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A system that can measure the attitude of a spinning rocket when coupled with a laser radar tracker was investigated. The attitude sensing system consists of at least two ground based laser transmitter/detector stations which illuminate the rocket with continuous wave lasers as it moves downrange. Pulses that are reflected from two roof type prisms onboard the spinning vehicle back to the two transmitting stations along with position data obtained from the tracking laser radar form the basis for determining the missile's pitch and yaw. A static bench scale demonstration, a dynamic computer simulation and sensitivity analysis of →

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ABSTRACT (cont'd):

this concept all continue to support this system as a viable alternative to the current photographic technique for determining missile attitude.

UWME-DR-6051101

A LASER SYSTEM FOR DETERMINATION OF ROCKET ATTITUDE USING TWO GROUND STATIONS

Final Report

by

John E. Nydahl and Kynric M. Pell

December 1976

United States Army Research Office
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The concept investigated was developed by personnel at the University of Wyoming and the Aeroballistics Directorate of the United States Army Missile Command Research and Engineering Laboratories. Mr. Robert G. Conard's continuing interest and encouragement has provided a basis for the investigations, which we gratefully acknowledge.

Studies of the use of laser systems for attitude determination of flight vehicles have served as thesis topics for three Master's Degree candidates (Mr. Mark Russell, Mr. Kuen-Der Lain and Mr. Noriyuki Inagaki) over the past three years. We wish to acknowledge their efforts in the investigations described.

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Co-Principal Investigator

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INTRODUCTION

Measurement of vehicle dynamics during flight on test ranges has been approached using both ground-based and onboard instrumentation. Onboard platforms and accelerometers require telemetry systems or recorders resulting in relatively expensive instrumentation which must be considered expendable in most tests. Onboard solar aspect sensors have been developed for spinning missiles which can be used to infer yawing, pitching and rolling motion of flight vehicles. The most successful of these is the Yawsonde developed at the Ballistic Research Laboratories.[1,2] Many flight systems are tested using only ground-based instrumentation employing primarily photographic techniques. Data reduction in these cases is essentially all manual with attendant high cost and relatively long data reduction time.

During the past four years, two novel concepts for measurement of position and attitude have been investigated by the University of Wyoming in cooperation with the U.S. Army Missile Command. The first system investigated incorporated three ground-based laser transmitter/detector stations and expendable retroreflecting elements located on the vehicles. This concept was investigated in considerable detail and the results of the studies are presented in reference 3. Research in the past year has been directed at a simplified system which requires only two ground based stations. When compared to current ground-based photographic techniques for determining both position and attitude, this system offers several advantages including: lower recurring costs; improved accuracy; automated data reduction; and applicability in low ambient light situations and in situations where the trajectory of the vehicle is not well established prior to flight.

SYSTEM CONCEPT

The system includes two ground-based transmitter/detector tracking stations, each incorporating one pulsed and one continuous wave (CW) laser of different frequencies. On board the vehicle, two different types of retroreflecting arrays are required.

One type of array is composed of either conventional corner cubes, reflective tapes and or paints which have the property of retroreflecting a portion of the collimated incident beam back parallel to itself regardless of the orinetation of the reflective surface. This array forms a retroreflecting band located on the perimeter of the vehicle body at one axial position. Illumination of and reflection by this retroreflecting band will then form the basis for a conventional laser radar tracking system.

A series of roof type prisms as shown in Figure 1 form a second array which is also mounted on the vehicle's surface. This particular reflector array will be designated here the single plane corner reflector. A plane which passes through the center of all the reflecting surfaces of the roof type array and is also normal to all these surfaces will be called the retroreflection plane. Collimated light incident on the single plane corner reflector and contained in its retroreflection plane ($\beta = 90^{\circ}$) is reflected back to the source. Two of these single plane corner reflectors are mounted on the surface of the vehicle in such a manner that their retroreflection planes are skewed relative to each other and the roll axis of the vehicle. The mathematical analysis to follow will consider the special case where the retroreflection plane of one of the arrays contains the roll axis. An illustration of an instrumented vehicle is provided in Figure 2.

As the vehicle flies downrange, it is tracked with the laser radar for determining the vehicle position as a function of time while also positioning the CW laser to provide continuous CW illumination of the vehicle. During each revolution of the spinning vehicle, two CW laser pulses are returned to each of the two tracking stations. The time interval between the pulses returned to two separate tracking stations and between the two pulses returned to each station provide sufficient data for determination of the vehicle attitude. A mathematical description of this system is presented in the next section.

MATHEMATICAL DESCRIPTION OF A SYSTEM

In order to describe the system mathematically, two right-hand orthogonal coordinate systems are utilized: an earth-fixed cartesian system and a vehicle based cartesian system. The earth-fixed system is defined with the origin located at the launch site; positive Z-axis pointing in the vertical upward direction from the center of earth; positive Y-axis in the downrange direction; and positive X-axis in the crossrange direction. The vehicle based system is defined with the origin located at the vehicle center of gravity; ω-axis coinciding with the vehicle roll axis with the positive direction pointing toward the nose; η-axis orientated perpendicular to ω and parallel to the X-Y plane of the earth-fixed system; ξ-axis orientated perpendicular to η and ω with its positive direction such that η, ω, ξ form a right hand orthogonal system.

The components of the position vectors of the ith ground station and the vehicle in the earth-fixed system are X_i, Y_i, Z_i and X_m, Y_m, Z_m respectively. Using the well-known transformation between the

$$\begin{pmatrix} \eta_i \\ \omega_i \\ \xi_i \end{pmatrix} = \begin{pmatrix} \cos(\delta_2) & \sin(\delta_2) & 0 \\ \sin(\delta_1) & -\sin(\delta_2)\cos(\delta_1) & \cos(\delta_2)\cos(\delta_1) \\ \cos(\delta_1) & \sin(\delta_1)\sin(\delta_2) & -\sin(\delta_1)\cos(\delta_2) \end{pmatrix} \begin{pmatrix} X_i - X_m \\ Y_i - Y_m \\ Z_i - Z_m \end{pmatrix}$$

earth-fixed and vehicle-fixed systems one obtains the following relationships for the coordinates of the ground stations in the vehicle-fixed coordinates:

$$\eta_i = \cos(\delta_2)(X_i - X_m) - \sin(\delta_2)(Y_i - Y_m)$$

$$\omega_i = \sin(\delta_2)\cos(\delta_1)(X_i - X_m) + \cos(\delta_2)\cos(\delta_1)(Y_i - Y_m) + \sin(\delta_1)(Z_i - Z_m) \quad (1)$$

$$\xi_i = -\sin(\delta_2)\sin(\delta_1)(X_i - X_m) - \cos(\delta_2)\sin(\delta_1)(Y_i - Y_m) + \cos(\delta_1)(Z_i - Z_m)$$

where δ_1 and δ_2 represent pitch and yaw respectively. Pitch is defined here to be the angle between the X-Y plane and the ω axis whereas yaw is defined to be the angle between the YZ plane and the projection of the ω axis into the X-Y plane as shown in Figure 3 and 4.

(a) Time Relationship Between Return Pulses

To establish the time relationship between return pulses, we assume that the missile position, attitude and the roll rate do not change during the time interval between the pulse reception at the ground stations. Assume that at time t_1 there is a pulse returned to the first ground station from the skewed corner reflector as shown in Figures 5 through Figure 7. At this moment if the position vectors of ground station 1 and 2 are η_1, ω_1, ξ_1 and η_2, ω_2, ξ_2, then it can be observed that, with a constant roll rate Ω for the flight vehicle, the time interval for reception of a second pulse from the second single plane array at the same station is

$$\Delta t_{11} = \frac{1}{\Omega}[2\pi - (\alpha - \theta_S)] \tag{2}$$

The time interval between pulses returned from the first array to the two different ground stations is:

$$\Delta t_{21} = \frac{1}{\Omega}(\theta_1 - \theta_2) \tag{3}$$

In terms of $\eta\omega\xi$ coordinates, Eq. (2) can be written as

$$\Omega\Delta t_{11} = 2\pi - \alpha - \arcsin[\frac{\omega_1 \tan(\gamma)}{(\eta_1^2 + \xi_1^2)^{\frac{1}{2}}}] \tag{4}$$

and Eq. (3) may be written as

$$\Omega\Delta t_{21} = \arctan(\frac{\xi_1}{\eta_1}) - \arctan(\frac{\xi_2}{\eta_2}) \tag{5}$$

Substituting Eq. (1) into Eqs. (4) and (5), it may be seen that the right sides of Eqs. (4) and (5) are functions of only two unknowns, that is, pitch (δ_1) and yaw (δ_2). The relative positions are assumed to be known from tracking data. Since Δt_{11}, Δt_{21} and Ω can be determined using data from the C.W. laser system, Eqs. (4) and (5) can in principle be solved for the pitch and yaw, using, for example, the Newton-Raphson technique.

(b) Mathematical Approach for Simulation

The mathematical description presented in the previous section assumed that the vehicle was fixed in space, and that Ω, δ_1 and δ_2 did not vary during the time intervals Δt_{11} and Δt_{21}. In the situation that arises during an actual flight test not only is the vehicle position changing but also Ω, δ_1 and δ_2 may vary. One approach to data reduction of flight test data would be to analyze the data as though the vehicle did meet the assumptions described in the previous section recognizing that some error could be introduced due to the vehicle dynamics. In order to gain some insight into the errors in the pitch and yaw angles determined using the static analysis a computer simulation a rocket trajectory was developed. The simulation provides the missile position and attitude as a function of time as well as the time at which pulses would be received from the two retroreflectors at the two ground stations. For this study a six degree of freedom trajectory simulation originally developed by Harris[4], and later modified by Russell[3] was again modified. The program developed by Russell was used to study the three ground station laser concept mentioned previously. Only those additional modifications required to simulate the two ground station - two single plane retroreflector concept are described here.

In the original program, two right-hand orthogonal coordinate systems are defined: an earth-fixed coordinate system and a body-fixed coordinate system. The coordinate systems used in this thesis also include an earth-fixed and a body-fixed system, however, they are defined differently than the original systems. The relationships between the coordinates originally defined and those used in this analysis may be seen in Figure 8. The body-fixed coordinates are obtained by rotating the earth-fixed system through three angles, λ, μ, and ν as shown in Figure 9. Other information which is needed in the mathematical approach of the simulation includes the direction cosines. These are defined in Figure 10. Then we have, from Figure 11 through Figure 13.

$$\delta_1 = -\arcsin(\ell_3)$$
$$\delta_2 = \arctan\left(\frac{\ell_2}{\ell_1}\right) \tag{6}$$

To determine the values of pitch (δ_1) and yaw (δ_2) at the moment when stations have return pulses, it is necessary to define an angle which is called the corner reflector angle (CRA). Suppose at time $t \leq 0$ the skewed and straight corner reflectors are arranged on the rocket in the ηωξ coordinate system as shown in Figure 14. Imagine that the rocket is rotating in the clockwise direction. Then if at time = t', ground station 1 has a return pulse from the straight corner reflector, the rocket must be orientated in the ηωξ coordinates as shown in Figure 15. Considering this situation and referring to Figure 16 the corner reflector angle (CRA) can be defined as

$$\text{CRA} = \arctan\left(\frac{m_3}{n_3}\right) \tag{7}$$

However, at this moment, the orientation for the position vector of the station 1 in ηωξ coordinate system is

$$\theta_1 = \arctan(\frac{\xi_1}{\eta_1}) \quad (8)$$

This implies that the criteria to ensure pulses are returned from the straight corner reflector to station 1 is

$$\arctan(\frac{m_3}{n_3}) = \arctan(\frac{\xi_1}{\eta_1}) \quad (9)$$

This concept can also be extended to ground station 2. Therefore, we can put the criteria to have pulses returned from the straight corner reflector in the general form:

$$\arctan(\frac{m_3}{n_3}) = \arctan(\frac{\xi_i}{\eta_i}) \quad (10)$$

To get a condition that station 1 has the signal returned from the skewed corner reflector, assume that at time = t, the rocket is orientated in the $\eta\xi\omega$ coordinate system as shown in Figure 15 and that station 1 has a pulse reception. Then, from the geometry, we have

$$\alpha - \theta_S = CRA + \theta_1 \quad (11)$$

Where θ_1 can be expressed as

$$\theta_1 = \arcsin[\frac{\omega_1 \tan\gamma}{(\eta_1^2 + \xi_1^2)^{\frac{1}{2}}}] \quad (12)$$

From Eq. (7) through Eq. (12) we obtain

$$\alpha - \arcsin\left[\frac{\omega_1 \tan\gamma}{(\eta_1^2 + \xi_1^2)^{1/2}}\right]$$

$$= \arctan\left(\frac{m_3}{n_3}\right) + \arctan\left(\frac{\xi_1}{\eta_1}\right) \tag{13}$$

Eq. (13) is the criteria for pulse return at the station 1 from the skewed corner reflector. Similarly, for ith ground station to have pulses returned, the mathematical expression is the same as Eq. (13) except we replace 1 by i.

(c) Sensitivity Analysis

In the previous sections, when the equations for the returned pulses were set up to determine pitch and yaw, it was assumed that the missile position, attitude and roll rate did not change during the time intervals which were related to the actual reception of pulses at the two ground stations for the skewed and straight corner reflectors. As has been mentioned, the time intervals between returned pulses are influenced by the dynamic change of the missile position, attitude and roll rate. To determine the magnitude of the error which may be introduced by approximating the actual dynamic situation with a steady state model, we will define the following time intervals: Δt_{ii}^{o} is the observed time interval between the passing of the skewed and straight retroreflection planes through the ith ground station. Δt_{ii}^{n} is the corresponding time interval predicted by the steady state model where the actual kinematic state occurring at the first received pulse is taken as the steady kinematic state of the missile. Δt_{ij}^{o} is the observed time interval between the passing of the straight retroreflection plane through the ith and jth ground stations. Δt^n_{ij} is the corresponding time interval predicted by the steady state model where the mean position, mean pitch and yaw, and mean roll rate occurring between the two pulse times are used as the steady kinematic state of the missile.

If the differences between the observed time intervals (Δt^o_{ij} and Δt^o_{ii}) and the corresponding time intervals predicted from the steady state model (Δt^n_{ij} and Δt^n_{ii}) are small, a linear variation between the two sets of time intervals in terms of kinematic differences may be appropriate. If this be the case, then the maximum error generated by the steady state model is approximately

$$\Delta t^o_{ii} - \Delta t^n_{ii} \leq [\sum_K (\frac{\partial \Delta t^n_{ii}}{\partial \phi_K})^2_{t_1} (\phi_{K,t_1} - \phi_{K,t_2})^2]^{\frac{1}{2}} \tag{14}$$

$$\Delta t^o_{ij} - \Delta t^n_{ij} \leq [\sum_K (\frac{\partial \Delta t^n_{ij}}{\partial \phi_K})^2_{t_n} (\phi_{K,t_2} - \phi_{K,n})^2]^{\frac{1}{2}} \tag{15}$$

where t_1 and t_2 designate the time when the ith ground station has the actual pulse reception, ϕ_{K,t_i} represents the kth kinematic parameter evaluated at time t_i, and $\phi_{K,n}$ represents the mean value of the kinematic parameter related to Δt^n_{ij}. The terms $(\frac{\partial \Delta t^n_{ii}}{\partial \phi_K})_{t_i}$ and $(\frac{\partial \Delta t^n_{ij}}{\partial \phi_K})_{t_n}$ are the sensitivities of the time intervals Δt^n_{ii} and Δt^n_{ij}. The parameter ϕ_K includes variables δ_1, δ_2, Ω_K, X_m, Y_m and Z_m. The various sensitivities are classified into two categories for the skewed relfector and the straight reflector.

(1) <u>The Skewed System</u>

The various sensitivities for this system are pitch, yaw, altitude, range, crossrange, and roll rate. Mathematically they correspond to $\frac{\partial \Delta t_{ii}}{\partial \delta_1}$, $\frac{\partial \Delta t_{ii}}{\partial \delta_2}$, $\frac{\partial \Delta t_{ii}}{\partial Z_m}$, $\frac{\partial \Delta t_{ii}}{\partial Y_m}$, $\frac{\partial \Delta t_{ii}}{\partial X_m}$ and $\frac{\partial \Delta t_{ii}}{\partial \Omega}$ respectively. Thus, if we use Eq. (4) and the parameter P_K to denote the variables δ_1, δ_2,

X_m, Y_m, and Z_m. We obtain

$$\frac{\partial \Delta t_{ii}}{\partial P_K} = \frac{\tan\gamma\left[\frac{\omega_i}{\eta_i^2 + \xi_i^2}\left(\eta_i \frac{\partial \eta_i}{\partial P_K} + \xi_i \frac{\partial \xi_i}{\partial P_K}\right) - \frac{\partial \omega_i}{\partial P_K}\right]}{\Omega(\eta_i^2 + \xi_i^2 - \omega_i^2 \tan^2\gamma)^{1/2}} \tag{16}$$

and

$$\frac{\partial \Delta t_{ii}}{\partial \Omega} = \frac{1}{\Omega^2}\left\{\alpha + \arcsin\left[\frac{\omega_i \tan\gamma}{(\eta_i^2 + \xi_i^2)^{1/2}}\right] - 2\pi\right\} \tag{17}$$

(2) The Straight System

The various sensitivities in this system have the same notation as in the skewed system except we replace Δt_{ii} by Δt_{ij}. If P_K indicates the variables δ_1, δ_2, X_m, Y_m, Z_m, then, from Eq. (5), the sensitivities are as follows:

$$\frac{\partial \Delta t_{ij}}{\partial P_K} = \frac{1}{\Omega}\left\{\left[\frac{\eta_j \frac{\partial \xi_j}{\partial P_K} - \xi_j \frac{\partial \eta_j}{\partial P_K}}{\eta_j^2 + \xi_j^2}\right] - \left[\frac{\eta_i \frac{\partial \xi_i}{\partial P_K} - \xi_i \frac{\partial \eta_i}{\partial P_K}}{\eta_i^2 + \xi_i^2}\right]\right\} \tag{18}$$

and

$$\frac{\partial \Delta t_{ij}}{\partial \Omega} = \frac{1}{\Omega^2}\left[\arctan\left(\frac{\xi_i}{\eta_i}\right) - \arctan\left(\frac{\xi_j}{\eta_j}\right)\right] \tag{19}$$

The expressions for the sensitivities can be rewritten using equations (1) and the expressions presented below:

$$\frac{\partial \eta_i}{\partial \delta_i} = 0 \tag{20}$$

$$\frac{\partial n_i}{\partial \delta_2} = -(X_i - X_m)\sin(\delta_2)-(Y_i - Y_m)\cos(\delta_2) \tag{21}$$

$$\frac{\partial \xi_i}{\partial \delta_1} = -(X_i - X_m)\sin(\delta_2)\cos(\delta_1)-(Y_i - Y_m)\cos(\delta_2)\cos(\delta_1)$$

$$-(Z_i - Z_m)\sin(\delta_1) \tag{22}$$

$$\frac{\partial \xi_i}{\partial \delta_2} = -(X_i - X_m)\cos(\delta_2)\sin(\delta_1)+(Y_i - Y_m)\sin(\delta_2)\sin(\delta_1) \tag{23}$$

$$\frac{\partial \omega_i}{\partial \delta_1} = -(X_i - X_m)\sin(\delta_2)\sin(\delta_1)-(Y_i - Y_m)\cos(\delta_2)\sin(\delta_1)$$

$$+ (Z_i - Z_m)\cos(\delta_2) \tag{24}$$

$$\frac{\partial \omega_i}{\partial \delta_2} = (X_i - X_m)\cos(\delta_2)\cos(\delta_1)-(Y_i - Y_m)\sin(\delta_2)\cos(\delta_1) \tag{25}$$

$$\frac{\partial n_i}{\partial X_m} = -\cos(\delta_2) \tag{26}$$

$$\frac{\partial n_i}{\partial Y_m} = \sin(\delta_2) \tag{27}$$

$$\frac{\partial n_i}{\partial Z_m} = 0 \tag{28}$$

$$\frac{\partial \xi_i}{\partial X_m} = \sin(\delta_2)\sin(\delta_1) \tag{29}$$

$$\frac{\partial \xi_i}{\partial Y_m} = \cos(\delta_2)\sin(\delta_1) \tag{30}$$

$$\frac{\partial \xi_i}{\partial Z_m} = -\cos(\delta_1) \tag{31}$$

$$\frac{\partial \omega_i}{\partial X_m} = -\sin(\delta_2)\cos(\delta_1) \tag{32}$$

$$\frac{\partial \omega_i}{\partial Y_m} = -\cos(\delta_2)\cos(\delta_1) \tag{33}$$

$$\frac{\partial \omega_i}{\partial Z_m} = -\sin(\delta_1) \tag{34}$$

(d) Error Analysis

One approach to the data reduction would be to analyze the data as though the vehicle were fixed in space, with a fixed attitude (pitch and yaw) and a constant roll rate. The effect of vehicle dynamics would be to introduce an error into the values of pitch and yaw calculated from the measured time intervals. In order to obtain an estimate of the magnitude of the error that could be introduced through this mechanism and also provide some insight with respect to which parameters play a dominant role in contributing to this error, the six degree of freedom simulation was exercised. The two ground stations were assumed to be located at 3000, 0, 0 and 3000, 2000, 0. Parameters for the geometry of the skewed retroreflectors which had to be preassigned included α, the circumferential angle, and γ, the inclination. Values of 60° and 15° were chosen for the respective quantities.

The output from the simulation run included:

a) For pulses retroreflected from the straight reflector

1. The time of pulse reception at ground station

number 1. (TIME1)

2. The time of pulse reception at ground station number 2. (TIME2)

3. The time difference between pulse reception at the two stations. (DTIME12)

4. The time difference between DTIME12 and the nominal time interval Δt_{ij}^{n}. (DTMF12)

5. The missile position midway between the positions at the time of pulse receptions. (XM, YM, ZM)

6. The average values of pitch, yaw and roll rate during the time interval DTIME12. (PITCH, YAW, ROLL).

7. The difference in the average and the extreme values for missile position during the interval DTIME12. (DXM, DYM, DZM)

8. The difference between the average and the extreme values of pitch, yaw and roll rate during the interval DTIME12. (DPITCH, DYAW, DROLL)

9. The sensitivity of the time interval to: Pitch, yaw, crossrange, altitude and a time midway between TIME1 and TIME2. (PITCH, YAWS, CROS, RANS, ALTS, ROLLS)

b) For pulse retroreflected from the skewed reflector

1. The ground station receiving the return pulse. (GSNO)

2. The time at which a pulse is received at a particular station. (TIMES)

3. Geometry related parameters described in the previous list.

These results are presented in tabular form in the following section.

RESULTS

The six degree of freedom trajectory simulation was given the mass and aerodynamic properties of a tactical rocket (ARROW) recently tested at the U.S. army missile command. This vehicle was selected as representative of the type of vehicle for which a laser system might be used in a flight test program. Information which was derived from the simulation included:

1. Pulse reception time at the two ground stations from the two retroreflectors.
2. Vehicle attitude, roll rate and position at the time of each pulse reception.

This information was then used in a Newton-Raphson solution of Eqs. (4) and (5) to provide calculated values of pitch (δ_1) and yaw (δ_2). It should be noted that average values of the geometric parameters were used in this solution which introduces the errors due to vehicle dynamics discussed previously. The pitch and yaw values obtained in this manner are presented in Table 1 where the values obtained from the simulation as well as the difference between the simulation and calculated results are also tabulated for comparison.

The maximum difference between the simulation result and the calculated pitch is 0.81°, with an average difference of 0.15°, and a most probable difference of 0.03°. It is interesting to note that this

TABLE 1 COMPARISION OF PITCH AND YAW FROM CALCULATION AND SIMULATION

TIMES	.19830E-01	.13752E 00	.25177E 00	.35914E 00	.45632E 00	.54073E 00
XM	-.11239E-18	-.14002E-02	-.12653E-01	-.34952E-01	-.73794E-01	-.13647E 00
YM	.10138E 00	.10430E 02	.41971E 02	.92338E 02	.15686E 03	.22783E 03
ZM	.53132E-02	.49519E 00	.17328E 01	.35799E 01	.57697E 01	.78891E 01
PITCH(S)	.30000E 01	.30024E 01	.27491E 01	.25245E 01	.17272E 01	.12594E 01
PITCH(C)	.30100E 01	.29741E 01	.26255E 01	.18582E 01	.12836E 01	.13908E 01
YAW(S)	-.40712E-16	.84885E-04	-.17904E-02	-.25100E-01	-.77917E-01	-.99320E-01
YAW(C)	.26030E-01	.20716E-01	.98488E-02	-.10478E 00	-.19879E 00	-.74494E-01
DPIT	.99915E-02	.28244E-01	.32358E 00	.66627E 00	.44368E 00	.13242E 00
DYA	.26030E-01	.20831E-01	.11639E-01	.79682E-01	.12087E 00	.25026E-01

TABLE 1 COMPARISION OF PITCH AND YAW FROM CALCULATION AND SIMULATION
(CONTINUED)

(CONTINUOUS)

TIMES	.61226E 00	.67279E 00	.72451E 00	.76925E 00	.80847E 00	.84327E 00
XM	-.21547E 00	-.29526E 00	-.36996E 00	-.44303E 00	-.51747E 00	-.59250E 00
YM	.29806E 03	.36441E 03	.42589E 03	.48255E 03	.53489E 03	.58341E 03
ZM	.97233E 01	.11317E 02	.12721E 02	.13951E 02	.15023E 02	.15967E 02
PITCH(S)	.14373E 01	.15655E 01	.13217E 01	.10544E 01	.10089E 01	.11072E 01
PITCH(C)	.15728E 01	.13737E 01	.10849E 01	.10025E 01	.10897E 01	.11726E 01
YAW(S)	-.53718E-01	-.30627E-01	-.75706E-01	-.12213E 00	-.11662E 00	-.76922E-01
YAW(C)	.65393E-02	-.11070E 00	-.20804E 00	-.16385E 00	-.68448E-01	-.28744E-01
DPIT	.13551E 00	.19177E 00	.23687E 00	.51981E-01	.80825E-01	.65319E-01
DYA	.60259E-01	.80077E-01	.13233E 00	.41724E-01	.48175E-01	.47974E-01

TABLE 1 COMPARISION OF PITCH AND YAW FROM CALCULATION AND SIMULATION
(CONTINUED)

(CONTINUOUS)

TIMES	.87449E 00	.90278E 00	.92865E 00	.95248E 00	.97456E 00	.99515E 00
XM	-.66575E 00	-.73574E 00	-.80247E 00	-.86685E 00	-.93004E 00	-.99300E 00
YM	.62857E 03	.67081E 03	.71052E 03	.74801E 03	.78354E 03	.81731E 03
ZM	.16811E 02	.17575E 02	.18275E 02	.18919E 02	.19513E 02	.20062E 02
PITCH(S)	.11771E 01	.11382E 01	.10220E 01	.90344E 00	.83748E 00	.83543E 00
PITCH(C)	.11511E 01	.10425E 01	.91977E 00	.84367E 00	.83242E 00	.86705E 00
YAW(S)	-.50258E-01	-.62055E-01	-.10214E 00	-.14197E 00	-.15776E 00	-.14434E 00
YAW(C)	-.55407E-01	-.13623E 00	-.19008E 00	-.19936E 00	-.16759E 00	-.11780E 00
DPIT	.25985E-01	.95672E-01	.10222E 00	.59778E-01	.50674E-02	.31616E-01
DYA	.15149E-01	.74180E-01	.87945E-01	.57391E-01	.96341E-02	.26539E-01

TABLE 1 COMPARISION OF PITCH AND YAW FROM CALCULATION AND SIMULATION
(CONTINUED)

(CONTINUOUS)

TIMES	.10144E 01	.10326E 01	.10497E 01	.10659E 01	.10813E 01	.10961E 01
XM	-.10563E 01	-.11200E 01	-.11839E 01	-.12473E 01	-.13094E 01	-.13692E 01
YM	.84951E 03	.88030E 03	.90281E 03	.93918E 03	.96549E 03	.99145E 03
ZM	.20572E 02	.21048E 02	.21492E 02	.21708E 02	.22301E 02	.22573E 02
PITCH(S)	.87425E 00	.91359E 00	.93980E 00	.92524E 00	.87841E 00	.81357E 00
PITCH(C)	.91266E 00	.93869E 00	.92977E 00	.88721E 00	.82411E 00	.75332E 00
YAW(S)	-.11237E 00	-.81328E-01	-.67950E-01	-.79748E-01	-.11318E 00	-.15623E 00
YAW(C)	-.76061E-01	-.60380E-01	-.76373E-01	-.11822E 00	-.17143E 00	-.21457E 00
DPIT	.38410E-01	.20102E-01	.10034E-01	.38026E-01	.54279E-01	.55350E-01
DYA	.36326E-01	.20748E-01	.84231E-02	.38473E-01	.58304E-01	.62638E-01

TABLE 1 COMPARISION OF PITCH AND YAW FROM CALCULATION AND SIMULATION
(CONTINUED)

(CONTINUOUS)

TIMES	.11101E 01	.11236E 01	.11366E 01	.11491E 01	.11612E 01	.11729E 01
XM	-.14260E 01	-.14798E 01	-.15312E 01	-.15818E 01	-.16336E 01	-.16391E 01
YM	.10173E 04	.10421E 04	.10661E 04	.10894E 04	.11122E 04	.11344E 04
ZM	.23029E 02	.23368E 02	.23697E 02	.24014E 02	.24321E 02	.24616E 02
PITCH(S)	.74895E 00	.69991E 00	.67611E 00	.67987E 00	.70698E 00	.74779E 00
PITCH(C)	.70613E 00	.67817E 00	.67787E 00	.70180E 00	.74133E 00	.78428E 00
YAW(S)	-.19357E 00	-.21185E 00	-.20385E 00	-.17060E 00	-.12117E 00	-.70526E-01
YAW(C)	-.24501E 00	-.24093E 00	-.20598E 00	-.14322E 00	-.82167E-01	-.26087E-01
DPIT	.42833E-01	.21742E-01	.17591E-02	.21930E-01	.34450E-01	.36779E-01
DYA	.51431E-01	.29079E-01	.21310E-02	.22380E-01	.39006E-01	.44436E-01

TABLE 1 COMPARISION OF PITCH AND YAW FROM CALCULATION AND SIMULATION
(CONTINUED)

(CONTINUOUS)

TIMES	.11842E 01	.11952E 01	.12059E 01	.12163E 01	.12265E 01	.12364E 01
XM	-.17503E 01	-.18180E 01	-.18912E 01	-.19668E 01	-.20390E 01	-.21004E 01
YM	.11561E 04	.11774E 04	.11982E 04	.12196E 04	.12396E 04	.12582E 04
ZM	.24898E 02	.25165E 02	.25416E 02	.25650E 02	.25868E 02	.26073E 02
PITCH(S)	.79110E 00	.82419E 00	.83619E 00	.81873E 00	.76722E 00	.68161E 00
PITCH(C)	.82010E 00	.83575E 00	.82307E 00	.77685E 00	.69628E 00	.58603E 00
YAW(S)	-.35872E-01	-.32414E-01	-.69302E-01	-.14654E 00	-.25302E 00	-.36688E 00
YAW(C)	.14782E-02	-.14239E-01	-.80776E-01	-.19527E 00	-.34245E 00	-.49414E 00
DPIT	.29001E-01	.11564E-01	.13115E-01	.41871E-01	.70936E-01	.95574E-01
DYA	.37351E-01	.18176E-01	.11474E-01	.48724E-01	.89431E-01	.12726E 00

TABLE 1 COMPARISION OF PITCH AND YAW FROM CALCULATION AND SIMULATION
(CONTINUED)

(CONTINUOUS)						
TIMES	.12460E 01	.12555E 01	.12647E 01	.12737E 01	.12826E 01	.12912E 01
XM	-.21429E 01	-.21598E 01	-.21489E 01	-.21152E 01	-.20746E 01	-.20569E 01
YM	.12775E 04	.12965E 04	.13151E 04	.13335E 04	.13515E 04	.13693E 04
ZM	.26270E 02	.26468E 02	.26640E 02	.26919E 02	.27194E 02	.27527E 02
PITCH(S)	.55742E 00	.43686E 00	.31024E 00	.22681E 00	.19499E 00	.29045E 00
PITCH(C)	.45734E 00	.32716E 00	.22925E 00	.19436E 00	.26890E 00	.50170E 00
YAW(S)	-.45759E 00	-.48986E 00	-.43056E 00	-.25596E 00	.38641E-01	.42993E 00
YAW(C)	-.61097E 00	-.64641E 00	-.55512E 00	-.30213E 00	.12443E 00	.70251E 00
DPIT	.11009E 00	.10770E 00	.80994E-01	.22451E-01	.73912E-01	.21125E 00
DYA	.15338E 00	.15655E 00	.12456E 00	.46167E-01	.85791E-01	.27358E 00

TABLE 1 COMPARISION OF PITCH AND YAW FROM CALCULATION AND SIMULATION
(CONTINUED)

(CONTINUOUS)

TIMES	.12997E 01	.13080E 01	.13161E 01	.13241E 01	.13319E 01	.13396E 01
XM	-.21063E 01	-.22789E 01	-.26357E 01	-.31242E 01	-.40508E 01	-.50354E 01
YM	.13868E 04	.14040E 04	.14210E 04	.14377E 04	.14542E 04	.14704E 04
ZM	.27904E 02	.28307E 02	.28637E 02	.28947E 02	.28947E 02	.28478E 02
PITCH(S)	.55153E 00	.10183E 01	.17085E 01	.25841E 01	.35187E 01	.42408E 01
PITCH(C)	.93491E 00	.15909E 01	.24465E 01	.33963E 01	.42019E 01	.44160E 01
YAW(S)	.85230E 00	.11998E 01	.13105E 01	.97706E 00	-.41649E-01	-.19837E 01
YAW(C)	.13524E 01	.19847E 01	.23888E 01	.23209E 01	.13915E 01	-.10313E 01
DPIT	.39328E 00	.57216E 00	.73798E 00	.81218E 00	.68319E 00	.17528E 00
DYA	.51009E 00	.78492E 00	.10783E 01	.13438E 01	.14332E 01	.95242E 00

difference, or pitch error, is distributed along the downrange direction with a maximum at the two extremes and a minimum near midrange. (see Figure 17)

The maximum difference between the simulation result and the calculated yaw is 1.44° whereas the average difference is 0.18°. The most probable error is 0.04°. Referring to Figure 17 it may be seen that the yaw error is also range sensitive. In contrast to the pitch error distribution which shows a degradation in performance at each end of the range shown, the yaw error is large only at the extreme downrange positions. In order to investigate the sources of these errors the sensitivity analysis described in the previous chapter was initiated. The simulation was again used to generate the pulse reception times for the two reflectors and two ground stations. In addition the program was modified to calculate and print out the various sensitivities and perturbation terms. As described in the previous discussion the calculations were done in two groups that is for the straight retroreflector with pulse reception at two different stations and for the skewed retroreflector system with pulse reception from the straight and skewed retroreflectors at the same station. The results are presented in Table 2 and 3 respectively. By multiplying the listed sensitivities by the appropriate perturbation terms the influence of each of the parameters on the time interval Δt_{ii} or Δt_{ij} may be obtained. The results of this operation are presented in abbreviated form in Table 4. In the interests of clarity only the order of magnitude of the parameters is indicated. It is immediately apparent that the error introduced by roll dynamics dominates the errors in Δt_{11}. On the other hand roll, position (range) and pitch dynamics all contribute to the errors in Δt_{12} in a substantial way. Relative magnitudes of the yaw and pitch contribution to the Δt errors may be thought of as yaw/pitch coupling in the Δt equation (Eqs. (4) and (5)). The Δt_{12} equation is weakly coupled to yaw throughout the first 1000 ft of flight and thereafter the magnitude of the pitch and yaw contributions become comparable. On the other hand the Δt_{11} equation is weakly coupled to pitch beyond 1000 feet and at ranges less than 1000 feet the pitch and yaw terms are comparable. A general observation which appears to hold for every parameter tabulated is the fact that the influence on the associated Δt is strongest at the shortest ranges and longest ranges with a minimum in the region of 1000 feet.

TABLE 2 VARIATIONS AND SENSITIVITIES OF STRAIGHT SYSTEM

TIME1	.11808E 00	.23317E 00	.34199E 00	.44116E 00	.52784E 00	.60145E 00
TIME2	.11873E 00	.23379E 00	.34249E 00	.44143E 00	.52803E 00	.60162E 00
DTIMF12	.64932E-03	.61920E-03	.50781E-03	.32030E-03	.18972E-03	.17373E-03
DTMF12	-.32228E-06	-.41460E-06	-.67683E-06	-.53011E-06	-.10902E-06	-.19451E-06
XM	-.61826E-03	-.10084E-01	-.30442E-01	-.65906E-01	-.12477E 00	-.20233E 00
YM	.72302E 01	.35435E 02	.83011E 02	.14567E 03	.21613E 03	.28575E 03
ZM	.35901E 00	.14847E 01	.32458E 01	.54069E 01	.75652E 01	.94458E 01
PITCH	.30007E 01	.29753E 01	.26277E 01	.18595E 01	.12813E 01	.13703E 01
YAW	.23011E-04	-.71076E-03	-.18863E-01	-.69031E-01	-.10141E 00	-.62594E-01
ROLL	-.30766E 04	-.31985E 04	-.34422E 04	-.38577E 04	-.44972E 04	-.53243E 04
DXM	.10626E-04	.40937E-04	.64405E-04	.79851E-04	.83494E-04	.10486E-03
DYM	-.48436E-01	-.10590E 00	-.13620E 00	-.11720E 00	-.84861E-01	-.87118E-01
DZM	-.21466E-02	-.40365E-02	-.49049E-02	-.38380E-02	-.24105E-02	-.22413E-02
DPITCH	-.18080E-04	.36227E-03	.14460E-02	.14206E-02	.25643E-03	-.37564E-03
DYAW	-.63141E-06	.14076E-04	.85601E-04	.96641E-04	-.51231E-05	-.72416E-04
DROLL	.17637E 00	.42089E 00	.77350E 00	.70487E 00	.89337E 00	.11547E 01
PITCHS	-.21513E-03	-.20771E-03	-.17326E-03	-.17253E-03	-.14803E-03	-.12507E-03
YAWS	-.75030E-05	-.70319E-05	-.56117E-05	-.34790E-05	-.20889E-05	-.18274E-05
CROS	-.21637E-06	-.20637E-06	-.16735E-06	-.10693E-06	-.63193E-07	-.57722E-07
RANS	-.32495E-06	-.30994E-06	-.25451E-06	-.16087E-06	-.95323E-07	-.87197E-07
ALTS	.75358E-08	.71316E-08	.63171E-08	.63184E-08	.60553E-08	.35348E-08
ROLLS	.21115E-06	.19372E-06	.14772E-06	.83168E-07	.42212E-07	.32667E-07

TABLE 2 VARIATIONS AND SENSITIVITIES OF STRAIGHT SYSTEM
(CONTINUED)

(CONTINUOUS)						
TIME1	.66366E 00	.71672E 00	.76250E 00	.80255E 00	.83802E 00	.86978E 00
TIME2	.66393E 00	.71584E 00	.76259E 00	.80262E 00	.83808E 00	.86984E 00
DTIME12	.16687E-03	.12487E-03	.85552E-04	.69651E-04	.67406E-04	.65482E-04
DTMF12	-.21099E-06	-.24467E-06	-.27119E-06	-.28900E-06	-.47300E-06	-.37964E-06
XM	-.28284E 00	-.35829E 00	-.43136E 00	-.50560E 00	-.59075E 00	-.65447E 00
YM	.35410E 03	.41542E 03	.47386E 03	.52688E 03	.57600E 03	.62170E 03
ZM	.11075E 02	.12507E 02	.13766E 02	.14863E 02	.15826E 02	.16684E 02
PITCH	.15734E 01	.13733E 01	.10839E 01	.10020E 01	.10898E 01	.11728E 01
YAW	-.27127E-01	-.66179E-01	-.11774E 00	-.12090E 00	-.83446E-01	-.52071E-01
ROLL	-.62740E 04	-.73074E 04	-.84050E 04	-.75359E 04	-.10671E 05	-.11362E 05
DXM	.11377E-03	.93306E-04	.73529E-04	.69487E-04	.75408E-04	.7[illegible]98E-04
DYM	-.94387E-01	-.76034E-01	-.55262E-01	-.47242E-01	-.47664E-01	-.47707E-01
DZM	-.22234E-02	-.17093E-02	-.11757E-02	-.94956E-03	-.91201E-03	-.68410E-03
DPITCH	.15535E-04	.40537E-03	.20579E-03	-.27500E-04	-.11332E-03	-.40639E-04
DYAW	.33942E-05	.74980E-04	.32321E-04	-.21910E-04	-.42532E-04	-.16652E-04
DROLL	.14525E 01	.13611E 01	.11177E 01	.10692E 01	.11739E 01	.12714E 01
PITCHS	-.10515E-03	-.91108E-04	-.77223E-04	-.69333E-04	-.62297E-04	-.55158E-04
YAWS	-.16422E-05	-.12226E-05	-.88139E-06	-.72465E-06	-.65908E-06	-.57730E-06
CROS	-.55661E-07	-.41671E-07	-.28571E-07	-.23177E-07	-.22600E-07	-.21935E-07
RANS	-.83653E-07	-.62745E-07	-.43138E-07	-.35152E-07	-.34062E-07	-.33005E-07
ALTS	.20975E-08	.27430E-09	.35532E-08	.31710E-08	.20911E-08	.13311E-08
ROLLS	.26632E-07	.17120E-07	.10213E-07	.73344E-08	.63471E-08	.55525E-08

TABLE 2 VARIATIONS AND SENSITIVITIES OF STRAIGHT SYSTEM
(CONTINUED)

(CONTINUOUS)

TIME1	.89851E 00	.92474E 00	.94888E 00	.97123E 00	.99205E 00	.10115E 01
TIME2	.89857E 00	.92477E 00	.94892E 00	.97127E 00	.99208E 00	.10116E 01
DTIME12	.58364E-04	.48463E-04	.39472E-04	.33552E-04	.30900E-04	.30240E-04
DTMF12	-.47476E-06	-.43067E-06	-.39649E-06	-.46690E-06	-.50496E-06	-.50375E-06
XM	-.72504E 00	-.79227E 00	-.85697E 00	-.92030E 00	-.98308E 00	-.10465E 01
YM	.56437E 03	.70450E 03	.74233E 03	.77816E 03	.81221E 03	.84466E 03
ZM	.17461E 02	.18170E 02	.18822E 02	.19424E 02	.19980E 02	.20496E 02
PITCH	.11510E 01	.10421E 01	.91928E 00	.84329E 00	.83224E 00	.86704E 00
YAW	-.57751E-01	-.95152E-01	-.13694E 00	-.15750E 00	-.14807E 00	-.11774E 00
ROLL	-.13030E 05	-.14191E 05	-.15345E 05	-.16493E 05	-.17633E 05	-.18765E 05
DXM	.73289E-04	.63412E-04	.54254E-04	.49103E-04	.48435E-04	.50365E-04
DYM	-.44025E-01	-.37531E-01	-.31292E-01	-.27184E-01	-.25522E-01	-.25413E-01
DZM	-.78895E-03	-.65540E-03	-.53255E-03	-.45016E-03	-.41129E-03	-.39895E-03
DPITCH	.80397E-04	.12398E-03	.91048E-04	.32769E-04	-.13981E-04	-.37052E-04
DYAW	.26638E-04	.43071E-04	.29481E-04	.38994E-05	-.17717E-04	-.27344E-04
DROLL	.12404E 01	.11159E 01	.97790E 00	.89109E 00	.87415E 00	.90291E 00
PITCHS	-.51123E-04	-.46735E-04	-.43404E-04	-.40386E-04	-.37777E-04	-.35499E-04
YAWS	-.52447E-06	-.44882E-06	-.38792E-06	-.34539E-06	-.31682E-06	-.29542E-06
CRUS	-.19595E-07	-.16277E-07	-.13256E-07	-.11317E-07	-.10448E-07	-.10235E-07
RANS	-.29493E-07	-.24547E-07	-.20053E-07	-.17128E-07	-.15806E-07	-.15457E-07
ALTS	.12971E-08	.17427E-08	.21326E-08	.22900E-08	.20213E-08	.15480E-08
ROLLS	.45157E-08	.34454E-08	.25980E-08	.20627E-08	.17811E-08	.16369E-08

TABLE 2 VARIATIONS AND SENSITIVITIES OF STRAIGHT SYSTEM
(CONTINUED)

(CONTINUOUS)						
TIME1	.10298E 01	.10471E 01	.10635E 01	.10790E 01	.10939E 01	.11080E 01
TIME2	.10299E 01	.10471E 01	.10635E 01	.10791E 01	.10939E 01	.11080E 01
DTIME12	.30035E-04	.29147E-04	.27418E-04	.24850E-04	.22074E-04	.19337E-04
DTMF12	-.52950E-06	-.64340E-06	-.63031E-06	-.66173E-06	-.57842E-06	-.60198E-06
XM	-.11102E 01	-.11741E 01	-.12377E 01	-.13001E 01	-.13603E 01	-.14176E 01
YM	.87566E 03	.90538E 03	.93372E 03	.96140E 03	.98791E 03	.10135E 04
ZM	.20977E 02	.21426E 02	.21846E 02	.22242E 02	.22618E 02	.22975E 02
PITCH	.91274E 00	.93877E 00	.92978E 00	.88712E 00	.82393E 00	.75908E 00
YAW	-.85273E-01	-.68416E-01	-.76353E-01	-.10711E 00	-.14968E 00	-.14887E 00
ROLL	-.19883E 05	-.20986E 05	-.22073E 05	-.23148E 05	-.24202E 05	-.25222E 05
DXM	.53918E-04	.55474E-04	.54301E-04	.50342E-04	.44866E-04	.38970E-04
DYM	-.25630E-01	-.25254E-01	-.24072E-01	-.22102E-01	-.19851E-01	-.17638E-01
DZM	-.39212E-03	-.37538E-03	-.35071E-03	-.31533E-03	-.27880E-03	-.24446E-03
DPITCH	-.34012E-04	-.75385E-05	.23447E-04	.46237E-04	.51375E-04	[illegible]
DYAW	-.23130E-04	-.39030E-05	.17683E-04	.32315E-04	.33175E-04	[illegible]
DROLL	.93704E 00	.95022E 00	.92938E 00	.87568E 00	.79021E 00	.7[illegible]241E 00
PITCHS	-.33505E-04	-.31746E-04	-.30182E-04	-.28781E-04	-.27528E-04	-.26416E-04
YAWS	-.27543E-05	-.25789E-05	-.23967E-06	-.22279E-06	-.20824E-06	-.19543E-06
CROS	-.10175E-07	-.99189E-08	-.93382E-08	-.84912E-08	-.75359E-08	-.66464E-08
RANS	-.15340E-07	-.14940E-07	-.14071E-07	-.12816E-07	-.11402E-07	-.10090E-07
ALTS	.11072E-08	.87518E-09	.91006E-09	.11559E-08	.14869E-08	.17525E-08
ROLLS	.15372E-08	.14176E-08	.12707E-08	.11021E-08	.93598E-09	.79251E-09

TABLE 2 VARIATIONS AND SENSITIVITIES OF STRAIGHT SYSTEM
(CONTINUED)

(CONTINUOUS)						
TIME1	.11216E 01	.11347E 01	.11472E 01	.11594E 01	.11712E 01	.11825E 01
TIME2	.11216E 01	.11347E 01	.11473E 01	.11594E 01	.11712E 01	.11826E 01
DTIME12	.17357E-04	.16048E-04	.15463E-04	.15491E-04	.15846E-04	.16297E-04
DTMF12	-.54599E-06	-.53751E-06	-.57083E-06	-.59872E-06	-.65757E-06	-.69322E-06
XM	-.14719E 01	-.15236E 01	-.15741E 01	-.16256E 01	-.16804E 01	-.17407E 01
YM	.10384E 04	.10625E 04	.10859E 04	.11088E 04	.11311E 04	.11529E 04
ZM	.23313E 02	.23648E 02	.23767E 02	.24275E 02	.24572E 02	.24857E 02
PITCH	.70586E 00	.67791E 00	.67766E 00	.70167E 00	.74131E 00	.78499E 00
YAW	-.21068E 00	-.20677E 00	-.17693E 00	-.12708E 00	-.77516E-01	-.37399E-01
ROLL	-.26211E 05	-.27172E 05	-.28106E 05	-.29016E 05	-.29904E 05	-.30771E 05
DXM	.34435E-04	.31827E-04	.31700E-04	.34223E-04	.39346E-04	.46045E-04
DYM	-.15948E-01	-.14890E-01	-.14484E-01	-.14637E-01	-.15100E-01	-.15649E-01
DZM	-.21917E-03	-.20524E-03	-.19625E-03	-.19631E-03	-.19912E-03	-.20139E-03
DPITCH	.27041E-04	.20339E-05	-.34170E-05	-.21864E-04	-.30056E-04	-.33177E-04
DYAW	.64839E-05	-.10764E-04	-.25772E-04	-.34040E-04	-.32648E-04	-.18654E-04
DROLL	.63520E 00	.59300E 00	.57671E 00	.58257E 00	.60073E 00	.62223E 00
PITCHS	-.25421E-04	-.24524E-04	-.23709E-04	-.22964E-04	-.22261E-04	-.21651E-04
YAWS	-.18698E-05	-.17478E-05	-.17131E-06	-.16389E-06	-.15630E-06	-.14956E-05
CROS	-.59507E-08	-.55125E-08	-.53308E-08	-.53526E-08	-.54734E-08	-.56574E-08
RANS	-.90381E-08	-.83723E-08	-.80826E-08	-.80929E-08	-.82812E-08	-.85104E-08
ALTS	.18746E-08	.17734E-08	.14788E-08	.10691E-08	.65875E-09	.36788E-09
ROLLS	.58304E-09	.61040E-09	.57047E-09	.55452E-09	.55189E-09	.55215E-09

TABLE 2 VARIATIONS AND SENSITIVITIES OF STRAIGHT SYSTEM
(CONTINUED)

(CONTINUOUS)						
TIME1	.11936E 01	.12043E 01	.12148E 01	.12250E 01	.12349E 01	.12446E 01
TIME2	.11936E 01	.12044E 01	.12148E 01	.12250E 01	.12349E 01	.12446E 01
DTIME12	.15544E-04	.15383E-04	.15719E-04	.14432E-04	.12616E-04	.10335E-04
DTIME12	-.73635E-06	-.77488E-06	-.75672E-06	-.73960E-06	-.65517E-06	-.56554E-06
XM	-.18075E 01	-.18801E 01	-.19556E 01	-.20288E 01	-.20923E 01	-.21391E 01
YM	.11742E 04	.11751E 04	.12155E 04	.12356E 04	.12553E 04	.12747E 04
ZM	.25125E 02	.25380E 02	.25517E 02	.25837E 02	.26043E 02	.26241E 02
PITCH	.82035E 00	.83603E 00	.82342E 00	.77710E 00	.69630E 00	.58566E 00
YAW	-.30510E-01	-.61166E-01	-.13282E 00	-.23613E 00	-.35072E 00	-.44696E 00
ROLL	-.31613E 05	-.32447E 05	-.33259E 05	-.34055E 05	-.34836E 05	-.35603E 05
DXM	.53054E-04	.57851E-04	.57465E-04	.49941E-04	.36447E-04	.18701E-04
DYM	-.16007E-01	-.15770E-01	-.15425E-01	-.14261E-01	-.12543E-01	-.10342E-01
DZM	-.19882E-03	-.18741E-03	-.17403E-03	-.15246E-03	-.12924E-03	-.10549E-03
DPITCH	-.20845E-04	-.18173E-05	.21265E-04	.46021E-04	.61402E-04	.65335E-04
DYAW	.71275E-05	.40476E-04	.67736E-04	.81284E-04	.71738E-04	.41202E-04
DROLL	.63604E 00	.63407E 00	.61220E 00	.56575E 00	.49737E 00	.40988E 00
PITCHS	-.21070E-04	-.20533E-04	-.20035E-04	-.19573E-04	-.17142E-04	-.14738E-04
YAWS	-.14073E-06	-.13387E-06	-.12811E-06	-.12437E-06	-.12344E-06	-.12360E-06
CROS	-.57545E-08	-.57122E-08	-.54817E-08	-.50431E-08	-.44052E-08	-.36115E-08
RANS	-.86524E-08	-.86024E-08	-.82864E-08	-.76658E-08	-.67424E-08	-.55642E-08
ALTS	.30084E-09	.50377E-09	.96838E-09	.16151E-08	.23031E-08	.28457E-08
ROLLS	.54655E-09	.52380E-09	.49538E-09	.44549E-09	.38095E-09	.30618E-09

TABLE 2 VARIATIONS AND SENSITIVITIES OF STRAIGHT SYSTEM
(CONTINUED)

(CONTINUOUS)

TIME1	.12541E 01	.12634E 01	.12724E 01	.12813E 01	.12900E 01	.12985E 01
TIME2	.12541E 01	.12634E 01	.12724E 01	.12813E 01	.12900E 01	.12985E 01
DTIME12	.78427E-05	.54932E-05	.37266E-05	.31124E-05	.42938E-05	.78373E-05
DTMF12	-.45511E-06	-.32594E-06	-.22794E-06	-.19768E-06	-.27382E-06	-.52716E-06
XM	-.21591E 01	-.21522E 01	-.21211E 01	-.20800E 01	-.20565E 01	-.20929E 01
YM	.12937E 04	.13124E 04	.13308E 04	.13487E 04	.13667E 04	.13842E 04
ZM	.26437E 02	.26548E 02	.26832E 02	.27154E 02	.27475E 02	.27345E 02
PITCH	.45644E 00	.32762E 00	.22711E 00	.19197E 00	.26695E 00	.50111E 00
YAW	-.49020E 00	-.44612E 00	-.28932E 00	-.11741E-01	.36732E 00	.79157E 00
ROLL	-.36359E 05	-.37113E 05	-.37865E 05	-.38615E 05	-.39363E 05	-.40117E 05
DXM	.24739E-05	-.62260E-05	-.82268E-05	-.66724E-05	-.12653E-05	.39317E-04
DYM	-.78974E-02	-.55627E-02	-.37747E-02	-.31866E-02	-.44175E-02	-.81583E-02
DZM	-.84536E-04	-.65846E-04	-.52271E-04	-.52705E-04	-.85906E-04	-.18345E-03
DPITCH	.55578E-04	.35712E-04	.15444E-04	-.25884E-05	-.34411E-04	-.15440E-03
DYAW	.48150E-05	-.27550E-04	-.45497E-04	-.59795E-04	-.10285E-03	-.17542E-03
DROLL	.31614E 00	.22574E 00	.15613E 00	.13296E 00	.18662E 00	.34751E 00
PITCHS	-.18353E-04	-.17977E-04	-.17613E-04	-.17252E-04	-.16898E-04	-.16553E-04
YAWS	-.13048E-06	-.13666E-06	-.14171E-06	-.14257E-06	-.13631E-06	-.12146E-06
CROS	-.27417E-08	-.17175E-08	-.13033E-08	-.11019E-08	-.15378E-08	-.28338E-08
RANS	-.42560E-08	-.29881E-08	-.20190E-08	-.16566E-08	-.22280E-08	-.40393E-08
ALTS	.30406E-08	.27036E-08	.17178E-08	.86556E-10	-.20414E-08	-.43140E-08
ROLLS	.22822E-09	.15680E-09	.10444E-09	.85721E-10	.11604E-09	.23984E-09

TABLE 2 VARIATIONS AND SENSITIVITIES OF STRAIGHT SYSTEM
(CONTINUED)

(CONTINUOUS)

TIME1	.13068E 01	.13149E 01	.13229E 01	.13308E 01	.13385E 01	.13460E 01
TIME2	.13068E 01	.13150E 01	.13230E 01	.13308E 01	.13385E 01	.13461E 01
DTIME12	.14397E-04	.23708E-04	.35700E-04	.48718E-04	.57088E-04	.61340E-04
DTMF12	-.93202E-05	-.14704E-05	-.25811E-05	-.37137E-05	-.46172E-05	-.48705E-05
XM	-.22436E 01	-.25699E 01	-.31235E 01	-.39193E 01	-.48943E 01	-.58413E 01
YM	.14015E 04	.14195E 04	.14353E 04	.14519E 04	.14681E 04	.14443E 04
ZM	.28248E 02	.28536E 02	.28724E 02	.28970E 02	.28560E 02	.27514E 02
PITCH	.73641E 00	.15744E 01	.24492E 01	.33997E 01	.41674E 01	.43344E 01
YAW	.11589E 01	.13168E 01	.10623E 01	.15486E 00	-.16484E 01	-.45216E 01
ROLL	-.40854E 05	-.41596E 05	-.42336E 05	-.42997E 05	-.43759E 05	-.44537E 05
DXM	.19380E-03	.62110E-03	.14795E-02	.28110E-02	.39135E-02	.32[illegible]E-02
DYM	-.14954E-01	-.24774E-01	-.37701E-01	-.51464E-01	-.62862E-01	-.65[illegible]8E-01
DZM	-.35426E-03	-.53437E-03	-.47219E-03	.36531E-03	.26512E-02	.63219E-02
DPITCH	-.46912E-03	-.11153E-02	-.20809E-02	-.28830E-02	-.22028E-02	.17379E-02
DYAW	-.26132E-03	-.17562E-04	.11343E-02	.40094E-02	.89755E-02	.14304E-01
DROLL	.64849E 00	.10758E 01	.16725E 01	-.47883E-04	-.78940E-04	.29[illegible]3E 01
PITCHS	-.16223E-04	-.15913E-04	-.15635E-04	-.15437E-04	-.15313E-04	-.15374E-04
YAWS	-.92998E-07	-.50218E-07	.10285E-07	.12082E-06	.27299E-06	.44093E-06
CROS	-.51503E-08	-.85307E-08	-.12797E-07	-.17443E-07	-.21307E-07	-.22404E-07
RANS	-.73036E-08	-.12136E-07	-.18491E-07	-.26067E-07	-.33610E-07	-.37941E-07
ALTS	-.61843E-08	-.68703E-08	-.54203E-08	-.76419E-09	.82209E-08	.22672E-07
ROLLS	.37620E-09	.61491E-09	.90373E-09	.12194E-08	.14557E-08	.14865E-08

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM

GSNO	1	2	1	2	1	2
TIMES	.19830E-01	.23877E-01	.13752E 00	.14147E 00	.25177E 00	.25554E 00
XM	-.11233E-13	-.93310E-13	-.14002E-02	-.16021E-02	-.12653E-01	-.13272E-01
YM	.10138E 00	.15361E 00	.10430E 02	.11159E 02	.41971E 02	.43394E 02
ZM	.53132E-02	.80503E-02	.49519E 00	.52596E 00	.17328E 01	.17965E 01
PITCH	.30000E 01	.30000E 01	.30024E 01	.30029E 01	.29471E 01	.27424E 01
YAW	-.40712E-15	.74015E-15	.84335E-04	.10535E-03	-.17904E-02	-.20827E-02
ROLL	-.30270E 04	-.30308E 04	-.30874E 04	-.30897E 04	-.32291E 04	-.32359E 04
DTMF	-.23675E-05	.67124E-08	-.18610E-05	-.77593E-05	-.10133E-05	-.64103E-04
DXM	-.60764E-03	-.62987E-03	-.86432E-02	-.35232E-02	-.17724E-01	-.17284E-01
DYM	.71304E 01	.71750E 01	.24877E 02	.24381E 02	.40904E 02	.37754E 02
DZM	.35155E 00	.35311E 00	.94551E 00	.96282E 00	.15081E 01	.14642E 01
DPITCH	.65163E-03	.68784E-03	-.26706E-01	-.27972E-01	-.31990E 00	-.31607E 00
DYAW	.22380E-04	.23643E-04	-.73157E-03	-.63018E-03	-.16987E-01	-.15856E-01
DROLL	-.47475E 02	-.45987E 02	-.11059E 03	-.10922E 03	-.11216E 03	-.20704E 03
PITCHS	-.17127E-17	.45196E-05	-.14910E-08	.44194E-05	-.11996E-07	.40765E-05
YAWS	-.88340E-04	-.12736E-03	-.86670E-04	-.12644E-03	-.52865E-04	-.11949E-03
CROS	.57173E-10	-.11402E-05	.57690E-08	-.11121E-05	.22189E-07	-.10442E-05
RANS	.16372E-05	.17105E-05	.16552E-05	.16776E-05	.15827E-05	.15011E-05
ALTS	.88421E-07	.12243E-06	.86817E-07	.12687E-06	.81537E-07	.11792E-06
ROLLS	-.32677E-04	-.31541E-04	-.31478E-04	-.30355E-04	-.28791E-04	-.27691E-04

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM
(CONTINUED)

(CONTINUOUS)

GSNO	1	2	1	2	1	2
TIMES	.35914E 00	.36254E 00	.45632E 00	.45919E 00	.54073E 00	.54312E 00
XM	-.34952E-01	-.35919E-01	-.73794E-01	-.75406E-01	-.13647E 00	-.13374E 00
YM	.92338E 02	.94281E 02	.15686E 03	.15906E 03	.22783E 03	.23003E 03
ZM	.35797E 01	.36490E 01	.57697E 01	.58400E 01	.78881E 01	.79470E 01
PITCH	.25245E 01	.25019E 01	.17272E 01	.17027E 01	.12584E 01	.12562E 01
YAW	-.25100E-01	-.26472E-01	-.77717E-01	-.79561E-01	-.995[illegible]-01	-.[illegible]E-01
ROLL	-.34964E 04	-.35030E 04	-.39464E 04	-.39544E 04	-.46204E 04	.[illegible]44E 04
DTMF	.57585E-05	-.11135E-03	.76441E-05	-.59125E-04	-.14069E-05	.16572E-04
DXM	-.30874E-01	-.30067E-01	-.50912E-01	-.49467E-01	-.65752E-01	-.63690E-01
DYM	.53214E 02	.51505E 02	.59283E 02	.57255E 02	.59033E 02	.57011E 02
DZM	.18232E 01	.17517E 01	.17904E 01	.17250E 01	.15555E 01	.14990E 01
DPITCH	-.66449E 00	-.64480E 00	-.44471E 00	-.42067E 00	.13160E 00	.13454E 00
DYAW	-.43834E-01	-.42636E-01	-.23506E-01	-.21852E-01	.36853E-01	.36384E-01
DROLL	-.36033E 03	-.35053E 03	-.54738E 03	-.53367E 03	-.70268E 03	-.68107E 03
PITCHS	-.14028E-07	.31378E-05	.20793E-07	.18732E-05	.53855E-07	.12200E-05
YAWS	-.76638E-04	-.10848E-03	-.68067E-04	-.94054E-04	-.58341E-04	-.78549E-04
CRUS	.45084E-07	-.93760E-06	.67852E-07	-.80065E-06	.84190E-07	-.65643E-06
RANS	.14523E-05	.14762E-05	.12964E-05	.13050E-05	.11076E-05	.11129E-05
ALTS	.54477E-07	.91531E-07	.39070E-07	.34904E-07	.24251E-07	.34593E-07
ROLLS	-.24579E-04	-.23584E-04	-.19316E-04	-.18489E-04	-.14107E-04	-.13459E-04

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM (CONTINUED)

(CONTINUOUS)

GSNO	1	2	1	2	1	2
TIMES	.61226E 00	.61430E 00	.67279E 00	.67454E 00	.72451E 00	.72599E 00
XM	-.21547E 00	-.21802E 00	-.29526E 00	-.29768E 00	-.36996E 00	-.37222E 00
YM	.29806E 03	.30020E 03	.36441E 03	.36641E 03	.42589E 03	.42771E 03
ZM	.97233E 01	.97763E 01	.11317E 02	.11364E 02	.12721E 02	.12762E 02
PITCH	.14373E 01	.14461E 01	.15655E 01	.15626E 01	.13217E 01	.13117E 01
YAW	-.53718E-01	-.52072E-01	-.30627E-01	-.31167E-01	-.75706E-01	-.77361E-01
ROLL	-.54702E 04	-.54787E 04	-.64347E 04	-.64064E 04	-.74810E 04	-.75144E 04
DTMF	-.28174E-05	.11778E-04	.31263E-05	-.15269E-04	.45099E-05	-.14737E-04
DXM	-.67250E-01	-.64735E-01	-.62733E-01	-.60704E-01	-.61314E-01	-.57214E-01
DYM	.55942E 02	.53995E 02	.51933E 02	.50080E 02	.47915E 02	.46294E 02
DZM	.13479E 01	.13014E 01	.11704E 01	.11470E 01	.10441E 01	.10059E 01
DPITCH	.13619E 00	.12728E 00	-.19177E 00	-.18767E 00	-.23754E 00	-.22798E 00
DYAW	.24574E-01	.22741E-01	-.35477E-01	-.35036E-01	-.41976E-01	-.43207E-01
DROLL	-.80235E 03	-.77674E 03	-.87344E 03	-.84444E 03	-.92287E 03	-.89170E 03
PITCHS	.35861E-07	.11375E-05	.18516E-07	.10076E-05	.34177E-07	.74191E-06
YAWS	-.47477E-04	-.65005E-04	-.42269E-04	-.44220E-04	-.35570E-04	-.45337E-04
CROS	.93033E-07	-.53235E-06	.96675E-07	-.43476E-06	.97235E-07	-.35956E-06
RANS	.93567E-06	.93781E-06	.79545E-06	.79871E-06	.68456E-06	.69632E-06
ALTS	.23406E-07	.33054E-07	.21576E-07	.29882E-07	.15700E-07	.21537E-07
ROLLS	-.10077E-04	-.96342E-05	-.71708E-05	-.69744E-05	-.53998E-05	-.51705E-05

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM
(CONTINUED)

(CONTINUOUS)

GSNO	1	2	1	2	1	2
TIMES	.76925E 00	.77052E 00	.80847E 00	.80958E 00	.84327E 00	.84427E 00
XM	-.44303E 00	-.44527E 00	-.51747E 00	-.51975E 00	-.59250E 00	-.59477E 00
YM	.48255E 03	.48421E 03	.53489E 03	.53641E 03	.58341E 03	.58443E 03
ZM	.13951E 02	.13985E 02	.15023E 02	.15054E 02	.15967E 02	.15994E 02
PITCH	.10544E 01	.10495E 01	.10089E 01	.10106E 01	.11072E 01	.11105E 01
YAW	-.12213E 00	-.12280E 00	-.11562E 00	-.11569E 00	-.76922E-01	-.75576E-01
ROLL	-.85825E 04	-.86166E 04	-.97171E 04	-.97519E 04	-.10874E 05	-.10910E 05
DTME	.12321E-05	-.23412E-05	-.13235E-05	.38633E-05	-.11901E-05	.25048E-05
DXM	-.62505E-01	-.60406E-01	-.63203E-01	-.61076E-01	-.61891E-01	-.59775E-01
DYM	.44277E 02	.42717E 02	.41067E 02	.37637E 02	.38243E 02	.36713E 02
DZM	.91145E 00	.87855E 00	.80185E 00	.77330E 00	.71611E 00	.69378E 00
DPITCH	-.52477E-01	-.47534E-01	.80838E-01	.79290E-01	.65544E-01	.62336E-01
DYAW	.12035E-02	.19240E-02	.33134E-01	.32287E-01	.24824E-01	.23521E-01
DROLL	-.95234E 03	-.92037E 03	-.97239E 03	-.94042E 03	-.78585E 03	-.95180E 03
PITCHS	.52950E-07	.54462E-06	.52231E-07	.46451E-06	.39398E-07	.43520E-06
YAWS	-.32076E-04	-.39270E-04	-.28502E-04	-.34224E-04	-.25613E-04	-.30211E-04
CROS	.96074E-07	-.30190E-06	.94076E-07	-.25745E-06	.91684E-07	-.22251E-06
RANS	.59705E-06	.59775E-06	.52748E-06	.52793E-06	.47131E-06	.47194E-06
ALTS	.10825E-07	.15130E-07	.91109E-08	.12802E-07	.59648E-08	.12358E-07
ROLLS	-.41068E-05	-.39365E-05	-.32066E-05	-.30761E-05	-.25613E-05	-.24596E-05

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM
(CONTINUED)

(CONTINUOUS)

GSNO	1	2	1	2	1	2
TIMES	.87449E 00	.87540E 00	.90278E 00	.90361E 00	.92865E 00	.92940E 00
XM	-.56575E 00	-.66795E 00	-.73574E 00	-.73782E 00	-.80247E 00	-.80445E 00
YM	.52857E 03	.52990E 03	.57091E 03	.67206E 03	.71052E 03	.71169E 03
ZM	.16811E 02	.16835E 02	.17575E 02	.17598E 02	.18275E 02	.18295E 02
PITCH	.11771E 01	.11776E 01	.11392E 01	.11354E 01	.10220E 01	.10191E 01
YAW	-.50258E-01	-.50018E-01	-.62055E-01	-.62987E-01	-.10214E 00	-.10350E 00
ROLL	-.12045E 05	-.12081E 05	-.13212E 05	-.13247E 05	-.14371E 05	-.14436E 05
DTMF	.31460E-05	-.10768E-05	.14715E-05	-.30572E-05	.16417E-05	-.28112E-05
DXM	-.59220E-01	-.57170E-01	-.55462E-01	-.54505E-01	-.54445E-01	-.52572E-01
DYM	.35782E 02	.34534E 02	.33647E 02	.32473E 02	.31777E 02	.30671E 02
DZM	.54892E 00	.62599E 00	.57374E 00	.57297E 00	.54601E 00	.52736E 00
DPITCH	-.25948E-01	-.26601E-01	-.95728E-01	-.93414E-01	-.10262E 00	-.98365E-01
DYAW	-.74661E-02	-.77594E-02	-.33054E-01	-.32209E-01	-.34766E-01	-.33462E-01
DROLL	-.98357E 03	-.95030E 03	-.97853E 03	-.94522E 03	-.97322E 03	-.94011E 03
PITCHS	.29790E-07	.40377E-05	.29758E-07	.35527E-06	.36234E-07	.30241E-05
YAWS	-.23263E-04	-.26770E-04	-.21340E-04	-.24323E-04	-.19745E-04	-.22130E-04
CROS	.99183E-07	-.19452E-06	.86777E-07	-.17182E-06	.84561E-07	-.15313E-06
RANS	.42551E-06	.42615E-06	.38907E-06	.38837E-06	.35677E-06	.35540E-05
ALTS	.85265E-08	.11570E-07	.75864E-08	.10205E-07	.62090E-08	.34317E-08
ROLLS	-.20901E-05	-.20075E-05	-.17385E-05	-.16709E-05	-.14703E-05	-.14138E-05

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM
(CONTINUED)

(CONTINUOUS)

GSNO	1	2	1	2	1	2
TIMES	.95243E 00	.95317E 00	.97456E 00	.97520E 00	.99515E 00	.99575E 00
XM	-.86695E 00	-.86876E 00	-.93004E 00	-.93193E 00	-.99300E 00	-.99489E 00
YM	.74801E 03	.74911E 03	.78354E 03	.78458E 03	.81731E 03	.81830E 03
ZM	.18719E 02	.18937E 02	.19513E 02	.19530E 02	.20062E 02	.20073E 02
PITCH	.90344E 00	.90052E 00	.83748E 00	.83654E 00	.83543E 00	.83617E 00
YAW	-.14197E 00	-.14288E 00	-.15796E 00	-.15796E 00	-.14434E 00	-.14336E 00
ROLL	-.15524E 05	-.15558E 05	-.16669E 05	-.16703E 05	-.17808E 05	.17342E 05
DTMF	.99345E-06	-.14085E-05	.14388E-06	-.33597E-07	-.42592E-06	.59724E-05
DXM	-.53405E-01	-.51588E-01	-.53184E-01	-.52393E-01	-.53457E-01	-.51607E-01
DYM	.30122E 02	.29079E 02	.28646E 02	.27659E 02	.27317E 02	.26392E 02
DZM	.50468E 00	.48697E 00	.46725E 00	.45076E 00	.43377E 00	.41372E 00
DPITCH	-.60117E-01	-.57257E-01	-.52577E-02	-.42830E-02	.31576E-01	.30708E-01
DYAW	-.15535E-01	-.14632E-01	.98703E-02	.99097E-02	.26571E-01	.25846E-01
DROLL	-.96785E 03	-.93504E 03	-.96253E 03	-.93003E 03	-.95671E 03	-.92447E 03
PITCHS	.42973E-07	.25793E-06	.45628E-07	.23170E-06	.43474E-07	.21560E-06
YAWS	-.18395E-04	-.20291E-04	-.17237E-04	-.16735E-04	-.16228E-04	-.17403E-04
CROS	.82457E-07	-.13755E-06	.80470E-07	-.12442E-06	.78579E-07	-.11324E-05
RANS	.33058E-06	.33008E-06	.30809E-06	.30730E-06	.28843E-06	.28767E-06
ALTS	.50159E-08	.69452E-08	.42851E-08	.60203E-08	.39905E-08	.55767E-08
ROLLS	-.12507E-05	-.12131E-05	-.10943E-05	-.10531E-05	-.95935E-06	-.92354E-06

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM (CONTINUED)

(CONTINUOUS)						
GSNO	1	2	1	2	1	2
TIMES	.10144E 01	.10150E 01	.10326E 01	.10331E 01	.10497E 01	.10502E 01
XM	-.10563E 01	-.10582E 01	-.11200E 01	-.11217E 01	-.11839E 01	-.11858E 01
YM	.84951E 03	.85046E 03	.88030E 03	.88121E 03	.90981E 03	.91069E 03
ZM	.20572E 02	.20587E 02	.21048E 02	.21061E 02	.21492E 02	.21505E 02
PITCH	.87425E 00	.87563E 00	.91859E 00	.91968E 00	.73980E 00	.73991E 00
YAW	-.11239E 00	-.11134E 00	-.91328E-01	-.80596E-01	-.67950E-01	-.67726E-01
ROLL	-.18938E 05	-.18972E 05	-.20053E 05	-.20087E 05	-.21153E 05	-.21186E 05
DTMF	-.54603E-06	.72983E-06	-.30461E-06	.32119E-06	.10030E-06	-.20484E-06
DXM	-.53877E-01	-.52075E-01	-.54094E-01	-.52278E-01	-.53784E-01	-.51766E-01
DYM	.26128E 02	.25233E 02	.25056E 02	.24178E 02	.24085E 02	.23361E 02
DZM	.40400E 00	.38999E 00	.37761E 00	.36453E 00	.35433E 00	.34207E 00
DPITCH	.38460E-01	.37102E-01	.20174E-01	.19097E-01	-.10001E-01	-.10136E-01
DYAW	.27071E-01	.26071E-01	.11708E-01	.11184E-01	-.83855E-02	-.84445E-02
DROLL	-.94415E 03	-.91225E 03	-.93133E 03	-.87786E 03	-.91763E 03	-.88852E 03
PITCHS	.38444E-07	.20597E-06	.33337E-07	.19781E-06	.30126E-07	.13810E-06
YAWS	-.15343E-04	-.16251E-04	-.14568E-04	-.15248E-04	-.13886E-04	-.14364E-04
CROS	.76792E-07	-.10351E-05	.73142E-07	-.95248E-07	.73627E-07	-.87915E-07
RANS	.27117E-06	.27058E-05	.25608E-06	.25560E-06	.24279E-06	.24232E-05
ALTS	.39421E-08	.54454E-08	.39314E-08	.53362E-08	.38209E-08	.51246E-08
ROLLS	-.84867E-06	-.81721E-06	-.75729E-06	-.72740E-06	-.68095E-06	-.65602E-06

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM
(CONTINUED)

(CONTINUOUS)

GSNO	1	2	1	2	1	2
TIMES	.10659E 01	.10664E 01	.10813E 01	.10818E 01	.10961E 01	.10965E 01
XM	-.12473E 01	-.12492E 01	-.13094E 01	-.13113E 01	-.13692E 01	-.13710E 01
YM	.73813E 03	.73902E 03	.96549E 03	.96630E 03	.99185E 03	.99262E 03
ZM	.21908E 02	.21920E 02	.22301E 02	.22312E 02	.22673E 02	.22584E 02
PITCH	.92524E 00	.92423E 00	.87841E 00	.87664E 00	.81367E 00	.81164E 00
YAW	-.77748E-01	-.80491E-01	-.11318E 00	-.11440E 00	-.15523E 00	-.15761E 00
ROLL	-.22233E 05	-.22270E 05	-.23310E 05	-.23342E 05	-.24359E 05	-.24337E 05
DTMF	.47637E-06	-.60497E-06	.69833E-06	-.77050E-06	.72224E-06	-.70836E-06
DXM	-.52719E-01	-.50923E-01	-.50849E-01	-.49103E-01	-.48394E-01	-.46726E-01
DYM	.23202E 02	.22403E 02	.22395E 02	.21628E 02	.21667E 02	.20937E 02
DZM	.33401E 00	.32247E 00	.31653E 00	.30562E 00	.30190E 00	.29154E 00
DPITCH	-.38068E-01	-.37157E-01	-.54426E-01	-.52758E-01	-.55547E-01	-.53608E-01
DYAW	-.27326E-01	-.26648E-01	-.36474E-01	-.35313E-01	-.32621E-01	-.31390E-01
DROLL	-.77870E 03	-.87814E 03	-.87120E 03	-.86074E 03	-.86271E 03	-.83326E 03
PITCHS	.27521E-07	.17622E-06	.31480E-07	.16304E-06	.34665E-07	.15013E-06
YAWS	-.13284E-04	-.13578E-04	-.12748E-04	-.12374E-04	-.12272E-04	-.12247E-04
CROS	.72242E-07	-.81423E-07	.73967E-07	-.75640E-07	.69815E-07	-.70478E-07
RANS	.23102E-06	.23342E-06	.22033E-06	.21971E-06	.21120E-06	.21013E-06
ALTS	.35575E-08	.47716E-09	.30028E-08	.45166E-08	.17979E-08	.38369E-08
ROLLS	-.61642E-06	-.57378E-06	-.56130E-06	-.54097E-06	-.51425E-06	-.49574E-06

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM
(CONTINUED)

(CONTINUOUS)

GSNO	1	2	1	2	1	2
TIMES	.11101E 01	.11105E 01	.11236E 01	.11240E 01	.11366E 01	.11370E 01
XM	-.14260E 01	-.14277E 01	-.14798E 01	-.14814E 01	-.15312E 01	-.15327E 01
YM	.10173E 04	.10181E 04	.10421E 04	.10428E 04	.10661E 04	.10658E 04
ZM	.23028E 02	.23038E 02	.23368E 02	.23378E 02	.23697E 02	.23726E 02
PITCH	.74876E 00	.74721E 00	.67791E 00	.69879E 00	.67611E 00	[illegible]
YAW	-.19357E 00	-.19444E 00	-.21185E 00	-.21202E 00	-.20385E 00	-.20371E 00
ROLL	-.25374E 05	-.25403E 05	-.26358E 05	-.26387E 05	-.27314E 05	[illegible]
DTMF	.57028E-05	-.47077E-06	.30760E-06	-.20932E-06	.14064E-07	[illegible]
DXM	-.45804E-01	-.44227E-01	-.43729E-01	-.42233E-01	-.42875E-01	-.41434E-01
DYM	.21011E 02	.20295E 02	.29416E 02	.19721E 02	.19871E 02	.17197E 02
DZM	.28974E 00	.27783E 00	.27743E 00	.26787E 00	.27016E 00	.25176E 00
DPITCH	-.43076E-01	-.41381E-01	-.21994E-01	-.20394E-01	.15354E-02	.14426E-02
DYAW	-.17109E-01	-.16245E-01	.50434E-02	.52397E-02	.15995E-01	.26374E-01
DROLL	-.83577E 03	-.80628E 03	-.81311E 03	-.78545E 03	-.77132E 03	-.75446E 03
PITCHS	.37930E-07	.13896E-06	.40171E-07	.13013E-06	.40773E-07	.12374E-06
YAWS	-.11359E-04	-.11692E-04	-.11471E-04	-.11197E-04	-.11127E-04	-.10754E-04
CRUS	.68770E-07	-.65235E-07	.67860E-07	-.61860E-07	.67001E-07	-.58200E-07
RANS	.20289E-06	.20162E-06	.17541E-06	.19405E-06	.18860E-06	.18726E-06
ALTS	.24267E-08	.34080E-08	.21437E-08	.30300E-08	.19747E-08	.23735E-08
ROLLS	-.47415E-06	-.45713E-06	-.43959E-06	-.42393E-06	-.40955E-06	-.37478E-06

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM
(CONTINUED)

(CONTINUOUS)

GSNO	1	2	1	2	1	2
TIMES	.11491E 01	.11495E 01	.11612E 01	.11615E 01	.11729E 01	.11732E 01
XM	-.15814E 01	-.15833E 01	-.16336E 01	-.16352E 01	-.16891E 01	-.16908E 01
YM	.10824E 04	.10901E 04	.11122E 04	.11127E 04	.11344E 04	.11351E 04
ZM	.24014E 02	.24023E 02	.24321E 02	.24330E 02	.24616E 02	.24624E 02
PITCH	.67997E 00	.68039E 00	.70538E 00	.70796E 00	.74790E 00	.74922E 00
YAW	-.17060E 00	-.16927E 00	-.12117E 00	-.11760E 00	-.70526E-01	-.69131E-01
ROLL	-.28244E 05	-.28272E 05	-.29151E 05	-.29177E 05	-.30035E 05	-.30061E 05
DTME	-.23798E-06	.25098E-06	-.39707E-06	.34502E-06	-.43917E-06	.33137E-06
DXM	-.43327E-01	-.42386E-01	-.46818E-01	-.45307E-01	-.51569E-01	-.49924E-01
DYM	.19371E 02	.18716E 02	.18710E 02	.18271E 02	.18481E 02	.17858E 02
DZM	.26109E 00	.25222E 00	.25145E 00	.24297E 00	.24059E 00	.23239E 00
DPITCH	.21775E-01	.21304E-01	.34401E-01	.35334E-01	.37053E-01	.35304E-01
DYAW	.41486E-01	.40247E-01	.43624E-01	.42115E-01	.31106E-01	.29600E-01
DROLL	-.77117E 03	-.74593E 03	-.75249E 03	-.72707E 03	-.73507E 03	-.71026E 03
PITCHS	.39595E-07	.11976E-06	.36709E-07	.11727E-06	.33365E-07	.11541E-06
YAWS	-.10812E-04	-.10361E-04	-.10523E-04	-.10002E-04	-.10258E-04	-.96732E-05
CROS	.55200E-07	-.54870E-07	.65453E-07	-.51874E-07	.64753E-07	-.49134E-07
RANS	.18235E-06	.18115E-06	.17660E-06	.17557E-06	.17132E-06	.17049E-06
ALTS	.19171E-08	.27814E-08	.19463E-08	.27750E-08	.20241E-08	.28147E-08
ROLLS	-.38312E-06	-.36757E-06	-.35979E-06	-.34710E-06	-.33903E-06	-.32711E-06

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM
(CONTINUED)

(CONTINUOUS)

GSNO	1	2	1	2	1	2
TIMES	.11842E 01	.11946E 01	.11752E 01	.11956E 01	.12059E 01	.12[illegible]2E 01
XM	-.17503E 01	-.17522E 01	-.18180E 01	-.18201E 01	-.18912E 01	-.1[illegible]35E 01
YM	.11561E 04	.11568E 04	.11774E 04	.11780E 04	.11962E 04	.11[illegible]8E 04
ZM	.24978E 02	.24906E 02	.25165E 02	.25173E 02	.25416E 02	.25[illegible]4E 02
PITCH	.79110E 00	.79230E 00	.82419E 00	.82490E 00	.83619E 00	.8[illegible]11E 00
YAW	-.35872E-01	-.35261E-01	-.32414E-01	-.32921E-01	-.69302E-01	-.71[illegible]2E-01
ROLL	-.30399E 05	-.30724E 05	-.31743E 05	-.31763E 05	-.32569E 05	-.3[illegible]93E 05
DTMF	-.36136E-06	.22766E-06	-.17580E-06	.[illegible]305E-07	.96172E-07	-.1[illegible]1E-06
DXM	-.57153E-01	-.55327E-01	-.62059E-01	-.60047E-01	-.64340E-01	-.6[illegible]E-01
DYM	.18035E 02	.17475E 02	.17716E 02	.17119E 02	.17371E 02	.1[illegible]4E 02
DZM	.22925E 00	.22045E 00	.21457E 00	.20719E 00	.20017E 00	.1[illegible]5E 00
DPITCH	.27222E-01	.28070E-01	.11872E-01	.11187E-01	-.12752E-01	-.1[illegible]17E-01
DYAW	.53676E-02	.47437E-02	-.28712E-01	-.28296E-01	-.6345[illegible]E-01	-.51[illegible]E-01
DROLL	-.71833E 03	-.67[illegible]E 03	-.70363E 03	-.67[illegible]E 03	-.68754E 03	-.5[illegible]5E 03
PITCHS	.29732E-07	.11404E-06	.26743E-07	.11193E-06	.252[illegible]4E-07	.1[illegible]7E-06
YAWS	-.10015E-04	-.93693E-05	-.97781F-05	-.90862E-05	-.96020E-05	-.8[illegible]E-05
CROS	.64139E-07	-.46542E-07	.63587E-07	-.44156E-07	.631[illegible]E-07	-.4[illegible]E-07
RANS	.16549E-06	.16575E-05	.16208E-06	.16134E-06	.15305E-06	.15717E-05
ALTS	.21076E-08	.28580E-08	.21570E-08	.28661E-08	.21379E-08	.2[illegible]5E-08
ROLLS	-.32045E-06	-.30921E-06	-.30374E-06	-.29311E-06	-.28864E-06	-.27[illegible]56E-06

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM
(CONTINUED)

(CONTINUOUS)

GSNO	1	2	1	2	1	2
TIMES	.12163E 01	.12167E 01	.12265E 01	.12268E 01	.12364E 01	.12367E 01
XM	-.19668E 01	-.19690E 01	-.20390E 01	-.20410E 01	-.21004E 01	-.21020E 01
YM	.12196E 04	.12192E 04	.12336E 04	.12391E 04	.1254[illegible]E 04	.125[illegible]E 04
ZM	.25550E 02	.25557E 02	.25868E 02	.25874E 02	.26073E 02	.26079E 02
PITCH	.81873E 00	.81769E 00	.76722E 00	.76516E 00	.68161E 00	.67356E 00
YAW	-.14654E 00	-.14939E 00	-.25302E 00	-.25645E 00	-.36689E 00	-.37009E 00
ROLL	-.33378E 05	-.33402E 05	-.34172E 05	-.34195E 05	-.34750E 05	-.34773E 05
DTMF	.42473E-05	-.35918E-05	.77159E-06	-.52495E-06	.10819E-05	-.[illegible]2545E-05
DXM	-.61964E-01	-.59317E-01	-.53287E-01	-.51323E-01	-.37670E-01	-.361[illegible]E-01
DYM	.17043E 02	.16471E 02	.16744E 02	.16177E 02	.16457E 02	.15[illegible]E 02
DZM	.18633E 00	.17783E 00	.17484E 00	.1688[illegible]E 00	.16807E 00	.15235E 00
DPITCH	-.41581E-01	-.40537E-01	-.70862E-01	-.[illegible]722E-01	-.95879E-01	-.[illegible]E-01
DYAW	-.39504E-01	-.36315E-01	-.97624E-01	-.94340E-01	-.80039E-01	-.75[illegible]E-01
DROLL	-.67643E 03	-.65357E 03	-.66409E 03	-.64157E 03	-.65239E 03	-.[illegible]E 03
PITCHS	.25546E-07	.10467E-06	.23159E-07	.[illegible]466E-07	.3313[illegible]E-07	.[illegible]3493E-07
YAWS	-.74252E-05	-.85713E-05	-.9[illegible]675E-05	-.83370E-05	-.912[illegible]E-05	-.[illegible]E-05
CROS	.62713E-07	-.39834E-07	.62373E-07	-.37874E-07	.6207[illegible]E-07	-.[illegible]E-07
RANS	.15445E-06	.15323E-06	.15114E-06	.14952E-06	.148[illegible]E-06	.14[illegible]04E-06
ALTS	.20337E-08	.26701E-08	.14288E-08	.24430E-08	.15279E-08	.21355E-08
ROLLS	-.27492E-06	-.26535E-06	-.26242E-06	-.25330E-06	-.25097E-06	-.24226E-06

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM
(CONTINUED)

(CONTINUOUS)

GSNO	1	2	1	2	1	2
TIMES	.12450E 01	.12463E 01	.12555E 01	.12558E 01	.12647E 01	[illegible]
XM	-.21427E 01	-.21433E 01	-.21578E 01	-.21599E 01	-.21439E 01	[illegible]
YM	.12775E 04	.12780E 04	.12965E 04	.12970E 04	.13151E 04	.13156E 04
ZM	.26270E 02	.26276E 02	.26468E 02	.26474E 02	.26630E 02	[illegible]
PITCH	.56742E 00	.56370E 00	.43586E 00	.43297E 00	.31024E 00	[illegible]
YAW	-.45759E 00	-.45750E 00	-.48786E 00	-.48961E 00	-.43054E 00	-.42732E 00
ROLL	-.35716E 05	-.35733E 05	-.36471E 05	-.36493E 05	-.37224E 05	-.37246E 05
DTMF	.12830E-05	-.64214E-06	.12368E-05	-.55772E-06	.10035E-05	[illegible]
DXM	-.16223E-01	-.15351E-01	.75580E-02	.77543E-02	.78079E-01	.27144E-01
DYM	.16185E 02	.15636E 02	.15722E 02	.15382E 02	.15646E 02	[illegible]
DZM	.16867E 00	.16307E 00	.17922E 00	.17341E 00	.20137E 00	[illegible]
DPITCH	-.11073E 00	-.10734E 00	-.10721E 00	-.10537E 00	-.83113E-01	[illegible]
DYAW	-.32507E-01	-.30574E-01	.43716E-01	.43524E-01	.14120E 00	[illegible]
DROLL	-.64377E 03	-.62205E 03	-.64217E 03	-.62053E 03	-.64072E 03	-.61215E 03
PITCHS	.40176E-07	.87214E-07	.48461E-07	.91164E-07	.56511E-07	.75154E-07
YAWS	-.89330E-05	-.79153E-05	-.85446E-05	-.77277E-05	-.86994E-05	-.75551E-05
CROS	.51775E-07	-.34327E-07	.61442E-07	-.32729E-07	.61013E-07	-.31146E-07
RANS	.14515E-06	.14281E-06	.14227E-06	.13982E-06	.13930E-06	.13717E-06
ALTS	.11511E-08	.17733E-08	.73740E-09	.13899E-08	.34857E-09	.10971E-08
ROLLS	-.24943E-06	-.23210E-06	-.23066E-06	-.22263E-06	-.22148E-06	-.21342E-06

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM
(CONTINUED)

(CONTINUOUS)

GSNO	1	2	1	2	1	2
TIMES	.12737E 01	.12740E 01	.12826E 01	.12828E 01	.12912E 01	[illegible]
XM	-.21152E 01	-.21140E 01	-.20746E 01	-.20736E 01	-.20569E 01	[illegible]
YM	.13335E 04	.13340E 04	.13515E 04	.13520E 04	.13673E 04	[illegible]
ZM	.26919E 02	.26926E 02	.27198E 02	.27207E 02	.27527E 02	[illegible]
PITCH	.21681E 00	.21488E 00	.17499E 00	.19578E 00	.27045E 00	[illegible]
YAW	-.25576E 00	-.24724E 00	.35541E-01	.46593E-01	.42893E 00	[illegible]
ROLL	-.37975E 05	-.37977E 05	-.38725E 05	-.38746E 05	-.37473E 05	[illegible]
DTMF	.36073E-05	-.67354E-08	-.67150E-06	.51557E-06	[illegible]	[illegible]
DXM	.35111E-01	.33950E-01	.18157E-01	.17136E-01	[illegible]	[illegible]
DYM	.15415E 02	.14895E 02	.15170E 02	.14662E 02	[illegible]	[illegible]
DZM	.23510E 00	.22781E 00	.27670E 00	.26835E 00	[illegible]	[illegible]
DPITCH	-.24840E-01	-.22912E-01	.71927E-01	.71201E-01	.21051E 00	[illegible]
DYAW	.24416E 00	.23756E 00	.32958E 00	.31874E 00	.35245E 00	[illegible]
DROLL	-.63722E 03	-.61731E 03	-.63765E 03	-.61645E 03	[illegible]	[illegible]
PITCHS	.62227E-07	.72308E-07	.63963E-07	.71105E-07	[illegible]	[illegible]
YAWS	-.85438E-05	-.73968E-05	-.83774E-05	-.72520E-05	-.82042E-05	[illegible]
CROS	.60493E-07	-.29842E-07	.57850E-07	[illegible]	[illegible]	[illegible]
RANS	.13517E-05	.13455E-05	.13294E-06	.13225E-06	[illegible]	[illegible]
ALTS	.69290E-10	.77110E-09	.26770E-11	.73272E-09	[illegible]	[illegible]
ROLLS	-.21282E-06	-.20548E-06	-.20466E-06	-.19761E-06	-.19676E-06	[illegible]

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM
(CONTINUED)

(CONTINUOUS)

GSNO	1	2	1	2	1	2
TIMES	.12997E 01	.13000E 01	.13080E 01	.13083E 01	.13161E 01	.13164E 01
XM	-.21063E 01	-.21092E 01	-.22789E 01	-.22869E 01	-.26357E 01	[illegible]
YM	.13869E 04	.13873E 04	.14040E 04	.14045E 04	.14210E 04	[illegible]
ZM	.27704E 02	.27715E 02	.28307E 02	.28319E 02	.28687E 02	[illegible]
PITCH	.55163E 00	.56204E 00	.10138E 01	.10367E 01	.17085E 01	[illegible]
YAW	.85230E 00	.86434E 00	.11778E 01	.12072E 01	.13105E 01	[illegible]
ROLL	-.40217E 05	-.40241E 05	-.40763E 05	-.40785E 05	-.41704E 05	[illegible]
DTMF	-.37367E-05	.20745E-05	-.57056E-05	[illegible]	-.77121E-05	[illegible]
DXM	-.13773E 00	-.13459E 00	-.29035E 00	-.28355E 00	[illegible]	[illegible]
DYM	.14676E 02	.14215E 02	.14473E 02	.14007E 02	.14266E 02	[illegible]
DZM	.34374E 00	.33303E 00	.32830E 00	.31721E 00	[illegible]	[illegible]
DPITCH	.39431E 00	.37485E 00	.57446E 00	.55877E 00	[illegible]	[illegible]
DYAW	.30636E 00	.29484E 00	.11795E 00	.10966E 00	[illegible]	[illegible]
DROLL	-.63417E 03	-.61357E 03	-.63228E 03	-.61202E 03	[illegible]	[illegible]
PITCHS	.39820E-07	.80297E-07	.11598E-07	.92407E-07	[illegible]	[illegible]
YAWS	-.80327E-05	-.67715E-05	-.78762E-05	[illegible]	[illegible]	[illegible]
CROS	.58371E-07	-.26129E-07	.57675E-07	-.24976E-07	[illegible]	[illegible]
RANS	.12634E-06	.12810E-06	.12333E-06	.12605E-06	[illegible]	[illegible]
ALTS	.94465E-09	.15747E-08	.21330E-08	.26428E-08	[illegible]	[illegible]
ROLLS	-.18967E-06	-.18318E-06	-.18285E-06	-.17658E-06	-.17645E-06	[illegible]

TABLE 3 VARIATIONS AND SENSITIVITIES OF SKEWED SYSTEM
(CONTINUED)

(CONTINUOUS)

GSNO	1	2	1	2	1	2
TIMES	.13241E 01	.13244E 01	.13319E 01	.13322E 01	.13396E 01	.13399E 01
XM	-.32243E 01	-.32482E 01	-.40508E 01	-.40835E 01	-.50354E 01	-.50723E 01
YM	.14377E 04	.14382E 04	.14542E 04	.14547E 04	.14704E 04	.14710E 04
ZM	.28947E 02	.28754E 02	.28947E 02	.28940E 02	.28478E 02	[illegible]
PITCH	.25341E 01	.26152E 01	.35187E 01	.35495E 01	.42408E 01	[illegible]
YAW	.97706E 00	.95487E 00	-.41649E-01	-.73317E-01	-.19837E 01	-.20737E 01
ROLL	-.42443E 05	-.42433E 05	-.43179E 05	-.43187E 05	-.43855E 05	[illegible]
DTMF	-.95255E-05	.20007E-05	-.10186E-04	-.72918E-06	-.69040E-05	[illegible]
DXM	-.59234E 00	-.67447E 00	-.83757E 00	-.81470E 00	-.90262E 00	[illegible]
DYM	.14073E 02	.13632E 02	.13723E 02	.13477E 02	.13825E 02	[illegible]
DZM	.21553E-01	.16085E-01	-.36403E 00	-.36193E 00	-.95704E 00	[illegible]
DPITCH	.30267E 00	.77734E 00	.64642E 00	.62002E 00	.97419E-01	.75142E-01
DYAW	-.81817E 00	-.80404E 00	-.15977E 01	-.15540E 01	-.25236E 01	[illegible]
DROLL	-.55405E 03	-.56403E 03	-.53017E 03	-.57238E 03	-.67892E 03	[illegible]
PITCHS	-.85351E-07	.12503E-06	-.15563E-06	.13296E-06	-.23586E-06	[illegible]
YAWS	-.76854E-05	-.65783E-05	-.77118E-05	-.63966E-05	-.78944E-05	[illegible]
CROS	.57159E-07	-.22526E-07	.57749E-07	-.21365E-07	.59509E-07	[illegible]
RANS	.11923E-06	.12127E-06	.11913E-06	.11812E-06	.12141E-06	[illegible]
ALTS	.60335E-08	.57895E-08	.84701E-08	.77694E-08	.10747E-07	[illegible]
ROLLS	-.17045E-06	-.16488E-06	-.16471E-06	-.15938E-06	-.16025E-06	[illegible]

TABLE 4

PRODUCTS OF SENSITIVITY AND VARIATION

(a) <u>Straight System</u>

Downrange	10	100	500	800	1000	1200	1500
Roll	.4E-07	.1E-06	.7E-08	.2E-08	.7E-09	.4E-09	.5E-08
Altitude	.1E-10	.3E-10	.3E-11	.4E-07	.4E-12	.1E-12	.1E-09
Range	.1E-07	.3E-07	.1E-08	.2E-09	.2E-09	.1E-09	.2E-08
Crossrange	.2E-11	.1E-10	.2E-11	.4E-12	.3E-12	.3E-12	.1E-09
Yaw	.5E-11	.4E-09	.1E-10	.6E-11	.4E-11	.1E-10	.5E-08
Pitch	.4E-08	.4E-06	.2E-08	.6E-09	.1E-08	.4E-10	.4E-07

TABLE 4 (cont.)

PRODUCTS OF SENSITIVITY AND VARIATION

(b) Skewed System

Downrange	10	100	500	800	1000	1200	1500
Roll	.15E-02	.7E-01	.4E-02	.1E-02	.4E-03	.2E-03	.1E-03
Altitude	.27E-07	.2E-06	.2E-07	.2E-08	.1E-08	.4E-09	.1E-07
Range	.10E-05	.7E-03	.2E-04	.1E-04	.4E-05	.3E-05	.1E-05
Crossrange	.10E-15	.3E-07	.2E-07	.1E-07	.4E-08	.2E-07	.2E-07
Yaw	.20E-08	.4E-05	.8E-07	.2E-06	.3E-06	.5E-06	.1E-04
Pitch	.10E-22	.2E-05	.2E-07	.1E-08	.5E-08	.1E-08	.1E-07

EXPERIMENTAL PROGRAM

(a) Description of the Experiment

The objective of the experimental program was to verify the system concept, in particular the mathematical formulation developed in the previous sections. It might be expected that problem areas not identified in the mathematical studies and earlier concept studies could be uncovered and investigated using the experimental apparatus.

Two static laser ground stations were fabricated, in addition to a model rocket equipped with two, 90° roof prisms. The ground stations were located on a line x = 30 ft. crossrange, and the rocket was systematically positioned at various y and z coordinates along the line x = 0 in the earth fixed system.

Each ground station incorporated a 3mw helium-neon laser operating at 6328 Å,* a spatial filter and collimator. A mounting ring for the photodetectors was fixed to the collimator. Two holes were drilled through the ring and the photodetectors were inserted from the back and epoxied in place (see Figure 18). No auxiliary optics were used in the detection system since it was found that an adequate signal was obtained without this complication. A simple amplifier for the signal from the photodetectors was housed in a small aluminum chassis box which was epoxied to the top of the laser.

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*Metrogic Model 420 Laser

The model rocket consisted of a short, heavy-walled, aluminum cylinder. At one axial position, two holes were bored through the wall of the cylinder. These holes were separated circumferentially by ninety degrees. One hole accomodated a mount for a straight reflector, and the other one accomodated a mount for a skewed reflector, allowing the angle γ for the reflector to be adjusted to a particular value prior to conducting the experiment. The details of the design of the rocket may be seen in Figure 19.

A steel drive shaft was attached to the back of the cylinder along the axis of the cylinder. The shaft was supported in cantilever fashion, with two ball bearings which were mounted in bearing blocks which were in turn attached to a base plate. An electric gear motor (9.61 rpm) was attached to the base plate and coupled to the drive shaft through a flexible coupling (see Figure 20).

Both lasers were mounted on heavy duty metal tripods to facilitate positioning and alignment. The model rocket was mounted on an L-bracket which was in turn attached to a rotary table. This arrangement provides a rather crude but rigid elevation over azimuth mount for the model.

In order to measure the various time intervals, two digital timers were used.* The output signals of the photodetectors were amplified in the amplifier located on top of each laser. The outputs of these amplifiers were used as inputs to the timers to initiate and terminate counting. A schematic representation of the detection/timing circuit is shown in

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*Universal Timer Model 7370
Hewlett Packard Timer Model 523DR

Figure 21. The detection/timing circuit was used to make three different types of measurements. Roll rate was measured using a signal from one laser ground station. The time interval for one complete revolution of the rocket was measured by starting and stopping the counter with consecutive pulses from a single photodetector. This measurement was checked with a nearly instantaneous measurement of the roll rate which was obtained by starting the counter with a pulse from a photodetector located in the mounting ring on top of the collimator, and stopping the counter with a pulse from a detector located in the same mounting ring directly below the center of the collimator. The time interval between return pulses to the two laser stations from the straight reflector was measured by starting the counter with the pulse received at station 1, and stopping the counter with the return pulse received at station 2. Simultaneously the time interval between pulse receptions from the straight and skewed reflectors at station 1 was measured. The same pulse which initiated counting in the previous measurement initiated counting on the second counter. This count was stopped however by a return pulse from the skewed reflector received at station 1.

It is apparent that with only two counters available, all three intervals of interest could not be measured simultaneously. In view of the fact that the gear motor is synchronous, and therefore the roll rate would only change with the line frequency, the roll rate was measured separately and assumed to remain constant. Although this seems to be a reasonable assumption, it has been found that significant frequency fluctuations occur in the service provided by the University

Power House. Therefore, the roll rate was measured before and after each attitude determination to check for constant roll rate.

(b) Results of the Experimental Program

Setting the angle γ and measuring the various angles to a high degree of accuracy ultimately required the use of lasers and large optical levers. The entire system including ground stations, model, and retro-reflectors were eventually aligned to an angular accuracy of .05°. Experiments were conducted with the model located at two different positions downrange and pitch and yaw attitudes varying from -20 to +20 degrees.

The measured time intervals were used to determine the pitch and yaw attitude using a Newton-Raphson technique as mentioned in the section entitled "Mathematical Description of the System". These tests indicate that, for the static system, the pitch and yaw can be determined to essentially the same accuracy as the experimental error associated with aligning the various components. Two demonstrations of this bench top system were conducted for army personnel.

CONCLUSIONS

In general, it may be concluded that both the analytical and experimental investigations of the skewed retroreflector two ground station system made to date indicate that such a system could be a useful range instrumentation technique. The analytical studies indicate that the pitch error due to dynamics in the short range area arises from roll rate and range errors introduced into the Δt_{12} equation. In this region the pitch and yaw solutions are weakly coupled and as a result the yaw solution remains quite good. Throughout the midrange region the solution for both pitch and yaw appear to be accurate to within a tenth of a degree which could be adequate for range instrumentation. At the extreme downrange position, yaw and pitch solutions are more strongly coupled and large errors in both pitch and yaw are encountered which would be inadequate for a range instrumentation system. This phenomenon was, however, due to an error in the simulation which caused the rocket to experience extremely large pitch and yaw rates (1500°/sec) in the neighborhood 1500 ft. downrange. These rates are unrealistically high.

It shouldbe pointed out that while almost all aspects of the ARROW vehicle simulation are quite typical of tactical missiles and rockets which would be tested, the extremely large roll acceleration throughout the trajectory is atypical. Since the roll error is significant in both Δt equations, it is anticipated that the error terms would typically be smaller than those presented here. It is therefore concluded that the indicated degradation of system performance at 1500 ft. downrange is not the result of an actual system limitation but rather the unrealistically high angular rates generated in the simulation.

Considerations such as ground station position optimization, retroreflector geometry optimization, and alternate methods of data analysis have not been addressed. Further, work in these areas could be expected to produce a more accurate system.

One limitation not pointed out previously is the fact that the 1500 feet range represents a maximum for retroreflection from the skewed reflector to ground station number 1. It is now apparent that somewhere near midrange an equation for Δt_{22} should have been substituted for Δt_{11} which could have allowed data reduction out to 2000 feet and could possibly result in imporved pitch and yaw solutions between 1300 feet and 2000 feet downrange. It should be noted that the yaw accuracy obtained is better than that associated with a similar system employing three ground stations and one single plane corner reflector onboard the vehicle[(3)].

In summary, the two station concept offers all of the advantages orginally anticipated for the three station system with the additional economic advantage of eliminating one ground station. It appears that yaw accuracy will be better than that associated with the three station system. Additional study covering ground station position optimization, retroreflector geometry optimization, and data analysis solutions are all required prior to implementing the concept as a range instrumentation technique.

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2. Mermagen, W.H. and Clay, W.H., "The Design of a Second Generation Yawsonde", BRL Memorandum Report No. 2368, April 1974.

3. Pell, K.M., Russell, J.J., Nydahl, J.E. and Lindberg, W.R., "A Laser System for Determination of Rocket Attitude and Roll Rate", UWME-DR-4061051, July 1974.

4. Harris, J.L., "Integrated System Simulation Development, A Six Degree of Freedom Rigid Body Simulation", U.S. Army Missile Command, RD-TR-69-3.

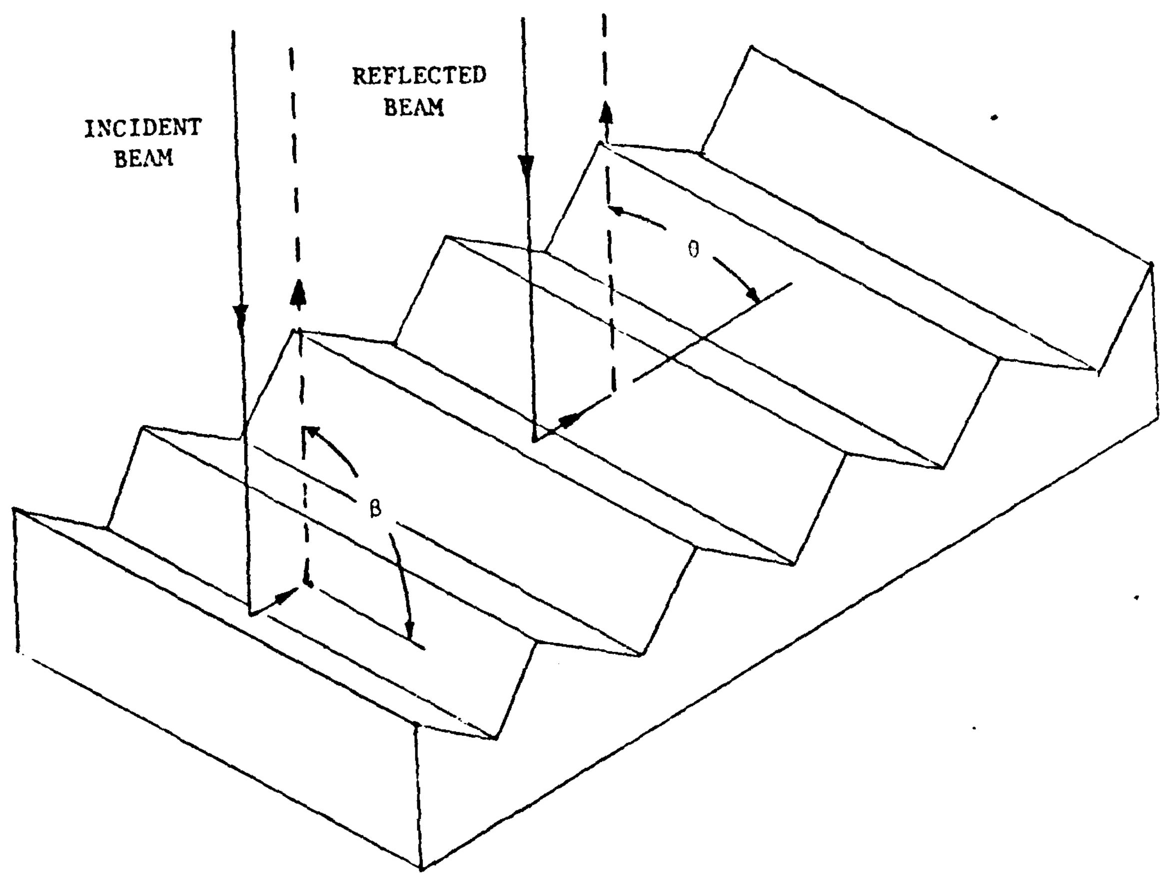


FIGURE 1 - SINGLE PLANE CORNER REFLECTOR

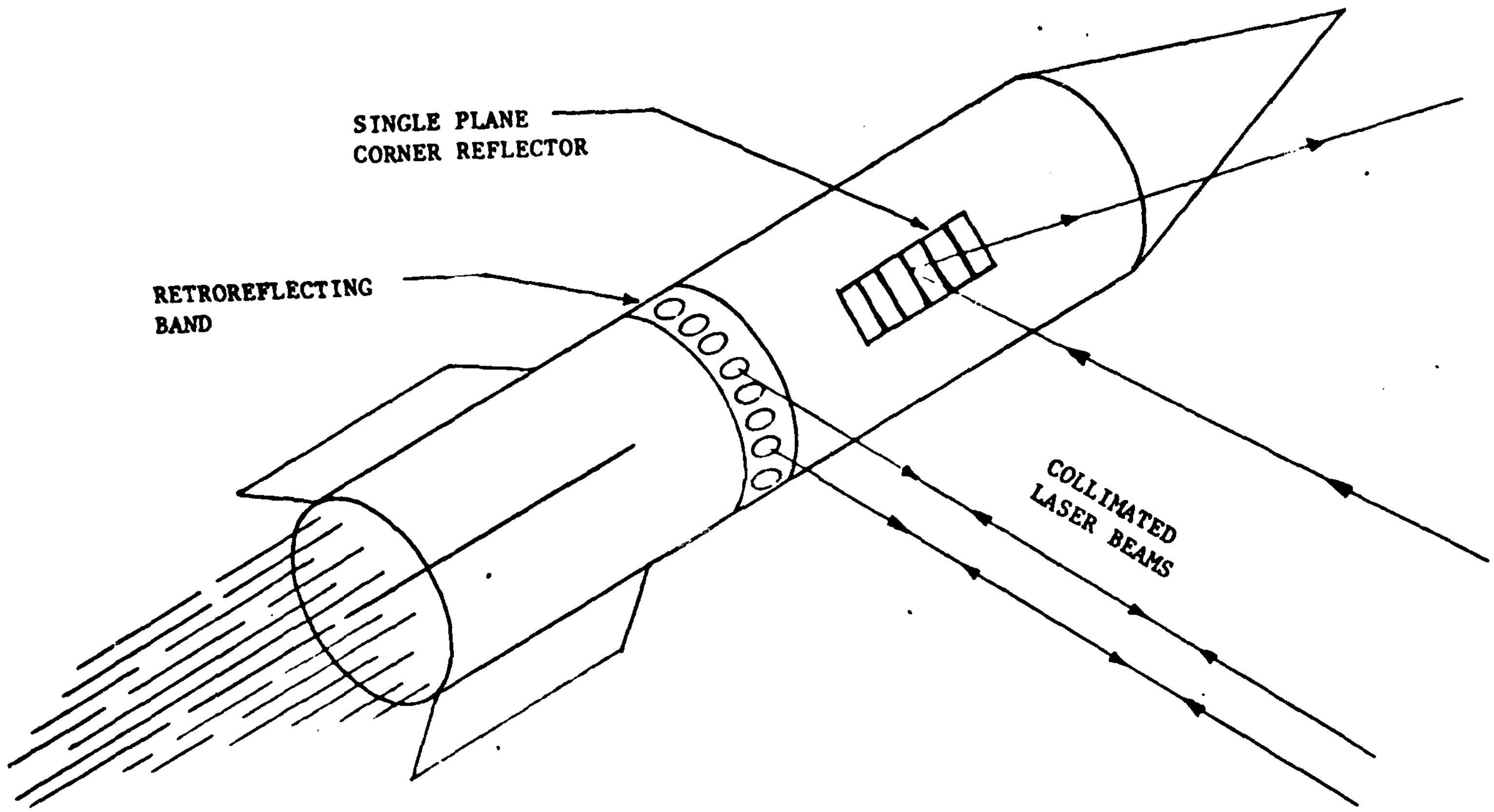


FIGURE 2 - ILLUSTRATION OF VEHICLE SHOWING RETROREFLECTORS

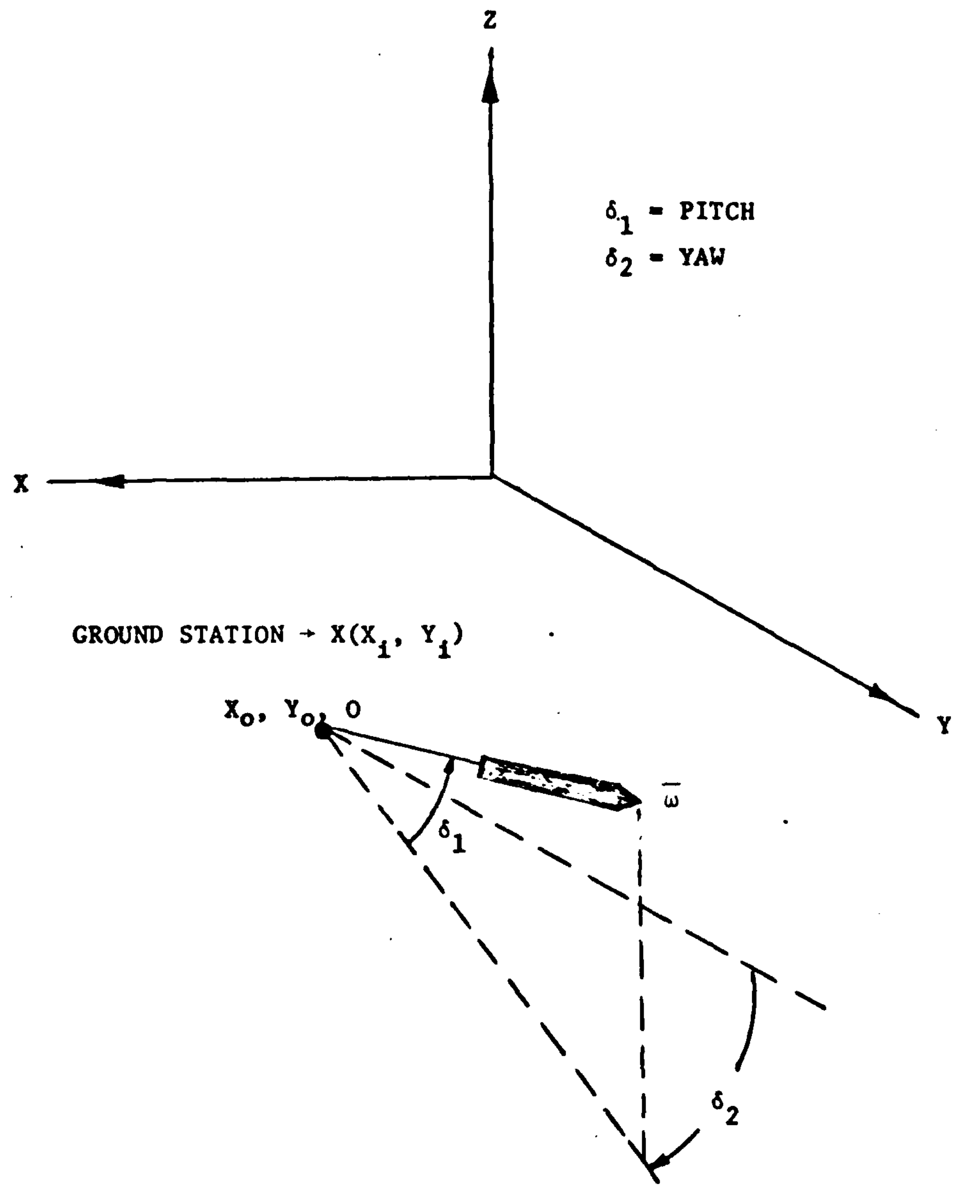


FIGURE 3 - X, Y, Z COORDINATE SYSTEM

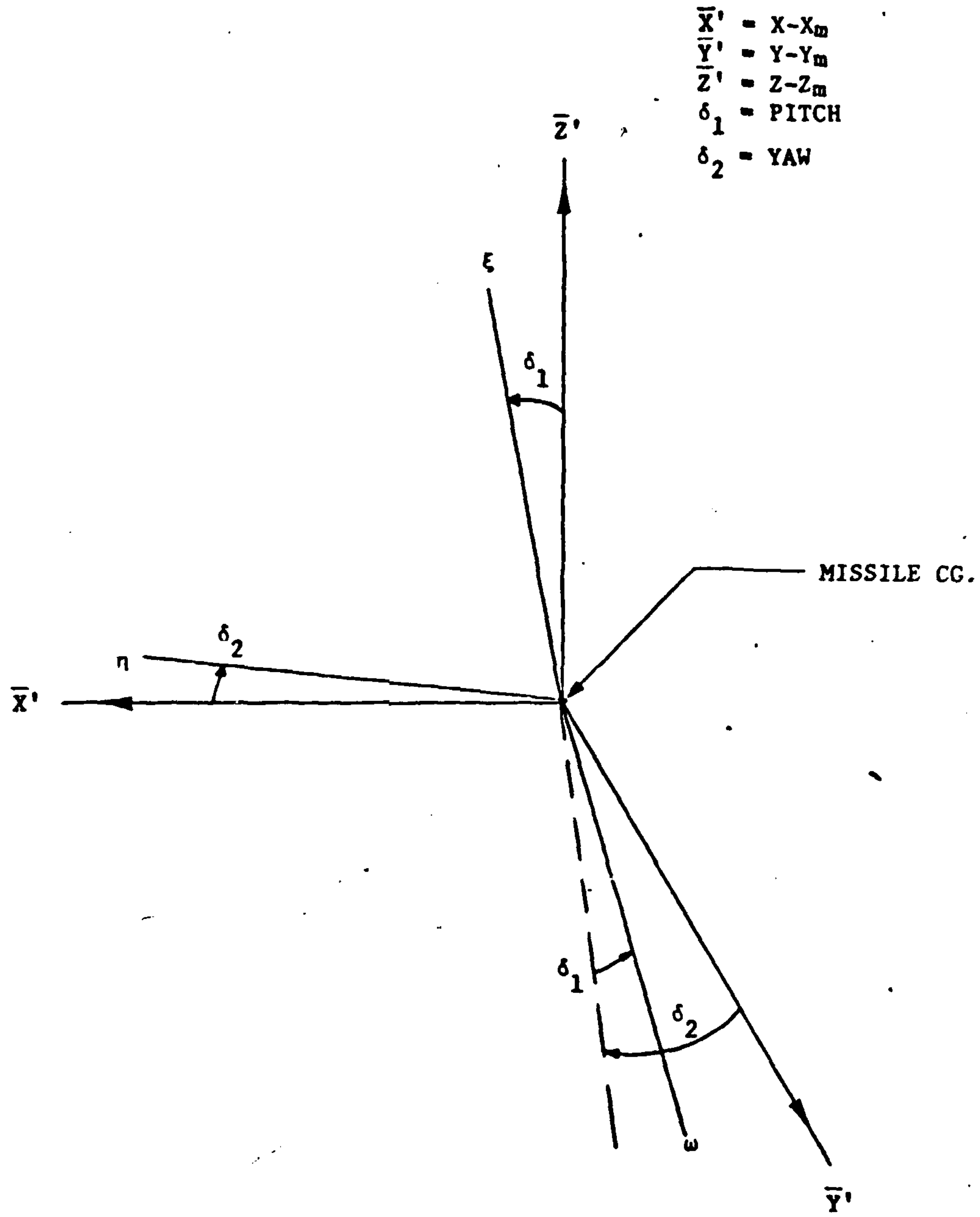
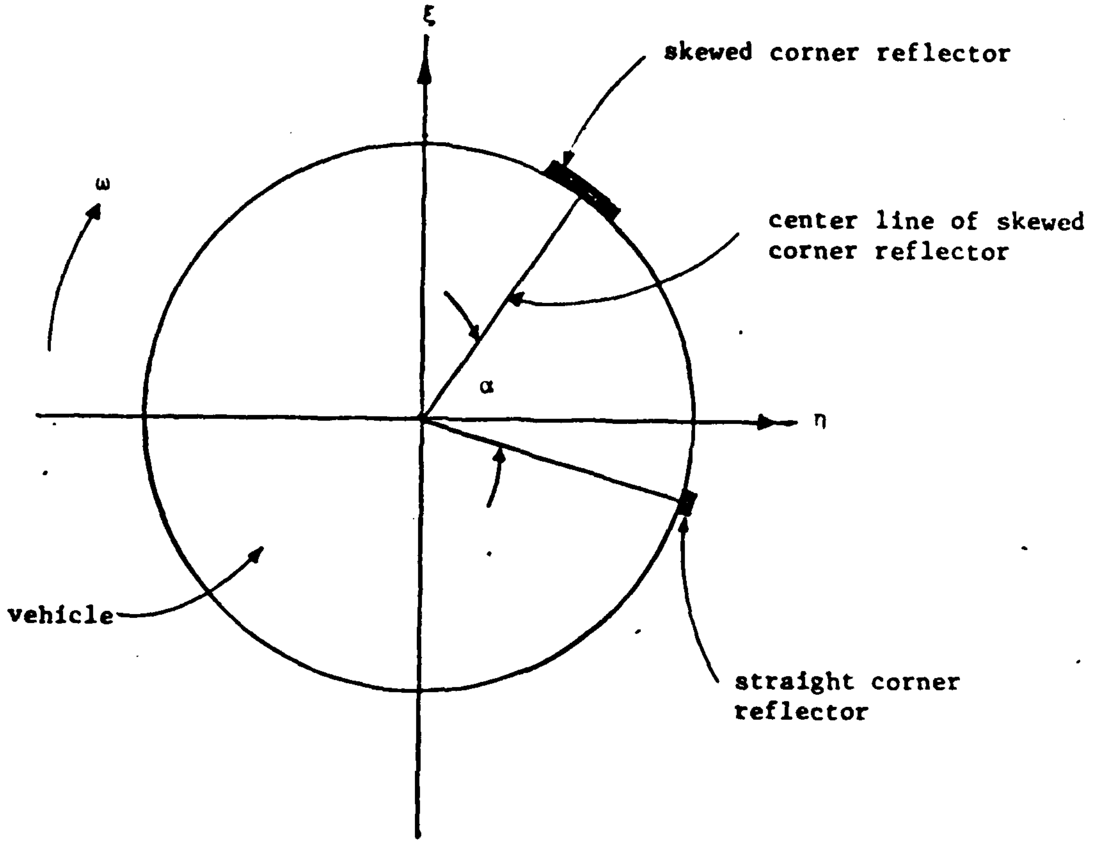
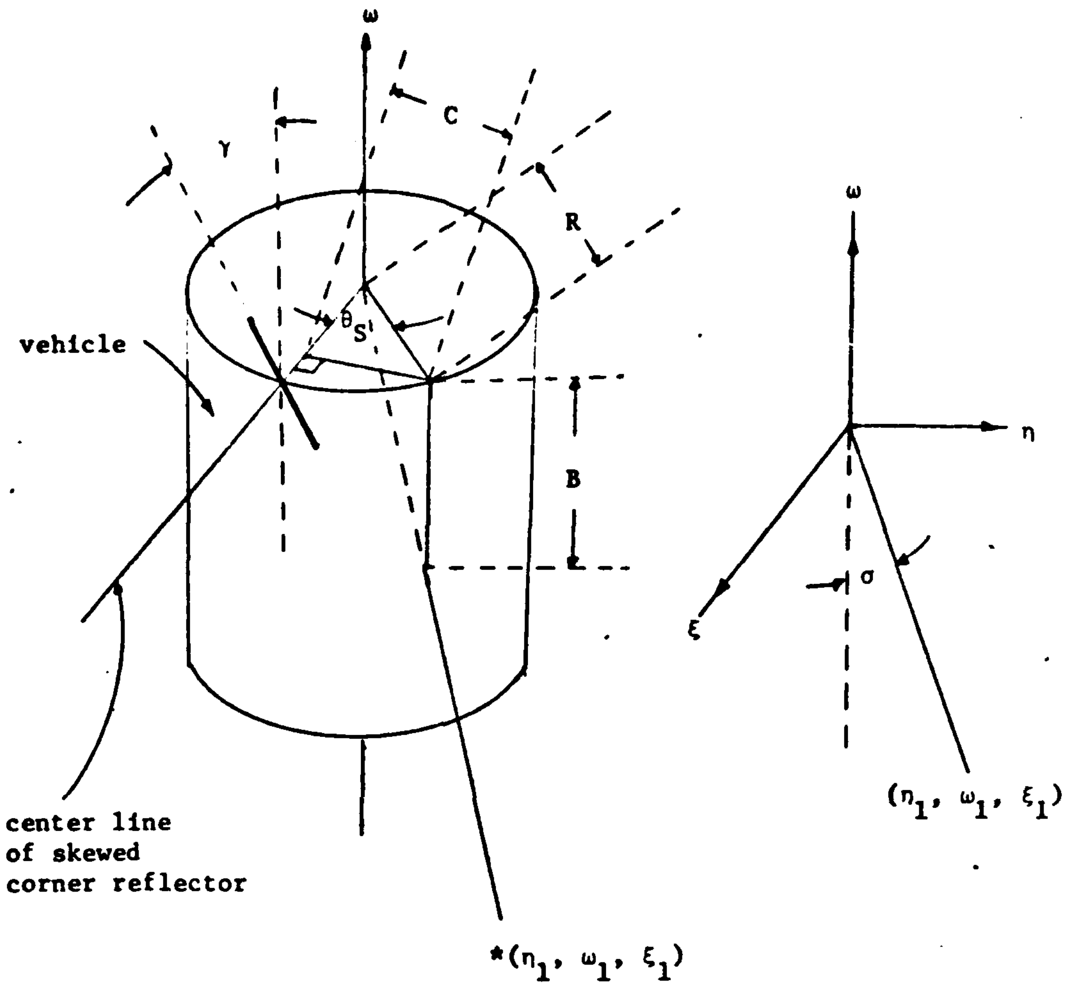


FIGURE 4 - $\overline{X}'$, $\overline{Y}'$, $\overline{Z}'$ COORDINATE SYSTEM



VEHICLE END VIEW

FIGURE 5 - CORNER REFLECTOR GEOMETRY RELATIVE TO VEHICLE

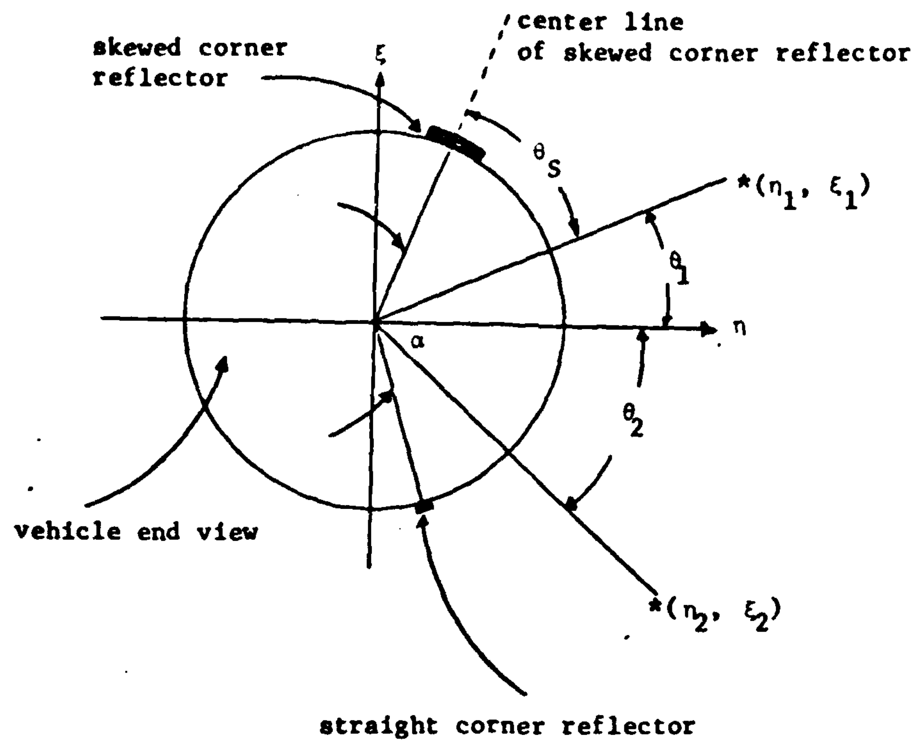


$$\tan(\gamma) = \frac{C}{B} \qquad \sin(\theta_S) = \frac{\tan(\gamma)}{\tan(\sigma)}$$

$$\tan(\sigma) = \frac{R}{B}$$

$$\sin(\theta_S) = \frac{C}{R} \qquad \tan(\sigma) = \frac{\omega_1}{(\eta_1^{\,2} + \xi_1^{\,2})^{\frac{1}{2}}}$$

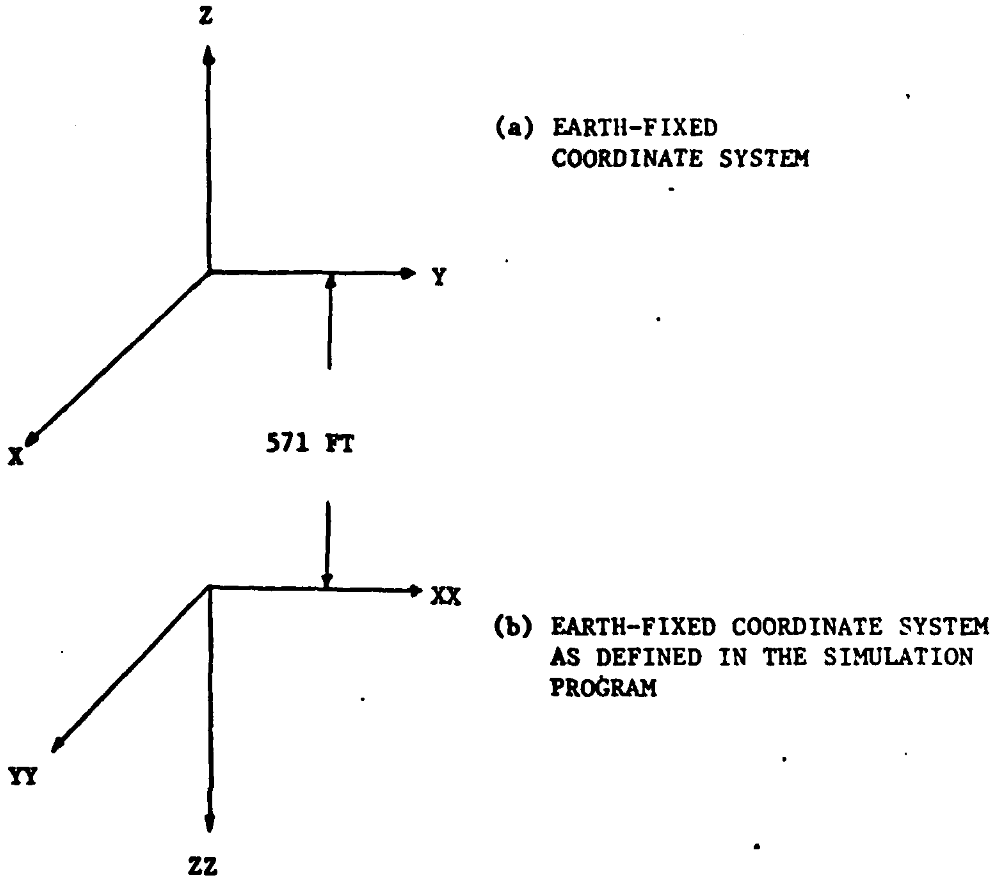
FIGURE 6 - GEOMETRY FOR ANALYSIS



$$\Omega\Delta t_{11} = 2\pi - (\alpha - \theta_S)$$

$$\Omega\Delta t_{21} = \theta_1 - \theta_2$$

FIGURE 7 - GEOMETRY FOR ANALYSIS
FROM VEHICLE END VIEW



X = YY

Y = XX

Z = -ZZ - 571

FIGURE 8 - RELATIONSHIPS BETWEEN TWO EARTH-FIXED COORDINATE SYSTEMS

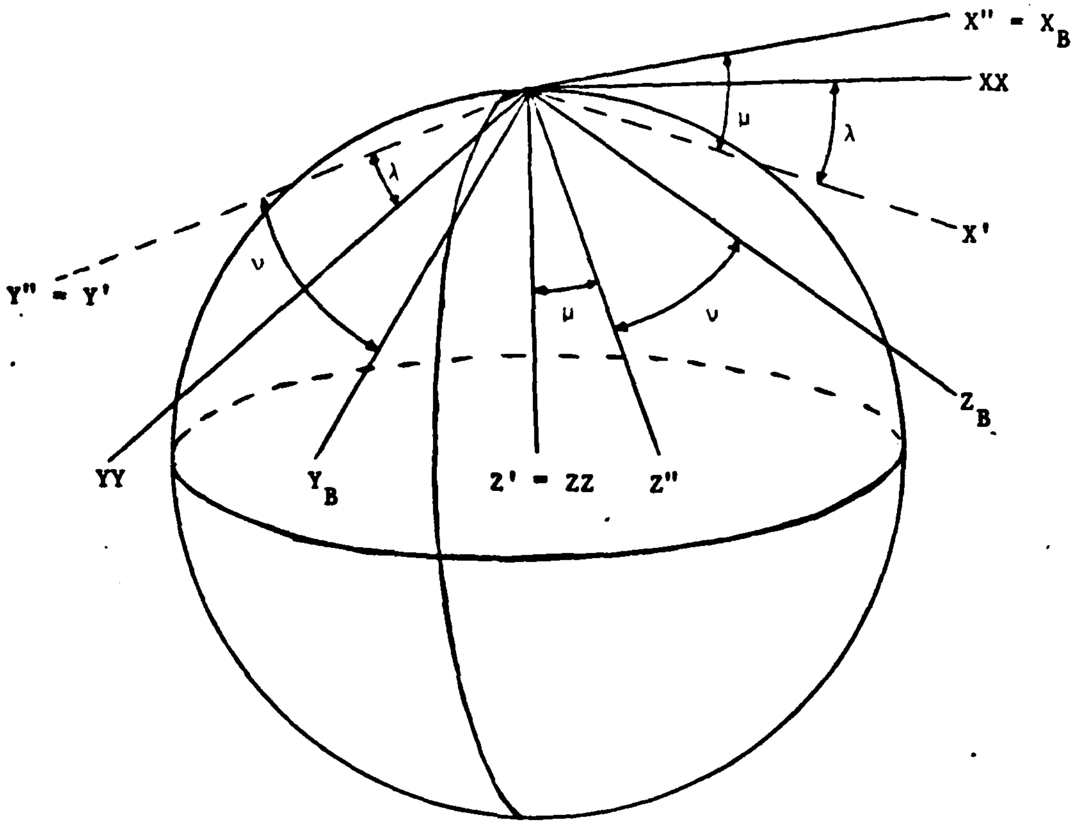


FIGURE 9 - RELATIONSHIP BETWEEN THE BODY FIXED

AND THE EARTH-FIXED COORDINATE SYSTEM

A rotation about the ZZ-axis through the angle λ produces the X'Y'Z' -coordinate system where Z' = ZZ. Then a rotation about Y' through the angle μ produces the X"Y"Z" -coordinate system where Y" = Y'. Finally, a rotation about the X" -axis through the angle ν produces the $X_BY_BZ_B$ -coordinate system.

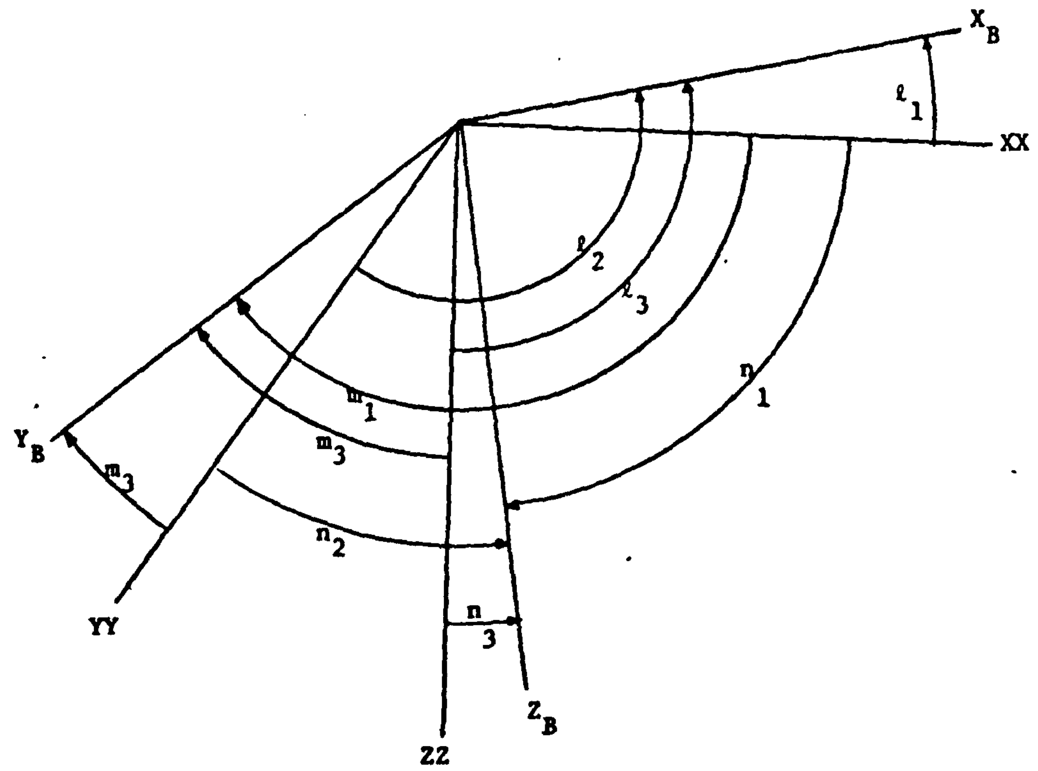


FIGURE 10 - DEFINITION OF DIRECTION COSINES

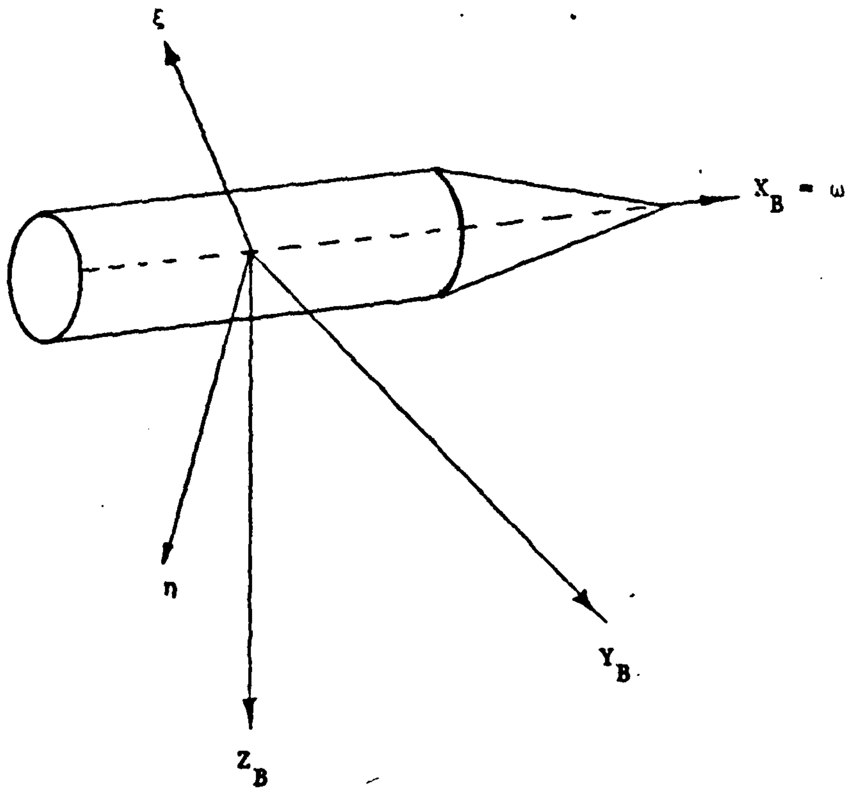
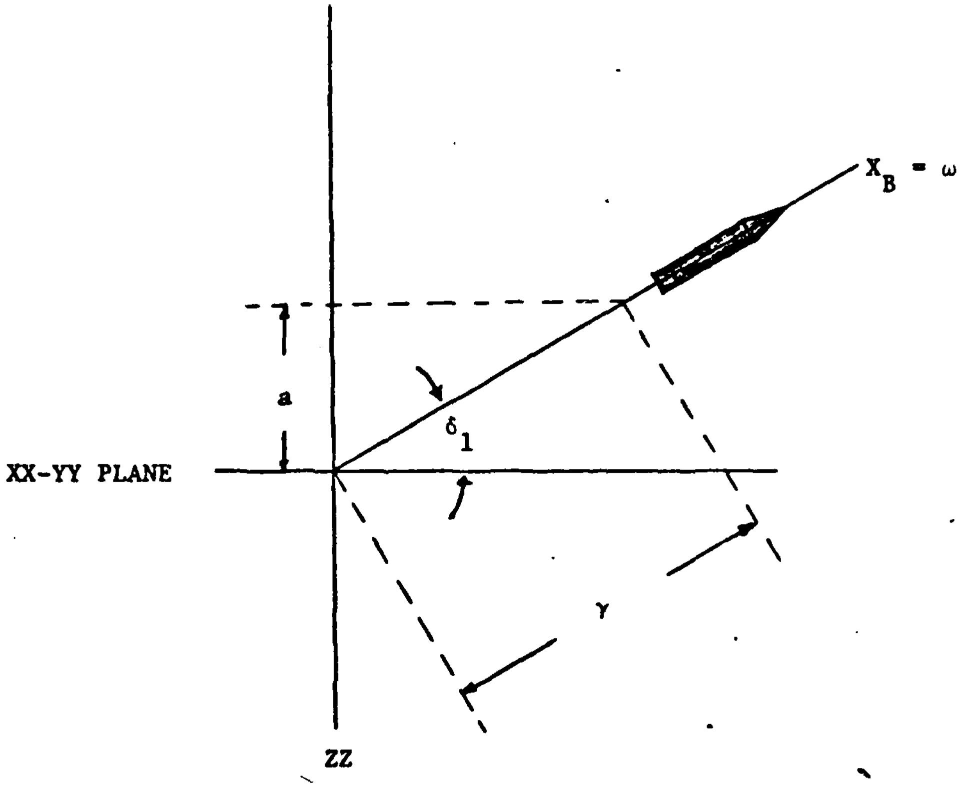


FIGURE 11 - DIFFERENCE BETWEEN ηωξ AND THE

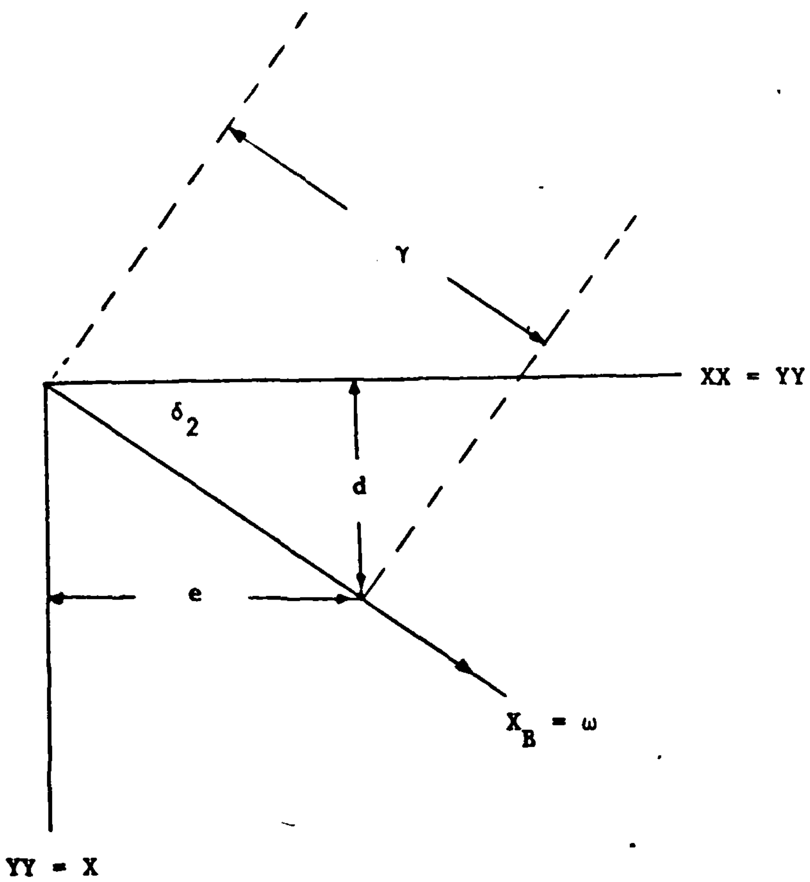
BODY-FIXED COORDINATE SYSTEM

η-axis always parallel to X-Y plane, Y_B and Z_B axis rotate at the same angular velocity as the vehicle does.



$$\sin(\delta_1) = \frac{a}{\gamma} = -\ell_3$$

FIGURE 12 - PITCH ANGLE IN TERMS OF DIRECTION COSINES



$$\tan(\delta_2) = \frac{d}{e} = \frac{d/r}{e/r} = \frac{\ell_2}{\ell_1}$$

FIGURE 13 - YAW ANGLE IN TERMS OF DIRECTION COSINES

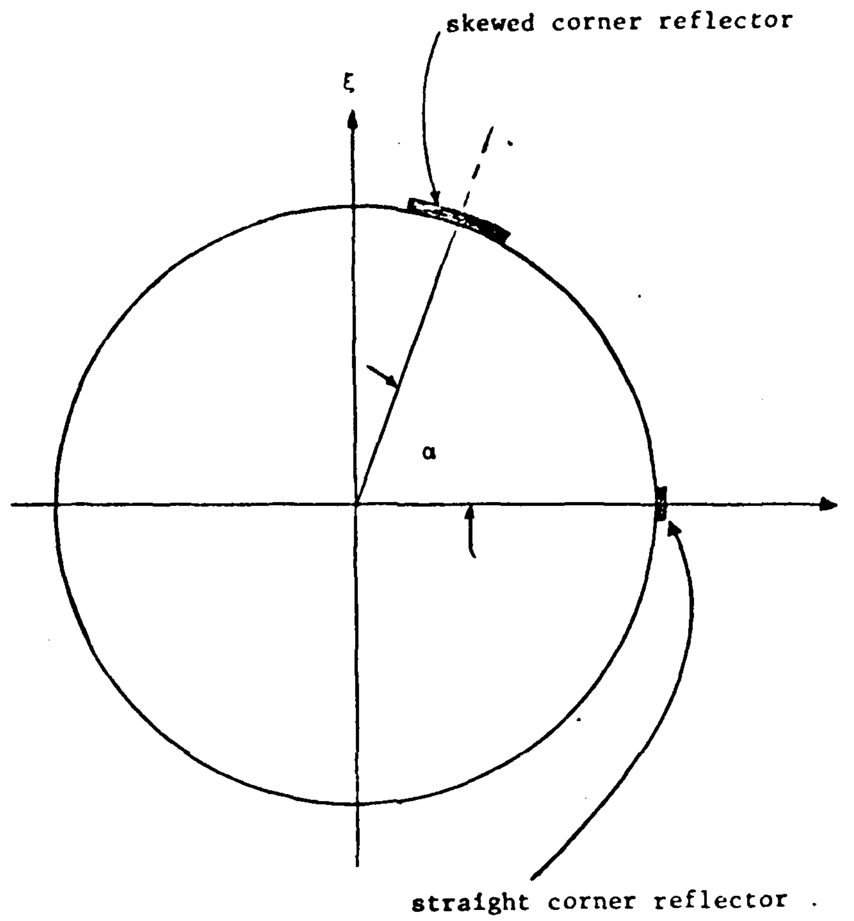
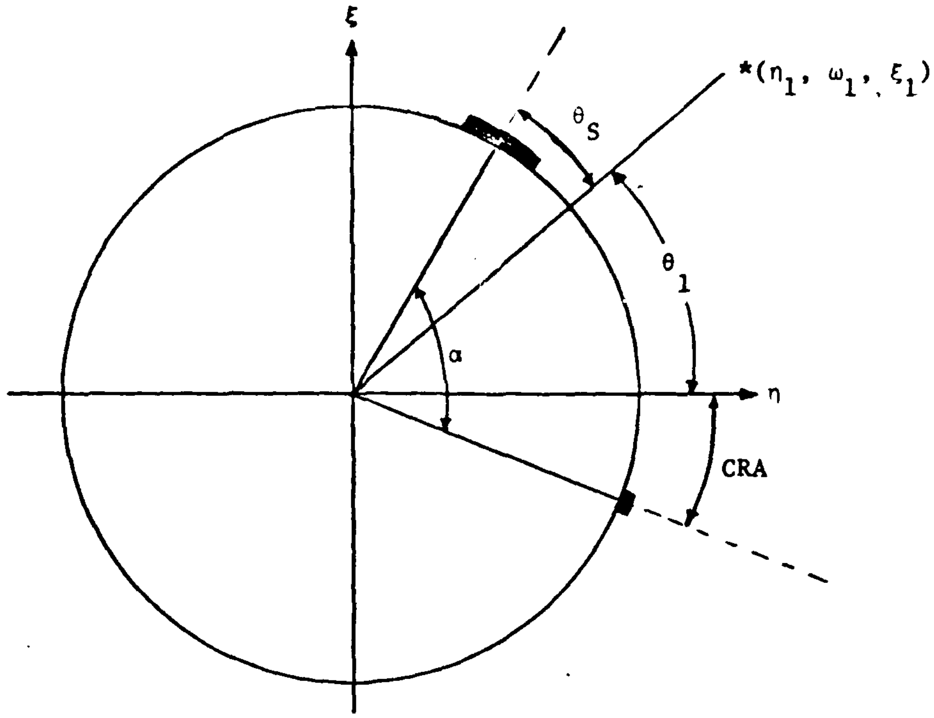
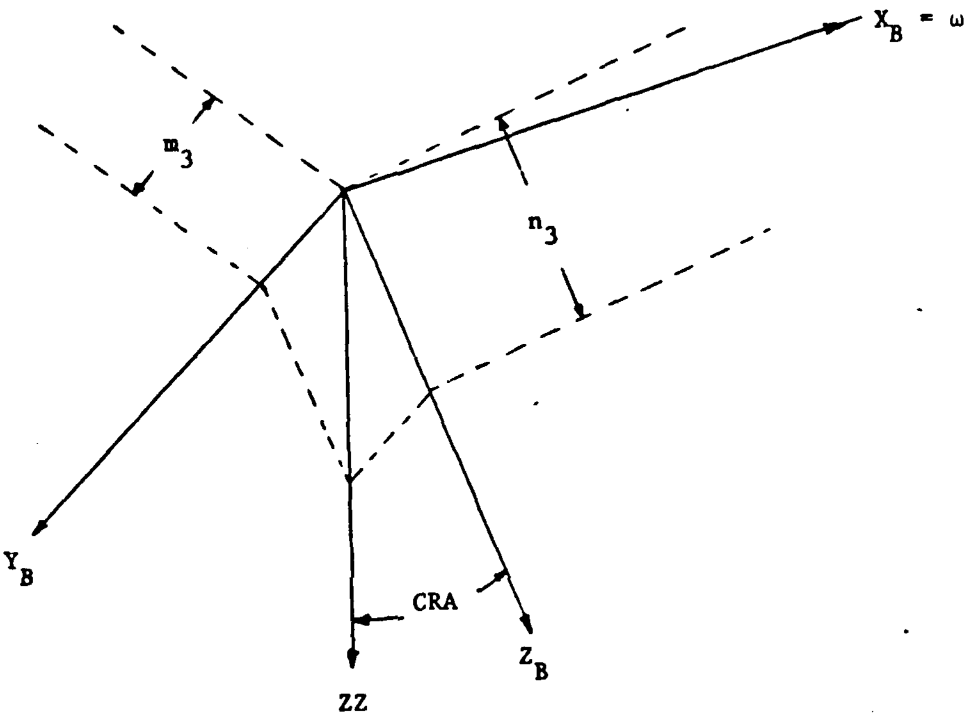


FIGURE 14 - GEOMETRY OF CORNER REFLECTOR AT t = 0



$$\alpha - \theta_S = \theta_1 + CRA$$

FIGURE 15 - GEOMETRY RELATING TO THE CORNER REFLECTOR ANGLE



$$\tan(CRA) = \frac{m_3}{n_3}$$

FIGURE 16 - CORNER REFLECTOR ANGLE IN TERMS OF DIRECTION COSINES

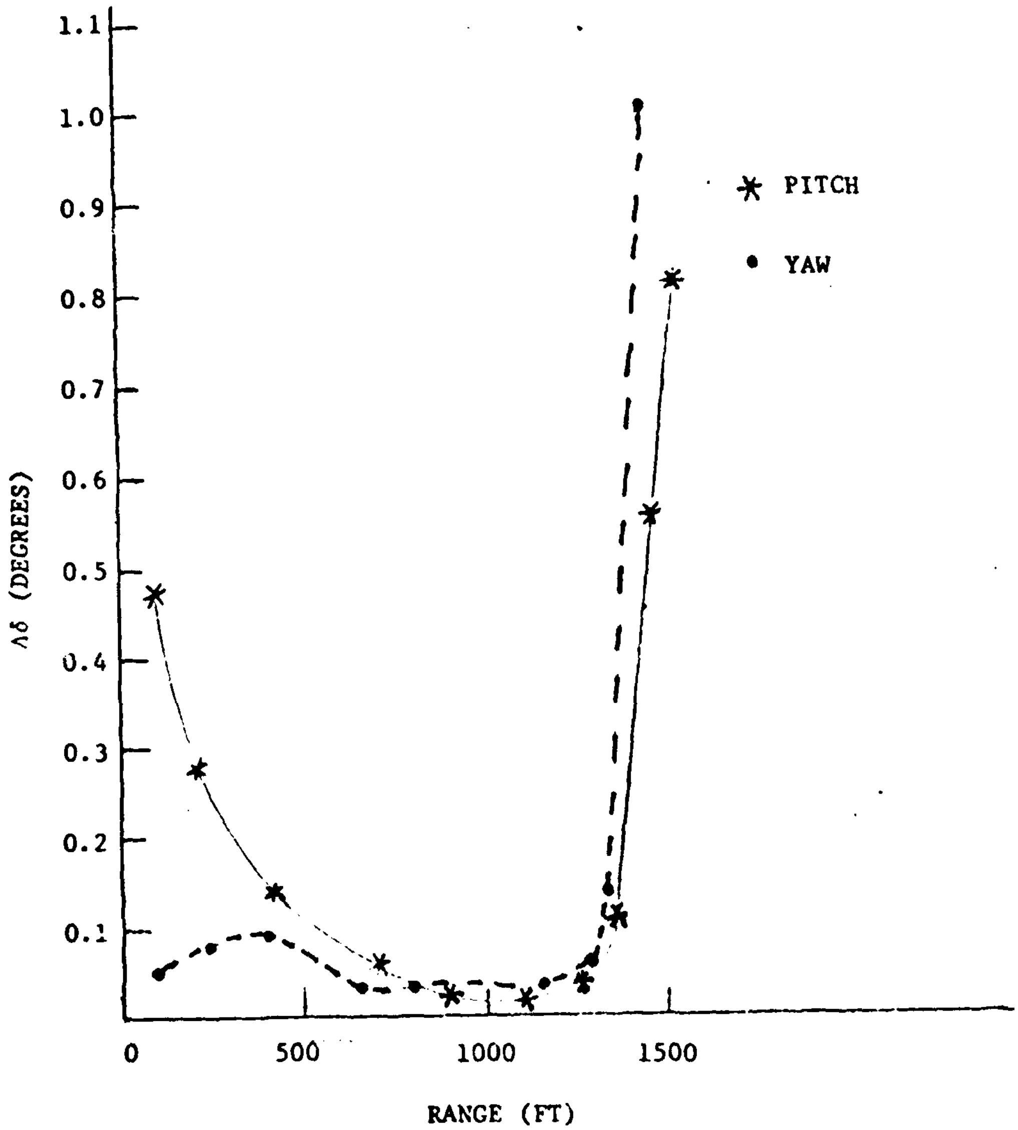


FIGURE 17 - PITCH AND YAW OF ERROR DISTRIBUTION WITH DOWNRANGE DISTANCE

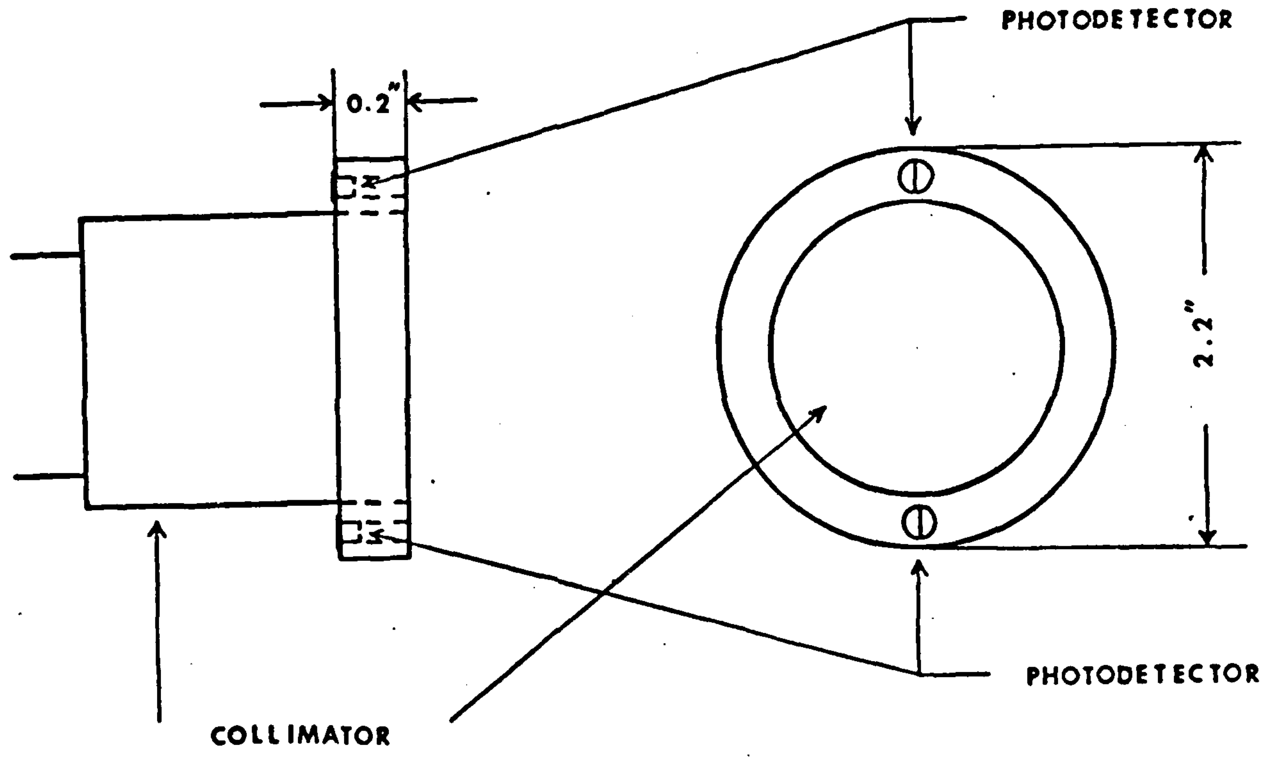


Figure 18. Schematic Drawing of Ring for Detectors

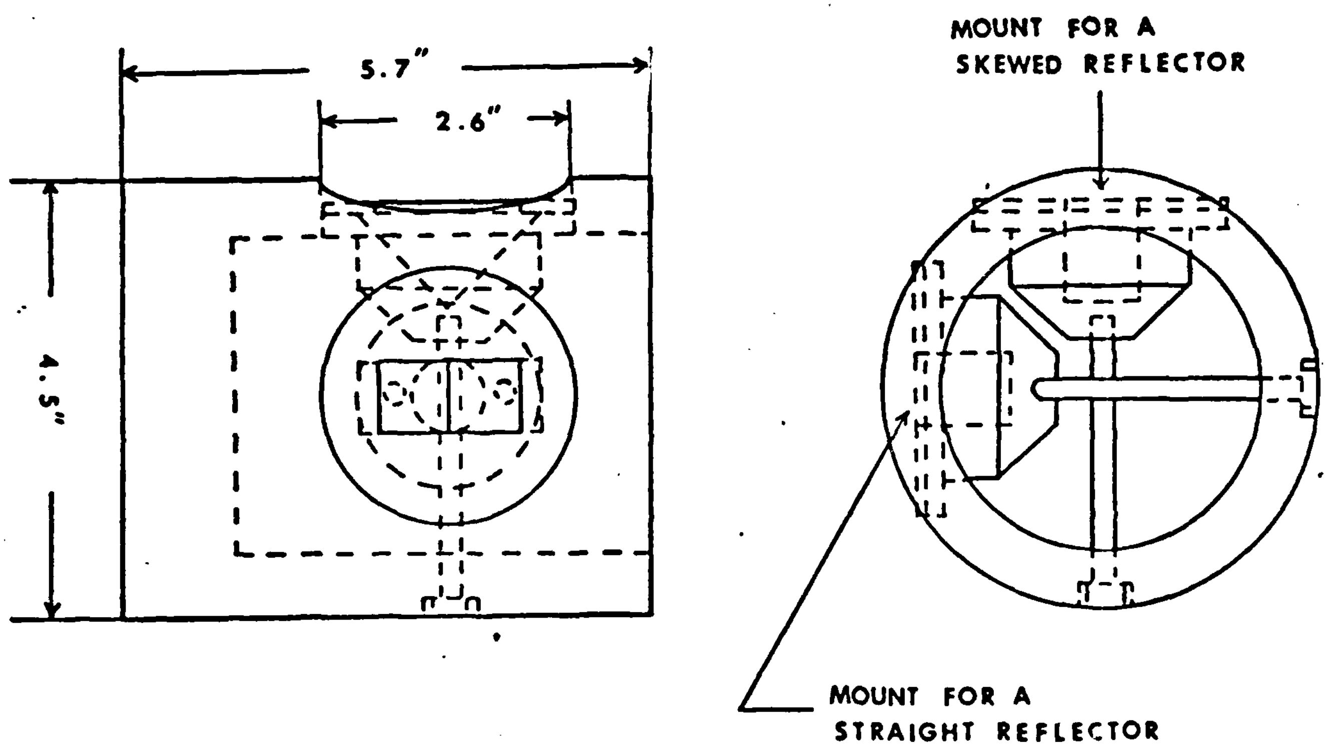


Figure 19. Schematic Drawing of Rocket Body

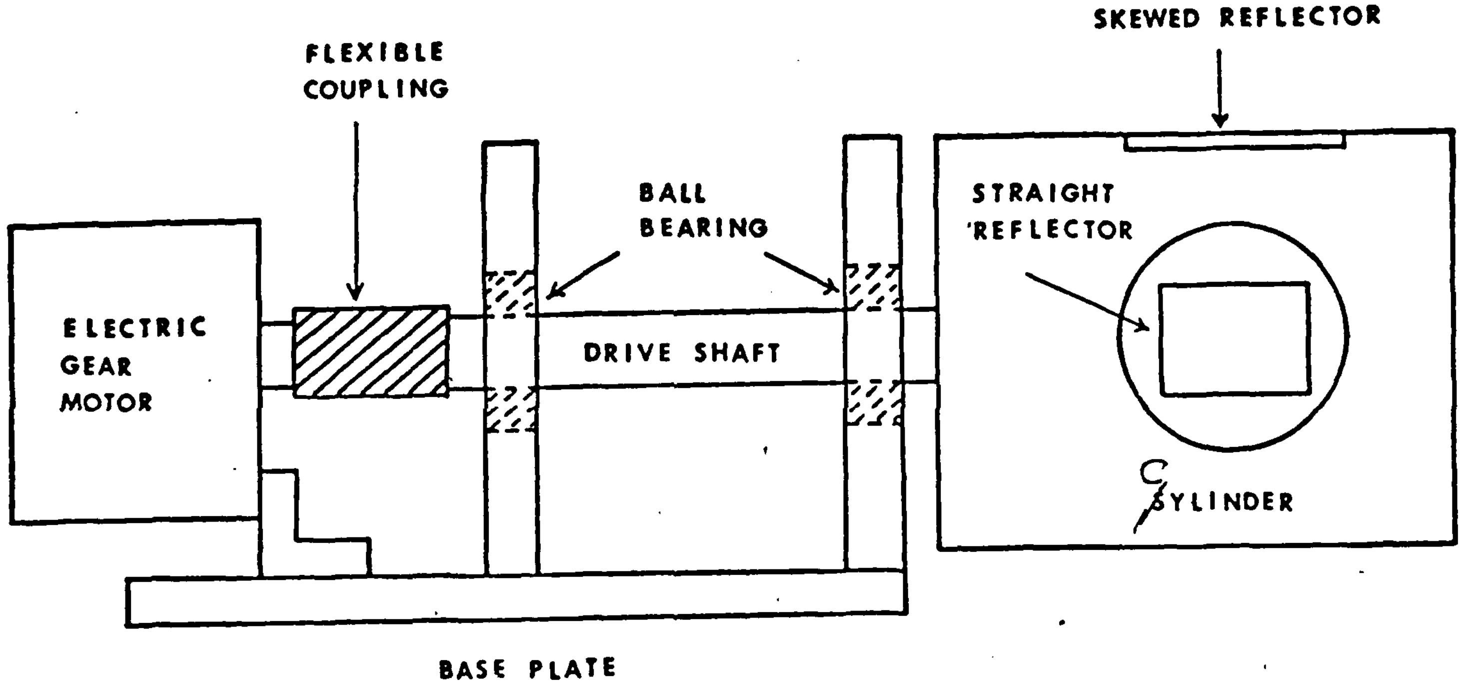


Figure 20. Schematic Drawing of Rocket Model

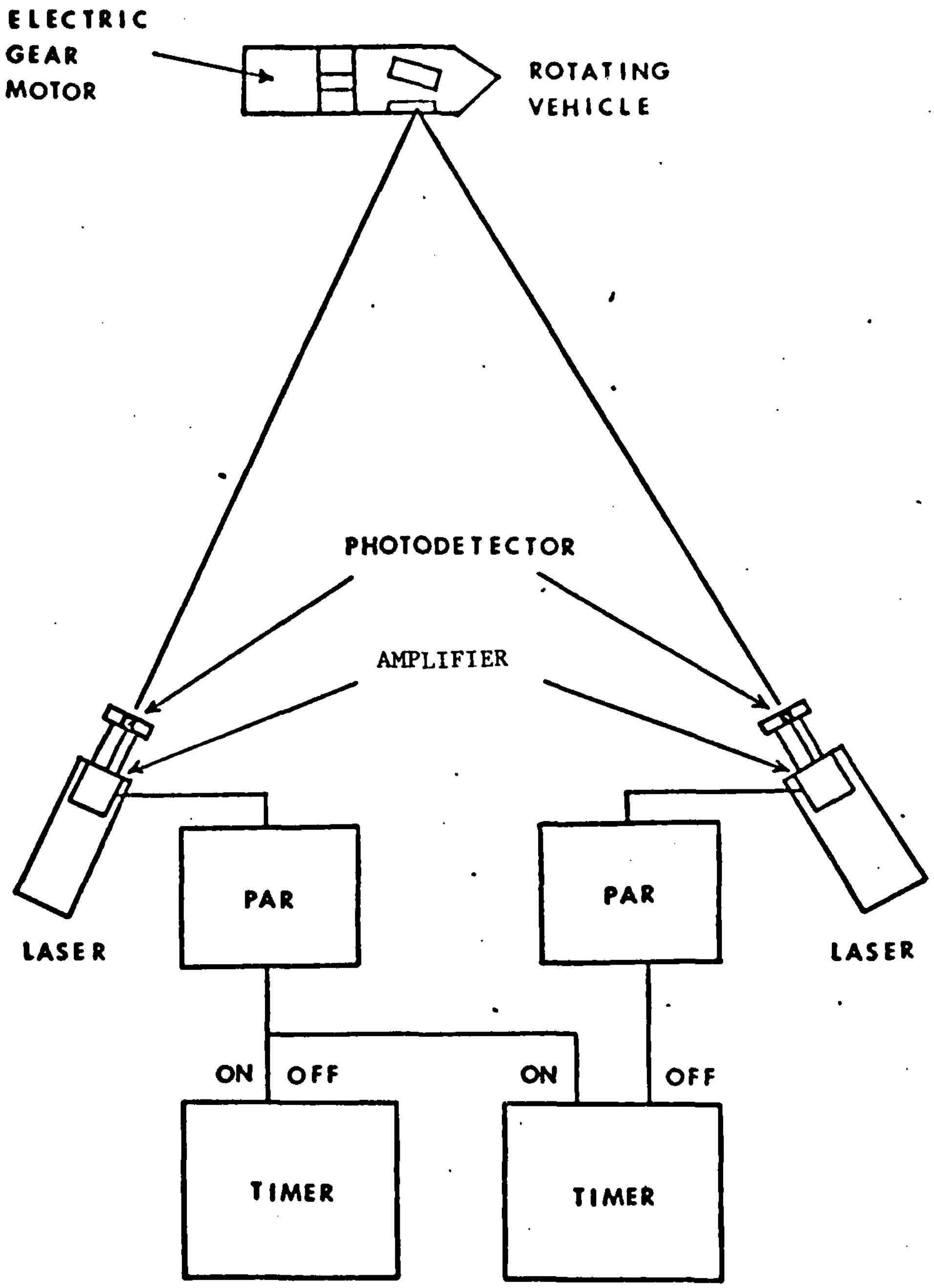


Figure 21. Schematic Representation of Detection/Timing Circuit