. 1923307-1				APPROVAL		SIZE CODE IDENT NO C 19315 1923319	
DO NOT MARK PART NO MARK PART NO AS SPECIFIED						APPROVAL		SCALE 4/1 SHEET 1 OF 1	

PART NO 1923308-1	MF	REVISIONS		DATE	APPROVED
	ZONE LTR	DESCRIPTION			



NOTE:
1 CEMENT SHIELD PER 1919269 (P5)

FIG. 3-11

* INDICATES SUBASSEMBLY * VENDOR ITEM - SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING		LIMITS OF ACCEPTABLE WORKMANSHIP ARE DEFINED IN NAVIGATION & CONTROL STANDARDS DS-103		UNLESS OTHERWISE SPECIFIED - DIMENSIONS ARE IN INCHES - TOLERANCES ON DECIMALS 2 PLACE 3 PLACE 4 PLACE $\pm .03$ $\pm .005$ $\pm .0005$		DR. PLATE CHK ENGR T D MET REL APPD		THE BENDIX CORPORATION NAVIGATION & CONTROL DIVISION TETERBORO NEW JERSEY U S A.	
HARDNESS				MATERIAL		CONTRACT NO		HOUSING & STATOR MACHINING ASSY.	
FINISH						APPROVAL		SIZE CODE IDENT NO C 19315 1923308	
THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION AND SUCH INFORMATION MAY NOT BE DISCLOSED TO OTHERS FOR ANY PURPOSE NOR USED FOR MANUFACTURING PURPOSES WITHOUT WRITTEN PERMISSION FROM THE BENDIX CORPORATION		PART REF ORIGINALLY DESIGNED FOR SPARK (NOTE 1) 1923307-1				APPROVAL		SCALE 2/1 SHEET 1 OF 1	

☐ DO NOT MARK PART NO
☐ MARK PART NO AS SPECIFIED





1. FLUORESCENT PENETRANT INSPECT FINISH A JOINED PART PER MIL-I-6866 TYPE I METHOD B
PER. 312115 (PS) TYPE II

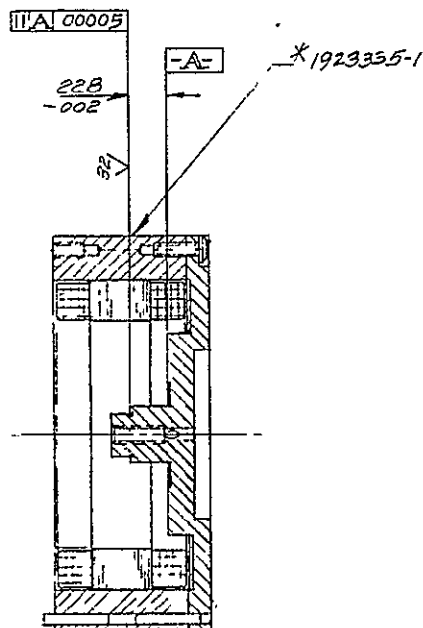
IMPORTANT
THIS PRODUCT IS TOXIC
USE ADEQUATE PRECAUTIONS

FIG. 3-13

[illegible]

☐ DO NOT MARK PART NO
☐ MARK PART NO. AS SPECIFIED

PART NO 19-135-1	REVISIONS			
	MF	ZONE	LTR	DESCRIPTION
				DATE
				APPROVED



NOTE

- 1 PEWORK AS SHOWN
- 2 PROTECT ALL SURFACES

IMPORTANT
THIS MATERIAL IS TOXIC
USE ADEQUATE PRECAUTIONS

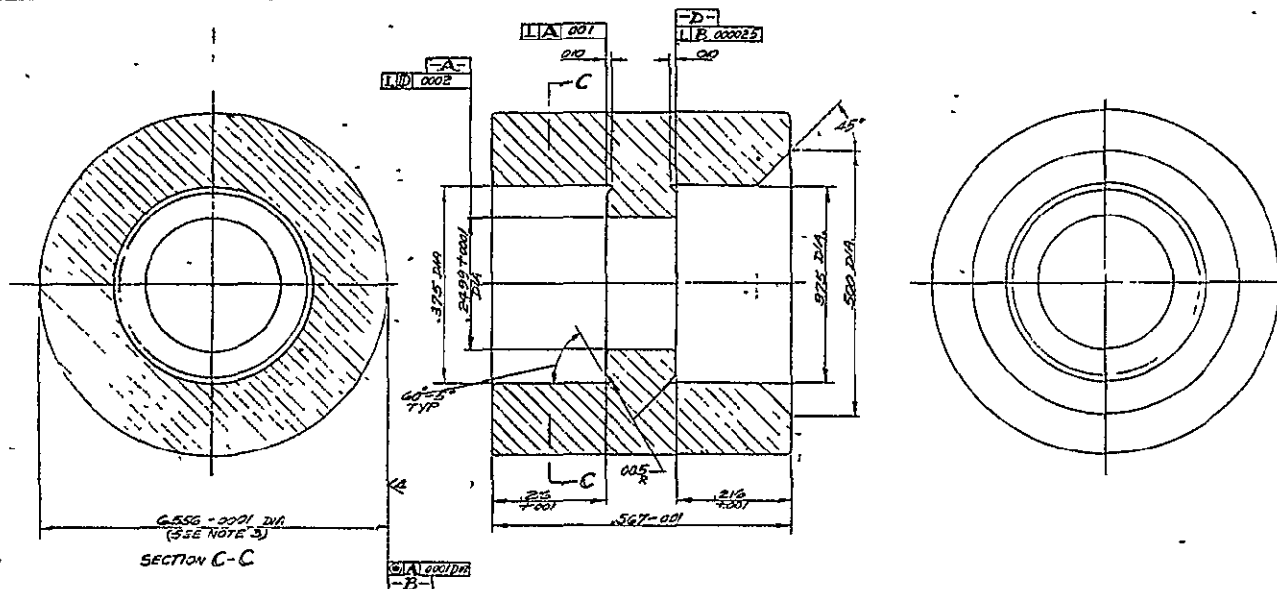
FIG. 3-14

**INDICATES SUBASSEMBLY * = VENDOR ITEM - SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING		- LIMITS OF ACCEPTABLE WORKMANSHIP ARE DEFINED IN NAVIGATION & CONTROL STANDARDS DS-103		UNLESS OTHERWISE SPECIFIED - DIMENSIONS ARE IN INCHES - TOLERANCES ON DECIMALS 2 PLACE 3 PLACE 4 PLACE $\pm .03$ $\pm .005$ $\pm .0005$		DR. A. LASHER 3/1/72 CHK ENGR. R. S. P. 3/1/72 T.O. 3/1/72 MET. 3/1/72 REL. APPD.		THE BENDIX CORPORATION NAVIGATION & CONTROL DIVISION TETERBORO, NEW JERSEY, U.S.A.	
HARDNESS		MATERIAL		CONTRACT NO.		BOTTOM COVER & MOTOR STATOR ASSY (PEWORK)		SIZE CODE IDENT NO C 19315 1981083	
FINISH				APPROVAL		APPROVAL C. L. P. 3/1/72		SCALE 2/1 SHEET 1 OF 1	
THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION AND SUCH INFORMATION MAY NOT BE DISCLOSED TO OTHERS FOR ANY PURPOSE NOR USED FOR MANUFACTURING PURPOSES WITHOUT WRITTEN PERMISSION FROM THE BENDIX CORPORATION		PART REF ORIGINALLY DESIGNED FOR SPIRAL GROOVE PUMP 135 TV							

☐ DO NOT MARK PART NO
☐ MARK PART NO AS SPECIFIED

PART NO
425/085-1

Mr.	REVISIONS		
	DESCRIPTION	DATE	APPROV
JONESLYR			



SECTION C-C

NOTES -

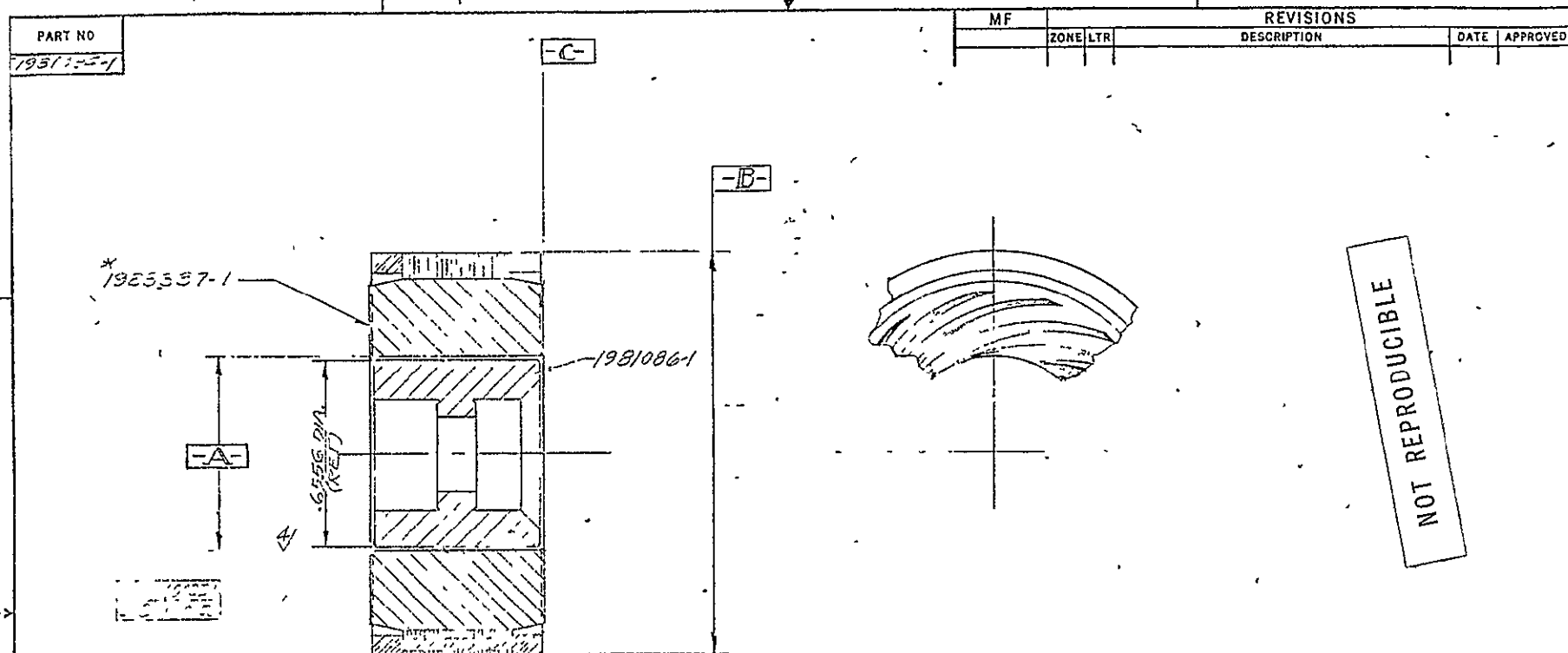
- 1. ROUND ALL EDGES AND
- 2. FINISH ¹⁰ EXCEPT WHERE OTHERWISE SPECIFIED
- 3. TAPE & OUT OF ROUNDNESS NOT TO EXCEED 0.00025 ON Ø D
- 4. PROCESS ROUGH PART PER 1919 BBT (P3)
- 5. FLUORESCENT PENETRANT INSPECT ROUGH, SEMI FINISHED & FINISH MACHINED PART (1913086-1)
- 6. PER MIL I 6866 TYPE I METHOD B PER 1919 I15 (P5) TYPE II
- 7. BERYLLIUM HANDLING & PROCESSING PER 1853048 (QMS).

IMPORTANT
THIS MATERIAL IS TOXIC
USE ADEQUATE PRECAUTIONS

FIG. 3-15

*REGISTERED IN BRASILEIRIA *PROPRIETARY ITEM - SEE SOURCE COUNTRY AND INTERNATIONAL CONTROL DESIGNATION		*LIMIT OF ACCEPTANCE INFORMATION SEE AGREEMENT IN BRASILEIRIA & CONTROL STANDARDS 82 131		MAXIMUM SIZE 4 1/2 x 6 1/2 MAX WEIGHT 100 GMS OR THEREOF MAX LENGTH 10 CM OR THEREOF TUBES 1 1/2" DIA OR THEREOF OR 1/2" OR THEREOF		SEE BENDIX CO. ACTION NAVIGATION & CONTROL DIVISION TETERBORO, NEW JERSEY, U.S.A.	
HARDNESS FINISH		MATERIAL BEVY LUMINER 1920E50A13 GR496 A		BEARING JOUPE-L (SEMI-FINISHED)		SIZE OF DOCUMENT D 19315	
THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION AND IS NOT TO BE DISCLOSED TO OTHERS IN ANY MANNER, NOR BEING REPRODUCED WITHOUT THE WRITTEN PERMISSION OF THE ATLAS CONTROL DIVISION		PART A/F ORIGINALLY DESIGNED FOR S 1346 29006 NO		APPROVAL D 19315		SCALE 3/1 SHEET 1	

12 DO NOT MAKE PART NO.
13 MAKE PART NO. AS SPECIFIED



NOTE:

- 1 MACHINE & LAP -A- SO THAT IT IS .00055 + .00055 LARGER THAN O.D. OF 1981086-1.
- 2 OUT-OF-ROUNDNESS & TAPER NOT TO EXCEED .000025.
- 3 AFTER LAPPING PARTS ARE MATCHING PAIR

IMPORTANT
THIS MATERIAL IS TOXIC
USE ADEQUATE PRECAUTIONS

FIG. 3-16

ENG D-111A

* INDICATES SUBASSEMBLY † VENDOR ITEM - SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING		- LIMITS OF ACCEPTABLE WORKMANSHIP ARE DEFINED IN NAVIGATION & CONTROL STANDARDS DS-103		UNLESS OTHERWISE SPECIFIED - DIMENSIONS ARE IN INCHES - TOLERANCES ON DECIMALS 2 PLACE 3 PLACE 4 PLACE $\pm .03$ $\pm .005$ $\pm .0005$		DR K LASHLEY CHK ENGR / T D MET REL APPD		THE BENDIX CORPORATION NAVIGATION & CONTROL DIVISION TETERBORO NEW JERSEY U.S.A.	
HARDNESS				MATERIAL				ROTOR ASSY (P-111111)	
FINISH						CONTRACT NO			
THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION AND SUCH INFORMATION MAY NOT BE DISCLOSED TO OTHERS FOR ANY PURPOSE NOR USED FOR MANUFACTURING PURPOSES WITHOUT WRITTEN PERMISSION FROM THE BENDIX CORPORATION		PART REF				APPROVAL		SIZE CODE IDENT NO C 19315 1981084	
		ORIGINALLY DESIGNED FOR SPIRAL GROOVE PUMP 110211				APPROVAL		SCALE 4/1 SHEET 1 OF 1	

- ☐ DO NOT MARK PART NO
☐ MARK PART NO AS SPECIFIED

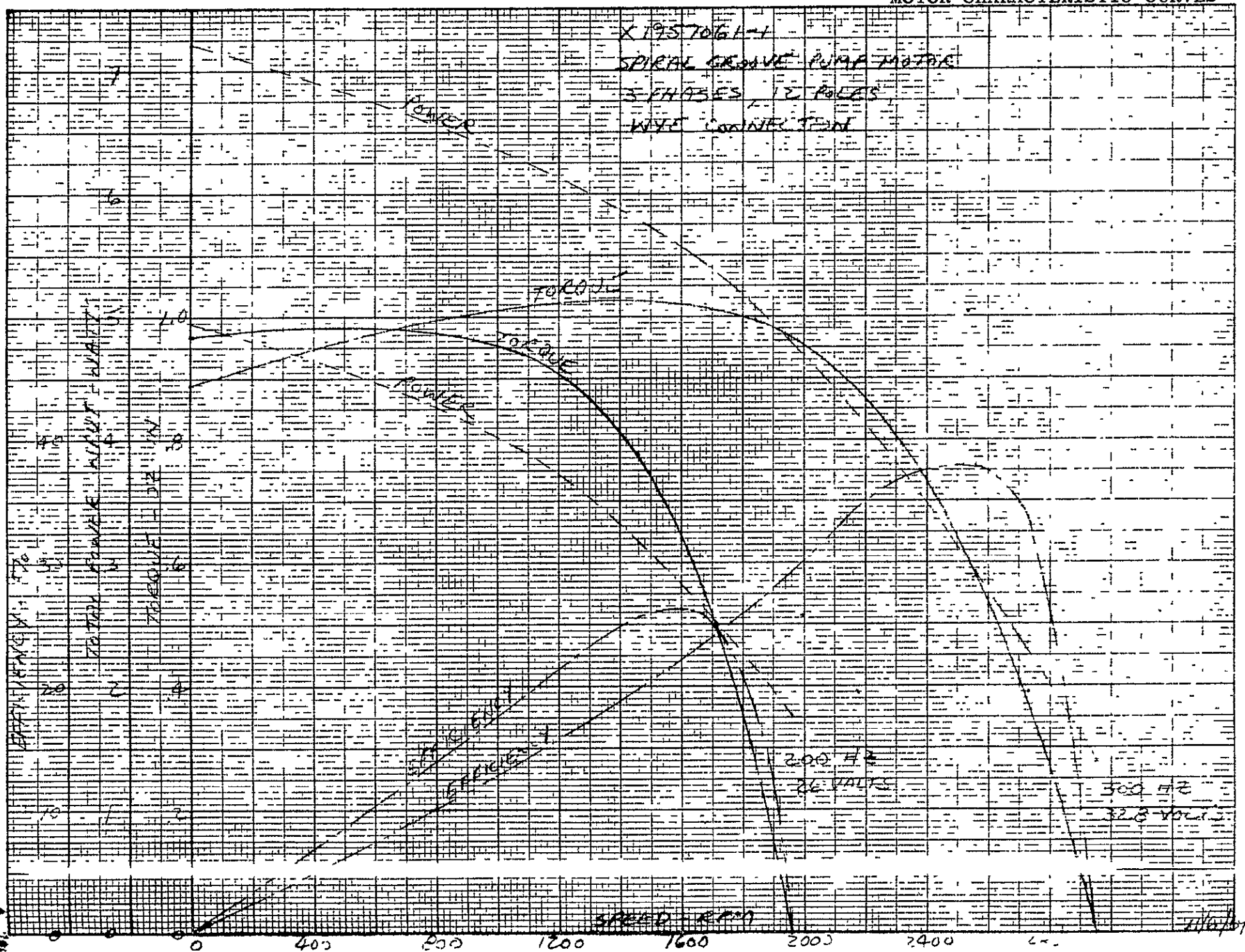
SPIRAL GROOVE PUMP MOTOR PARAMETERS

Type:	Squirrel Cage Induction Motor
Number of Phases:	3 (Y-connected)
Number of Poles:	12
Number of Stator Slots:	45
Number of Rotor Slots:	54
Stator D.C. Resistance:	170 Ω /phase
Excitation:	3 Phase, 300 $\sim$, 36 volts line-to-line
No-Load Speed:	2950 rpm at 300 $\sim$
Stall Torque:	.9 in-oz at 300 $\sim$, 36v
Stall Current:	118 ma
Running Torque:	.65 in-oz at 2500 rpm
Running Current:	72 ma
Input Power:	3.1 watts
Efficiency:	32%

FIGURE 3-17

FIGURE 3-18

MOTOR CHARACTERISTIC CURVES



PART NO
1957061

MF		REVISIONS			
	ZONE	LTR	DESCRIPTION	DATE	APPROVED

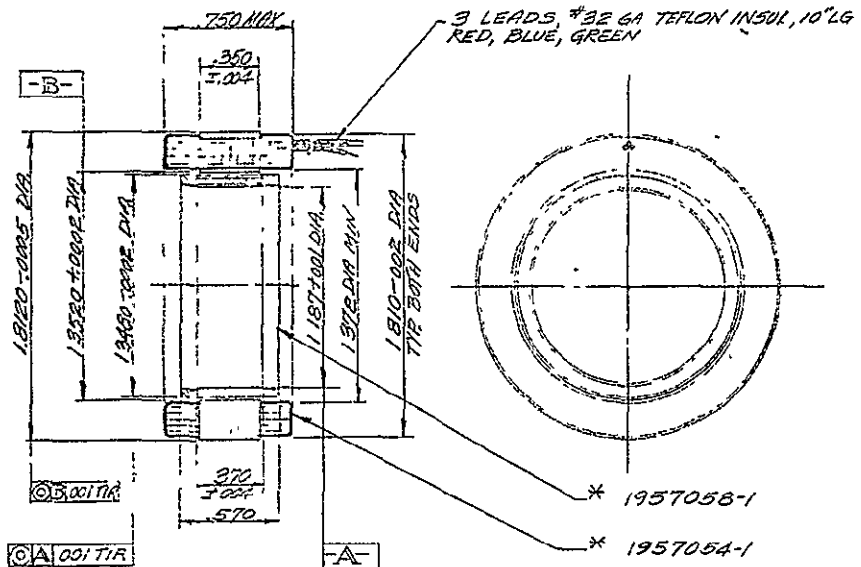


FIG. 3-19

* INDICATES SUBASSEMBLY + VENDOR ITEM - SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING		- LIMITS OF ACCEPTABLE WORKMANSHIP ARE DEFINED IN NAVIGATION & CONTROL STANDARDS DS-163		UNLESS OTHERWISE SPECIFIED - DIMENSIONS ARE IN INCHES - TOLERANCES ON DECIMALS 2 PLACE 3 PLACE 4 PLACE $\pm .03$ $\pm .005$ $\pm .0005$		DR M. LASNER CHK ENGR T D MET REL APPD		THE BENDIX CORPORATION NAVIGATION & CONTROL DIVISION TETERBORO NEW JERSEY U.S.A.	
HARDNESS				MATERIAL		CONTRACT NO		MOTOR ASSEMBLY & OUTLINE	
FINISH						APPROVAL		SIZE CODE IDENT NO. C 19315 1957061	
THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION AND SUCH INFORMATION MAY NOT BE DISCLOSED TO OTHERS FOR ANY PURPOSE NOR USED FOR MANUFACTURING PURPOSES WITHOUT WRITTEN PERMISSION FROM THE BENDIX CORPORATION		PART REF ORIGINALLY DESIGNED FOR PUMP FOR SPINNING PUMP				APPROVAL		SCALE 2/1 SHEET 1 - 1	

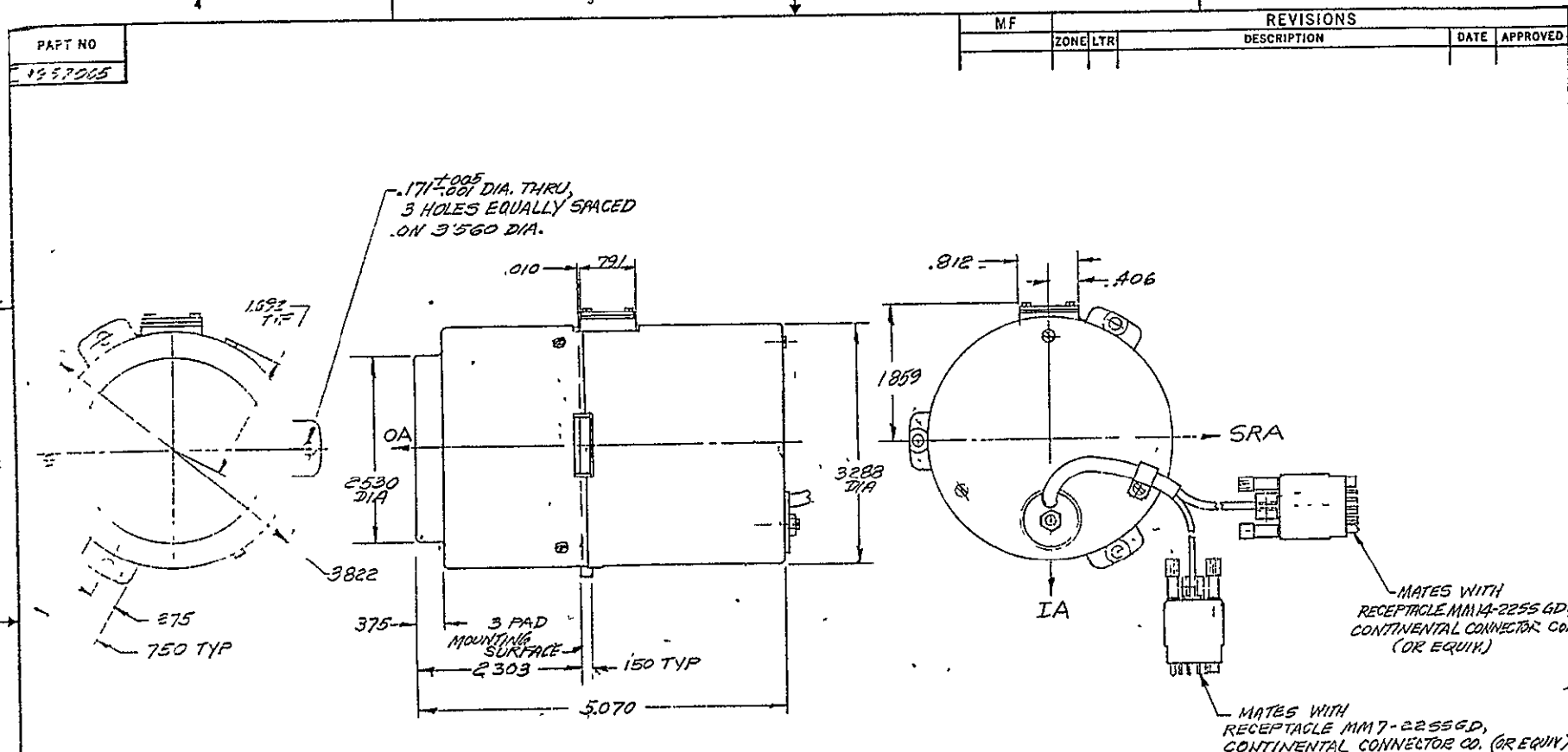
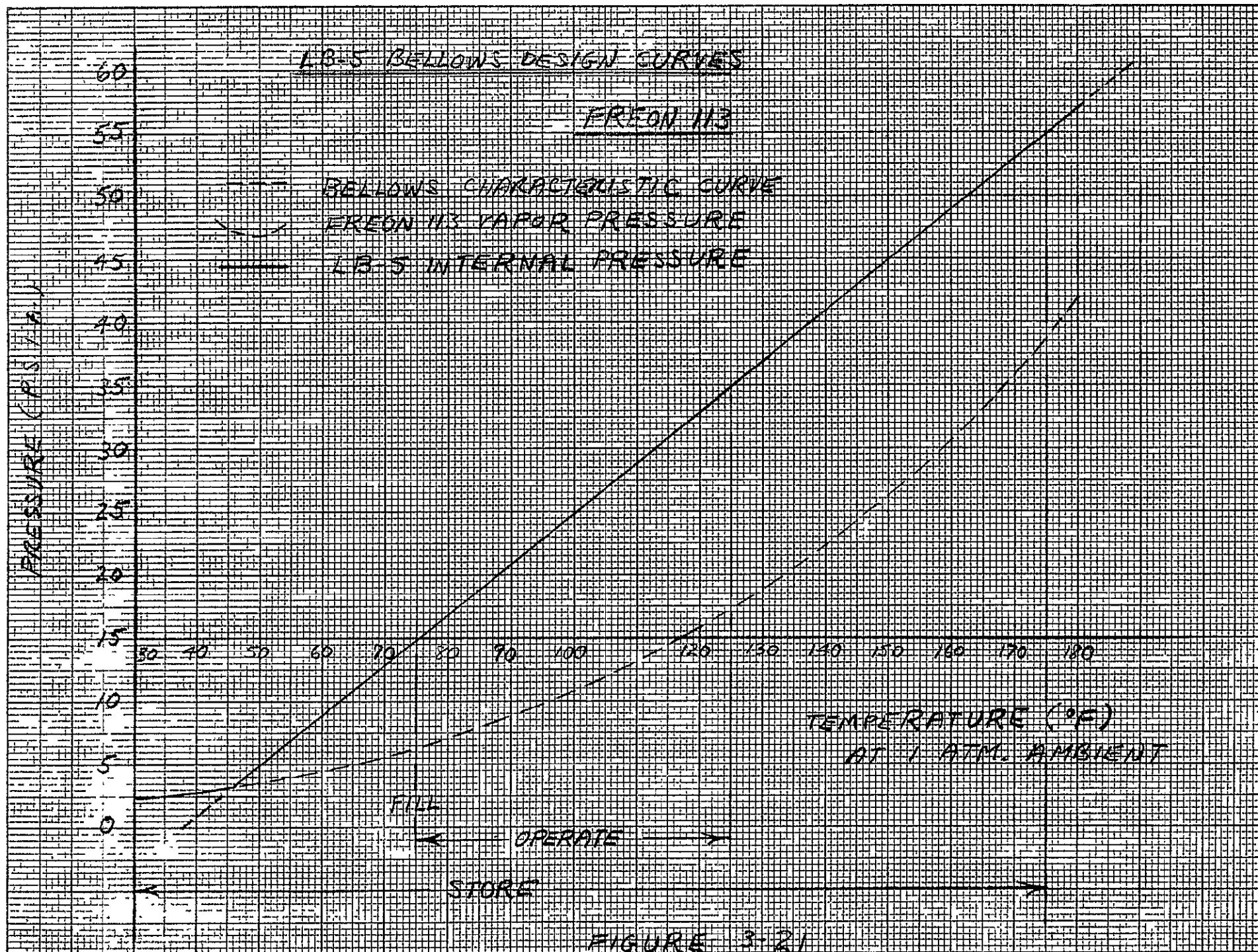


FIG. 3-20

* INDICATES SUBASSEMBLY + VENDOR ITEM - SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING		- LIMITS OF ACCEPTABLE WORKMANSHIP ARE DEFINED IN NAVIGATION & CONTROL STANDARDS DS-103		UNLESS OTHERWISE SPECIFIED - DIMENSIONS ARE IN INCHES - TOLERANCES ON DECIMALS 2 PLACE ± 03 3 PLACE ± 005 4 PLACE ± 0005		DR K LASHER 2211 Y89 CHK ENGR T D MET REL APPD		THE BENDIX CORPORATION NAVIGATION & CONTROL DIVISION YETERBORD, NEW JERSEY, U S A	
HARDNESS				MATERIAL				CONTRACT NO APPROVAL APPROVAL	
FINISH								OUTLINE	
THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION AND SUCH INFORMATION MAY NOT BE DISCLOSED TO OTHERS FOR ANY PURPOSE, NOR USED FOR MANUFACTURING PURPOSES WITHOUT WRITTEN PERMISSION FROM THE BENDIX CORPORATION		PART REF ORIGINALLY DESIGNED FOR LB - 3715 GYRO 19570201						SIZE CODE IDENT NO C 19315 1957065	
DO NOT MARK PART NO MARK PART NO AS SPECIFIED								SCALE 1/1 SHEET 1 OF 1	



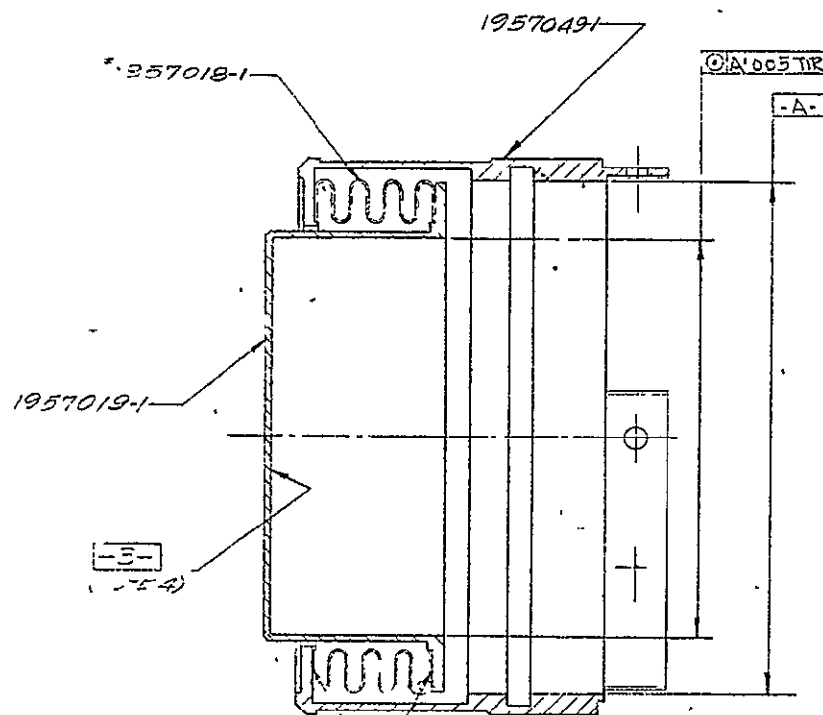
LB5 BELLOWS DESIGN PARAMETERS

Outer Diameter:	3.0 in (nominal)
Inner Diameter:	2.5 in (nominal)
Height:	0.7 in
Spring Rate:	2500 lbs/in (nominal)
Expansion Capability:	.100 in (compression)
Effective Area:	6.0 in ² (nominal)
Temperature Range:	0°F - 200°F
Material:	Corrosion Resistant, Non-Magnetic
Ends:	Flush
Use:	Static, 5000 cycles
Maximum Internal Pressure:	60 psi
Medium:	Freon 113, Freon E2

FIGURE 3-22

PART NO
1957038-1

MF	REVISIONS			
	ZONE	LTR	DESCRIPTION	DATE



NOT REPRODUCIBLE

NOTE -

- 1 SPRING RATE 2100 TO 3200 LB/IN., TO BE MEASURED & DOCUMENTED FOR EACH ASSEMBLY
- 2 STROKE 0.00 MAX. (COMPRESSION)
- 3 HELIUM LEAK TEST, LEAK RATE NOT TO EXCEED $4 \times 10^{-8} \text{ CM}^3/\text{SEC}$ (DOCUMENT)
- 4 FINISH EACH ASSEMBLY; VIBRATION SCRIBE $\frac{3}{32}$ HIGH CHARACTERS
MIL-STD-130 ON SURFACE **-B-**

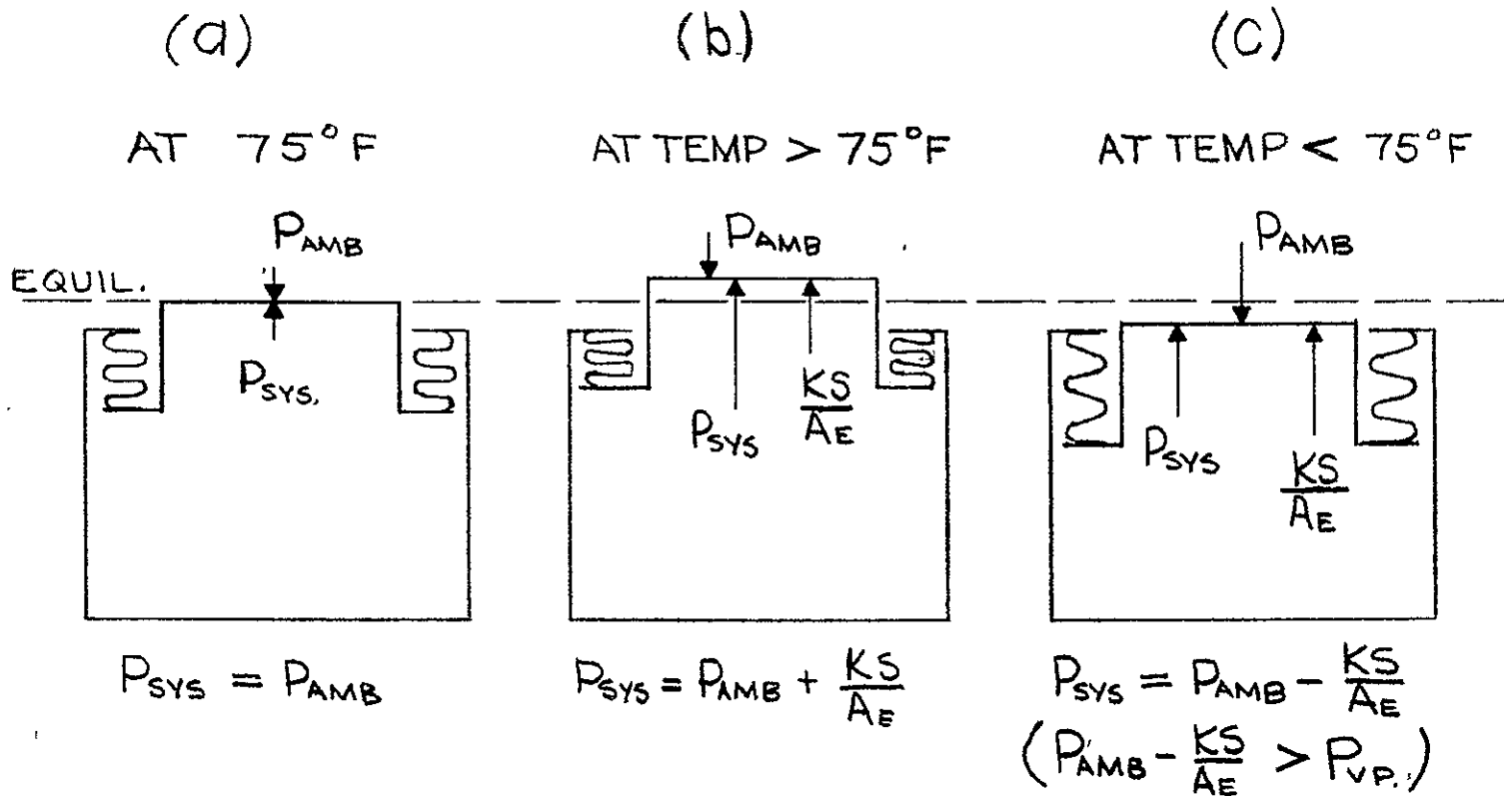
SILVER BRAZE

FIG. 3-24

* INDICATES SUBASSEMBLY + VENDOR ITEM - SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING	- LIMITS OF ACCEPTABLE WORKMANSHIP ARE DEFINED IN NAVIGATION & CONTROL STANDARDS DS-103	UNLESS OTHERWISE SPECIFIED - DIMENSIONS ARE IN INCHES - TOLERANCES ON DECIMALS 2 PLACE 3 PLACE 4 PLACE $\pm .03$ $\pm .005$ $\pm .0005$	DR & LAC CHK ENGR T D MET REL APPD	THE BENDIX CORPORATION NAVIGATION & CONTROL DIVISION TETERBORO NEW JERSEY U.S.A.
HARDNESS		MATERIAL SEE DETAILS	CONTRACT NO.	BELLOWS & HOUSING ASSY
FINISH			APPROVAL	SIZE CODE IDENT NO C 19315 1957038
THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION AND SUCH INFORMATION MAY NOT BE DISCLOSED TO OTHERS FOR ANY PURPOSE NOR USED FOR MANUFACTURING PURPOSES WITHOUT WRITTEN PERMISSION FROM THE BENDIX CORPORATION	PART REF ORIGINALLY DESIGNED FOR LIQUID BORE GAS GYRO 1957038-1		APPROVAL	SCALE 2/1 SHEET 1 OF 1

DO NOT MARK PART NO
MARK PART NO AS SPECIFIED

SCHEMATIC REPRESENTATION OF BELLOWS OPERATION



NOTE :

P_{AMB} = ATMOSPHERIC PRESSURE (FROM 0 → 15 PSIA)
 P_{SYS} = LB-5 SYSTEM PRESSURE (PSIA)
 K = BELLOWS SPRING RATE (LBS/IN)
 S = BELLOWS DEFLECTION FROM EQUILIBRIUM (IN)
 A_E = EFFECTIVE BELLOWS AREA (IN²)
 $P_{V.P.}$ = VAPOR PRESSURE OF FILL LIQUID (PSIA)

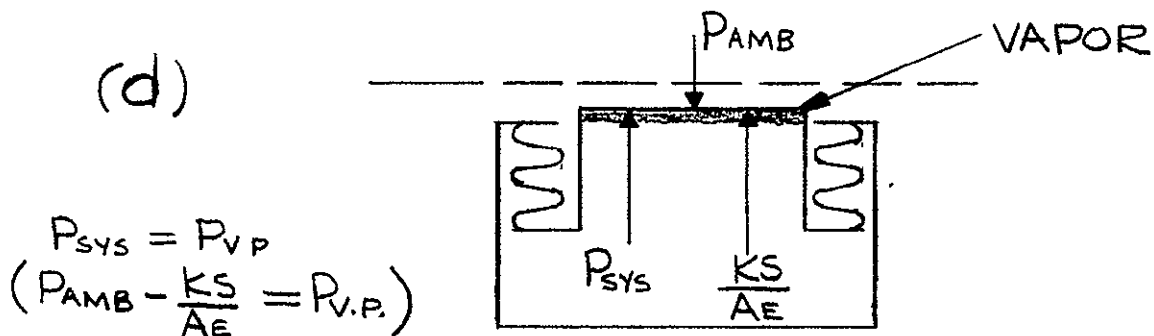


FIGURE 3-25

EFFECT OF AMBIENT PRESSURE ON LG-S INTERNAL PRESSURE

FREON 113

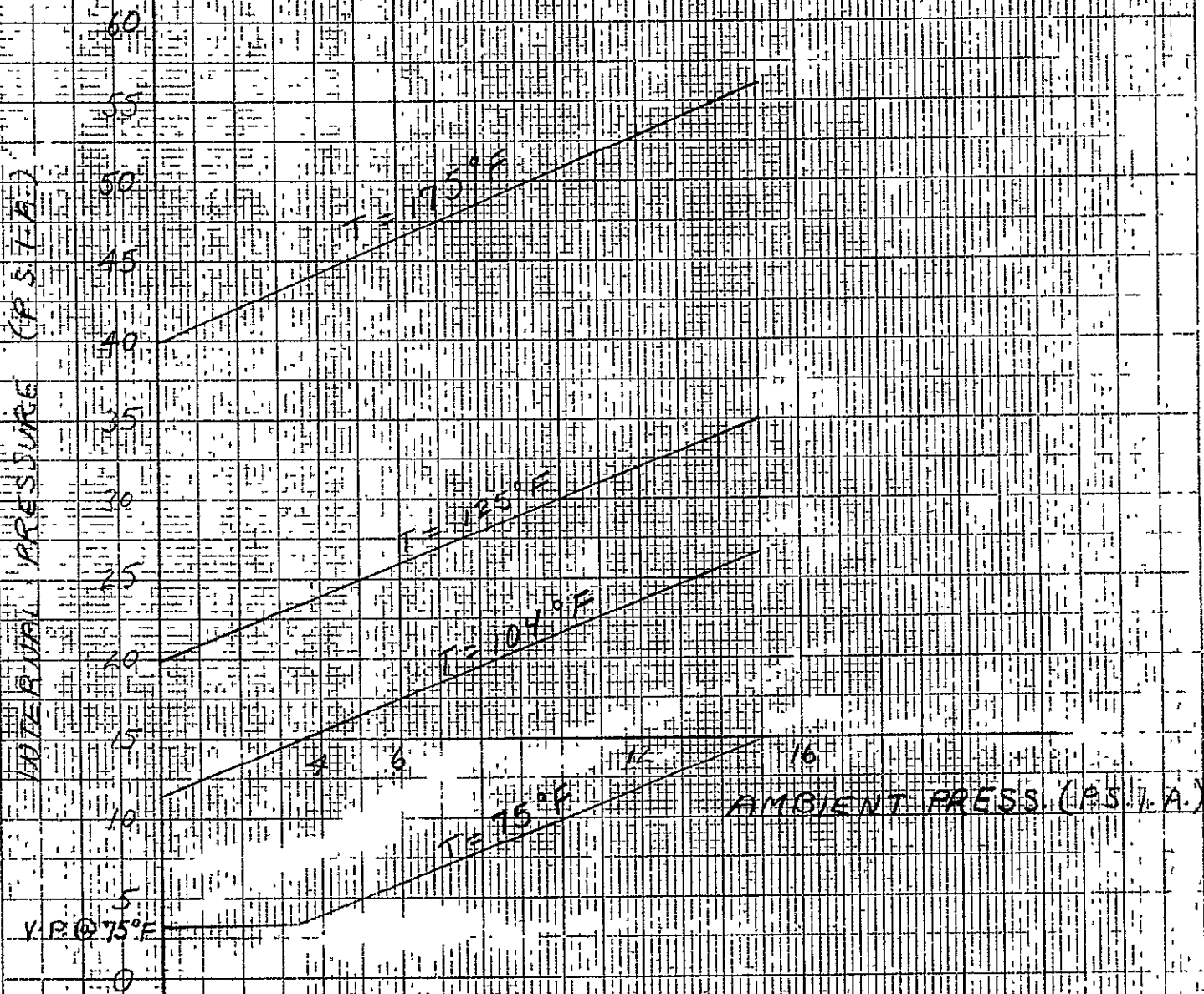
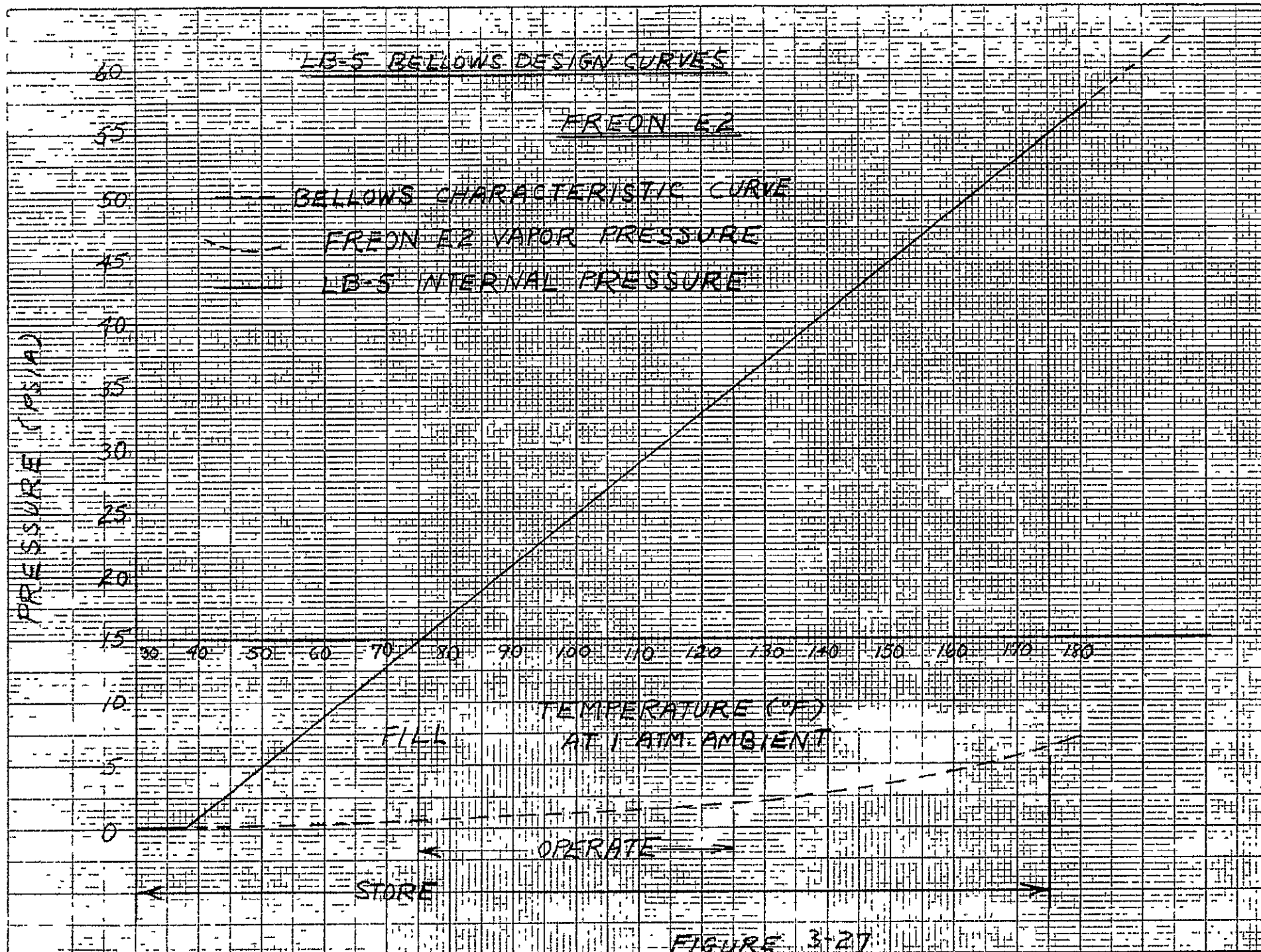


FIGURE 3-26



EFFECT OF AMBIENT PRESSURE ON LB5 INTERNAL PRESSURE

FREON E2

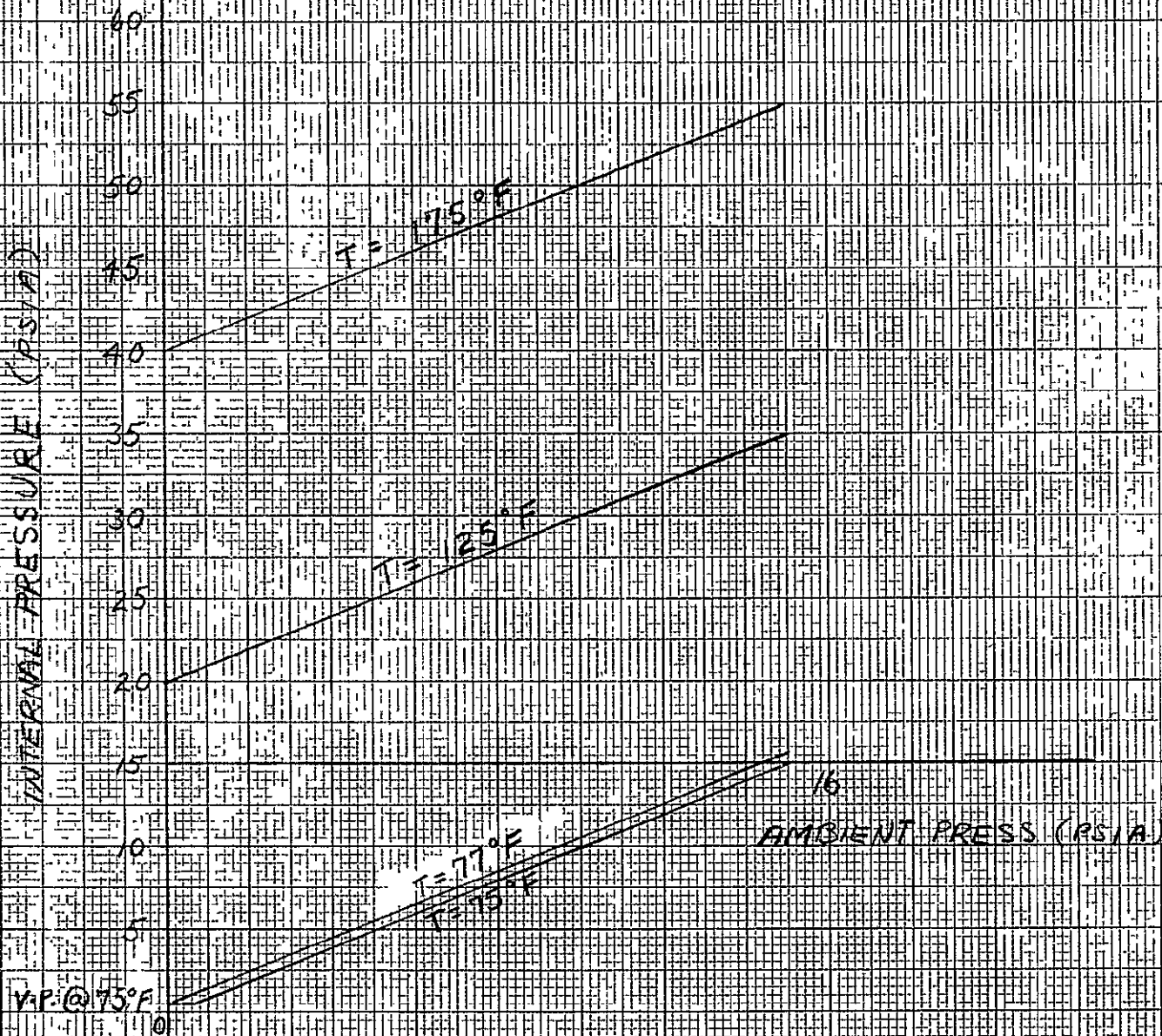
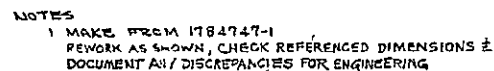


FIG 3-28



SECTION A A

FIG. 3-29

*MEMORANDUM TRANSMISSION *VERSION ITEM - SEE SOURCE CONTROL ON SPECIFICATION CONTROL DRAWING		*NUMBER OF ACQUISITION APPROVED ARE 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038 1039 1040 1041 1042 1043 1044 1045 1046 1047 1048 1049 1050 1051 1052 1053 1054 1055 1056 1057 1058 1059 1060 1061 1062 1063 1064 1065 1066 1067 1068 1069 1070 1071 1072 1073 1074 1075 1076 1077 1078 1079 1080 1081 1082 1083 1084 10	
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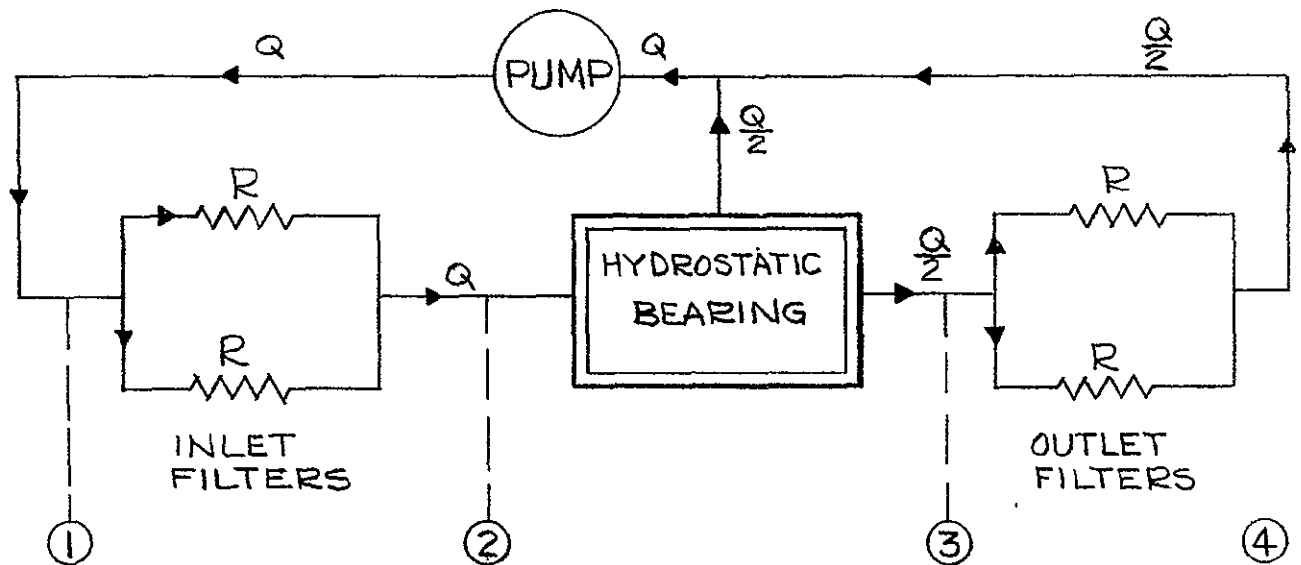
PART NO		MF	REVISIONS			
			LTR	DESCRIPTION	DATE	APPROVED
1957027-1	1.62 APPROX 1957030-1 4 REQ'D 1957029-1 4.38 DIA. REF 1957031-1 2 REQ'D 1957032-1 1957028-1 NOTE - 1 ASSEMBLE AS PER ENG. INSTRUCT.					

FIG. 3-30

* = INDICATES SUBASSEMBLY † = VENDOR ITEM - SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING - LIMITS OF ACCEPTABLE WORKMANSHIP ARE DEFINED IN NAVIGATION & CONTROL STANDARDS-103	HARDNESS FINISH THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION AND SUCH INFORMATION MAY NOT BE DISCLOSED TO OTHERS FOR ANY PURPOSE NOR USED FOR MANUFACTURING PURPOSES WITHOUT WRITTEN PERMISSION FROM THE BENDIX CORPORATION	UNLESS OTHERWISE SPECIFIED - DIMENSIONS ARE IN INCHES - TOLERANCES ON DECIMALS 2 PLACE 3 PLACE 4 PLACE ± .03 ± .005 ± .0005 MATERIAL SEE DETAILS	DR. SHEPHERD CHK T D MET. S. L.	THE BENDIX CORPORATION NAVIGATION & CONTROL DIVISION TETERBORO, NEW JERSEY, U.S.A. FILTER ASSEMBLY CONTRACT NO. APPROVAL APPROVAL	SIZE B CODE IDENT NO 19315 1957027 SCALE ~ SHEET 1 OF 1
☒ DO NOT MARK PART NO ☐ MARK PART NO AS SPECIFIED	PART REF ORIGINALLY DESIGNED FOR LIQUID ELECTRIC GYRO X1957040-1				

LB-5 FLOW PATH SCHEMATIC

(SEE FIG. 3-1 FOR REFERENCE)



- $Q = \text{FLOW (CCM)}$
- $R = \text{RESTRICTION TO FLOW PER FILTER (PSI/CCM)} - \underline{\text{LINEAR}}$
- $\Delta P = QR \text{ (PSI)}$
- $\frac{1}{R_{IN}} = \frac{1}{R} + \frac{1}{R} ; \therefore R_{IN} = \frac{R}{2} \text{ AND } R_{OUT} = \frac{R}{2}$
- $P_2 - P_1 = \Delta P_{12} = QR_{IN} = QR/2$
- $P_4 - P_3 = \Delta P_{34} = Q/2 R_{OUT} = QR/4$
- $\Delta P_{FILTERS} = \Delta P_F = \Delta P_{12} + \Delta P_{34} = Q \frac{3R}{4}$

NOTE :

$$P_3 - P_2 = \Delta P_{BRG} = 8 \text{ (PSI)} = QR_{BRG}.$$

$$\therefore R_{BRG} = 8/Q = 8/16 = .5 \text{ PSI/CCM.}$$

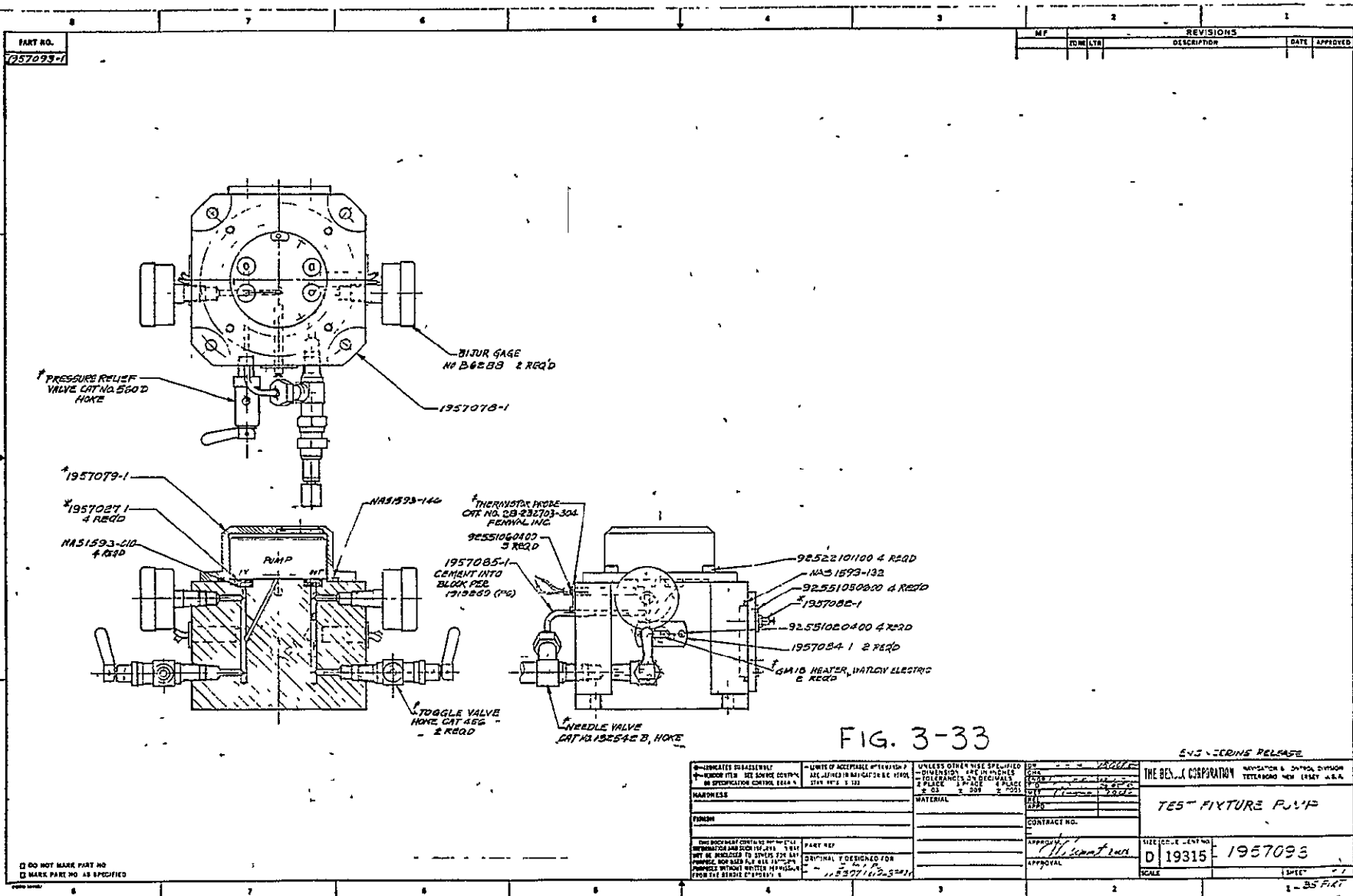
(FREON 113 @ 125°F)

FIGURE 3-31

1B5 FILL FLUID CHARACTERISTICS

	<u>FREON 113</u>	<u>FREON E2</u>
Chemical Name:	Trichlorotrifluoroethane Fluorinated Ether	
Density at 75°F (g/cm ³):	1.56	1.66
Density at 125°F (g/cm ³):	1.50	1.59
Viscosity at 75°F (cp):	.67	1.10
Viscosity at 125°F (cp):	.48	.68
Coefficient of Expansion (in ³ /in ³ °F):	9.1x10 ⁻⁴	8.6x10 ⁻⁴
Boiling Point at 1 ATM (°F):	118	214
Boiling Point at 2 ATM (°F):	160	267
Freezing Point (°F):	-30	-190
Thermal Conductivity (btu/hr ft °F):	.05	.05
Air Absorption (wt % at S.T.P.):	.02	.03
Toxicity:	low	low
Flammability:	none	none
Appearance:	clear, white	clear, white
Surface Tension (dynes/cm):	19.0	18.7
Di-electric Strength:	high	high
Vapor Pressure at 75°F (psia):	6.15	.54
Vapor Pressure at 125°F (psia):	16.9	2.05

FIGURE 3-32



SCHEMATIC REPRESENTATION OF S.G. PUMP TEST FIXTURE

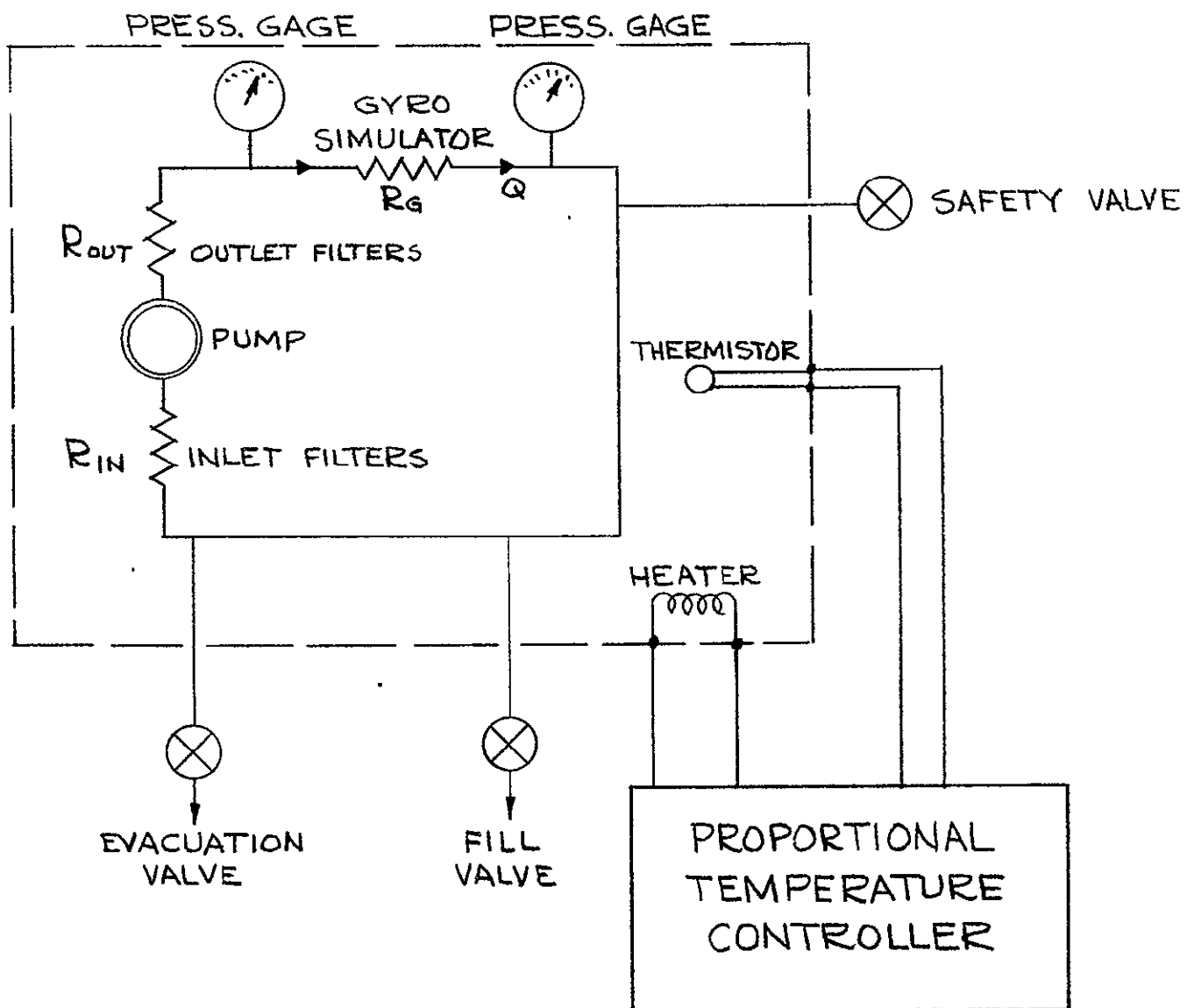


FIGURE 3-34

MOD I SPIRAL GROOVE PUMP TEST DATA

Configuration Number	1	2	3
Rotor Material	Al ₂ O ₃	Al ₂ O ₃	Al ₂ O ₃
Thrust Pad Material	Al ₂ O ₃	Al ₂ O ₃	Al ₂ O ₃
Housing Material	Be	Be	Be
Radial Support	Ball Brg.	Ball Brg	Ball Brg
Number of Grooves	12	12	12
Groove O.D.(in)	1.10	1.10	1.10
Groove I.D.(in)	0.67	0.67	0.67
Test Liquid	Freon 113	Freon 113	Freon 113
Ambient Temperature (°F)	125	125	125
Ambient Pressure (psig)	15.0	15.0	15.0
Axial g-cap at 2000 rpm (g's)	> 30	>30	>30
Radial g-cap at 2000 rpm (g's)	> 30	>30	>30
Slew rate cap. at 2000 rpm (rad/sec)	>20	>20	>20
Gap/Side (in)	.0002	.0001	.0001
Radial Seal (in)	.010	.020	.005
psi*/rpm	2.16x10 ⁻³	2.19x10 ⁻³	2.77x10 ⁻³
Drag Torque (in-oz/rpm)	1.60x10 ⁻⁴	1.77x10 ⁻⁴	1.68x10 ⁻⁴
Performance Index (psi*/in-oz)	13.0	12.3	16.5
ΔP* at 300~, 36v (psi)	5.8	5.8	7.4
Speed at 300~, 36v (rpm)	2680	2650	2665
Input power at 300~, 36v(watts)	2.56	2.86	3.1
Efficiency at 300~, 36v (psi/watts)	2.26	2.02	2.39

* Across LB5 Simulator

FIGURE 3-35

MOD I SPIRAL GROOVE PUMP TEST DATA

Configuration Number	4	5
Rotor Material	Al ₂ O ₃	Al ₂ O ₃
Thrust Pad Material	Al ₂ O ₃	Al ₂ O ₃
Housing Material	Be	Be
Radial Support	Ball Brg	Ball Brg
Number of Grooves	12	12
Groove O.D. (in)	1.10	1.10
Groove I.D. (in)	0.67	0.67
Test Liquid	Freon 113	Freon 113
Ambient Temperature (°F)	125	125
Ambient Pressure (psig)	15.0	15.0
Axial g-cap at 2000 rpm (g's)	20	20
Radial g-cap at 2000 rpm (g's)	20	20
Slew rate cap at 2000 rpm (Rad/sec)	> 17	> 17
Gap/Side (in)	.0001	.00025
Radial Seal (in)	.000	.000
psi*/rpm	2.69x10 ⁻³	2.0 x 10 ⁻³
Drag Torque (in-oz/rpm)	4.48x10 ⁻⁴	4.77x10 ⁻⁴
Performance Index (psi*/in-oz)	6.1	4.19
ΔP* at 300~, 36v (psi)	5.7	4.0
Speed at 300~, 36v (rpm)	2120	1990
Input Power at 300~, 36v (watts)	4.5	5.5
Efficiency at 300~, 36v (psi/ watt)	1.27	.73

*Across LB5 Simulator

FIGURE 3-36

MOD II SPIRAL GROOVE PUMP TEST DATA

Configuration Number	1	2	3
Rotor Material	Be	Be	Be
Thrust Pad Material	Be	Be	Be
Housing Material	Be	Be	Be
Radial Support	Ball Brg	Ball Brg	Ball Brg
Number of Grooves	12	12	12
Groove O.D. (in)	1.10	1.10	1.10
Groove I.D. (in)	0.67	0.67	0.67
Test Liquid	Freon 113	Freon 113	Freon 113
Ambient Temperature (°F)	125	125	125
Ambient Pressure (psig)	15	15	15
Axial g-cap at 2000 rpm (g's)	>30	>30	>30
Radial g-cap at 2000 rpm(g's)	>30	>30	>30
Slew Rate cap at 2000 rpm (rad/sec)	>20	>20	>20
Gap/Side (in)	.00033	.00025	.0001
Radial Seal (in)	.005	.005	.005
psi*/rpm	0.84×10^{-3}	1.94×10^{-3}	2.43×10^{-3}
Drag Torque (in-oz/rpm)	1.08×10^{-4}	1.77×10^{-4}	1.61×10^{-4}
Performance Index (psi*/in-oz)	7.8	11.0	15.1
ΔP^* at 300~, 36v (psi)	2.3	5.2	6.5
Speed at 300~, 36v (rpm)	2780	2650	2675
Input Power at 300~, 36v(watts)	2.3	3.4	2.6
Efficiency at 300~, 36v (psi/watt)	1.0	1.53	2.5

* Across LB5 Simulator

FIGURE 3-37

JOURNAL BEARING SPIRAL GROOVE PUMP TEST DATA

Configuration Number	1	2	3
Rotor Material	Be	Be	Be
Thrust Pad Material	Be	Be	Be
Housing Material	Be	Be	Be
Radial Support	Journal Brg	Journal Brg	Journal Brg
Number of Grooves	12	12	12
Groove O.D. (in)	1.10	1.10	1.10
Groove I.D. (in)	0.67	0.67	0.67
Test Liquid	Freon 113	Freon 113	Freon 113
Ambient Temperature (^o F)	125	125	125
Ambient Pressure (psig)	15	15	15
Axial g-cap at 2000 rpm (g's)	> 30	> 30	> 30
Radial g-cap at 2000rpm(g's)	> 30	> 30	> 30
Slew Rate cap at 2000rpm (rad/sec)	> 20	> 20	> 20
Gap/side (in)	.0003	.0002	.0001
Radial Seal (in)	.020	.020	.005
psi*/rpm	1.21×10^{-3}	1.75×10^{-3}	2.33×10^{-3}
Drag Torque (in-oz/rpm)	2.72×10^{-4}	2.22×10^{-4}	2.0×10^{-4}
Performance Index (psi*/in-oz)	4.45	7.9	11.7
ΔP^* at 300~, 36v (psi)	3.3	4.5	6.1
Speed at 300~, 36v (rpm)	2700	2540	2600
Input Power at 300~, 36v(watts)	2.4	2.85	2.90
Efficiency at 300~, 36v(psi/ watt)	1.37	1.58	2.1

*Across LB5 Simulator

FIGURE 3-38

JOURNAL BEARING SPIRAL GROOVE PUMP TEST DATA

Configuration Number	4
Rotor Material	Be
Thrust Pad Material	Be
Housing Material	Be
Radial Support	Journal Brg
Number of Grooves	12
Groove O.D. (in)	1.10
Groove I.D. (in)	0.67
Test Liquid	Freon E2
Ambient Temperature (°F)	125
Ambient Pressure (psig)	15
Axial g-cap at 2000 rpm (g's)	>30
Radial g-cap at 2000 rpm (g's)	>30
Slew Rate cap at 2000 rpm (rad/sec)	>20
Gap/Side (in)	.0001
Radial Seal (in)	.005
psi*/rpm	2.40×10^{-4}
Drag Torque (in-oz/rpm)	2.36×10^{-4}
Performance Index (psi*/in-oz)	10.2
ΔP^* at 300~, 36v (psi)	6.1
Speed at 300~, 36v (rpm)	2540
Input Power at 300~, 36v(watts)	3.0
Efficiency at 300~, 36v (psi/ watt)	2.03

*Across LB5 Simulator

FIGURE 3-39

DETERMINATION OF OPTIMUM PUMP EXCITATION

MOD I PUMP, CONF #1:

.0002 in GAPS, .010 in SEAL:

Frequency (cps)	Voltage (volts)	ΔP (psi)	Rotor Speed (rpm)	Input Power (watts)	Efficiency (psi/watt)
200	26	3.8	1820	1.7	2.22
250	30	4.8	2230	2.0	2.40
300	36	5.8	2680	2.6	2.26
400	45	7.5	3420	3.9	1.92

* Across LB5 Simulator

FIGURE 3-40

THE EFFECT OF SHEAR GAP SIZE ON PERFORMANCE INDEX FOR THE SPIRAL GROOVE PUMP

FREON 113 @ 125°F
THRU LBS SIMULATOR
(2 CCM/PSI)

○ MODILPUMP, .005 RADIAL SEAL

△ JOURNAL BRG PUMP, .020 SEAL

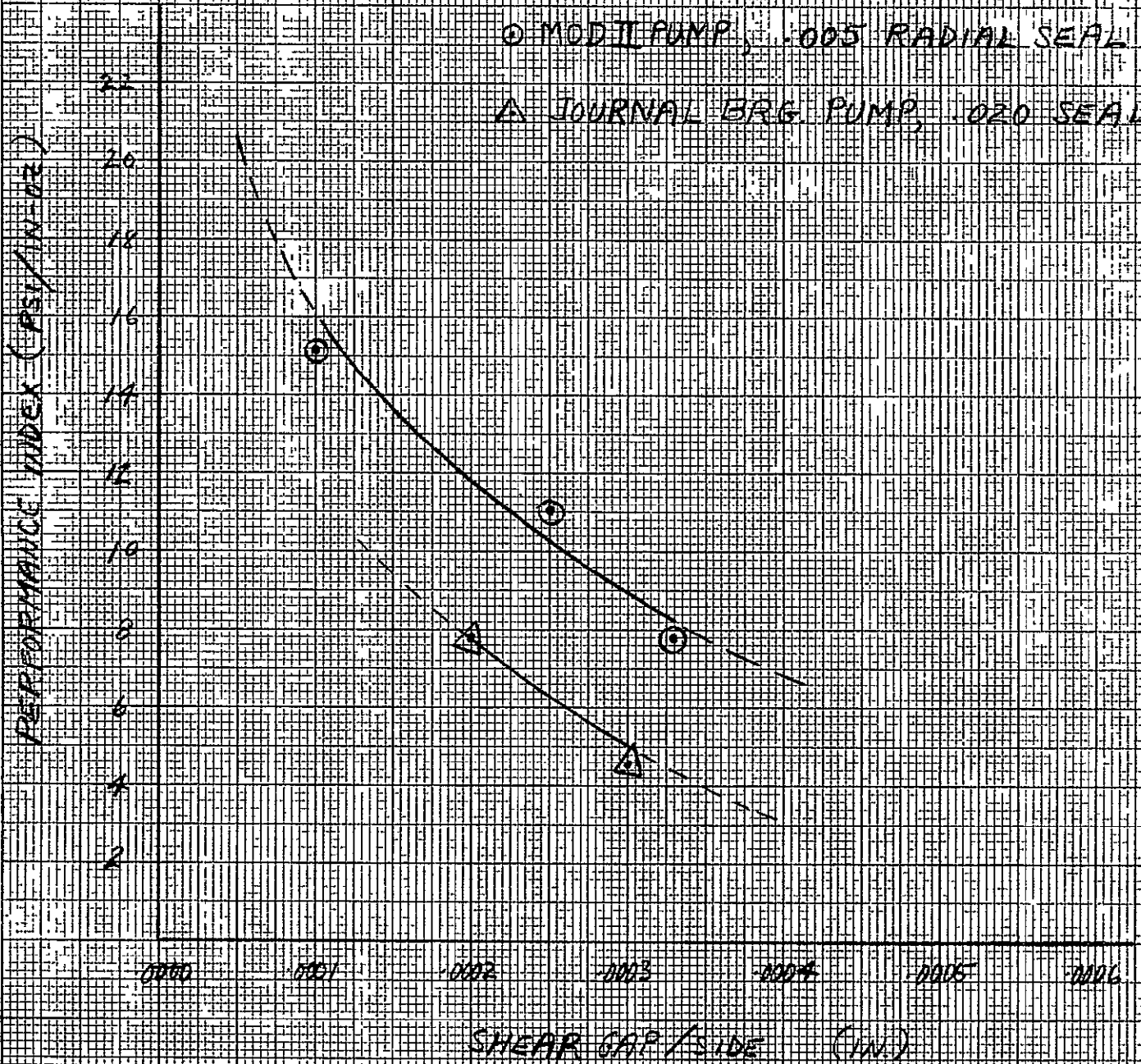
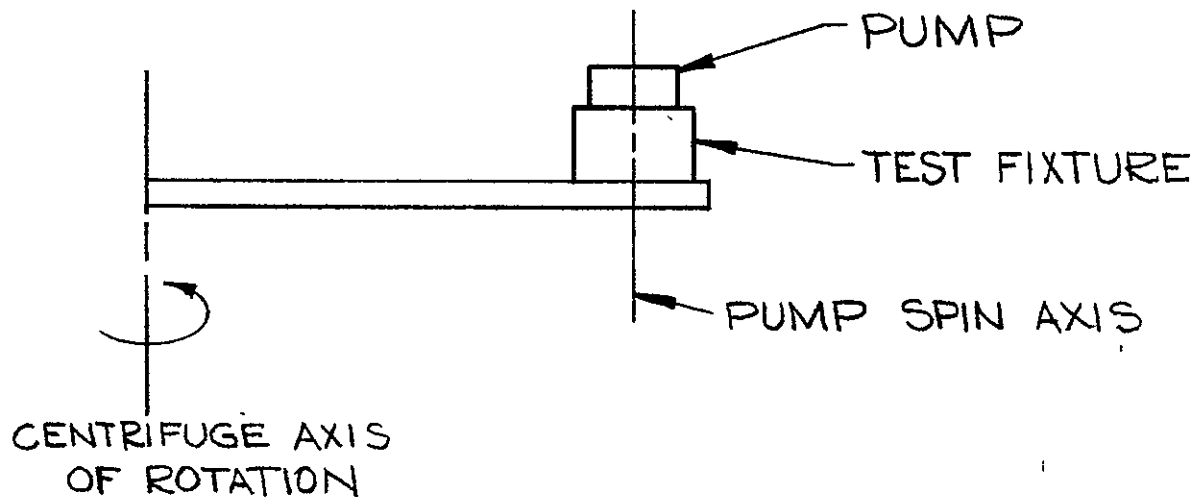


FIGURE 3-4L

SCHEMATIC REPRESENTATION OF CENTRIFUGE TESTING OF THE SPIRAL GROOVE PUMP

(a) RADIAL "g"-CAPABILITY



(b) AXIAL "g"-CAPABILITY + SLEW RATE CAPACITY
(SIMULTANEOUS)

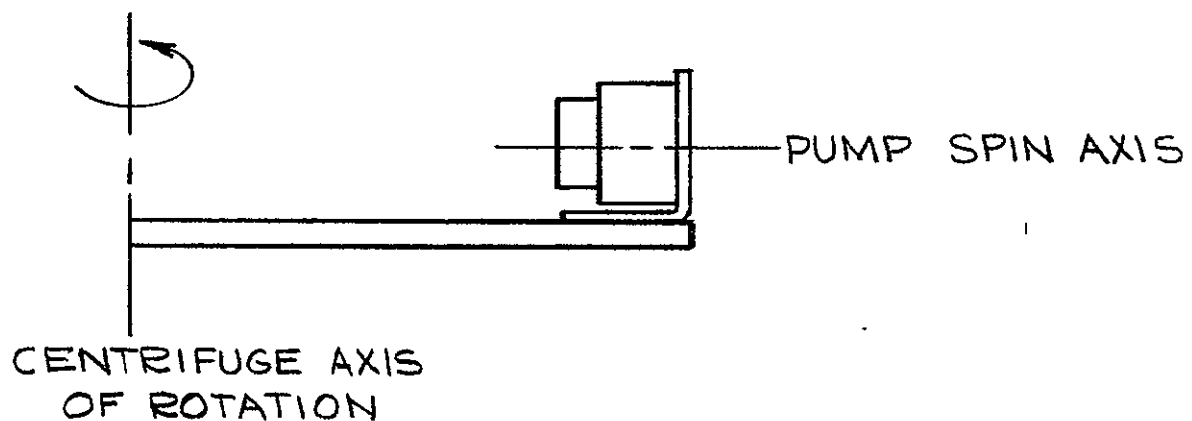


FIGURE 3-42

BELLOWS TEST SET-UP

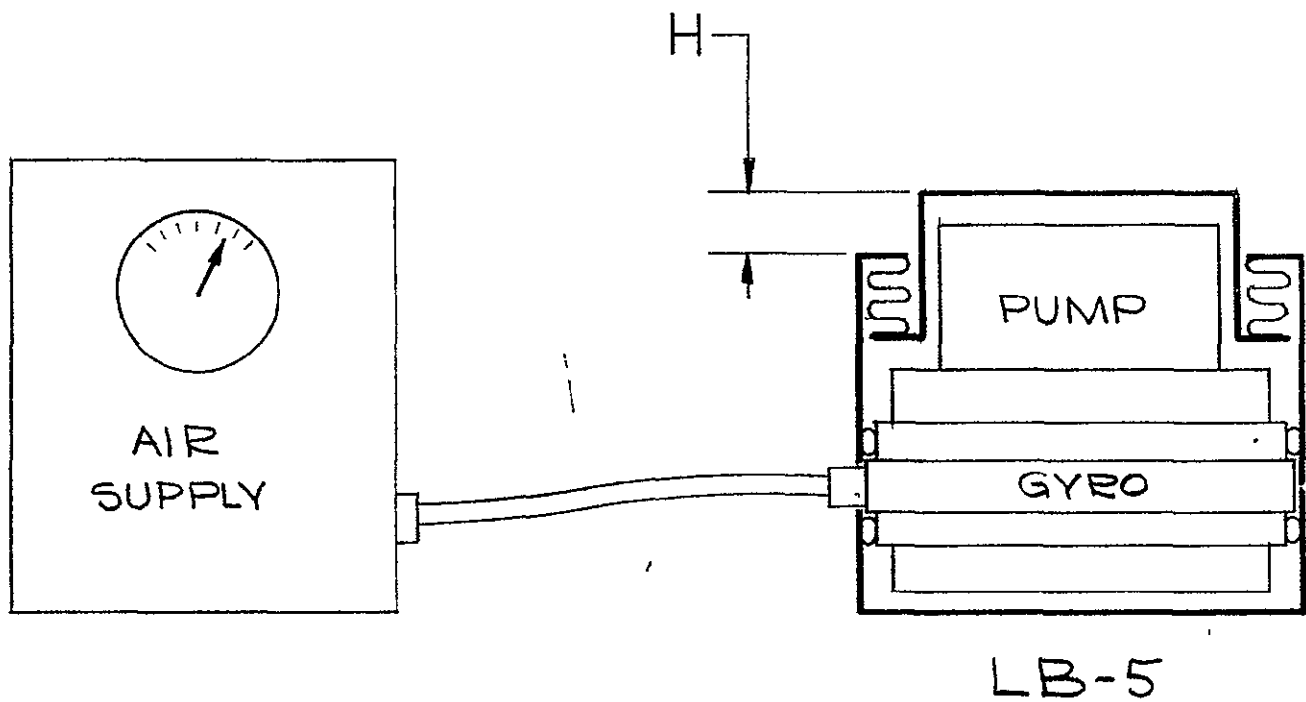


FIGURE 3-43

BELLOWS TEST DATA

INT. PRESSURE* (PSIG)	DIMENSION H		
	(IN)		
	S/N FX-2 (LB5 #1)	S/N 30 B5078 (LB5 #2)	SN/30B5076 (LB5 #3)
0	.188	.340	.300
10	.204	.357	.321
20	.220	.377	.339
30	.238	.398	.360
40	.255	.418	.381
0	.189	.342	.300

* At 1 Atmosphere Ambient Pressure

FIGURE 3-44

BELLOWS SCALE FACTOR CURVES

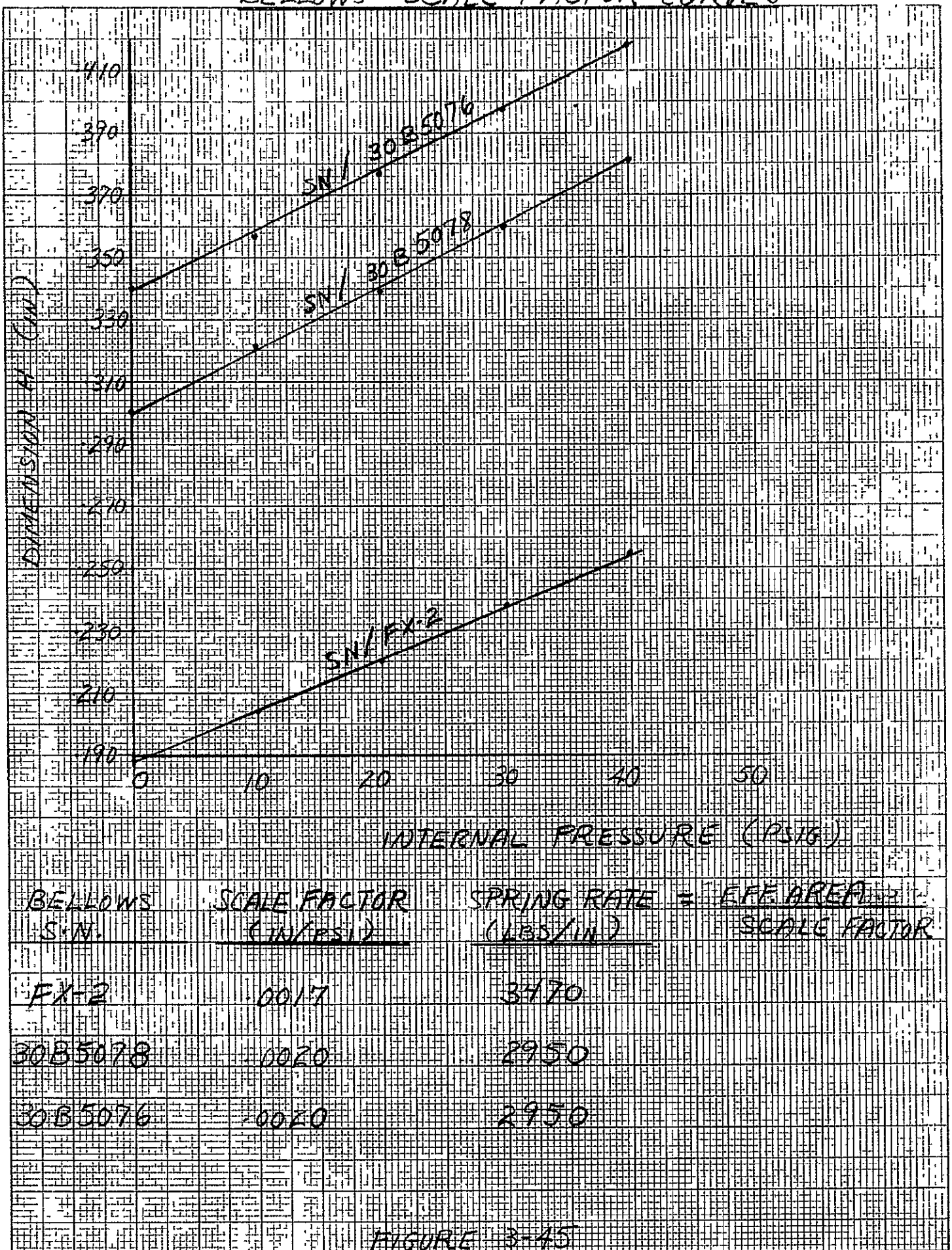


FIGURE 3-45

SUPPLEMENTARY SHEET

COMPARATIVE AND GYRO CYLINDER POWER

AB-5 K/D Gyro
Type No. 1.B5

Serial No. 5A1

CYLINDER NO. _____

LIQUID BEARING CONTINUOUS TEST

Date		3/10/70	3/11/70	3/11/70	3/11/70	3/11/70
M'ex	TYPE	+060	+057	+060	+061	+057
M'ex	TYPE	+068	+065	+050	+060	+052
M'cz	STANDARD SATURATED TEST	+043	+087	+062	+075	+077
M'cz	STANDARD SATURATED TEST	+059	+084	+084	+081	+081
M'cy	STANDARD SATURATED TEST	+074	+060	+063	+064	+052
M'cy	STANDARD SATURATED TEST	+066	+070	+067	+056	+056
M'ep	STANDARD SATURATED TEST	+002	+003	+002	+007	+010
M'ep	STANDARD SATURATED TEST	+003	+007	+006	+006	+010
M'ua	3RD CUT	-099	-021	-079	-007	-097
M'ua	3RD CUT	-023	-004	-096	-099	-099
M'uaa	AFTER 3RD CUT	+002	+085	+003	+052	+077
M'uaa	AFTER 3RD CUT	+013	+064	+013	+076	+072
M'c avg.		+059	+068	+062	+067	+062
M'c avg.		+061	+073	+068	+066	+063
MC avg PUMP	MC	300	300	300	300	300
MC g PUMP	LT	34	34	34	34	34
BELL	EXT	—	223	—	—	—
Map (avg)			② 425			
Map (a)						
Mua (Avg)	NOTE: N1 ATTEMPT MADE TO COMPENSATE FOR MC (Heater Com. in Pass). THREE CUTS MADE TO ACHIEVE DESIRED VIBRANCE $\pm 1/4$ IN.					
Mua (a)	PUMP POWER 2.87 WATTS @ 30 Hz 26V					
M'uaa (Avg)	"	"	2.82 WATTS @ 30 Hz 26V			
M'uaa (a)	"	"	0.17 WATTS MINIMUM FLUCT IN 161/170.			
Std No.		S2	S2	S2	S2	S2
WHEEL POWER		7.0	7.0	7.0	6.8	7.0

FIGURE 3-46

3-577

SUMMARY SHEET

CONSTANT AND Q SENSITIVE DATA

NOT REPRODUCIBLE

AR-5 K1 Gyro

Type No.

LB-5

Serial No.

1

CYLINDER NO.

Date		3/12		3/12/70		3/12/70		3/12/70	
M'cx		+053		+057		+048		+060	
M"cx		+056		+058		+058		+056	
M'cs		+078		+074		+082		+077	
M"cz		+078		+082		+080		+079	
M'cy		+054		+065		+066		+050	
M"cy		+026		+063		+086		+055	
M'ep		+007		+003		+018		+004	
M"ep		+002		+004		+007		+002	
M'uia		-200		-222		-230		-213	
M"uia		-202		-212		-204		-207	
M'usra		+076		+047		+044		+028	
M"usra		+096		+077		+054		+011	
M'c avg.		+062		+065		+065		+062	
M"o avg.		+053		+068		+075		+063	
He-avg PUMP	REG	300		300		400		400	
He-o PUMP	EXC.	34		34		26		26	
BELOW	EXT							221	
Mop (avg)									
Mop (o)									
Mula (Avg)		4811		4811		4811		4811	
Mula (o)		3/10-6		3/12-6		3/12-6		3/12-6	
M'usra (Avg.)									
M"usra (o)									
Std No.		5-2		5-2		5-2		5-2	
Per 6-2		10		7.0		7.2		7.0	

FIGURE 3-47

3-78

SUMMARY SHEET

CONSTANT AND G SENSITIVE DRIFTS

AN-5 K/D Gyro
Type No. 60-5

Serial No. 1

CYLINDER NO. _____

Date	2	3/14/70	3/14/70	3/16/70					
M'cx	2	+053	+058	+050					
M''cx	2	+055	+059	+057					
M'cz	2	+074	+075	+074					
M''cz	2	+071	+078	—					
M'cy	2	+052	+051	+049					
M''cy	2	+060	+062	—					
M'ep	2	+002	+002	+006					
M''ep	2	+002	+001	+002					
M'uia	2	-218	-207	-230					
M''uia	2	-245	-236	—					
M'usra	2	+052	+029	+051					
M''usra	2	+070	+096	—					
M'c avg.	2	+060	+061	+058					
M''c avg.	2	+062	+066	—					
M'c avg.	2	—	—	—					
M'PUMP FCR	2	400	400	400					
PUMP EXC.	2	26	26	26					
Mep (avg)	2	—	—	—					
Mep (a) BELOW EXT	2	—	.223	—					
Muia (Avg)	2	—	—	—					
Muia (a)	2	—	—	—					
M'usra (Avg)	2	—	—	—					
M'usra (a)	2	—	—	—					
Std No.	2	5-2	5-2	—					
POWER	2	68	68	—					

NOT REPRODUCIBLE

FIGURE 3-47(a) 3-79

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND SENSITIVE DRIFTS

WAS GYRO 123

AB-5 K Gyro

Type No. LB5

Serial No. SN2

CYLINDER NO. _____

NOTE: 670 Hz BEAT IN

Date	15 JULY 70	15 July	15 July	15 July	15 July	
M'cx	—	-.073	3.84	-.024	-.025	
M''cx			185 mm @ 185 mm			
M'cz	-.036	-.031		—	+0.013	
M''cz						
M'cy	-.070	-.080	26.0 V	—	-.024	
M''cy						
M'ep	—	+0.005	47.26 V	+0.0064	+0.001	
M''ep						
M'uia	+0.041	+0.047	36.5 V	—	+0.062	
M''uia						
M'usra	-.119	-.107	TO 36.5 V	—	-.052	
M''usra						
M'c avg.	—	-.062	OVER EXCITED	—	-.012	
M''c avg.						
Mc avg						
Mc σ						
Mep (avg)						
Mep (σ)						
Muia (Avg)						
Muia (σ)						
M'usra (Avg.)						
M'usra (σ)						
Std No.						

SCARCE
CURRENT
(SAME
AS 123
AIR BEARING)

"BURPED"

(2)

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND S SENSITIVE DRIFTS

AB-5 K/ Gyro

Type No. LB5

Serial No. SN2

CYLINDER NO. _____

Date	15 JULY	16 JULY	16 JULY	16 July	16 JULY
M'cx	-028	-010	-028	-030	-029
M''cx					
M'cz	+020	+009	+001	+014	+008
M''cz					
M'cy	-011	-038	-058	-045	-041
M''cy					
M'ep	+006	+005	-001	-002	-002
M''ep					
M'uia	+057	+064	+060	+057	+058
M''uia					
M'usra	-087	-080	-101	-119	-127
M''usra					
M'c avg.	-006	-013	-029	-020	-021
M''c avg.					
Mc avg					
Mc σ					
Mep (avg)					
Mep (σ)					
Muia (Avg)					
Muia (σ)					
M'usra (Avg.)					
M'usra (σ)					
Std No.					

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND S SENSITIVE DRIFTS

AB-5 K/ Gyro

Type No. LB5

Serial No. 512

CYLINDER NO. _____

(3)

Date	16 JULY	16 JULY	16 JULY	16 JULY	16 JULY
M'cx	-032	-031	-028	-034	
M''cx					
M'cz	+003	-006	+016	-006	
M''cz					
M'cy	-047	-047	-037	-042	
M''cy					
M'ep	+002	-004	-008	-004	
M''ep					
M'uia	+058	+062	+051	+046	
M''uia					
M'usra	-064	-057	-066	-072	
M''usra					
M'c avg.	-025	-028	-016	-027	
M''c avg.					
Mc avg					
Mc σ					
Mep (avg)					
Mep (σ)					
Muia (Avg)					
Muia (σ)					
M'usra (Avg.)					
M'usra (σ)					
Std No.					

RE-MOUNTED

SHUT DOWN - STORED - RE-RUN (13 HRS STORAGE)

4

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND S SENSITIVE DRIFTS

AB-5 K Gyro

Type No. LB5

Serial No. SN 2

CYLINDER NO. _____

Date	17 JULY	17 JULY	17 JULY	17 JULY	17 JULY
M'cx	-035	-035	-033	-013	-011
M''cx					
M'cz	+001	+002	+004	-006	+002
M''cz					
M'cy	-040	-032	-038	-006	-010
M''cy					
M'ep	-005	+001	-007	+005	+009
M''ep					
M'uia	+045	+046	+046	+055	+042
M''uia					
M'usra	-064	-060	-065	-060	-084
M''usra					
M'c avg.	+025	-022	+022	-008	-006
M''c avg.					
Mc avg					
Mc σ					
Mep (avg)					
Mep (σ)					
Muia (Avg)					
Muia (σ)					
M'usra (Avg.)					
M'usra (σ)					
Std No.					

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND 9 SENSITIVE MEASUREMENTS

FLKON 115
PUMP SQ 2B
NO MU-METAL COVERS

AB-5 K Gyro
Type No. LB5

Serial No. 3

CYLINDER NO. HYD120

Date		8-7-70		8-10-70		8-11-70		8-11-70	
M'cx		+0.112		+0.093		+0.111		+0.103	
M''cx									
M'cz		+0.123		+0.111		+0.111		+0.120	
M''cz									
M'cy		+0.045		+0.045		+0.082		+0.055	
M''cy									
M'ep		+0.197		+0.172		+0.161		+0.153	
M''ep									
M'ua		-0.243		-0.194		-0.237		-0.230	
M''ua									
M'usra		-0.197		-0.248		-0.225		-0.277	
M''usra									
M'c avg.		+0.093		+0.083		+0.101		+0.093	
M''c avg.									
Mc avg									
Mc σ									
Mep (avg)									
Mep (σ)									
Mua (Avg)									
Mua (σ)									
M'usra (Avg.)									
M usra (σ)									
Std No.									

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND SENSITIVE POINTS

FREON 113

PUMP # SQ 2B

NO MU-METAL COVERS

AB-5 K Gyro

Type No. LB5Serial No. 3CYLINDER NO. HYDRO.

Date		8-5-70		8-5-70		8-5-70		8-6-70	
M'cx		+116		+125		+116		+116	
M''cx									
M'cz		+137		+154		+132		+122	
M''cz									
M'cy		+075		+069		+080		+062	
M''cy									
M'ep		+160		+163		+153		+174	
M''ep									
M'uia		-152		-074		-147		-205	
M''uia									
M'usra		-271		-266		-260		-278	
M''usra									
M'c avg.		+109		+116		+109		+100	
M''c avg.									
Mc avg									
Mc σ									
Mep (avg)									
Mep (σ)									
Muia (Avg)									
Muia (σ)									
M'usra (Avg.)									
M'usra (σ)									
Std No.									

NOT REPRODUCIBLE

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND ϕ SENSITIVE DRIFTS

FREON 113
PUMP # 5Q 2R
NO MU-METAL COVER

AB-5 K ☒ Gyro
Type No. LB5

Serial No. 2CYLINDER NO. HYDRO

Date		8-6-70		8-6-70		8-6-70		8-7-70	
M'cx		+117		+124		+116		+105	
M''cx									
M'cz		+115		+121		+126		+110	
M''cz									
M'cy		+062		+057		+038		+053	
M''cy									
M'ep		+170		+180		+175		+185	
M''ep									
M'ua		-0204		-0153		-0077		-0236	
M''ua									
M'usra		-0276		-0203		-0203		-0203	
M''usra									
M'c avg.		+098		+101		+095		+089	
M''c avg.									
Mc avg									
Mc σ									
Mep (avg)									
Mep (σ)									
Hua (Avg)									
Hua (σ)									
M'usra (Avg.)									
M'usra (σ)									
Std No.									

NOT REPRODUCIBLE

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND S SENSITIVE DRIFT

FICEUN 113
PUMP SQ 213
NO MU-METAL COVERS

AB-5 K Gyro
Type No. L35

Serial No. 3

CYLINDER NO. HYDRO

Date		8-11		8-11					
M'cx	26 volts	+098	26 volts	+095					
M''cx									
M'cz	400 cps	+116	400 cps	+123					
M''cz									
M'cy	400 cps	+043	400 cps	+042					
M''cy									
M'ep	Pump	+162	Pump	+161					
M''ep									
M'ua	Spin motor	-206	Spin motor	-211					
M''ua									
M'usra	34", 185 mm/phase	-243	34", 185 mm/phase	-240					
M''usra									
M'c avg.	Spin motor	+086	Spin motor	+087					
M''c avg.									
Mc avg	Spin motor		Spin motor						
Mc σ									
Mep (avg)	Spin motor		Spin motor						
Mep (σ)									
Mua (Avg)	Spin motor		Spin motor						
Mua (σ)									
M'usra (Avg.)	Spin motor		Spin motor						
M usra (σ)									
Std No.	Spin motor		Spin motor						

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND SENSITIVE POINTS

FREON E2
PUMP# SQ1BJ (JOURNAL BRG.)
NO MU-METAL COVERS

AB-5 K Gyro

Type No. LB5Serial No. 3CYLINDER NO. HYDRO

Date		8-20-70	8-20-70	8-20-70	8-21-70		
M'ox	400 ~, 26 volts	+103	+098	+103	+106		
M''ox							
M'cz	400 ~, 26 volts	+138	+128	+134	+135		
M''cz							
M'cy	400 ~, 26 volts	+052	+063	+056	+054		
M''cy							
M'ep	400 ~, 26 volts	+173	+173	+185	+180		
M''ep							
M'uia	400 ~, 26 volts	+108	+128	+134	+132		
M''uia							
M'usra	400 ~, 26 volts	-076	-065	-058	-036		
M''usra							
M'c avg.	400 ~, 26 volts	+098	+096	+098	+098		
M''c avg.							
Mc avg	400 ~, 26 volts						
Mc σ							
Mep (avg)	400 ~, 26 volts						
Mep (σ)							
Muia (Avg)	400 ~, 26 volts						
Muia (σ)							
M'usra (Avg.)	400 ~, 26 volts						
M'usra (σ)							
Std No.	400 ~, 26 volts						

All Freon E2 tests: 34 ~, 800 ~, 185 mm

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND 9 SENSITIVE READINGS

FREON EL
PUMP # SQ1BJ (JOURNAL BRG.)
NO MU-METAL COVERS

AB-5 K Gyro

Type No. LBS

Serial No. 3

CYLINDER NO. HYDRO.

Date	8-21-70	8-21-70	8-21-70	8-21-70
M'cx	+ .101	+ .109	+ .128	+ .111
M''cx				
M'cz	+ .124	+ .118	+ .119	+ .133
M''cz				
M'cy	+ .059	+ .053	+ .047	+ .048
M''cy				
M'ep	+ .153	+ .179	+ .170	+ .173
M''ep				
M'ua	+ .132	+ .169	+ .174	+ .160
M''ua				
M'usra	- .024	+ .010	- .001	- .003
M''usra				
M'c avg.	+ .095	+ .093	+ .098	+ .097
M''c avg.				
Mc avg				
Mc σ				
Hep (avg)				
Hep (σ)				
Mua (Avg)				
Mua (σ)				
M'usra (Avg.)				
M'usra (σ)				
Std No.				

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND SENSITIVE DRIFTS

FREON E2
PUMP# SQ1BJ (JOURNAL 1326)
NO MU-METAL COVERS

B-5 K/ Gyro

Type No. LBS

Serial No. 3

CYLINDER NO. HYDRO.

Date	8-21-70	8-24-70	8-24-70	8-24-70
M'ox	+119	+116	+102	+106
M"ox				
M'cz	+135	+124	+114	+105
M"cz				
M'cy	+047	+045	+034	+047
M"cy				
M'ep	+179	+138	+152	+148
M"ep				
M'ua	+163	+180	+193	+185
M"ua				
M'usra	-005	-007	-007	-015
M"usra				
M'c avg.	+100	+095	+083	+086
M"c avg.				
Mc avg				
Mc σ				
Mep (avg)				
Mep (σ)				
Mua (Avg)				
Mua (σ)				
M'usra (Avg.)				
M'usra (σ)				
Std No.				

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND G SENSITIVE DRIFTSFREON E2
PUMP # SQIBJ (JOURNAL BRG.)
NO MU-METAL COVERSAB-5 K// Gyro
Type No. LBSSerial No. 3CYLINDER NO. HYDRO.

Date	8-24-70	8-25-70	8-25-70	8-25-70
M'cx	+ 124	+ .113	+ .120	+ .113
M''cx				
M'cz	+ .109	+ .108	+ .113	+ .116
M''cz				
M'cy	+ 036	+ .024	+ .033	+ .030
M''cy				
M'ep	+ .140	+ .163	+ .160	+ .143
M''ep				
M'ua	+ .180	+ .164	+ .173	+ .184
M''ua				
M'usra	- .012	.000	+ .015	+ .030
M''usra				
M'c avg.	+ 090	+ .082	+ .089	+ .090
M''c avg.				
Mc avg				
Mc σ				
Hep (avg)				
Hep (σ)				
Mua (Avg)				
Mua (σ)				
M'usra (Avg.)				
M usra (σ)				
Std No.				

CONSTANT AND 0 SENSITIVE DEPTHS

CYLINDER NO. HYDRO

Date	8-25-70
M'ex	+ 115
M''ex	
M'cz	+ 104
M''cz	
M'cy	+ 040
M''cy	
M'ep	+ 150
M''ep	
M'uia	+ 160
M''uia	
M'usra	+ 015
M''usra	
M'c avg.	+ 086
M''c avg.	
Mc avg	
Mc σ	
Mep (avg)	
Mep (σ)	
Muia (Avg)	
Muia (σ)	
M'usra (Avg.)	
M usra (σ)	
Std No.	

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND G SENSITIVE ERRORS

FREON E2
PUMP # SQ1BT (JOURNAL RIG)
WITH MU-METAL COVERS

1B-5 K// Gyro

Type No. LBSSerial No. 3CYLINDER NO. HYDRO

Date		8-27-70	8-29-70	8-29-70	8-29-70		
M'cx		+0.121	+0.130	+0.132	+0.118		
M''cx							
M'cz		+0.138	+0.120	+0.131	+0.120		
M''cz							
M'cy		+0.116	+0.107	+0.104	+0.112		
M''cy							
M'ep		+0.002	+0.024	+0.014	+0.020		
M''ep							
M'uia		+0.270	+0.246	+0.269	+0.262		
M''uia							
M'usra		-0.154	-0.184	-0.178	-0.178		
M''usra							
M'c avg.		+0.125	+0.119	+0.122	+0.117		
M''c avg.							
Mc avg							
Mc σ							
Mep (avg)							
Mep (σ)							
Muia (Avg)							
Muia (σ)							
M'usra (Avg.)							
M'usra (σ)							
Std No.							

Unit dismounted and closed up (mu-metal covers)

Unit remounted again

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND S SENSITIVE DRAFTS

FREON CC
PUMP# SQIBJ (TOURNAL BRG.)
WITH MV-METAL COVERS

LB

AB-5 K/D Gyro

Type No. LB5Serial No. 3CYLINDER NO. HYDRO.

Date	8-29-70	8-29-70	8-29-70	8-31-70
M'cx	+129	+127	+114	+120
M''cx				
M'cz	+122	+133	+131	+133
M''cz				
M'cy	+112	+110	+106	+112
M''cy				
M'ep	+011	+013	+013	+016
M''ep				
M'uia	+262	+272	+269	+271
M''uia				
M'usra	-175	-172	-172	-154
M''usra				
M'c avg.	+121	+123	+117	+122
M''c avg.				
Mc avg				
Mc σ				
Mep (avg)				
Mep (σ)				
Muia (Avg)				
Muia (σ)				
M'usra (Avg.)				
M usra (σ)				
Std No.				

FIGURE 3-67

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND S SENSITIVE RELATES

FREDN E2
PUMP# SQ 18 J (JOURNAL BRG)
WITH MU-METAL COVERS

L/B
AB-5 K/D Gyro
Type No. LB-5

Serial No. 3

CYLINDER NO. HYDRLO

Date	8-31-70	8-31-70	8-31-70	8-31-70
M'cx	+121	+132	+114	+123
M"cx				
M'cz	+132	+136	+127	+129
M"cz				
M'cy	+113	+120	+107	+106
M"cy				
M'ep	+013	+022	+019	+008
M"ep				
M'uia	+262	+277	+265	+267
M"uia				
M'usra	-150	-146	-155	-154
M"usra				
M'c avg.	+122	+128	+116	+119
M"c avg.				
Mc avg				
Mc σ				
Mep (avg)				
Mep (σ)				
Muia (Avg)				
Muia (σ)				
M'usra (Avg.)				
M usra (σ)				
Std No.				

DATA SHEET NO. 14

SUMMARY SHEET

CONSTANT AND SENSITIVE SETTINGS

FILED E2
PUMP SQ1BJ (JOURNAL FILE)
WITH MU-METALS COVERS

LBS

AB-5 K/ Gyro

Type No. LBS

Serial No. 3

CYLINDER NO. HYDRO

Date	8-31-70	9-1-70	9-1-70	9-2-70	
M'cx	+ .117	+ .131	+ .123	+ .123	
M''cx					
M'cz	+ .131	+ .131	+ .141	+ .126	
M''cz					
M'cy	+ .106	+ .095	+ .097	+ .110	
M''cy					
M'ep	+ .012	+ .014	+ .006	+ .021	
M''ep					
M'uia	+ .275	+ .253	+ .261	+ .216	
M''uia					
M'usra	- .147	- .177	- .153	- .150	
M''usra					
M'c avg.	+ .118	+ .119	+ .120	+ .120	
M''c avg.					
Mc avg					
Mc σ					
Mep (avg)					
Mep (σ)					
Muia (Avg)					
Muia (σ)					
M'usra (Avg.)					
M usra (σ)					
Std No.					

Unit removed from stand - stored O.A. vertical at 75°F overnight

EFFECT OF MU-METAL COVERS ON LB5 #3 DRIFT COEFFICIENT

<u>DRIFT COEFF</u>	<u>WITHOUT MU-METAL COVERS</u>		<u>WITH MU-METAL COVERS</u>	
	<u>MAG (°/HR)</u>	<u>S.D. (°/HR)</u>	<u>MAG (°/HR)</u>	<u>S.D. (°/HR)</u>
Mex	+.111	.0083	+.123	.0061
McZ	+.121	.0110	+.130	.0059
Mcy	+.045	.0106	+.108	.0063
Mc	+.093	.0056	+.120	.0031
Mep	+.162	.0149	+.014	.0057
Muia	+.160	.0237	+.265	.0079
Musra	-.016	.0286	-.163	.0127

FIGURE 3-65

Date	Start Time	Init. Drift (°/hr)	Stabilized Temp/Time	To p. Stabilized Drift °/hr	No. of Data Parts	Run Time Test hrs	Total	Standard Deviation	No. Pts. Std. Dev.	Remarks	
4/6	8:38 AM	+0.068	25°C	+0.066	35°C 3 hrs	216	7.5	4258.5	3.5x10 ⁻⁴	72	
4/7	8:37 AM	+0.062	25°C	+0.058	35°C 3 hrs	246	7.5	4266.0	2.1x10 ⁻⁴	72	
4/8	10:37 AM	+0.059	25°C	+0.058	35°C 3 hrs	174	5.5	4271.5	8.6x10 ⁻⁴	72	
4/9	8:48 AM	+0.058	25°C	+0.060	35°C 3 hrs	246	7.5	4279.0	4.2x10 ⁻⁴	72	
4/10	8:09 AM	+0.052	25°C	+0.057	35°C 3 hrs	265	8.0	4287.0	1.3x10 ⁻⁴	72	
4/13	8:11 AM	+0.058	25°C	+0.058	35°C 3 hrs	268	8.0	4295.0	1.3x10 ⁻⁴	72	
4/14	10:05 AM	+0.054	25°C	+0.058	35°C 3 hrs	205	6.0	4301.0	1.2x10 ⁻⁴	72	
4/15	8:27 AM	+0.055	25°C	+0.058	35°C 3 hrs	252	7.5	4308.5	0.6x10 ⁻⁴	72	
4/16	8:11 AM	+0.052	25°C	+0.059	35°C 3 hrs	269	8.0	4316.5	4.1x10 ⁻⁴	72	
4/20	8:09 AM	+0.051	25°C	+0.055	35°C 3 hrs	270	8.0	4324.5	2.5x10 ⁻⁴	72	
4/21	8:02 AM	+0.048	25°C	+0.049	45°C	270	8.0	4332.5	1.1x10 ⁻⁴	72	
4/22	8:14 AM	+0.052	25°C	+0.053	45°C	1116	31.0	4363.5	5.6x10 ⁻⁴	72	
4/23	8:08 AM	+0.051	25°C	+0.054	45°C	270	8.0	4371.5	4.2x10 ⁻⁴	72	
4/27	8:12 AM	+0.057	25°C	+0.054	45°C	270	8.0	4379.5	0.8x10 ⁻⁴	72	
4/28	8:24 AM	+0.053	25°C	+0.053	45°C	252	7.5	4387.0	1.7x10 ⁻⁴	72	
4/29	8:10 AM	+0.050	25°C	+0.053	45°C	270	8.0	4395.0	0.8x10 ⁻⁴	72	
4/30	8:20 AM	+0.050	25°C	+0.049	45°C	1120	31.0	4426.0	0.6x10 ⁻⁴	72	
5/1	16:05 PM										

NOT REPRODUCIBLE

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FIGURE 3-66

Received

Date	Start Time	Init. Drift (°/hr)	Start Temp	Temp. Stabilized Drift (°/hr)	Temp/Time	No. of Data Pairs	Run Time		Standard Deviation	No. Pts. Std. Dev.	Remarks
							Test Hrs.	Temp			
5/4	10:08 AM	+0.037	25°C	+0.050	45°C	216	6.0	4432.0	0.2×10^{-4}	72	
5/5	10:24 AM	+0.036	25°C	+0.050	45°C	218	5.0	4437.0	1.9×10^{-4}	72	
5/7	8:14 AM	+0.035	25°C	+0.052	45°C	265	8.0	4445.0	1.9×10^{-4}	72	
5/8	12:12 PM	+0.049	25°C	+0.051	45°C	144	4.0	4449.0	1.8×10^{-4}	72	
5/11	8:11 AM	+0.030	25°C	+0.049	45°C	1125	31.5	4480.5	0.2×10^{-5}	72	
5/12	10:10 PM										
5/13	8:00 AM	+0.032	25°C	+0.050	45°C	288	8.0	4488.5	0.3×10^{-4}	72	
5/14	3:17 AM	+0.049	25°C	+0.050	45°C	288	8.0	4496.5	1.3×10^{-4}	72	
5/15	8:14 AM	+0.047	25°C	+0.049	45°C	269	8.0	4504.5	1.3×10^{-4}	72	
5/18	7:58 AM	+0.032	25°C	+0.048	45°C	288	8.0	4512.5	0.5×10^{-4}	72	
5/21	8:19 AM	+0.047	25°C	+0.048	45°C	288	8.0	4520.5	0.5×10^{-4}	72	
5/26	8:31 AM	+0.054	25°C	+0.052	45°C	288	8.0	4528.5	0.1×10^{-4}	72	
5/27	8:11 AM	+0.048	25°C	+0.051	45°C	288	8.0	4536.5	1.7×10^{-4}	72	
5/29	8:08 AM	+0.031	25°C	+0.032	45°C	288	8.0	4544.5	0.5×10^{-4}	72	
6/1	9:07 AM	+0.051	25°C	+0.049	45°C	252	8.0	4579.5	0.5×10^{-4}	72	
6/2	12:38 AM	+0.053	25°C	+0.052	45°C	93	3.0	4547.5	0.7×10^{-4}	72	
6/3	8:19 AM	+0.033	25°C	+0.051	45°C	288	8.0	4555.5	1.3×10^{-4}	72	
6/4	8:20 AM	+0.053	25°C	+0.049	45°C	288	8.0	4563.5	0.3×10^{-4}	72	

(*) Start
Time

FIGURE 3-67

[illegible]

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JOB NO

NOT REPRODUCIBLE

FIGURE 3-69