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RING LASER GYRO - A STATUS REPORT,(U)
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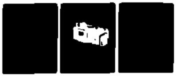

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RING LASER GYRO

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Space Sciences Meeting

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RING LASER GYRO - A STATUS REPORT

BY

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ABSTRACT

A general review of laser gyros is presented. Basic concepts of the gas ring laser will be reviewed. These will include the "lock-in" phenomena, geometric performance factors, and other problem areas. Various biasing methods to eliminate some of these basic problems will be presented. Salient features of the laser gyro which are unique for gyro instruments will be shown with data. Various laser gyro design parameters will be reviewed with respect to projected performance requirements for various applications.

In the early 1960's the demonstration of a large square laser gyro in the laboratory initiated a new technology. The ring laser potential as an inertial quality sensor was quickly demonstrated with gyroscopes of smaller sizes and since the unit was basically an electro-optical device, many advantages as compared to conventional sensors were cited. These include: no moving parts, rapid reaction, long lifetime, low cost of ownership, extremely wide rate range and inherently digital output.

As the state-of-the-art of mirror technology progressed, laser gyros of smaller sizes have been demonstrated until lasers as small as 6.8 cm perimeter have been operated as rate sensors. The family of Litton laser gyro at the present time is shown in Figure 1. The largest, 28 cm, gyro is suitable for high quality inertial navigation and the performance of the smaller gyros is more in the order of various attitude heading and reference application or missiles guidance and control. The performance goals of each of these instruments is shown in Table I.

Although the classical laser gyro, as described above, is planar in nature, the device can be out-of-plane. The only requirement for a ring laser to sense rotation is that the optically reentrant cavity must have a net projected area along some axis. A line drawing example of a square planar laser gyro is shown in Figure 2a; Figure 2b shows an example of an out-of-plane ring laser with four mirrors. The input axes of each is marked.

There are two basic types of active ring laser gyros. The first and most common utilizes two linearly polarized optical oscillators, each going in opposite directions around the cavity. These two oscillators have a difference frequency given by the standard formula

$\Delta V = \frac{4A}{\lambda P} \Omega$, where A is the projected area of the optical figure, P is the perimeter, λ is the wavelength of the light wave and Ω is the angular rotation rate.

TABLE I
TYPICAL LASER GYRO PARAMETERS

Parameter	A/C Nav	High Accuracy Missile	Medium Accuracy Missile	Low Accuracy Missile
Size, cu in.	50	25	16	3.4
Weight, lbs*	3.5	2.5	1.6	0.35
Long-term bias repeatability, deg/hr†	0.01	0.1	1.0	10.0
Random drift, deg/hr$^{\frac{1}{2}}$	0.003	0.01	0.5	5-50‡
Angular resolution, arc-sec	0.9	1.5	4	8
Long-term axis stability, arc-sec	5	15	15	50
Scale factor linearity, ppm	<5	<10	300	0.1%
Scale factor repeatability, ppm†	<5	<50	50	50
Reaction time from -65°F, sec	<0.1	<0.1	<0.1	<0.1
Power, watts	3	2	2	1.5
Angular rate, deg/sec	360	800	≥1000	≥3600
Linear g's	>50	100	>100	>100
Lifetime, operating hrs	15,000	15,000	>1000	TBD

*Instrument only

†Turnon-to-turnon

‡Unlocked

The second general type of ring laser has four optical oscillators, two going in each direction around the cavity. The oscillators are distinguished by different polarization states; e.g., right and left-handed circularly polarized. This type of gyro is represented in Figure 3.

Both of these types of ring lasers display various types of coupling phenomena which gives rise to errors. The best known of these is called "lock-in". This phenomenon causes the frequencies of the oscillators to entrain at low rotation rates and this causes the difference frequency to be zero. This phenomenon is counteracted by various nonreciprocal methods of biasing the optical frequencies differentially. These mechanizations may be mechanical, such as body dither, or may be magneto-optical such as Faraday effect.

In the multioscillator type of gyro polarization dependent reciprocal biases are used in conjunction with the nonreciprocal biases to additionally bias the optical oscillators. Heterodyne information is then processed to extract rotation information from the biases.

All of these various optical configurations and biasing methodologies have been investigated both experimentally and theoretically at Litton. The goal of this extensive design tradeoff study was to choose the best suited concepts for a high performance development program.

A portion of the tradeoff study was conducted to show geometry dependent advantages or disadvantages of body dithered gyros. The final result of this study was that a four-mirror square gyro was an optimum design. As an example, a square was compared to a triangle of equal scale factor and the study showed the following advantages:

1. Smaller volume due to optimized area to perimeter ratio
2. Lower lock-in due to the angle of incidence variation of scattered light
3. Easier fabrication in production due to square nature and rectilinear tooling
4. Increased tolerance to vibration and shock due to length, width and thickness aspect ratios
5. Lower angular momentum transmitted to the inertial system due to the lower inertia of the square.

Similar studies were done with respect to various bias mechanizations. The result of this program was a square body-dithered laser gyro. The inherently simple optical design combined with Litton ultralow scatter laser gyro mirrors allows this instrument to perform sufficiently for various strategic and tactical missile requirements as well as for aircraft navigation.

The Litton program has developed two major candidate laser gyros for the various guidance applications. The first is the LG-2717 missile gyro. This gyro is a 17.3 cm optical perimeter, 0.63 micron, body dithered laser gyro. The gyro, Figure 4, features completely self-contained electronics for ease of demonstration. Only 28 vdc power is required for operation. A performance summary of several of these instruments is shown in Table II. It should be noted that all this data is completely uncompensated. Four of the gyros were recently delivered to the Naval Weapons Center at China Lake, California, as part of the Alternate Source Phase I Interagency program.

TABLE II
LG-2717 RLG ATP TEST DATA

Bias

Gyro S/N	Avg Bias °/hr	Bias Repeat °/hr 1σ	Random Walk $^\circ/\sqrt{hr}$
5	-0.060	0.067	0.022
6	+0.212	0.021	0.008
7	-1.414	0.033	0.011
8	-0.113	0.049	0.0155
9	0.627	0.030	0.0037
10	-0.22	0.050	0.0098

Scale Factor

Gyro S/N	Avg SF $\widehat{\mathrm{Sec}}$/CT	SF Repeat PPM	SF Linearity PPM
5	2.998800	2.25	3.88
6	3.003184	6.79	3.23
7	3.001515	3.65	2.38
8	2.998588	4.47	5.75
9	2.9990705	2.18	4.59
10	3.003530	9.98	4.39

Tests include operation over temperature range of -40° to +88°C

Under the independent internal research and development program, three LG-2717 gyros were designed into a strapdown navigation system shown in Figure 5. This system, LN-90, was flown in a Litton company aircraft to demonstrate both laser gyro strapdown guidance and the performance potential of the 17 cm size gyro. The summary of these flights is shown in Figure 6. The nominal performance for the system is 1.2 nm/hr CEP.

A second major development program is the LG-2728, 28 cm laser gyro. This unit, Figure 7, is designed for aircraft navigation, cruise missiles and other high performance applications.

A summary of data of several prototype models of these gyros is shown in Table III. An example of a turn-on drift run of a typical 28 cm gyro is shown in Figure 8a. As can be seen, this data is basically 1 count limited. Each count is equal to 1.8 $\widehat{\text{sec}}$. The random drift is numerically calculated at 0.002°/hr$^{1/2}$. A typical scale factor measurement from one of the 28 cm gyros is shown in Figure 8b. The 1 sigma value from -250°/hr to +250°/hr is 0.26 ppm. This extreme linearity of scale factor is unique to a laser gyro. Typical high quality conventional mechanical gyros demonstrate about 50 ppm linearities. In addition, mechanical gyros typically also show scale factor asymmetry. It is this laser capability coupled with inherent simplicity and inherently high dynamic range that makes the gyro so attractive for various strapdown guidance applications.

TABLE III
28 cm GYRO PARAMETER DATA

Gyro #	Bias	Random Walk (°/hr$^{1/2}$)	Scale Factor Linearity (ppm)
56	0.020	0.0033	1.2
59	0.007	0.0029	0.2
61	0.08	0.0029	0.2
63	0.014	0.0023	1.4

A commercial version of the LG-2728 (designated LG-8028B) is used in the Litton LTN-90 Inertial Reference System which has recently been selected by Airbus Industries for the Airbus A-310 airliner as standard equipment. The LTN-90 is shown in Figure 9.

For strategic applications drift performance must be further improved. An example of the potential of a laser gyro drift rate is shown in Figure 10a. This data was taken with an uncased 28 cm gyro in a laboratory environment. This is a 15 hour data run. Again the count resolution limits the data at 100 second sample intervals. Consequently, the mean of the data was subtracted from the data set and a simple compensation to temperature was applied. The residuals of this operation are then summed with a 10 interval running lo-pass filter and shown in Figure 10b. The vertical scale of this plot represents heading error of the gyro in angle.

To demonstrate the angular resolution of a laser gyro, a simple experiment was run measuring the phase information of the heterodyne signal instead of just counting complete cycles. In this experiment a body-dithered gyro was sinusoidally angularly moved through a peak-to-peak range of about 1.1 $\widehat{\text{sec}}$ at approximately 2.5 Hz rate. This motion was in addition to the standard mechanical dither. This data is shown in Figure 11. A computer best fit to one of these cycles is typically 0.05 $\widehat{\text{sec}}$. This enhanced resolution can be utilized for faster alignments or better pointing accuracy.

In summary, the body-dithered laser gyros have shown a capability to perform the navigation and guidance function in many applications. As size and cost continue to drop, more applications will become feasible. This will include various missiles, aircraft and marine applications. As continued improvement occurs over the next decade and life characteristics are established, the cost of ownership will drop dramatically compared to present convention equipment, thus further enhancing the laser gyros future in inertial guidance.

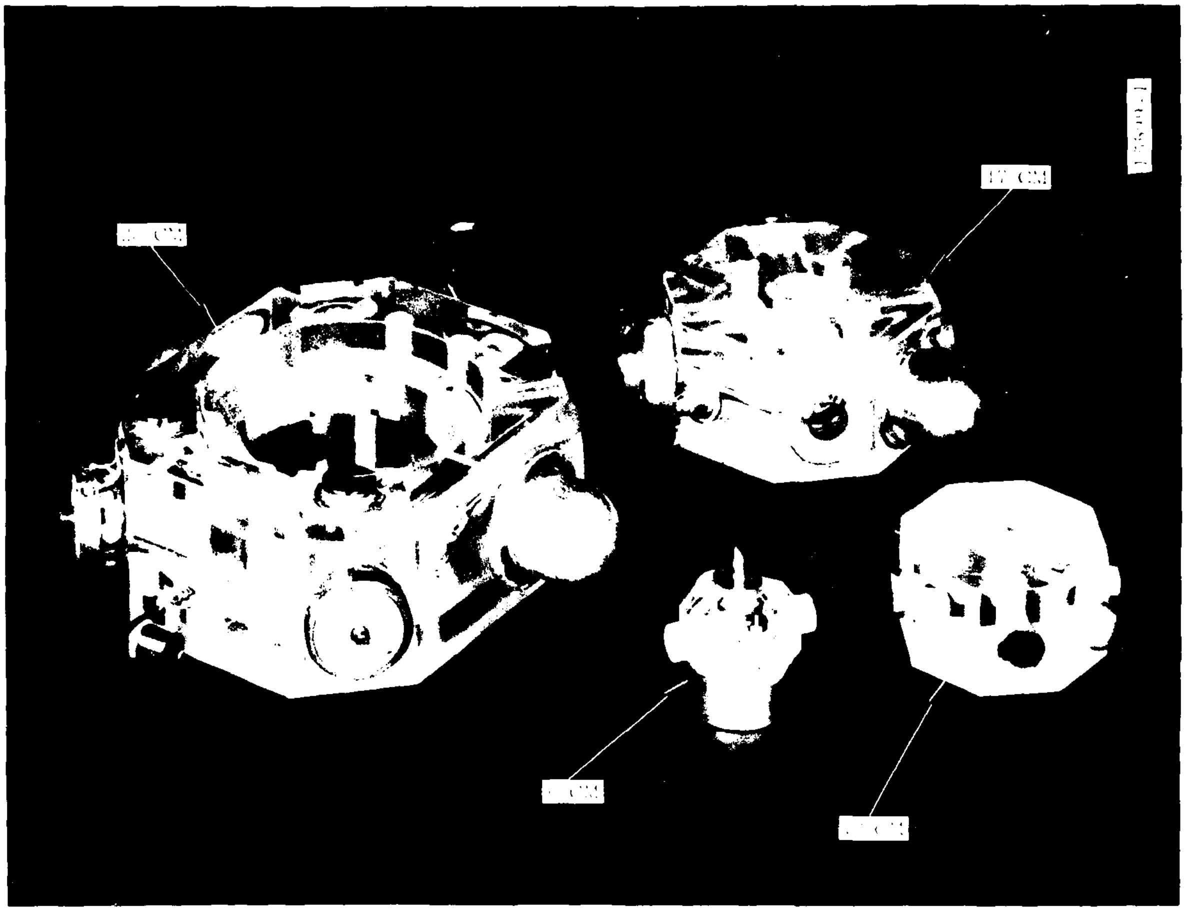

Figure 1. Litton Family Gyros

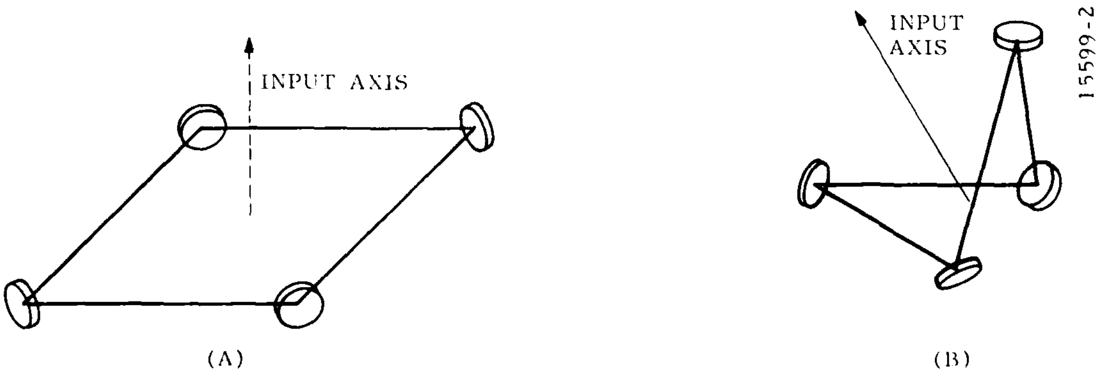

Figure 2. Line Drawings of Planar and Non-Planar Laser Gyros

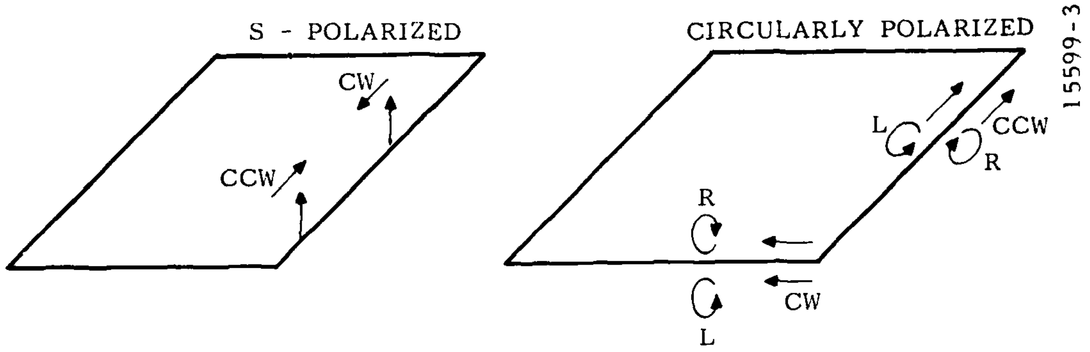

Figure 3. Linearly Polarized Gyro and Circularly Polarized Gyro

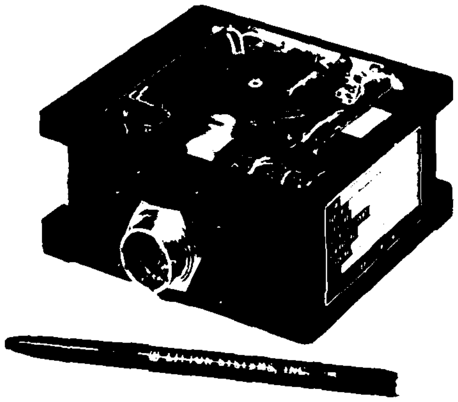

Figure 4. Litton 17 cm Laser Gyro, LG-2717

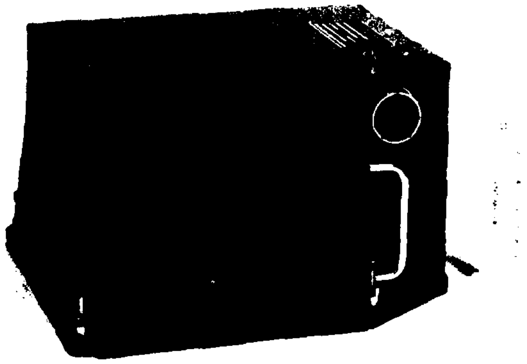

Figure 5. LN-90 Laser Gyro Strapdown System

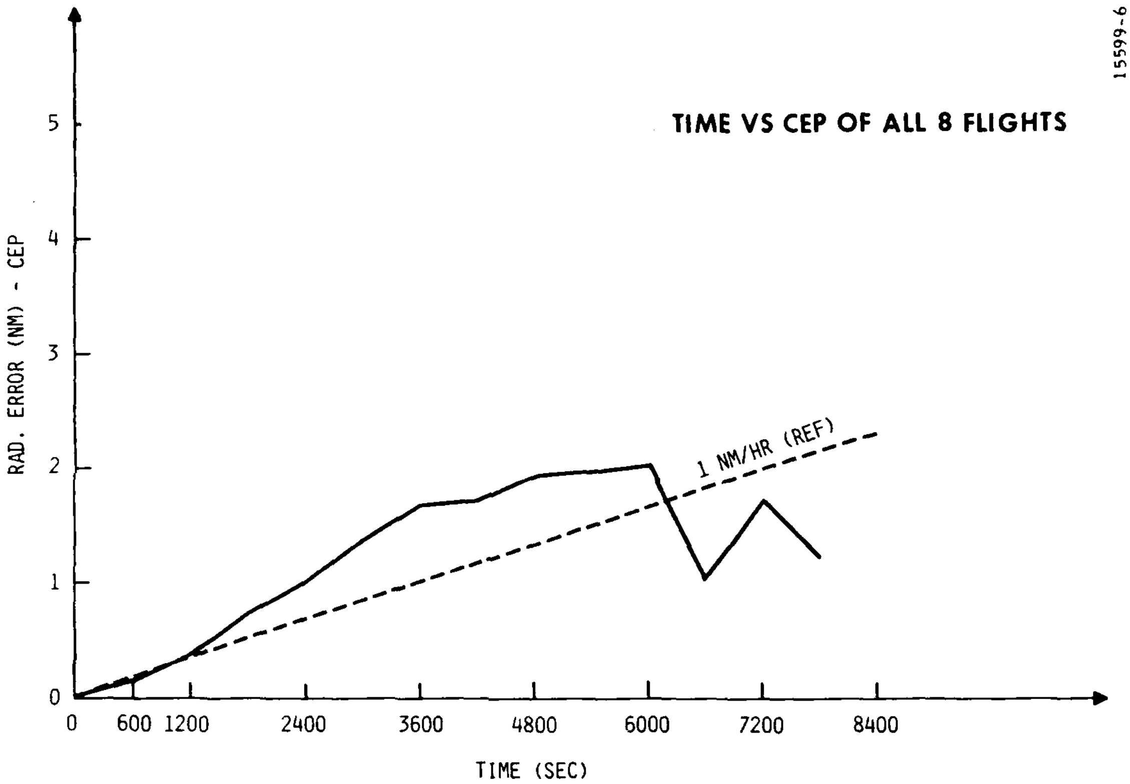

Figure 6. Summary of Test Flight of the Litton LN-90 System

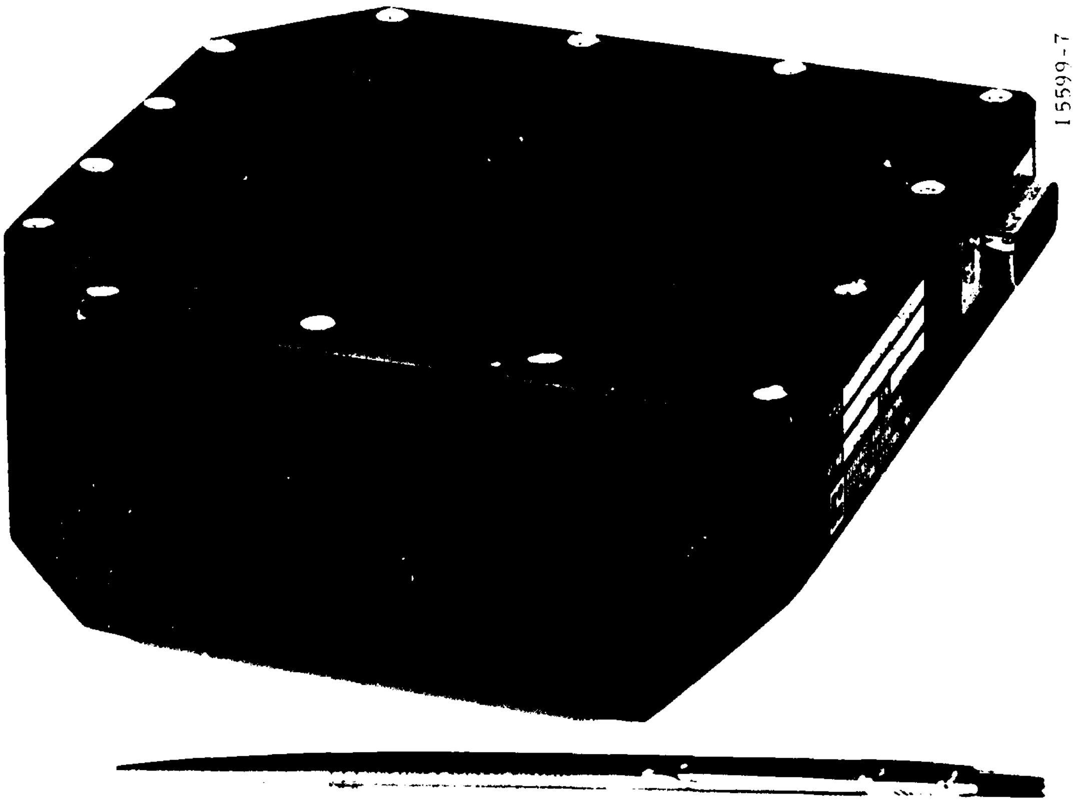

Figure 7. LG-2728 Aircraft Navigation Laser Gyro

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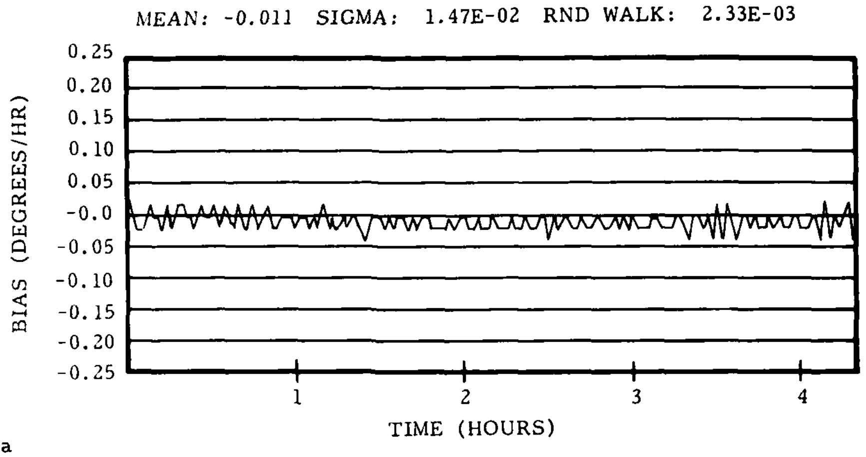
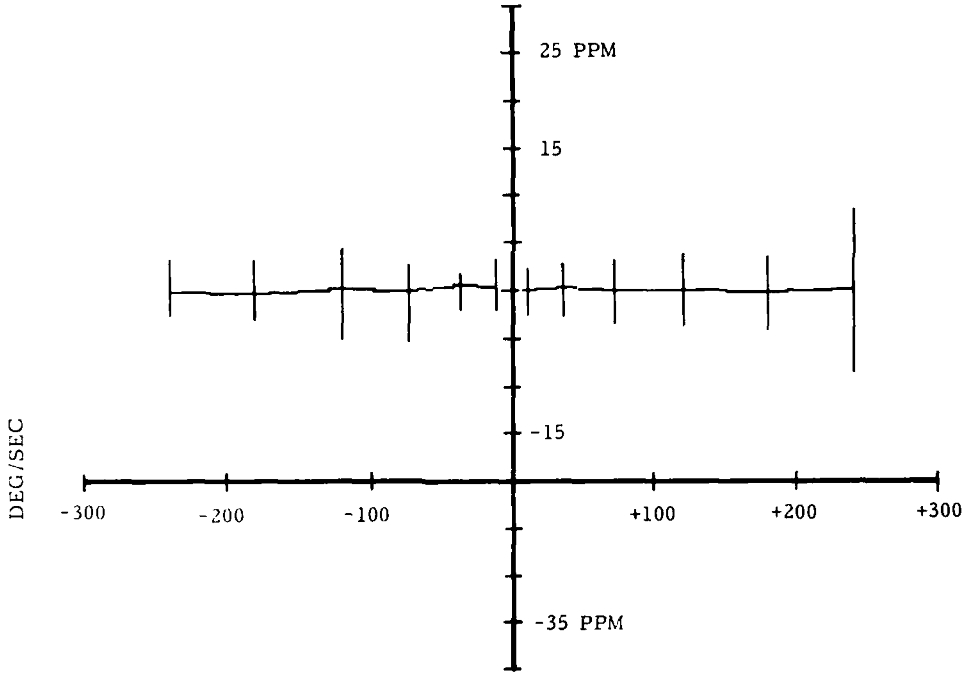


8a
DRIFT RUN



NOMINAL BIAS = 4.548616 CTS/SEC
K NOMINAL = 1.834867 ARCSEC/CT
MEAN K OF ALL RATES = 1.834867 ARCSEC/CT
MEAN PPM OF ALL RATES = 0.089171
MEAN PPM STD DEV = 0.261140

8b
SCALE FACTOR

Figure 8. Summary Data on Prototype Gyros

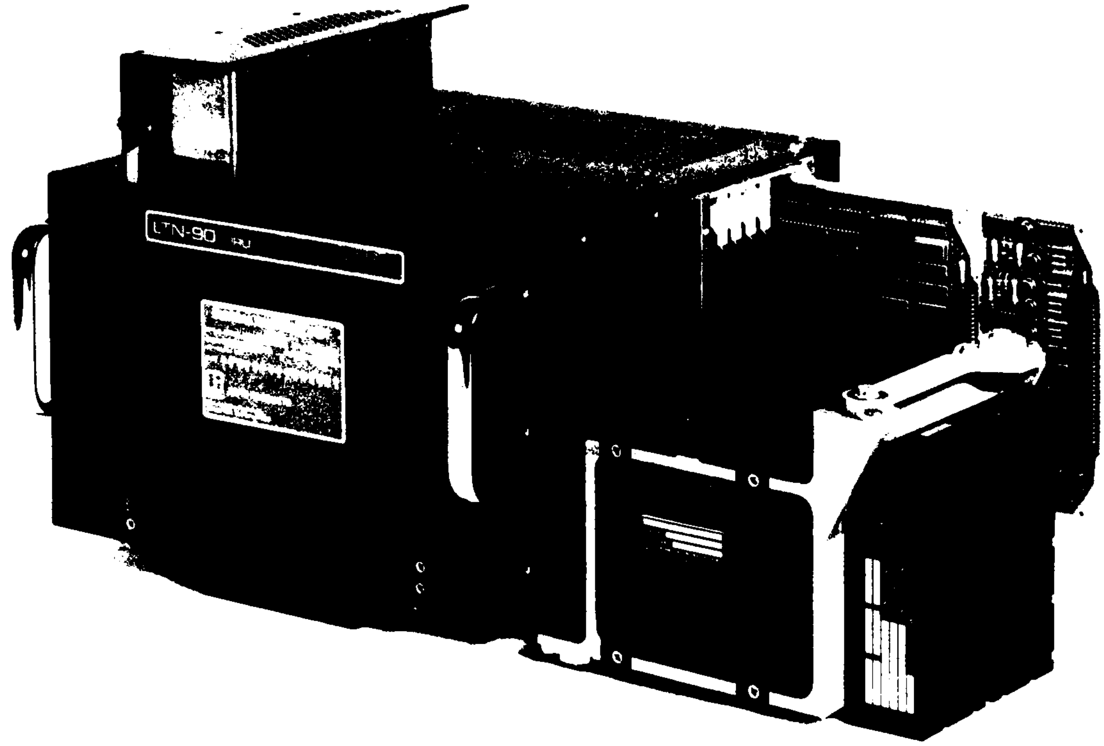


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Figure 9. Litton Aero Products LTN-90 System

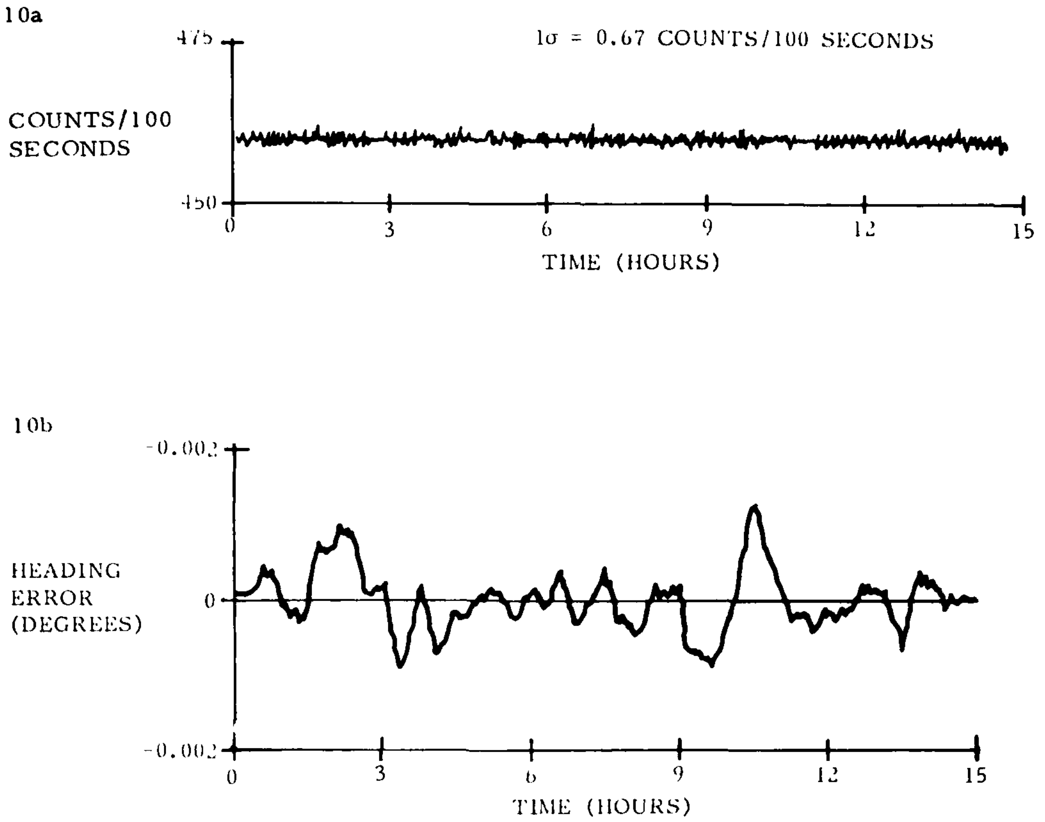

Figure 10. 28 cm Ring Laser Gyro Data

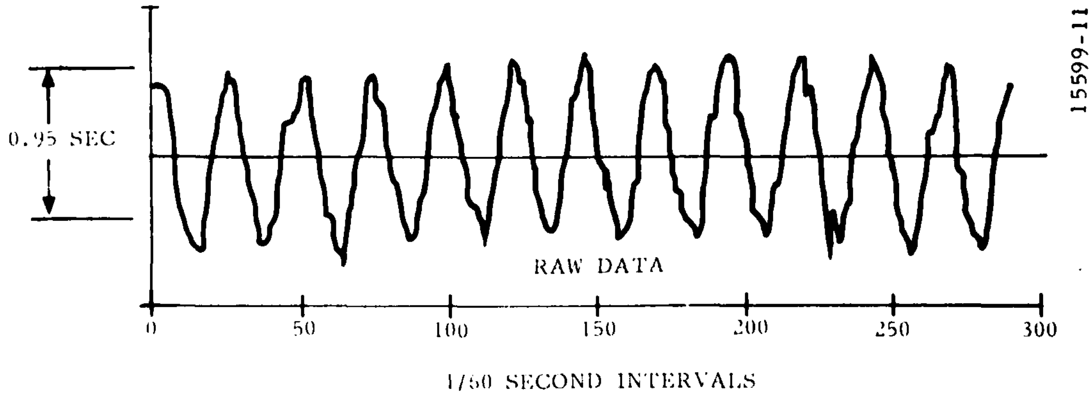

Figure 11. Angular Resolution of Laser Gyro