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STORAGE RELIABILITY OF MISSILE MATERIEL PROGRAM, GYROSCOPE ANAL--ETC(U)

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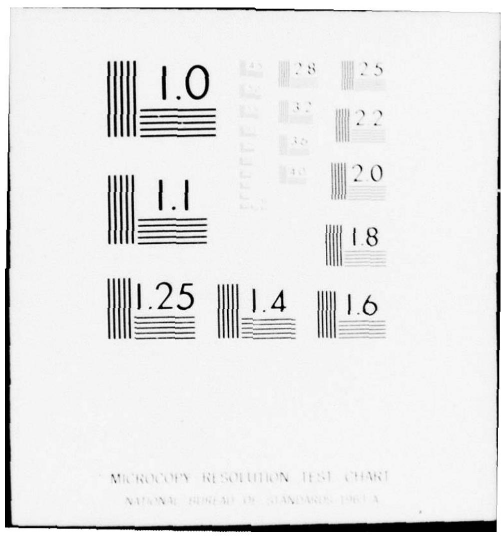
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GYROSCOPE ANALYSIS

LC-78-EM1 FEBRUARY 1978

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This report documents findings on the non-operating reliability of gyroscopes. Based on 835 million part-hours, the storage failure rate for rate gyroscopes is 133 fit (failures per billion hours) with one sided 90% confidence limit at 175 fit. Catastrophic failures are 55 percent of the total, spares usage is 3 times the failure rate. Elements of gyroscope construction are reviewed and important factors for gyroscope storage reliability are identified. This information is part of a research program being conducted by

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20. Abstract (cont'd)

the U. S. Army Missile R&D Command, Redstone Arsenal, Alabama. The objective of this program is the development of non-operating (storage) reliability prediction and assurance techniques for missile materiel. This report updates and replaces report LC-76-EM1 dated February 1978.

(2)

STORAGE RELIABILITY
OF
MISSILE MATERIEL PROGRAM

GYROSCOPE ANALYSIS

LC-78-EM1 FEBRUARY 1978

Prepared by: D. F. Malik

PROJECT DIRECTOR
C. R. PROVENCE
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ABSTRACT

This report documents findings on the non-operating reliability of gyroscopes. Long term non-operating data has been analyzed and reliability predictions have been developed for gyroscopes.

This report is a result of a program whose objective is the development of non-operating (storage) reliability prediction and assurance techniques for missile materiel. The analysis results will be used by U. S. Army personnel and contractors in evaluating current missile programs and in the design of future missile systems.

The storage reliability research program consists of a country wide data survey and collection effort, accelerated testing, special test programs and development of a non-operating reliability data bank at the U. S. Army Missile R&D Command, Redstone Arsenal, Alabama. The Army plans a continuing effort to maintain the data bank and analysis reports.

This report is one of several issued on electromechanical devices and other missile materiel. For more information, contact:

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SECTION 1

INTRODUCTION

Materiel in the Army inventory must be designed, manufactured and packaged to withstand long periods of storage and "launch ready" non-activated or dormant time. In addition to the stress of temperature soaks and aging, they must often endure the abuse of frequent transportation and handling and the climatic extremes of the forward area battle field environment. These requirements generate the need for special design, manufacturing and packaging product assurance data and procedures. The U. S. Army Missile Research & Development Command has initiated a research program to provide the needed data and procedures.

This report updates report LC-76-EM1, dated May 1976, and covers findings from the research program on gyroscopes. The program approach on these devices has included literature and user surveys, data bank analyses, data collection from various military systems and special testing programs.

SECTION 2

SUMMARY

The expected intrinsic storage failure rate for rate gyroscopes is 133 fits (failures per billion hours) and a 90% confidence that the true failure rate lies below 175 fits. The following factors are suggested as being consistent with the data available:

- For free gyros, multiply by a factor of 2.
- For replacement rate, multiply by a factor of 3.

This study is based upon the 835 million part-hours collected to date containing 209 failures. The data includes eight missile programs, three space applications and one report for which the application was not identified. Nearly all of the data is for rate gyros. For gyroscopes showing failures, a range of failure rates from 121 to 524 fit was observed.

A comparison with operating data indicates that the operating failure rate in a ground environment is about 196 times the storage failure rate, and the operating failure rate in the missile launch environment is about 4000 times the storage failure rate.

It is concluded from the data analysis that the non-operating reliability of gyroscopes has improved in the last ten years; that substantially more reliable gyros are within the state of the art but only at great expense; that novel techniques in development look promising from a reliability standpoint; and that a number of things can be done to improve storage reliability. A noteworthy feature of the data is that replacements due to testing, handling, and misidentification of system problems are more common than true storage failures.

SECTION 3

ELEMENTARY PRINCIPLES OF GYRO DESIGN AND CONSTRUCTION

3.1 Physical Principles

A gyroscope is used to detect angular motion with respect to inertial (Newtonian) space. The usual construction is a spinning wheel, the angular momentum of which remains fixed in space if no external torques are applied. If such a wheel is forced to move about one axis, it will precess about another, and the precession motion, which can be conveniently measured, is proportional to the forced rotation. The usual construction uses single axis bearings for both the spining wheel and the precession axes.

Some other principles are known, and have been demonstrated. These will appear in production versions in the next few years and are discussed in Section 3.4.

3.2 Classification of Gyroscopes

A primary distinction among gyros is between single degree of freedom and two degree of freedom gyros. Single degree of freedom gyros have only one gimbal axis, which means only one set of gimbal bearings, only one torquer and only one pickoff. Rate gyros and integrating rate gyros are single degree of freedom designs. In order to create a stable platform, three single degree of freedom units are used, and a set of three or four platform gimbals, each with a pick-off and servo drive, is used to align the platform as a whole. Thus, the reliability of the gyros is only part of the consideration of the reliability of a platform.

A two degree of freedom gyro (also called a free gyro) incorporates two gimbals, each with a pickoff and torquer, into the gyro itself. These gyros are often used in systems which provide a small alignment torque. The idea is that the gyro does not respond to disturbances, but that it does respond to the time-weighted average alignment torque. The process is called erection. Erection time constants on the order of ten minutes are typical. (In servo terms, the gyro acts as a filter for high frequency inputs.) Some examples are:

artificial horizon - the gyro is erected to local vertical;

gyrocompass - the gyro is erected to local vertical and the earth's spin vector (true north);

directional gyro - erected to local vertical and geomagnetic field (magnetic north). A great many arrangements can be used, a typical one is a damped pendulum within the gyro gimbals, the offsets of which create driving signals to the gyro torquers.

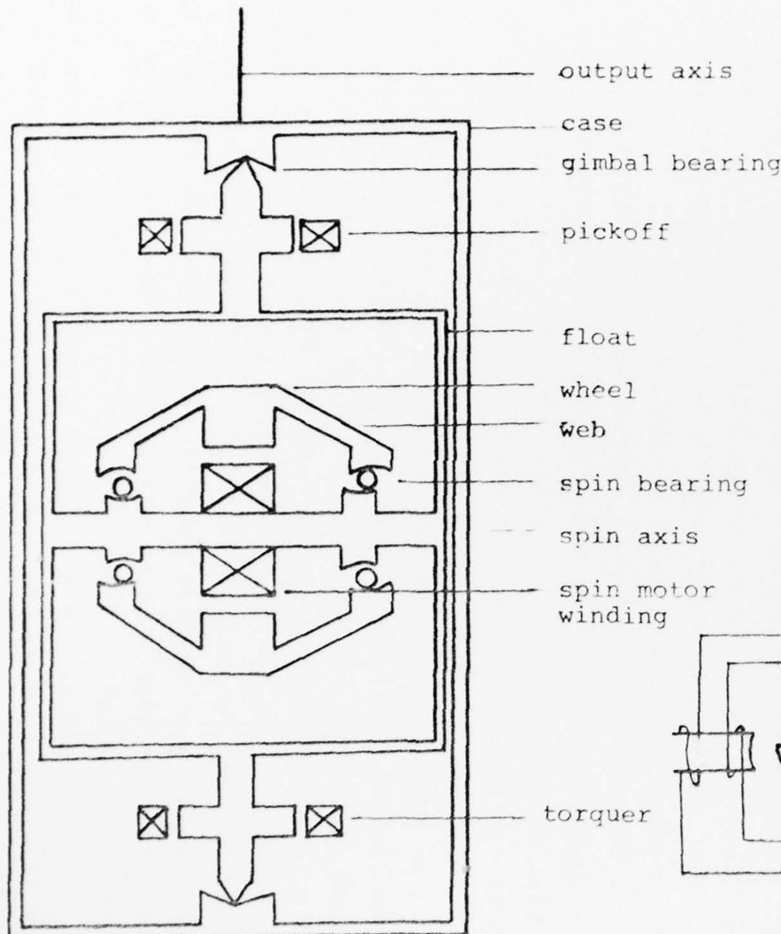
The local gravity vector does not provide a reference for a system in free fall, such as a missile or a space vehicle. In such cases, a horizon sensor can be used, or the sun and stars can be used to calculate local vertical. Some systems erect to the local vertical before the mission begins, but not during the mission (pure inertial guidance).

3.3 Components of Gyroscopes

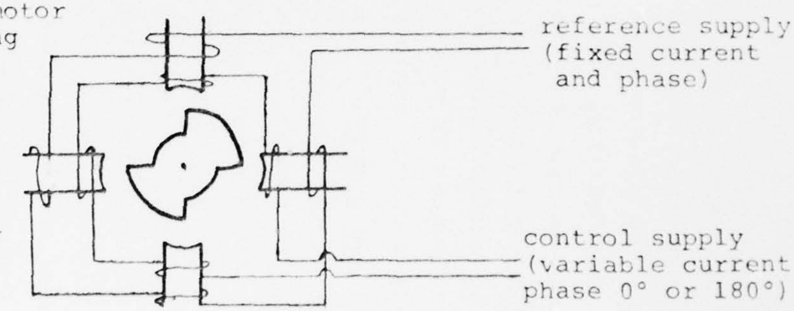
Because of its complexity, it is convenient to think of a gyro in terms of its functional components. These are described below. Figure 3-1 shows their arrangement.

3.3.1 Wheel - The purpose of the wheel is to provide a large ratio of angular momentum to the disturbance torques in the system. Speeds of 12,000 or 24,000 rpm are typical. The wheel may be split into symmetrical halves, and the web of the wheel may be shaped to make the wheel isoelastic. Typical construction consists of a heavy rim supported by a conical web.

3.3.2 Spin bearings - The spin bearings support the wheel both radially and axially, while allowing relatively free rotation. Ball bearings are typical, and provide a comparatively rigid support. They can be designed to be isoelastic and to provide axial support by using a large contact angle (about 35°). Note that torque about the spin axis does not constitute a disturbance torque for the gyro although it does consume power and create waste heat. Lubrication must be kept near a minimum, because excess lubricant cannot be controlled as to position, so that it can create mass unbalance. Typical



GYRO CROSS SECTION



VARIABLE RELUCTANCE TORQUER

A variable reluctance pickoff can be the same design, but only the induced voltage is read at the control winding, no current flows there.

FIGURE 3-1. GYROSCOPE COMPONENTS

ball bearings have a definite wearout life. (If the lubricant completely prevents contact between the balls and the races, the life becomes indefinite.)

Gas bearings have also been used for spin bearings. A typical design uses the spin itself to pull gas into the bearing so that no external supply is required. Such a design has an unlimited operating life, but has a wearout life based on the number of starts, typically 1000. The high contact stress when not operating can produce adhesion.

3.3.3 Spin motor - The spin motor is typically a synchronous motor of the hysteresis type, either two or four pole. The supply is typically two phase 400 hertz. If the scale factor is critical a synchronous design must be used, but in systems where the gyro is simply driven to null an induction motor may be used. Power for the spin motor must be provided without introducing disturbance torques, typical practice is to use flexible leads in a configuration which can be compensated. Neither the hysteresis nor the induction design require electrical connection to the wheel assembly.

Where the gyro is only needed for a few minutes, a spring or squib may be used to bring the wheel up to speed before the start of the mission. Aircraft often use a jet of air driven from the engine vacuum as a power source, since the gyro can then be made independent of electrical failure.

3.3.4 Gimbal - The gimbal ring should be rigid, or at least isoelastic, and must be carefully balanced. The gimbal bearings have little motion, but must be as nearly torque free as possible. Some designs use ball bearings with dither or counter rotation of the fixed raceway to eliminate breakaway friction, such designs can reduce the friction of ball bearings by a factor of ten. Gas bearings are sometimes used, but an external gas supply is necessary, and care must be taken to avoid contamination.

Some designs use a fluid to float the weight supported on the gimbal bearings. The bearing load can be reduced by a factor of 1000 in this way, thus reducing those torques which are proportional to the bearing load. The bearings in such a design are typically either a jewel or a set of taut wires. The flotation fluid is also used to provide viscous damping in the integrating rate gyro. As the viscosity varies rapidly with temperature, either the temperature must be controlled, or some form of compensation introduced. Compensation typically uses the volumetric change of the fluid with temperature to create a mechanical displacement which adjusts the damping geometry.

3.3.5 Pickoff - The pickoff reads the angle thru which the gimbal bearing axis has been turned. It is important that the pickoff not introduce a reaction torque, so potentiometers are suitable only in low accuracy systems. Typical pickoffs are a differential transformer or an optical readout. A variable reluctance design can eliminate the moving coil and its connections in a differential transformer.

3.3.6 Torquer - The torquer is almost invariably electromagnetic. The design can be very like that of the pickoff, except that currents flow in both sets of coils. The desired torque is determined in an electrical network outside the gyro.

3.4 Design Trends - Some design trends have been identified which can be expected to improve reliability. Solder joints, which tend to produce contamination both from the flux and from spattering, are being replaced by welded joints, both for electrical connections and for the seal. Grease in ball bearings is being replaced by oil, which does not have the tendency to separate and is better fixed in position. There is also a tendency to replace the ball bearings by gas bearings, although gas bearings lack the stiffness and isoelasticity of ball bearings. For gimbal bearings, an enclosed design which eliminates the external gas supply may solve the contamination problem. An internal pump recirculates the fill fluid in such a design.

Some characteristics are varied to meet performance and other requirements. Frequency, voltage, and waveform of both the wheel drive and pickoff; and composition and pressure of the fill gas are examples. Some standardization might be desirable, certainly it would permit longer and better controlled production runs.

The gyros for which data has been collected have unit costs ranging from 400 to 25,000 dollars. The selection of a gyro for a missile system is determined by a cost trade-off rather than by the performance state-of-the-art. Nevertheless, testing and screening should probably be a significant part of the unit cost.

Improvements in performance, size, weight, and power have also been made over the years, but are not considered pertinent to this study. Typical values for current designs are: cylindrical outline, one inch diameter by two and a half inches long, less than one half pound, less than 15 watts.

Radically different designs have been studied, and some are currently under development. See Ref. 14 for a review. Electrostatic suspension, the laser gyro, and the oscillating gyro are examples. The operating principles are described below:

(a) In place of a wheel on bearings, one can use a free spinning sphere, which is held in place by radial electromagnetic or electrostatic forces. The sphere is contained in an evacuated chamber so that no spin power is required after the initial spinup, and the readout is optical.

(b) The time required for a light beam to traverse a rotating system of mirrors varies with the speed of rotation and the direction of travel. By using a split monochromatic (laser) beam, an interference pattern can be generated which defines the rotation rate. The resulting laser gyro has no moving parts.

(c) A mass at the end of a cantilever beam of circular cross section vibrating in the primary mode preserves its plane of oscillation against rotation about the axis of the beam. The resulting gyro has no bearing requirement, the only movement being the oscillation.

Only gyroscopes of the usual construction are discussed elsewhere in this report.

3.5 Acceptance Type Tests

Sample information on tests of two gyro programs is summarized below. Since the differences in storage reliability of the programs are not statistically significant, they cannot be correlated with the test procedures.

3.5.1 Program B Gyro Acceptance Tests

Insulation Test

Gyro:	NGT 2.5 ua at 250 ± 25 vdc between blue lead and gyro case at 25°C, min of 3 sec.
Heater:	NGT 5.0 ua at 500 ± 50 vdc between heater leads and gyro case at 25°C, min of 3 sec.
Synchronization Time:	NGT 3.0 seconds at 160 ± 10°F with 24.3 $^{+.5}_{-.0}$ Vtrms at 1200 + 6 hz for a period of 4.0 ± 1.0 sec.
Gyro Motor Operational Test:	Reduced motor input to 0.5 ± 0.5 Vtrms, must maintain synchronous speed.
Motor Input Current:	NGT 0.480 amps rms at 160 ± 10°F, motor input to 11.5 ± 0.5 Vtrms.
Pickoff Input Current:	NGT 0.150 amps rms at 160 ± 10°F.
DC and AC Null:	DC output - MGT 1.0 mVdc (0.10 degrees/sec.) with power applied to pick off, heater, and motor. AC output - NGT 5 mVrms with motor power off.
Gyro Sensitivity and Pickoff Phasing:	Pickoff DC output - 10 mVdc ± 4%/ deg./sec at 160 ± 10°F, with table speed 10 ± 0.1 deg./sec, CW and CCW.
Full Scale (Stop Setting), and Mechanical Hysteresis	
Full Scale:	Rate table speed at CW direction and gyro stopped, constant AC output - rate table speed = 150 ± 30 deg/sec CW at 160 ± 10°F.

Rate table speed at CCW direction same as above conditions and speed output.

Hysteresis:

Null Shift: NGT 0.5 mVdc (0.05 deg/sec) per conditions of TRS-MSL-012.

Tumble Test: NGT 0.80 mVdc (0.08 deg/sec) at 160 ± 10°F.

Oscillation: NGT 1.5 mVdc (peak to peak)(0.15 deg/sec) at 160 ± 10°F.

Damped Natural Frequency: NLT 57 hz at 160 ± 10°F.

Demodulated Null/ Temperature Effects: DC output bandwidth values 1.0 mVdc (0.10 deg/sec) at 50 temp cycles at - 32 ± 5°C to 71 ± 5°C.

Thermal Sensitivity: DC output bandwidth values 0.8 mVdc (0.08°/sec) at 3 temp cycles at -32 ± 5°C to 71 ± 5°C.

Pre-Field Screening. The major item in which the failed component was used, was subjected to the following run time and enronmental stress screening prior to shipment to the field.

Run Time: 32 hours total run time of which 16 hours of the total time the item is subjected to a high temperature cycle of 61°C for a period of 1 hour on and 1 hour off.

Shock: 50 g - 5 millisecond half sine shock 1 plane.

Random Vibration: 3 planes for 6 minutes each plane at approximately .02 g^2/hz from 20 to 2000 hz.

3.5.2 Program F Gyro Acceptance Tests

(Tests performed at room temperature only)

Motor Excitation - 26v, 1ø, 400 Hz (1.0 µf capacitor)

Pickoff Excitation - 10v, 1ø, 4800 Hz (90K load)

Sync. Time

AC Null

Zero Set

Mass Unbalance ($\pm$ 1g)

Automatic Linearity Plot (scale factor, linearity, and hysteresis)

Megger

Mechanical Inspection

SECTION 4
DATA ANALYSIS

4.1 Data Description

Data was collected from twelve sources, eight of which are missile programs. The data summarized in Table 4-1 represents 835 million gyro non-operating hours with 209 failures reported. The failure rates for each source are calculated in fits (failures per billion hours) and are the maximum likelihood values. One failure is assumed in the failure rate calculation if there were no failures reported. Failures attributable to design defects which have been corrected, to mishandling, to conditions outside design requirements, and to erroneous attribution of system problems have not been included.

Where identified, the data includes gyros with ages up to 6.3 years. For several sources, it was necessary to estimate the part non-operating hours as indicated in Table 4-1. These estimates are conservative and part non-operating hours could have been greater than indicated. Each data source is described in more detail below.

Some differences could be anticipated between the data sources due to differences in the design and in the testing (screening) in the various programs. For the programs with large exposure, the components listed represent production over extended periods of time, which means that both the design and the production process have varied. Since those failures which were remedied are not counted, the failure rates should represent those attained at the end of the project, i.e., by the "mature" design.

For examples, a step was added to gyro manufacture in Source M-2 to saturate the exposed plastic with the damping fluid by exposing it under high pressure. This prevents subsequent change in the volume of the damping fluid. In the gyros for Missile M, a set of sliding contacts was replaced

TABLE 4-1. GYRO NON-OPERATING DATA

SOURCE	NO. OF DEVICES	MILLION PART STORAGE HRS.	FAILURES	FAILURE RATE IN FITS
A	-	34.367	18	524.
B	15	.076	0	(<13158.)
L	6	.331	0	(<3021.)
M-1	115	4.44*	0	(<225.)
M-2	102	3.94*	1	254.
MISSILE				
E-1	4370	63.802	23	360.
F	120	2.628	0	(<380.)
G	39	1.118	0	(<894.)
H	5355	85.1	13	153.
I	8280	82.36	10	121.
M	-	30.6*	16	523.
T	12000	525.6	128	244.
U	15	.657	0	(<1522.)
TOTALS		835,019	209	250.3

*Estimated part hours

by a flex lead, and later the material of the flex leads was changed to avoid a corrosion problem.

Each data source is described in more detail below.

4.1.1 Source A Data

Source A represents a reliability study performed under contract to RADC. This source identified the type and quality grades for the devices, however, it provided no information regarding storage conditions or individual programs.

4.1.2 Source B Data

The storage data under Source B actually represents standby data in an orbiting satellite environment. No failures were indicated in 76 thousand gyro standby hours.

4.1.3 Source L Data

Source L represents a special test program for gyros designed for a surface-to-surface missile. Six gyros were stored in a controlled environment for 6.3 years with no failures reported.

4.1.4 Source M Data

The first entry in Table 4-1 under source M represents spacecraft platform gyros which are man-rated. These are the most expensive gyros in Table 4-1. The platforms stored in a controlled environment were retested once per year. None of the gyros have been outside of the operational specifications. Average age is 5.3 years.

The second entry under source M also represents spacecraft gyros. These gyros, stored under the same conditions, are man-rated, however they are used in a redundant configuration. One failure was reported as a result of a spin bearing seizure. Other failures attributed to damping fluid volume loss were not included since they were considered design defects.

4.1.5 Missile E-1 Data

Missile E-1 data consists of 874 missiles stored for 20 months. The missiles were stored in containers exposed to external environmental conditions in the northeast U. S. They were also transported once from coast to coast. Each missile contains five rate gyros. A total of twenty three gyro failures were reported.

4.1.6 Missile F Data

Missile F data consists of 120 missiles, 60 of which were stored for one year and 60 for two years. The missiles in storage containers experienced the following environments: 30 missiles stored outside in the Arctic on wooden racks with canvas covers; 30 missiles stored outside in the southeast desert under open sided metal roof sheds; 30 missiles stored outside in the canal zone under open sided metal roof sheds; and 30 missiles stored in the southeast U. S. in bunkers. No gyro failures have been reported.

4.1.7 Missile G Data

Missile G data consists of 39 missiles stored for periods from 28 months to 56 months for an average storage period of 39 months. The missiles in storage containers experienced the following environments: 12 missiles stored outside in the southeast desert; 12 missiles stored outside in the northeast U. S.; 12 missiles stored on the Gulf Coast; and 23 missiles stored in bunkers in the southeast U. S. No gyro failures have been reported.

4.1.8 Missile H Data

Missile H data represents field data from a recent army missile program fielded in the 1970's. The major item in which the devices were assembled was subjected to operating times at high and low temperatures, shock and vibration. The missiles were transported overseas and stored for various lengths of time. No tests were run until the missiles were removed from storage and returned to the states. Storage durations varied from 6 months to 6 years with an average time of 1.8 years. Storage environments included cannister time in a controlled environment, cannister time subject to outside elements and missile time on pallets and on launchers. A number of samples were also run through road tests under field conditions. Each missile containing five rate gyros. Thirteen gyro failures have been reported.

4.1.9 Missile I Data

Missile I data consists of 2,070 missiles stored for periods from 1 month to 40 months for an average storage period of 14 months. Approximately 80 percent of the missiles were stored in U. S. depots while the remainder were stored at various bases around the country. Ten gyro failures have been reported.

4.1.10 Missile M Data

Missile M data represents a surface-to-surface missile. Data was available on approximately 13 years of depot repair history. The data includes some operating time, typically 290 hours. Failure anlaysis was performed on these gyros indicating the main failure mode to be "open torquer windings."

4.1.11 Missile T Data

Missile T data represents a surface-to-air missile. Data on a 3000 missile inventory for an average of 5 years is included. At test, missile ages ranged from 6 months to 8 years. The missiles, built in the 1954 time frame, contained a gyro package with three rate gyros and one free gyro. The data indicated 128 gyro package failures. Periodic testing performed on the gyro packages was limited. It consisted of swinging the missile and observing gyro outputs for proper polarity. Only catastrophic failures could be seen, and these are identified only to the package level.

4.1.12 Missile U Data

Missile U data represents an air-to-surface missile. Data on 15 missiles stored for five years is included. Five missiles were stored for a year in a tropic zone and five in an arctic zone. No failures in the gyros themselves were reported, however, three failures in solder joints to gyro initiators were attributed to corrosion from heat, humidity and salt (tropic zone). Solder is chemically attacked under these conditions, and these failures are classified as a design defect.

4.2 Data Evaluation

Pooling all of the sources results in 209 failures in 835.019 million storage hours giving a failure rate of 250 fits. A decision was made to remove the data set for Missile T because failures were identified only at the platform level and may have been a result of other components. The remaining sources show 81 failures in 309.418 million storage hours giving a failure rate of 262 fits (virtually the same as with Missile T included).

The failure rates for those sources showing failures ranged from 121 to 524 fits. A test of significance (described in Appendix A) was performed to test whether a single failure could describe all the data sets. The test indicated that there was a significant difference with three data sets having signfiicantly higher failure rates. These three data sets were placed into a separate group. Then the two groups were tested and no significant differences were indicated. The pooled data for the two groups are shown in Table 4-2.

The group 1 data in Table 4-2 includes source A data for which little detail is available, however, at least a major portion is from the 1960's time frame. Missile E-1 is early 1960's program with the tests performed in 1968. Missile M is also late 50's and early 1960 technology. Therefore the data in group 1 primarily represents 1960 technology.

The group 2 data represents a wide range of applications. Sources B, M-1 and M-2 represent spacecraft programs while missile programs F and G represent mid to late 1960's technology and missiles H and I early 1970 technology. The lower failure rate for this group would tend to indicate an improvement in gyro design for storage reliability. Therefore, a non-operating failure rate for current technology gyros is estimated to be 133 fits and a 90% confidence that the time failure rate lies below 175 fits.

TABLE 4-2. POOLED DATA GROUPS

GROUP 1

SOURCE	NO. OF DEVICES	MILLION PART STORAGE HRS.	FAILURES	FAILURE RATE IN FITS
A	-	34.367	18	524.
Missile E-1	4370	63.802	23	360.
Missile M	-	30.6	16	523.
TOTALS		128.769	57	443.

GROUP 2

SOURCE	NO. OF DEVICES	MILLION PART STORAGE HRS.	FAILURES	FAILURE RATE IN FITS
B	15	.076	0	(<13158.)
L	6	.331	0	(<3021.)
M-1	-	4.44	0	(<225.)
M-2	-	3.94	1	254.
MISSILE				
F	120	2.628	0	(<380.)
G	39	1.118	0	(<894.)
H	5355	85.1	13	153.
I	8280	82.36	10	121.
U	15	.657	0	(<1522.)
TOTALS		180.65	24	133.

Nearly all of the data analyzed is for rate gyros. Free gyros with two, rather than one, sets of gimbal bearings should not exceed twice the failure rate as that calculated for rate gyros.

Field data has indicated that component replacement rates exceed component failure rates. This results from replacements for components accidentally damaged (overheating is a common cause) or replacements for components removed without test in the course of trying to repair a system. The data from Missile M indicated the replacement rate approached three times the failure rate.

4.3 Operational/Non-Operational Reliability Comparison

Operational failure rate data for rate gyroscopes was extracted from report RADC-TR-74-268, Revision of RADC Non-electronic Reliability Notebook, D, F. Cottrell, et al, Martin Marietta Aerospace, dated October 1974. This data is shown in Table 4-3 and compared with the non-operating failure rate prediction. Comparing the common environment (ground) indicates a non-operating to operating ratio of 1 : 196.

TABLE 4-3. OPERATIONAL/NON-OPERATIONAL RELIABILITY COMPARISON

ENVIRONMENT	PART HRS. (10^6)	NO. OF FAILURES	FAILURE RATE IN FITS	$\lambda_{op}/\lambda_{no}$
Non-operating				
Ground, Fixed	180.65	24	133	-
Operating				
Ground	1.269	33	26005	196.
Ground, Mobile	.012	3	333333	2506.
Airborne	14.56	5413	371798	2795.
Missile	.048	26	541667	4073.
Helicopter	.255	65	254902	1917.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

Data collected has primarily been for rate gyros. The demonstrated intrinsic storage failure rate for rate gyros is near 133 fits. Data indicates that the non-operating reliability of gyroscopes has improved in the last ten years. Substantially higher reliability for gyros is within the state of the art but only at a significantly higher expense. Novel techniques in development look promising from a reliability standpoint.

Areas identified which are important factors in gyro storage reliability are discussed below.

5.1 Spin bearing lubrication - One program has adopted a procedure of operating the gyro every 6 months while in storage, and has incorporated a spin detector so that rotation of the wheel can be verified easily. Some lubricants are more liable to separate than others, and selection of lubricant is important. Drying or oxidation are other concerns. The lubrication problem can be avoided entirely by using hydrodynamic spin bearings, which use the fill gas as a lubricant.

5.2 Creep due to temperature change - This effect appears because it is not possible to build the gyro from a single material - insulators, conductors, and magnetic materials are used. Storage at constant temperature is a possible solution.

5.3 Creep and dimensional change due to phase change - This effect can be thought of as a low temperature annealing process. Possibly material selection could be used to minimize the effect.

Both of the creep effects can be accommodated by rebalancing the gyro as needed.

5.4 Magnetic fields - Since the gyro contains magnetic material, the magnetic environment needs to be controlled also. Large fields will change the permanent magnetism, resulting in uncompensated torques. Mu-metal shields may be used in high precision designs.

5.5 Adhesion - A program using gas bearings reports adhesion due to high contact pressure when the gyro is stored undisturbed. The bearing materiel was a ferrous base, not ceramic. A possibility is to store gas wheel bearings with the wheel spinning (power on). Another is to turn the gyro over periodically.

Gimbal gas bearings could be mechanically supported in storage, which would also be desirable for shipping (shock and vibration).

5.6 Burn-in - An MIT paper (Ref. 7, p. 475) comments that "A test program ... (should be) made equal to 10 or 15 percent of Required Reliability Performance Life." No supporting data is given, but an artificial example is shown.

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Note: Inertial guidance is a fast-moving field. The current literature should be surveyed for recent developments. (This survey made January 1975.) Much of the literature is classified.

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