THE DESIGN AND BUILD OF A GAS BEARING GYROSCOPE POSSESSING HIGH "G" AND STERILIZATION CAPABILITY AND UTILIZING A LOW POWER GAS BEARING SPINMOTOR AND HIGH FREQUENCY PUMP

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First Quarterly Progress Report
for period
3 January 1967 - 31 March 1967

Prepared for

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ABSTRACT

The first quarter's work on the design, build and test of a gas bearing gyroscope possessing high g and sterilization capability and utilizing a low power gas bearing spinmotor and high frequency pump, has produced a spinmotor to meet the power and sterilization requirements. The high frequency pump implementations has progressed to a dummy gyro assembly (no spinmotor). Future work includes the beginning of the gyro build.

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ILLUSTRATIONS

SECTION I
SUMMARY

The purpose of this contract is to build a gas bearing gyroscope possessing high "G" and sterilization capability utilizing a low power gas bearing spinmotor and high frequency fluid pump.

The following items are an overview of the progress, problems, future work and recommendations of this contract.

PROGRESS (First Quarter)

- The gas bearing spinmotor has demonstrated:
  - Low Power
  - High "G" Capability
  - Sterilization Capability
- The high frequency pump has demonstrated:
  - Sterilization Capability
  - Gimbal support in a closed system

PROBLEMS (First Quarter)

- The gas bearing spinmotor aniso coefficient is $0.1^\circ/\mathrm{hr}\ G^2$ at frequencies less than 250 cps versus contract requirement of $0.05^\circ/\mathrm{hr}\ G^2$ between 20 - 2000 cps.

- The gas bearing stall power is 7.05 watts versus requirement of 5 watts.
- The alkane 695 fluid previously selected under Contract 950604 Mod 3 did not meet viscosity and density requirements.

FUTURE WORK (Next Quarter)

- A search for a more suitable fluid
- The beginning of the gyro build

RECOMMENDATIONS

JPL consideration of the recommended specification changes shown in Table 3.

SECTION II
PROGRESS

GG159E GAS BEARING SPINMOTOR DEVELOPMENT

The gas bearing spinmotor design was based on previous experience with the GG159C, D and GG334 spinmotors. The GG159 spinmotors possess both the high "G" and sterilization capability while the GG334 spinmotors possess the low power characteristic desired for the GG159E.

SPINMOTOR DESIGN

The GG159E design effort used an "umbrella stator" as shown in Figure 1. This stator allowed more flexibility of journal and thrust bearing size than the previous GG159 designs which were fixed in minimum dimensions by the stator O. D.

The primary design considerations for the gas bearing support were the 200 "G" shock requirement and the three-watt running power goal. The short duration shock capability is a function of bearing area for both the journal bearing and the thrust bearings. The power is a function of bearing drag and is related to the thrust OD^4, journal OD^3, and journal length. Table 1 shows a comparison of these parameters for the GG159C, D, and E spinmotors.

Table 1. Area and Drag Parameters

		GG159 C&D	GG159E
Thrust	Area	0.855	0.5
	OD	0.94	0.69
	$(OD)^4$	0.77	0.23
Journal	Area	0.49	0.5
	OD	0.58	0.4
	$(OD)^3 XL$	0.19	0.05

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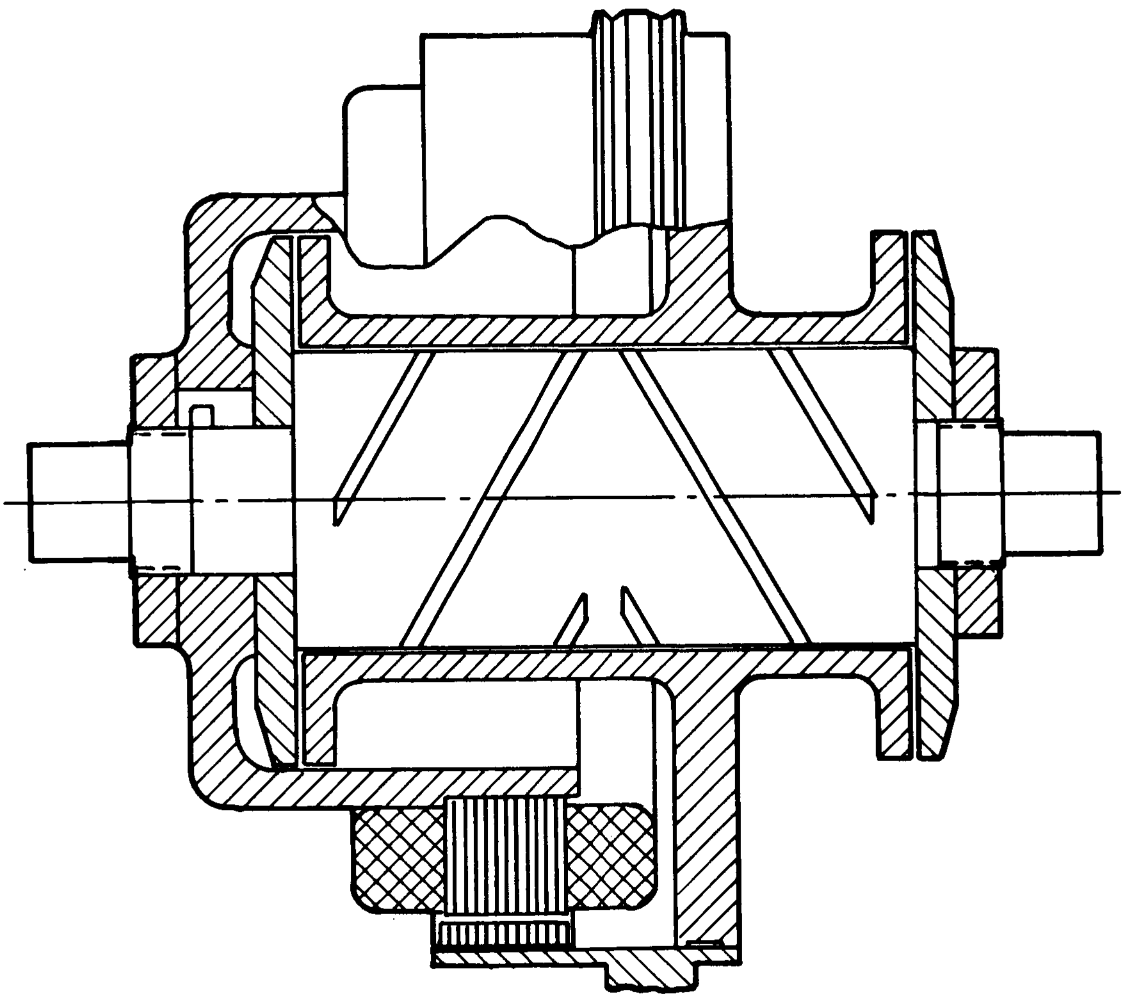

Figure 1. The GG159E Layout

The GG159 C and D thrust area of 0.855 was found to possess a "G" capability in excess of 300 "G's" required in contract 950604. The journal had a 200 "G" capability with an area of 0.49 inch^2. A value of 0.5 inch^2 was selected for both thrust and journal for the GG159E.

Squeeze film support is the only consideration in using size or area as design criteria. Due to the short duration of the shock, the load carrying capability is mainly obtained at frequencies higher than 500 cps. Figures 2 and 3 show the increased support obtained by reducing the number from 18 to 6 patterns in both the GG159 and GG334 spinmotors. The GG159E spinmotor utilizes the six-pattern pad and is very similar to the GG334.

The journal bearing utilizes a three-pattern shaft to suppress half speed whirl rather than the lobing used in the GG159 C and D. Independent work on the GG334 and GG258 has shown that patterning is superior to lobing for small diameter shafts.

GAS BEARING MOTOR BUILD

The materials used in this spinmotor are:

MATERIALS	PART
High density alumina ceramic	motor and shaft sleeve
High temperature epoxies	joints
High temperature solder	electrical connection
Instrument grade beryllium	stator mount
303 stainless steel	nuts
Iron cobalt alloy (Va-Permendur)	stator laminations
Iron cobalt alloy (GE P6 alloy)	hysteresis ring laminations
High density tungsten alloy	momentum ring
Zirconium alloy	shaft

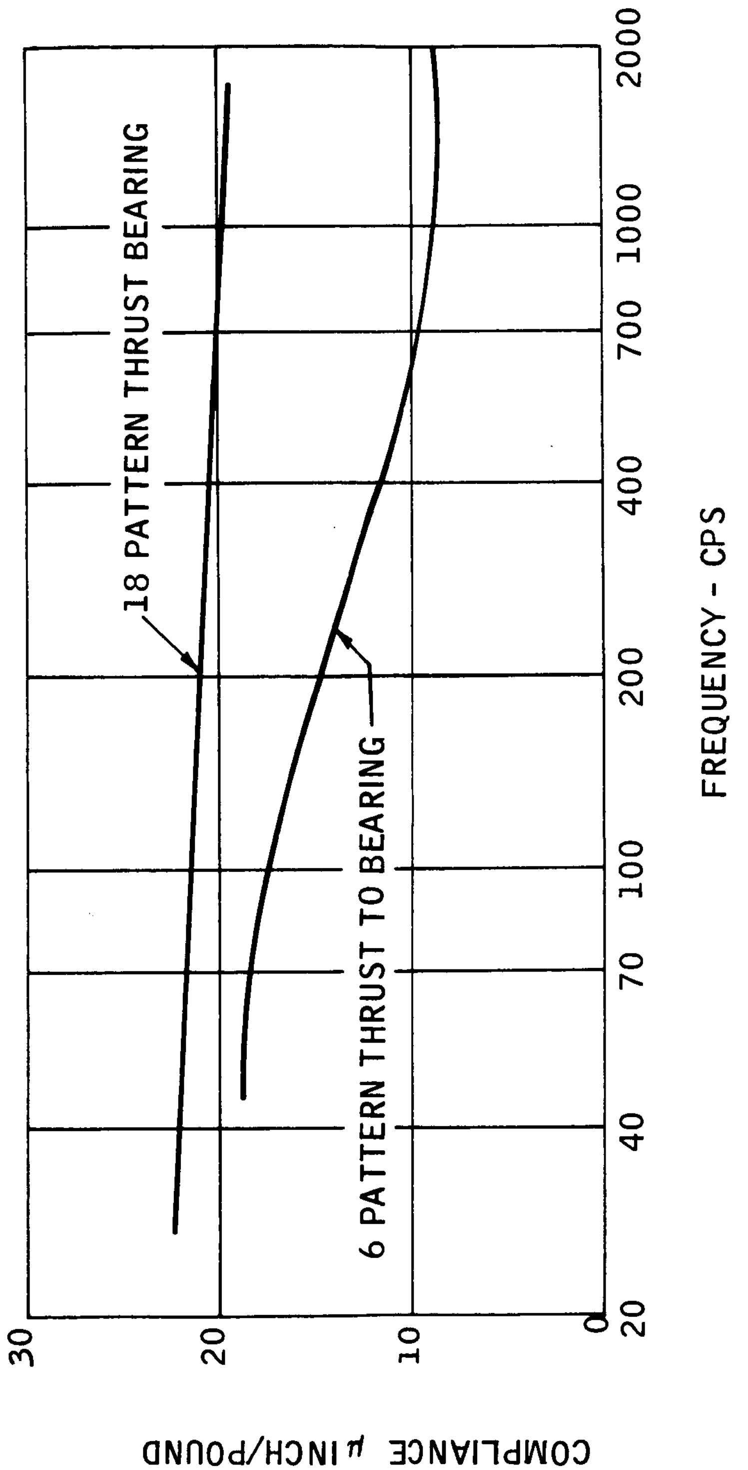

Figure 2. GG159 Thrust Bearing Frequency Response

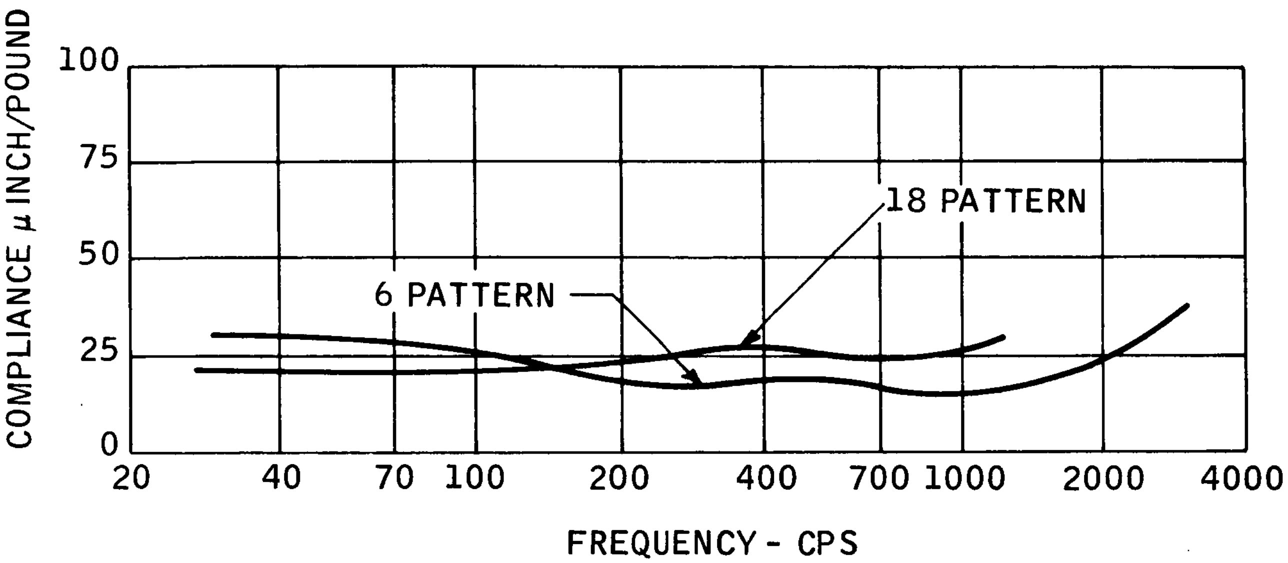

Figure 3. GG 334 Thrust Bearing Frequency Response

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The materials were used in the GG159D2 gyro with the exception of the hysteresis ring, beryllium, and stainless steel.

The laminated hysteresis ring, the item of greatest concern, has held up under shock and sterilization with no visible degradation.

GAS BEARING SPINMOTOR TESTS

Shock

The GG159E gas bearing spinmotor of Figure 1 was exposed to shock levels up to 230 "G's" on the journal and thrust axis. The shock was a 1.0 and 1.5 millisecond duration half sine shock pulse and no bearing contact was made at any time during this shock testing. Figures 4 and 5 show the shock displacement plotted against the magnitude of the shock pulse with the waveforms at various positions. The ringing of the gas bearing caused the upswing of the displacement vs. "G" level curve. Figures 6 through 12 show the shock and displacement waveforms and are referenced on Figures 4 and 5.

Assuming a terminal peak waveform of 0.7 ms were to be imposed on this motor, the ringing would be less than the 1.5 ms waveform at 200 "G" due to a lower slope. The ringing would occur upon the fall of the shock after 0.7 ms when the gas bearing was centered, and less apt to make bearing contact i.e., more room to travel when oscillating. The amplitude of the displacement waveforms is in terms of micro-inches and the level exceeds the gas bearing clearance because bending occurs in the shaft and mount. In the previous contract (950604) there was a fixture error determined of 0.14 micro inch/"G". This has been subtracted out of Figures 4 and 5 and the remaining displacements are then bending plus gas bearing displacement. The positive determination of no bearing contact is made by observing the lissajous pattern of the motor TIR and motor voltage. A minute change in the pattern can be easily observed and indicated bearing contact i.e., a loss of synchronism of physical rotor rotation to electrical field rotation.

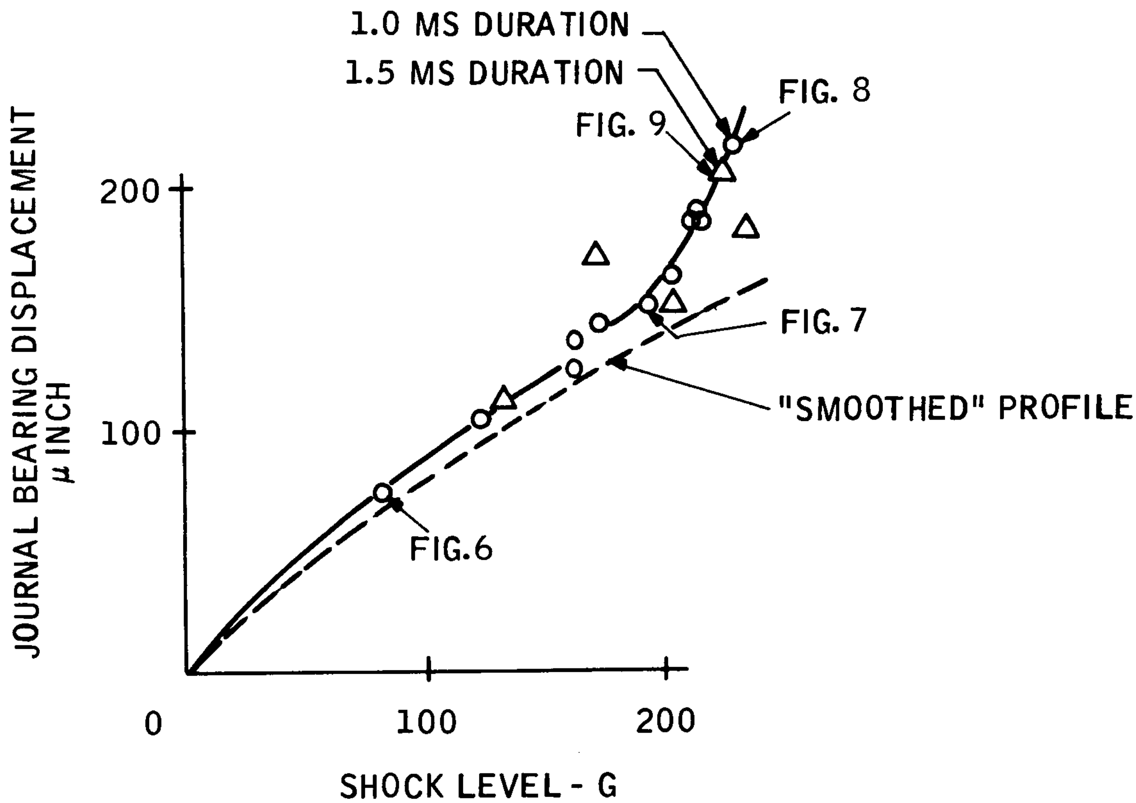

Figure 4. GG159E Bearing Displacement versus Shock Magnitude

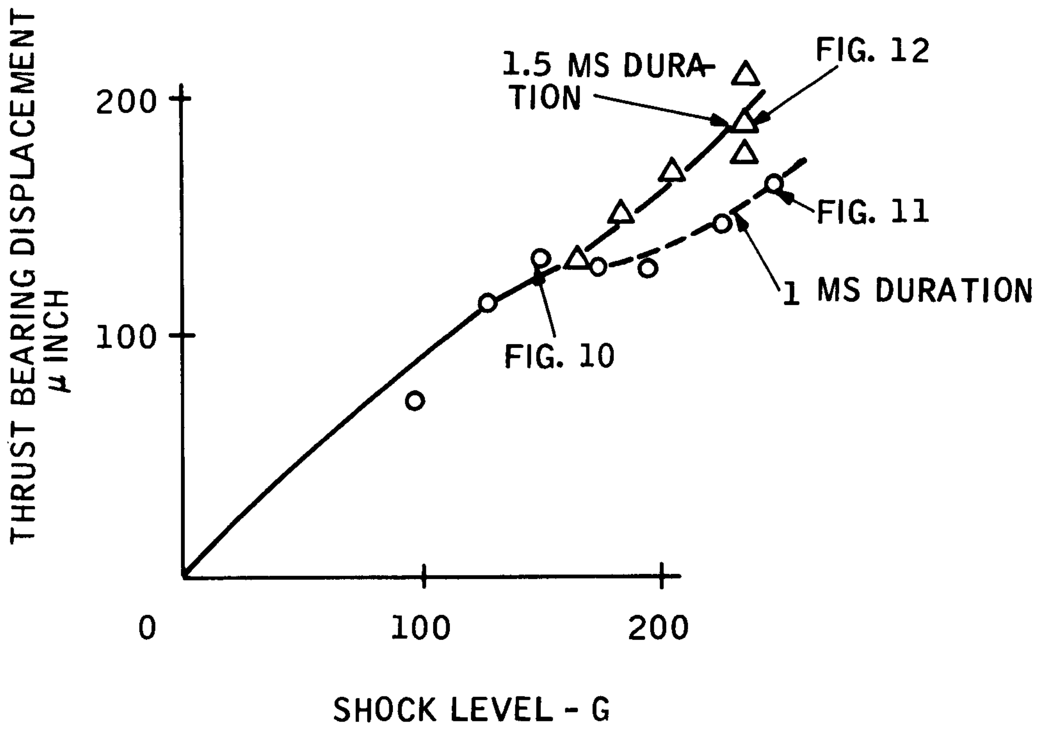

Figure 5. GG159E Bearing Displacement versus Shock Magnitude

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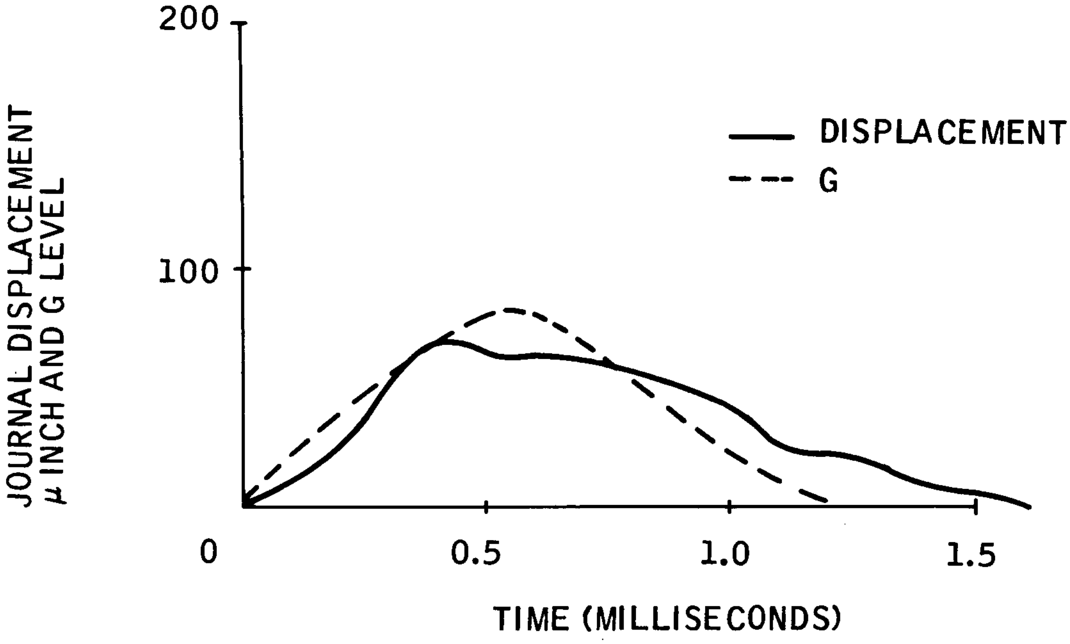

Figure 6. GG159E Displacement During Shock Environment

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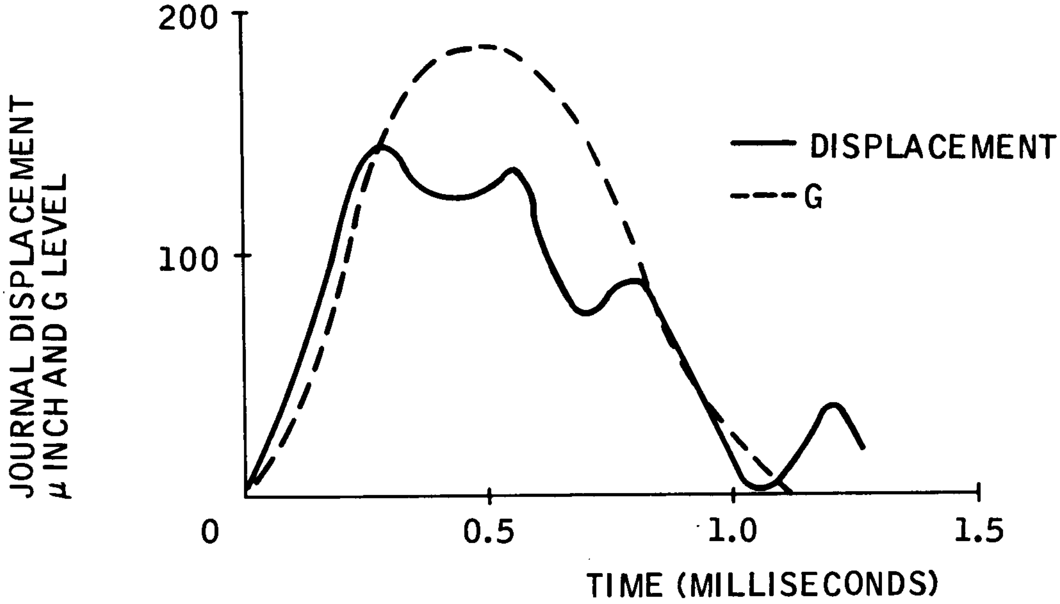

Figure 7. GG159E Displacement During Shock Environment

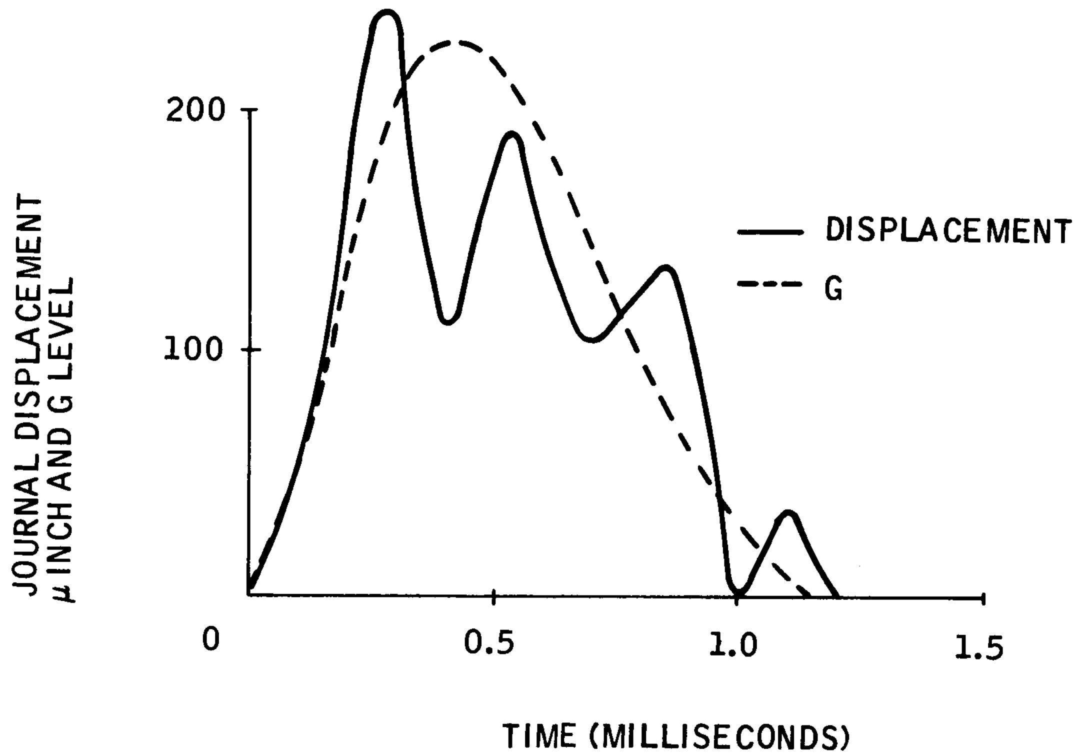

Figure 8. GG159E Displacement During Shock Environment

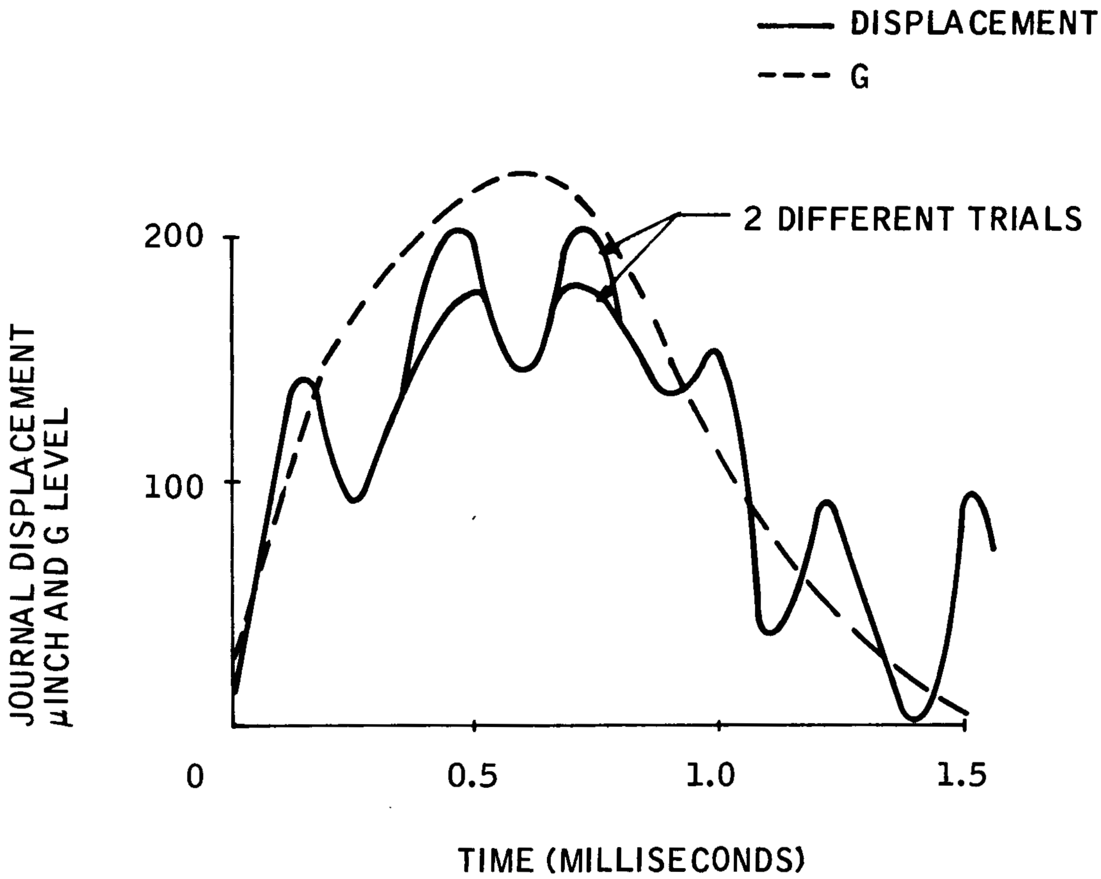

Figure 9. GG159E Displacement During Shock Environment

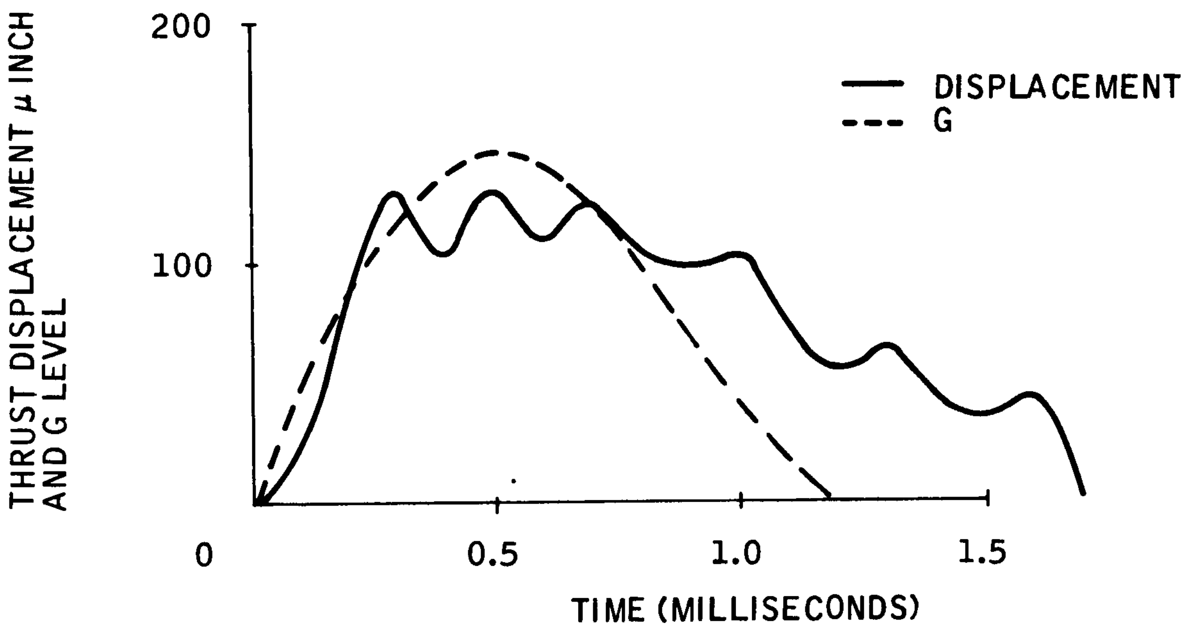

Figure 10. GG159E Displacement During Shock Environment

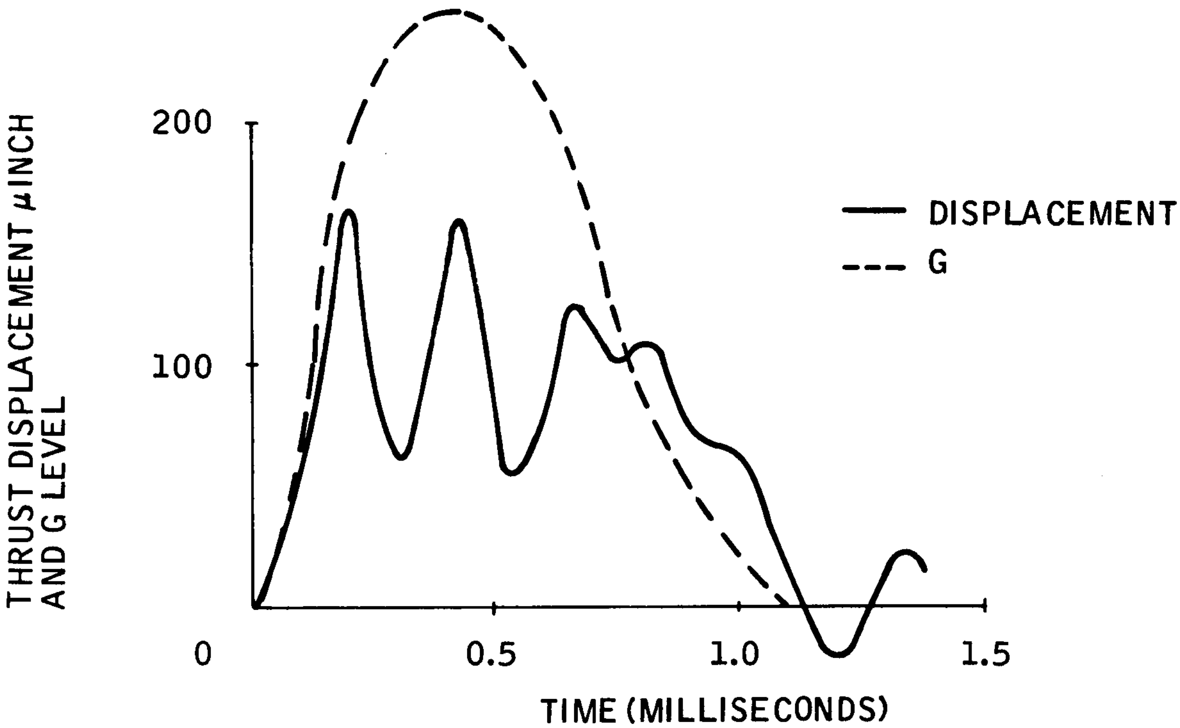

Figure 11. GG 159E Displacement During Shock Environment

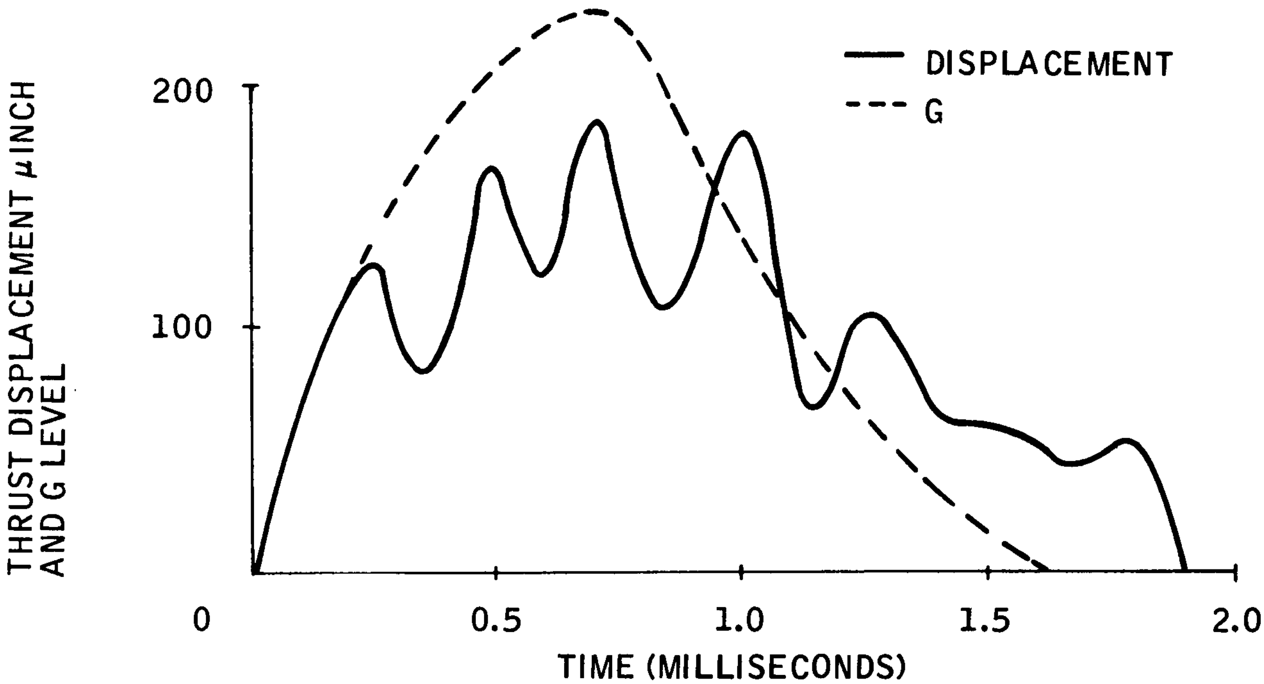

Figure 12. GG159E Displacement During Shock Environment

Anisoelastic Coefficient

The motor has an anisoeleastic coefficient as seen in Figure 13. Data is taken from the sinusoidal vibration, both displacement and time phase, and when operated on by the G^2 drift computer program, produces the anisoelastic coefficient of the gas bearing spinmotor as shown. The gimbal of the GG159 C and D class will add a small additional term which is flat in frequency response. The G^2 coefficient exceeds contractural requirements in the low frequency range and meets requirements above 250 cps.

Power

The contractural requirement of four watts has been met with this high "G" sterilizable gas bearing spinmotor. Figure 14 shows the power as a function of exitation voltage. In the design section, an improvement of four was shown in the drag torque terms, however, half of this improvement is utilized to provide increased torque margin. The resulting performance is a motor that will marginally start and run at 16 volts and operate at 26 volts with less than four-watt sync power and less than eight-watt stall power. The stall power is further discussed in the contractural comparison section.

Random Noise

An exposure of the GG159E gas bearing spinmotor to random noise as specified in the JPL spec No. 30250B 4.3.3.3(a) modified by amendment No. 2 was successful. No bearing contact was made, and the displacement was linear to displacements and was less than those encountered in the shock testing. The lack of bearing contact was determined again by observing the synchronism of displacement and motor voltage.

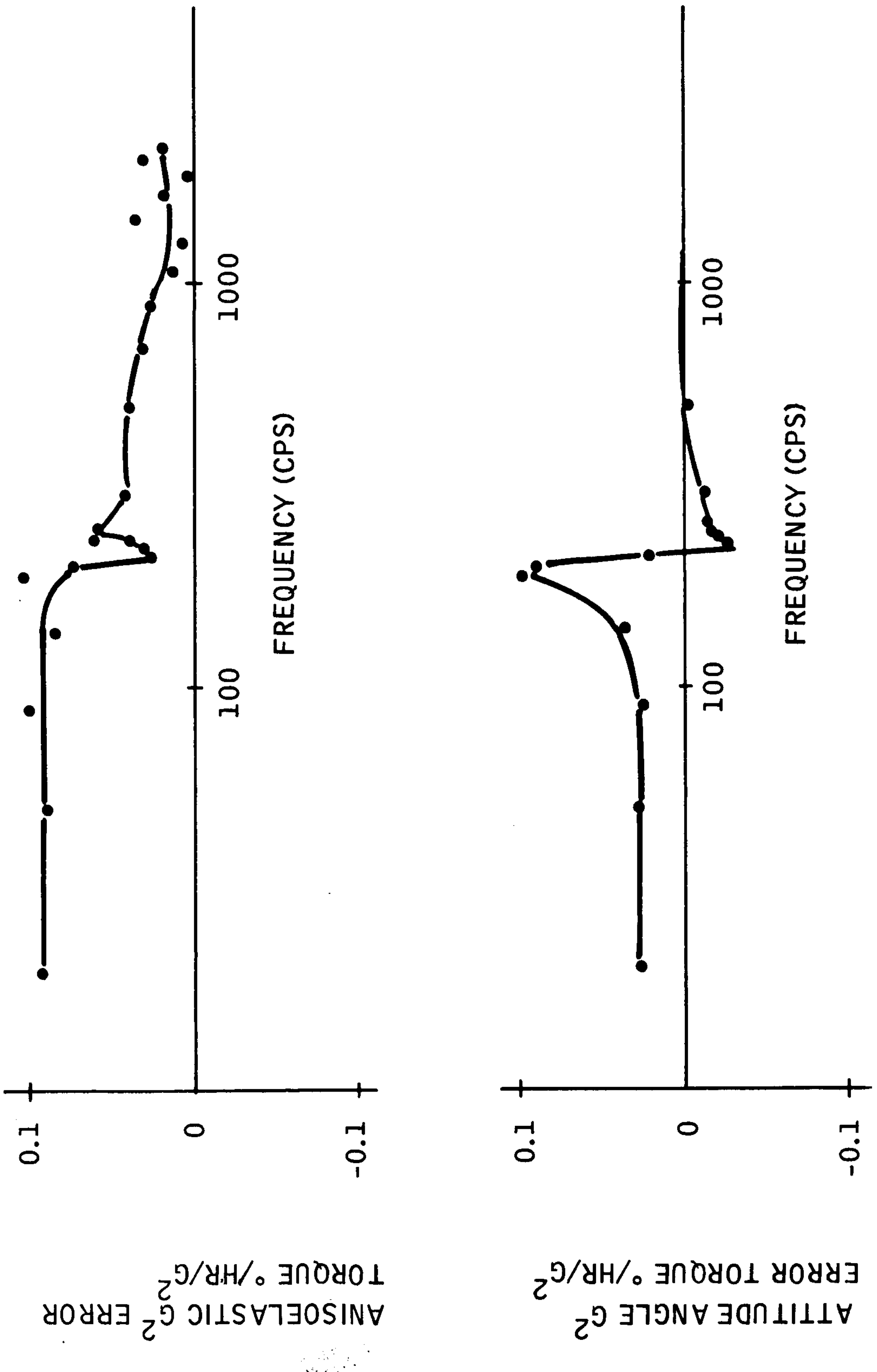

Figure 13. Anisoelastic Coefficients

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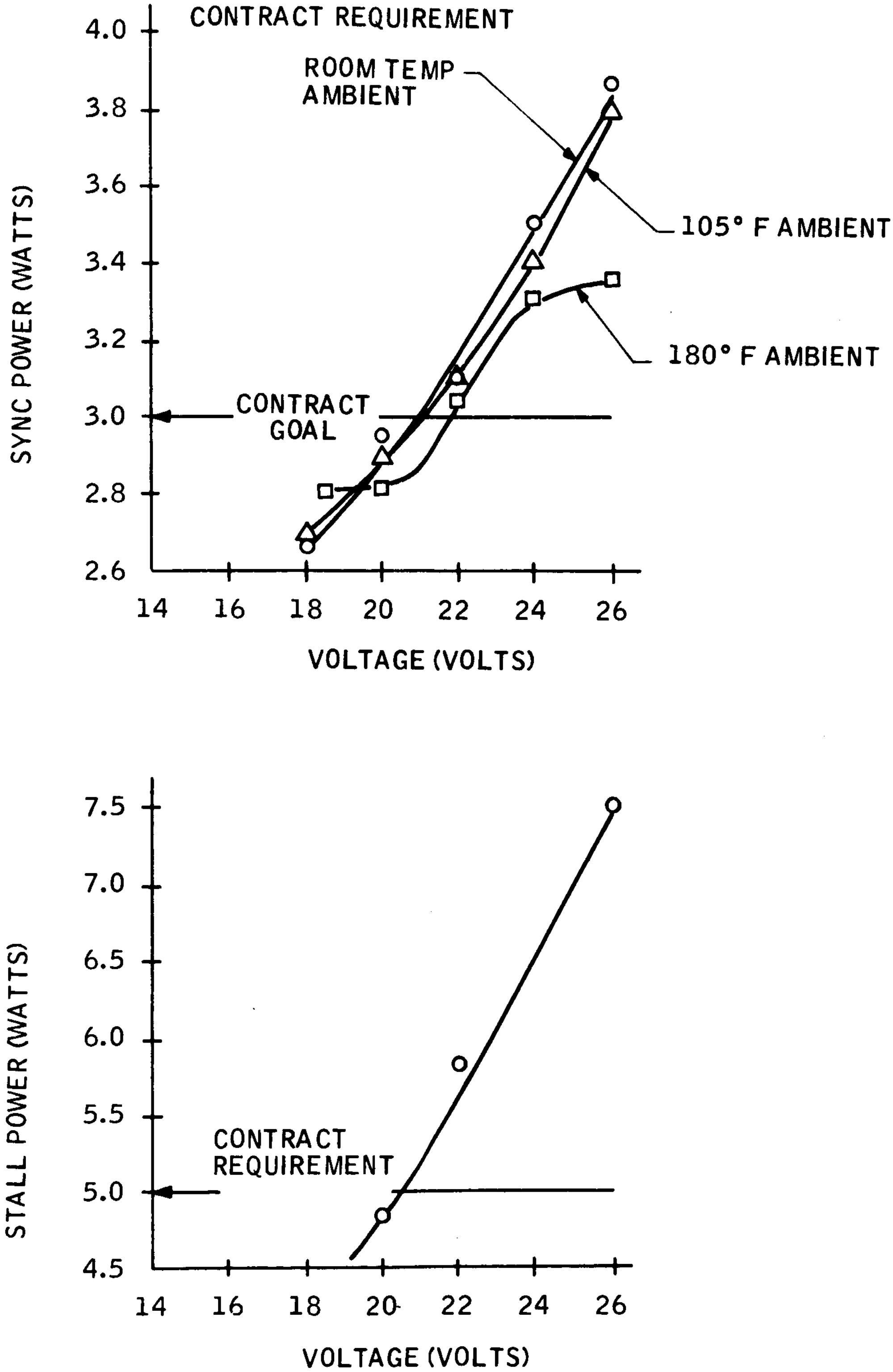

Figure 14. GG159E Power

Sterilization

Sterilization of the GG159E gas bearing spinmotor was performed in a GG159 gimbal in an oven which maintained a "water break free" environment during the entire test. The gimbal was not sealed. The starting voltage increased by three volts and varied in this +3 volt band as the test progressed. Starting voltage was measured after 46 hours, 72 hours, 72 hours, and 144 hours, for a total of 334 continuous hours at 300 F (150 C). The power, run up, and run down times were unchanged from the first motor build through vibration, shock, and sterilization environments.

HIGH FREQUENCY PUMP DEVELOPMENT

The high frequency pump development program which was initially started under JPL Contract No. 950604 has been continued under this contract. Whereas the emphasis on the previous development program was to demonstrate the feasibility of the high frequency pump concept, the object of the current effort is to develop the necessary hardware to implement the high frequency pump into an operational high "G" sterilizable gyro.

DETERMINATION OF A MOUNTING SCHEME

The following methods of mounting the pump plate were designated and tested:

- Lead coated aluminum V seals
- Solid spacers
- O-Rings

The test was implemented with a manometer and flow meter, the excitation frequency was variable and a valve allowed flow control.

The results of these tests are shown in Table 2 where the aluminum V seals were selected as the best method of holding the piezo electric pumping assembly.

Table 2. Results of Three High Frequency Pump Mounting Schemes

	ADVANTAGE	DISADVANTAGE
V-seals	1) Simple construction 2) Highest pressure and flow 3) Bender plate clamping force is virtually constant with temperature 4) Mounting system is not degraded after exposure to sterilization temperatures	1) The most frequency sensitive
Solid Spacer	1) Simple Construction	1) Bender plate clamping force would be sensitive to temperature 2) Pressure-flow output curve is erratic
O-Rings	1) Simple Construction	1) Bender plate clamping force would be sensitive to temperature 2) O-Ring may take a "set" change output characteristics 3) Pressure-flow output is less than with V-seals

CARTRIDGE PUMP DESIGN

A cartridge type high frequency pump assembly was designed and the layout is shown in Figure 15. The pump assembly was purposely designed to fit into a GG159D2 case and utilize the same plumbing, gyro mounting, and seals. The lead coated aluminum V-seals were chosen for this design because of the high pressure flow output obtained from the initial tests and the high probability of being able to withstand sterilization temperatures without damaging the bender plate and/or alter the pumping characteristics.

The basic parts of the pump assembly are the pump housing, rectifier plate, lead coated aluminum V-seals, rectifier retaining ring, and piezo plate assembly.

The piezo plates making up the piezo plate assembly are lead coated zicconate titanate ceramic. The plates are coated with sputtered gold to create the conductive surface which is approximately 50 angstroms thick. The plates are axially polarized and epoxied together so that the positive side of one plate is epoxied with conductive epoxy to the negative side of the adjacent plate. After the terminals are attached and excited with an AC voltage, the assembly will bend like a bimetal structure undergoing a cyclical temperature change. The pumping orifice is ground directly into the bender assembly. The piezo pumping plate assembly is shown in Figure 16.

When the cartridge type high frequency pump was completed, the alkane 695 damping fluid was received from the vendor. Tests were then run on the pump mounted in a gyro case to determine the resonant frequency as well as the pressure and flow output versus frequency. The results are plotted in Figure 17. As can be seen from the curve, the peak pressure and flow output occurred at about 540 cps which is well above the anticipated design point of 400 cps. This assembly was exposed to 300°F for 100 hours at this time and no change in the output was observed.

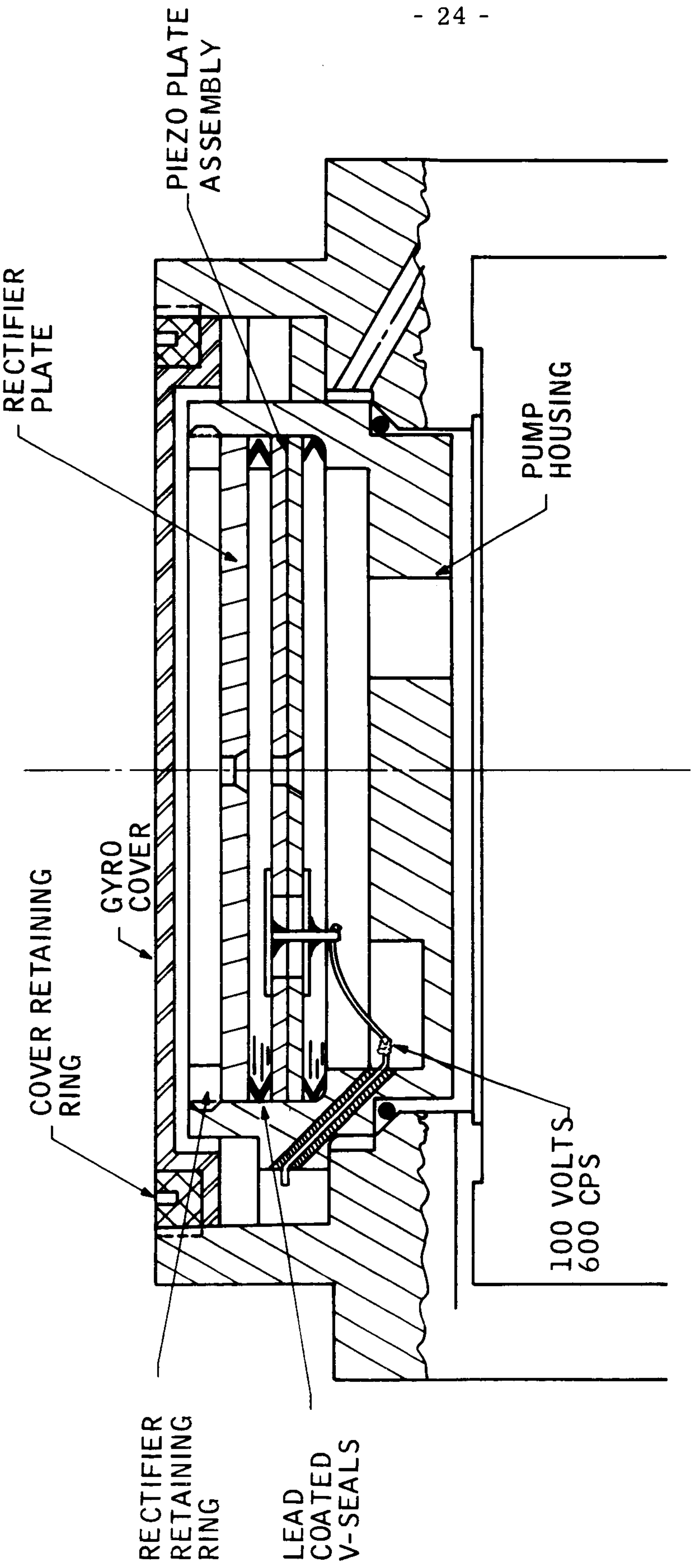

Figure 15. High Frequency Pump Layout

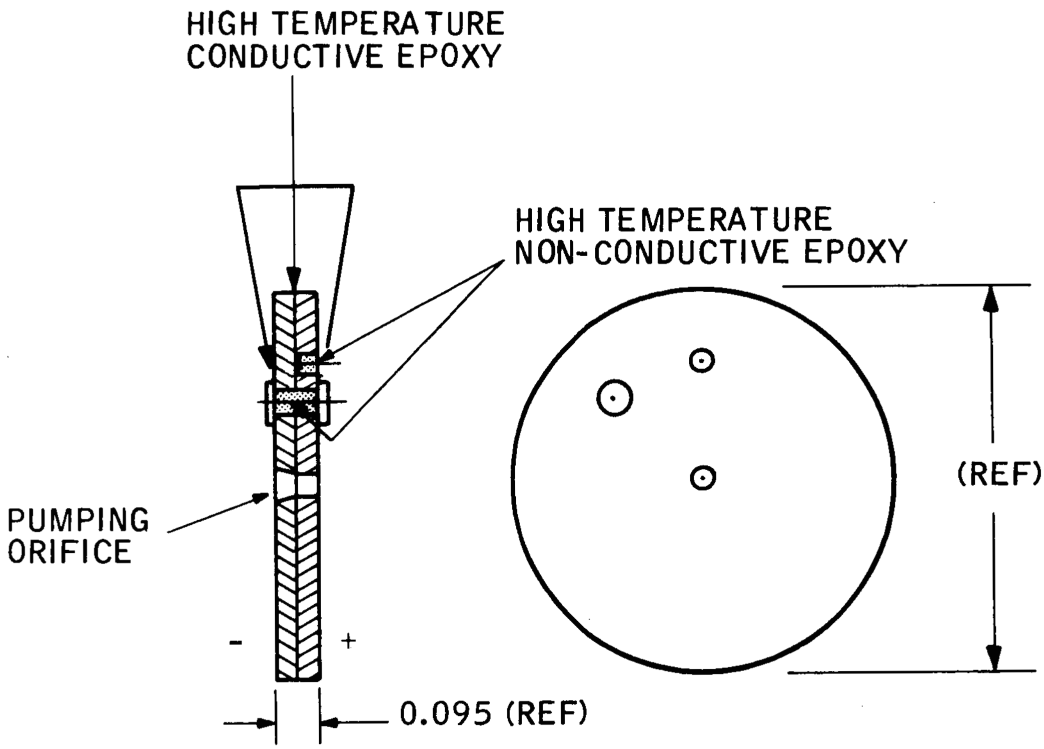

Figure 16. Piezo Pumping Plate Assembly

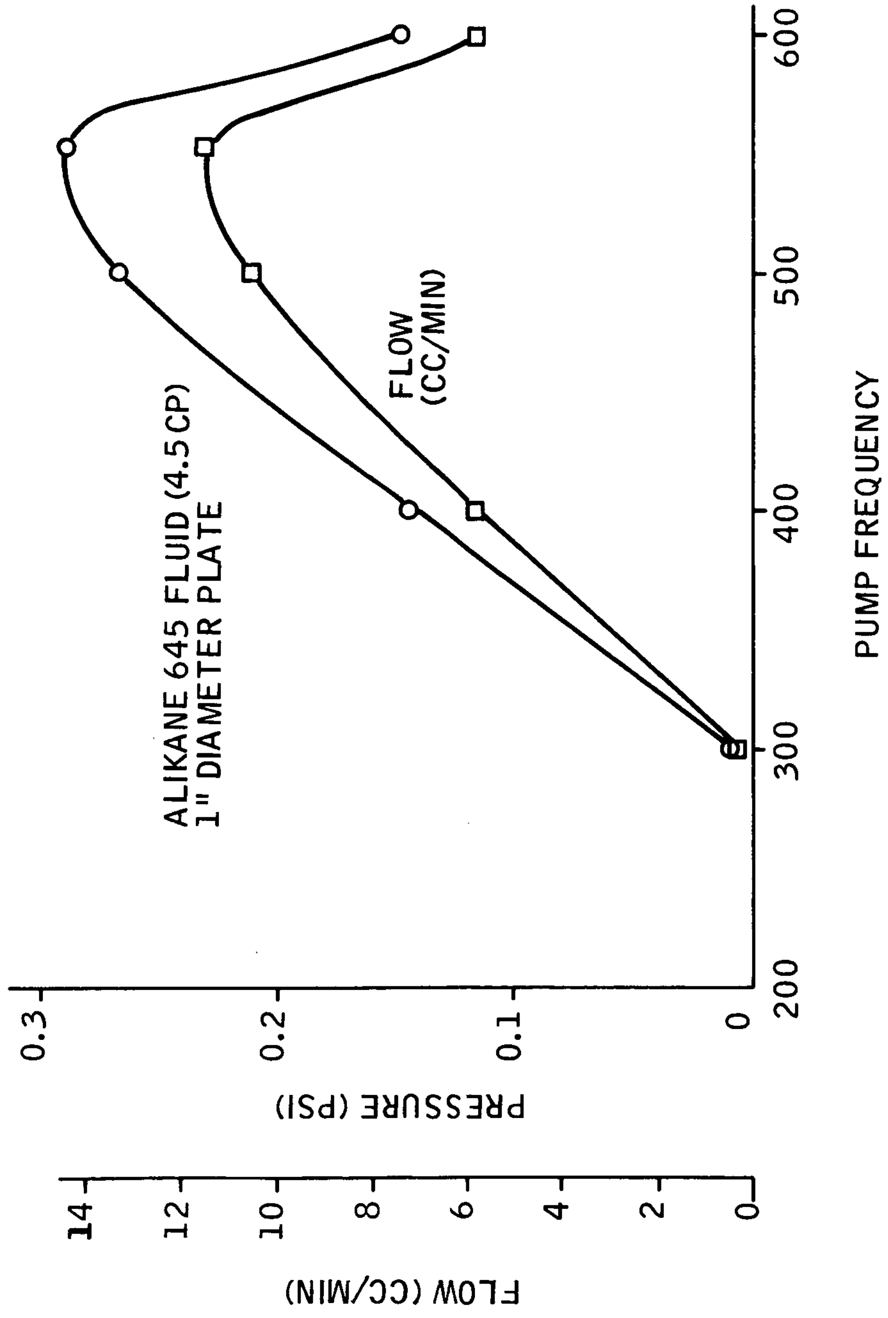

Figure 17. Piezo Pump Pressure and Flow versus Frequency

Since the cartridge assembly was desirable for early dummy gyro assemblies and tests, the resonant frequency was not thought to be the immediate problem. There are seven variables involved in the resonance of this system and the problem will be reconsidered in the near future. The parameters involved in the natural frequency are:

- Plate spacing
- Rectifier compliance
- Gyro cover spacing and compliance
- Fluid density
- Fluid viscosity
- Plate diameters
- Bender plate mass

DUMMY GYRO

The viscosity of the purchased alkane 695 fluid was low by 30 percent and the density was low by 3 percent as compared with the purchase specification. This created pump support and flotation problems on the GG159 dummy gyro (no spin-motor) evaluation of the high frequency pump. Marginal support was obtained and further evaluation with a fluid with proper parameters is required to access the true capability of the pump.

An additional problem of a 2000 micron vapor pressure makes the gyro filling extremely difficult. Elimination of entrapped gas is required for proper operation of the high frequency pump. It is estimated that a maximum of 200 micron vacuum pump down during fill will be required to obtain the most efficient pump operation. A search for a better fluid will be undertaken during the next quarter.

CONTRACTURAL COMPARISON

The expected performance of the GG159E gyroscope compared to the contract work statement is shown in Table 3 in terms of exceptions to the stated requirement.

Table 3. Contract Work Statement and Present Exceptions to the Contract

Parameter	Contractual Requirement	GG159E Gyro
G-sensitive Drift (MU_{SRA})	0.50/hr/g	-
G-sensitive Drift (MU_{IA})	0.46°/hr/g	-
Non-g-sensitive Drift (RT Total uncompensated)	0.30°/hr	-
Fluid Pumping Torque Drift	0.25°/hr	0.5°/hr
RMS Drift Stability (runup to runup)	0.01°/hr	-
Drift Stability (cooldown)		
g-sensitive	0.05°/hr/g RMS	-
non-g-sensitive	0.03°/hr RMS	-
Random Drift		
OAV (1δ)	0.008°/hr	-
IAV (1δ)	0.015°/hr	-
Anisoelastic Coefficient (20 to 2000 cps)	$0.05°/hr/g^2$	$0.15°/hr/g^2$
Wheel Angular Momentum	$100,000\ gm\ cm^2/sec$	-
Damping (Max over 50°F to 130°F)	1800 dyne-cm-sec	11,500
Damping (nominal at 115°F)	500 dyne-cm-sec	1,800
Gimbal Freedom (OA Nominal)	±0.5 degrees	-
Wheel Speed	24,000 RPM	-
Operating Temperature	50°F to 130°F, 115°F Nominal	-
Weight (Max)	1.0 lbs	1.1
Dimensions (Max)		
Length	3.0 inches	-
Diameter (exclusing flange)	2.12 inches	-
Motor Life		
Run	18,000 hours	-
Starts and Stops	10,000	-
Spinmotor		
Frequency	800 cps, 3 phase	800 cps, 2 phase
Voltage (Start and Run)	26 volts L-L	-
Power Start	5.0 watts	8.0 watts
Power Run	4.0 watts (3.0 watts design goal)	-
Torque Margin (Liftoff and synchronization)	5 ¢ rated voltage Min.	-
Altitude (Start and Run)	Unlimited	-
Pickoff		
Frequency	7200 cps	-
Voltage	10.5 volts RMS	-
Sensitivity	26 mv/mr	-
Null Voltage	3.0 mv	-
Linearity	1.0¢	-
Torquer		
Scale Factor	400 deg/hr/ma ± 10¢	-
Linearity	0.01¢	
D-C Resistance (70°F)	137 ohms	-
Inductance (70+F)	0.7 mh	-
Slew Rate Capability (Minimum)	10,000°/hr	-
Temperature Sensitivity (100°F to 130°F)	0.04¢ change	-
Heaters		
Warmup	120 volts, 265 ohms	-
Control Heater	32 volts, 140 ohms	-
Temperature Sensor (115°F)	780 ohms	-
Hydrostatic Suspension		
Frequency	400 cps sine wave or square wave	600 cps sine or square wave
Voltage (Maximum)	100 volts RMS	-
Power (Maximum)	0.3 watts	-
Spinmotor Running Detector Output	10 mv at 400 cps	-
Electrical Connections	Header - solid pin type	-