Drift Compensation and Acceleration Resolution for a Rotating Platform IMU

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Theme

THE Delco Carousel IMU in the Titan IIIC vehicle is similar to the conventional inertial platform except that two sets of the inertial instruments are mounted on a platform which rotates at 1 rpm about an inertially fixed axis. Derivations of navigation equations for acceleration resolution and drift compensation for the IMU are presented. The equations have been checked out and implemented in the flight computer.

Contents

The Carousel VB is an all attitude, 4 gimbal, inertial platform (see Fig. 1) in which two orthogonal gyros are mounted into a carousel which rotates at 1 rpm relative to an inertial azimuth defined by the third gyro. The accelerometers are similarly mounted. With this configuration, gyro fixed torque drift and accelerometer bias of the carousel instruments become sinusoidally modulated in inertial space.[1] Hence, uncompensable errors in these parameters cannot grow in the carousel plane. Figure 1 illustrates the Carousel VB gimbal and platform configuration and its mounting within the Titan IIIC vehicle. All four gimbal angles and the carousel angle are shown at zero. The nonrotating element is called the turret and the instrument axes are included for all instruments.

The flight computer program is divided into three segments. First, the ground align and level program sets up the system and performs a final update on several IMU parameters. After go inertial and liftoff of the Titan IIIC, the guidance and navigation program determines desired vehicle attitude and cutoffs. Finally, the digital autopilot program generates specific engine gimbal and ACS nozzle commands based upon actual vehicle attitude relative to desired attitude.

The ground align and level program uses torquing of the two carouseling gyros to maintain the system level during final countdown before liftoff. Specifically, the carousel bearing axis is aligned with the local gravity vector using the carousel accelerometer outputs for closing the loop. This torquing takes into account gyro misalignments, accelerometer misalignments and the local North component of Earth rate. The turret gyro remains untorqued, and hence inertial, resulting in rotation of the turret relative to the Earth's surface at minus the local vertical component of Earth rate.

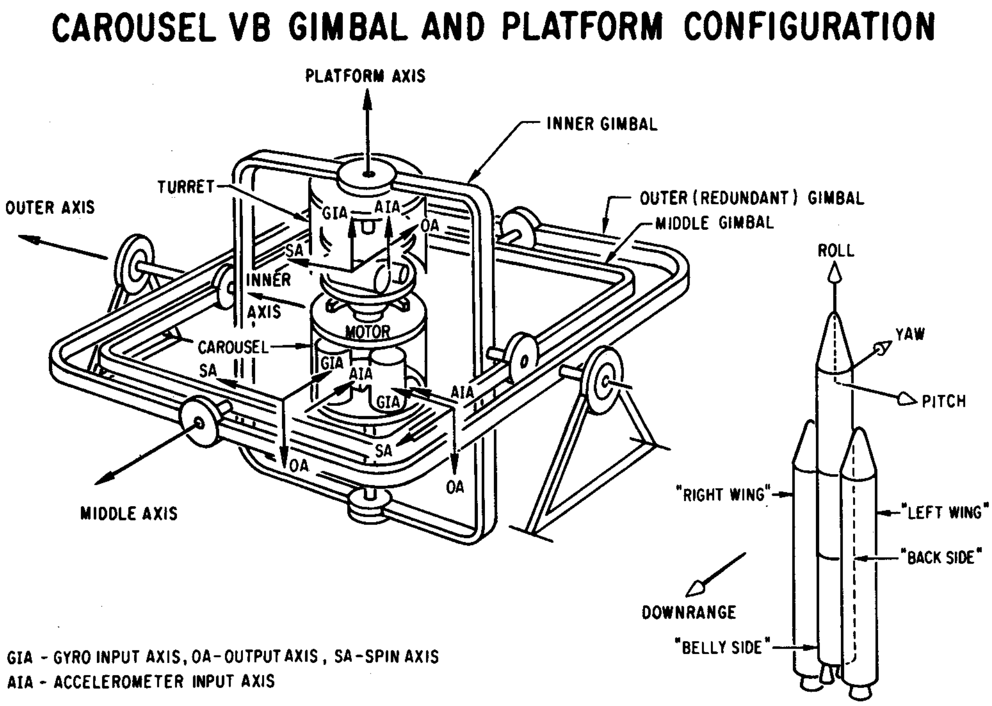

Fig. 1 Carousel V vehicle and gimbal axes (zero gimbal angles).

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Index categories: LV/M Guidance Systems (Including Command and Information Systems); Spacecraft Navigation, Guidance, and Flight-Path Control Systems.

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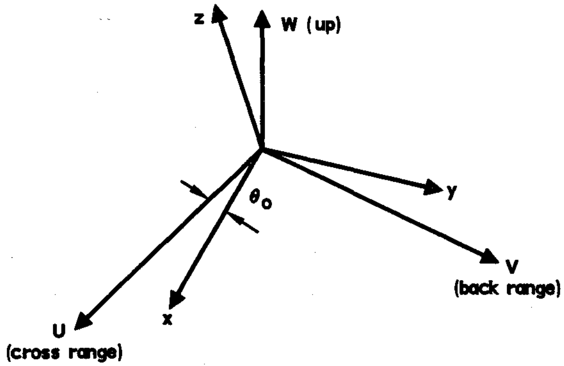

Fig. 2 Carousel platform drift compensation.

The ground align and level program continuously determines the location of the carouseling instruments in azimuth and, at go inertial, all torquing ceases and instrument position is passed to the guidance and navigation program.

Let U, V, W: cross-range-back range-up launch centered *inertial* (LCI) coordinate system; x, y, z: carousel platform coordinate system.[2] The x-y platform rotates about the z-axis at 1 rpm. Let θ_o be the carousel angle (x-axis from cross range at "go-inertial" time. Let ω_x, ω_y, ω_z be the compensable drift rates (fixed-torque drift and unbalanced) of the x, y, z gyros (whose input axes are along the x, y, z system), respectively. Let ω_c be the carousel rate of the platform. Define

$$M = \begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix}$$

whose *rows* are the direction cosines of the x, y, z axes in the U-V-W inertial system.

Then

$$\frac{dM}{dt} = -\begin{bmatrix} 0 & -(\omega_c+\omega_z) & \omega_y \\ (\omega_c+\omega_z) & 0 & -\omega_x \\ -\omega_y & \omega_x & 0 \end{bmatrix} M \tag{1}$$

with

$$M(0) = \begin{bmatrix} \cos\theta_o & \sin\theta_o & 0 \\ -\sin\theta_o & \cos\theta_o & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

By solving Eq. (1), the attitude of the Carousel platform can be obtained. However, because of the high carousel rate, integration of Eq. (1) would have to be carried out at such a high frequency as to be prohibitive. (Note that the drift rates ω_x, ω_y, ω_z are *not* constants.) Therefore, a modified set of drift compensation equations is devised and mechanized. Define a U', V', and W' coordinate system (drifting LCI) as follows:

$$\begin{bmatrix} U' \\ V' \\ W' \end{bmatrix} = \begin{bmatrix} \cos\theta_t & -\sin\theta_t & 0 \\ \sin\theta_t & \cos\theta_t & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \tag{2}$$

where x, y, and z are the gyro input axes and $\theta_t = \omega_c t + \theta_o$ is the carousel angle. The U', V', W' system coincides with the U, V, W system at go-inertial.

The compensable gyro drifts ω_x, ω_y, and ω_z can then be resolved through the carousel angle θ_t into the U', V', and W' coordinate system by the transformation (2). In the actual mechanization of the drift compensation equations, the drift rates are resolved about the "midpoint" of the gyro position during the past 1 sec interval.

$$\begin{bmatrix} \omega_U' \\ \omega_V' \\ \omega_W' \end{bmatrix} = \begin{bmatrix} \cos(\theta_t') & -\sin(\theta_t') & 0 \\ \sin(\theta_t') & \cos(\theta_t') & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \end{bmatrix}$$

where $\theta_t' = \omega_c(t-0.5)+\theta_o$.

The drift rates ω_U', ω_V', and ω_W' are then utilized to calculate the attitude of the drifted LCI coordinates in the *inertial* U, V, and W system. Thus,

$$\frac{d\phi^T}{dt} = -\begin{bmatrix} 0 & -\omega_W' & \omega_V' \\ \omega_W' & 0 & -\omega_U' \\ -\omega_V' & \omega_U' & 0 \end{bmatrix} \phi^T \tag{3}$$

with $\phi^T(0) = I$, the identity matrix. The *rows* of ϕ^T are the direction cosines of the U', V', W' axes in the inertial LCI system.

The magnitudes of ω_U', ω_V', and ω_W' are low enough so that Eq. (3) can be integrated on a 1-sec basis via simple second-order Runge-Kutta integration.

The attitude of the gyro input axes in the LCI inertial frame (U, V, W) can be calculated as follows:

$$M = \begin{bmatrix} \cos\theta_t & \sin\theta_t & 0 \\ -\sin\theta_t & \cos\theta_t & 0 \\ 0 & 0 & 1 \end{bmatrix} \phi^T \tag{4}$$

where $\theta_t = \omega_c t + \theta_o$, and recall that the rows of M represent the direction cosines of the respective gyro input axes in the *inertial* LCI coordinate system.

Velocity and position update: The x, y accelerometers are rotating at 1 rpm. Readings from the accelerometer are resolved into the U', V', W' system at 40-msec intervals. Let ΔV_x, ΔV_y be the accelerometer readings at the end of a 40-msec interval. Then

$$\begin{bmatrix} \Delta V_U' \\ \Delta V_V' \end{bmatrix} = \begin{bmatrix} \cos\theta_t & -\sin\theta_t \\ \sin\theta_t & \cos\theta_t \end{bmatrix} \begin{bmatrix} \Delta V_x \\ \Delta V_y \end{bmatrix}$$

Knowing the Φ matrix, Eq. (3), the incremental velocities can be integrated in the U, V, W inertial frame. The equations have been adopted and implemented in the TIIIC flight program.[2]

References

[1] "Final Error Analysis Report," USGS Program, EP2291, Aug. 15, 1972, Delco Electronics, General Motors Corp., Dayton, Ohio.

[2] Darnaud, T. E., Kleinbub, D. L., Liang, A. C., and Shaul, J. B., "Guidance, Control, and Ground Equations for SSLV C-26," TOR-0172(2112-02)-11-Vol. I, Reissue A, Rev. 1, June 26, 1972, Aerospace Corp., El Segundo, Calif.