Fluidic Inertial Platform

Rolf K. Brodersen*
Martin Marietta Corporation, Orlando, Fla.

Nomenclature

s = Laplace operator
$scfm$ = standard cubic feet per minute
K = gain
K_{comp} = feedback gain
P = pressure
PDM = pulse duration modulation
T = gyro pickoff time constant
T_{comp} = feedback time constant

Theme

THIS article describes the development of a fluidic inertial platform feasibility model for line-of-sight inertial guidance (LOS-IG) of an air-to-surface missile.†

In this guidance scheme, it is assumed that the pilot acquires the target before the missile is launched and that he aims the missile at a predicted intercept point, toward which it flies essentially a straight line course. The platform, which is uncaged at launch, provides steering signals in pitch, roll, and yaw, and can serve as a mounting base for accelerometers. Since it is the critical element in the fluidic missile guidance and control system, a demonstration of its feasibility was considered essential.

The following system requirements were projected for the fluidic inertial platform feasibility model 1) angular freedom: $\pm 10°$ in pitch, yaw, and roll, 2) typical operating time: 1 minute, 3) total error after one minute operating time: not to exceed typically 0.25° in pitch, yaw, or roll, 4) typical maximum g-load: 20g along roll; 5g along pitch and yaw axes, 5) fluidic signal transfer: 4 channels for test purposes, and 6) weight, size, power consumption, and environmental conditions: compatible with typical ASM requirements.

Contents

The small angular freedom projected for a LOS-IG system made a gimballess platform the preferred design concept. A spherical gas-bearing approach that lends itself well to the incorporation of fluidic pickoffs and signal as well as power transfer was selected. The low friction of the gas film minimizes control torque requirements as compared to a ball-bearing support, and thereby minimizes size and weight of platform and cold gas supply.

As a result of tradeoff studies, the design concept shown schematically in Fig. 1 emerged. Table 1 summarizes the major parameter values for the feasibility model.

A 3 in. diam gas-bearing stator sphere is mounted on a base which contains caging mechanisms and signal/power manifolding by use of a shaft that carries supply and signal flow in internal passages. The platform is attached to the lower bearing shell: it carries two gyros, three fluidic reaction-jet modules, balancing mechanisms and manifolding.

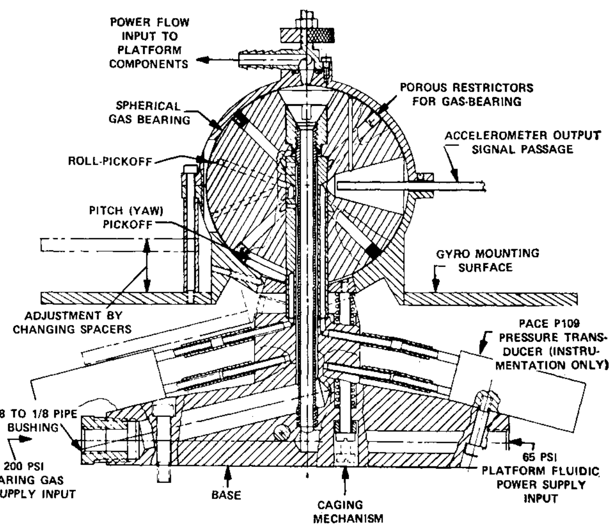

Fig. 1 Fluidic platform assembly cross section schematic.

As a result of tradeoff studies, a control system evolved that combined a proportional linear preamplifier with a bistable power amplifier chain and a capacitor-resistor feedback loop. Output of the amplifier chain feeds supersonic diverter-type reaction-jets that produce the control torque for platform stabilization.

Preliminary analysis led to the following over-all performance design goals 1) settling time, t_s, from initial offset angle, θ_o, (at uncaging) to error-band, θ_m, not to exceed 3 seconds, 2) $\theta_o \leq 1.0°$ for $t_s \leq 3$ seconds, 3) $\theta_m < 0.25°$ for $t > t_s$, 4) limit-cycle amplitude $\leq 0.15°$, and 5) steady-state hangoff error, $\theta_{ss} \leq 0.15°$.

This design goal was to apply for a platform with a maximum moment of inertia $J \leq 2 \times 10^5$ gm-cm^2, and for a maximum disturbance torque $\Delta M \leq 5 \times 10^4$ dyne-cm.

Since cross-coupling problems were not expected to be serious, the single-axis system shown in Fig. 2 was simulated on a digital computer to determine the approximate range of parameter variation that assures acceptable platform performance. Both gyrodynamic and misalignment torques were approximated in the simulation; a control torque $M \geq 3 \times 10^5$

Table 1 Platform design summary

Flow requirements	
Reaction jets	3×6 *scfm* @ 65 psig
Gas-bearing	5.2 *scfm* @ 200 psig
Dimensions	
Gas-bearing diameter	3.0 in.
Gas-bearing gap	0.0013 in.
Gyro diameter (typ)	2.5 in.
Gyro length (typ)	2.5 in.
Platform model O.D.	10.0 in.
Weight	
Gyro (typ)	1.25 lb
Platform model (without base)	12 lb

Presented as Paper 70-1009 at the AIAA Guidance, Control, and Flight Mechanics Conference, Santa Barbara, Calif., August 17–19, 1970; submitted August 26, 1970; synoptic received July 15, 1971; revision received November 1, 1971. Full paper is available from AIAA. Price: AIAA members, \$1.50; nonmembers, \$2.00. Microfiche \$1.00. **Order must be accompanied by remittance.** Work performed under Contract N00019-67-C-0267 with Naval Air Systems Command, Washington, D.C.

Index category: Launch Vehicle and Missile Guidance Systems.

* Senior Research Scientist Seekers and Inertial Sensors Department.

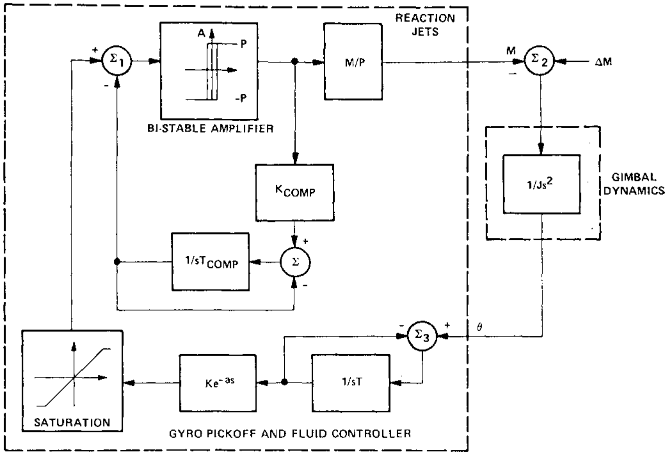

Fig. 2 Platform control system, block diagram.

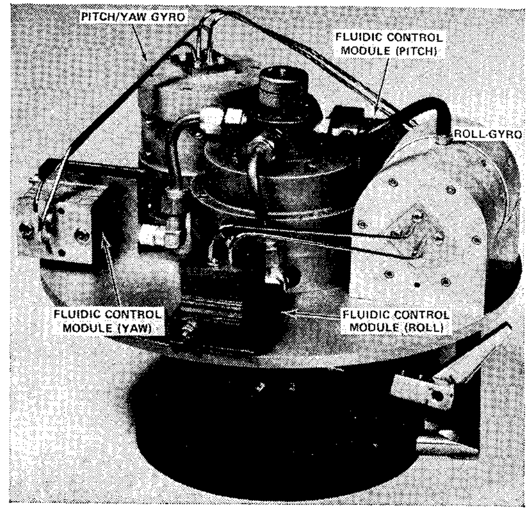

Fig. 4 Fluidic inertial platform.

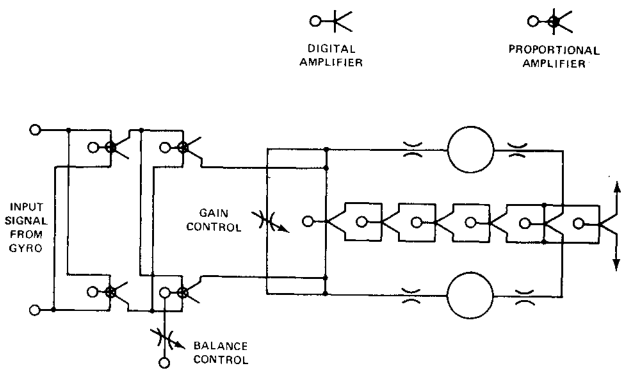

Fig. 3 Platform control circuit diagram.

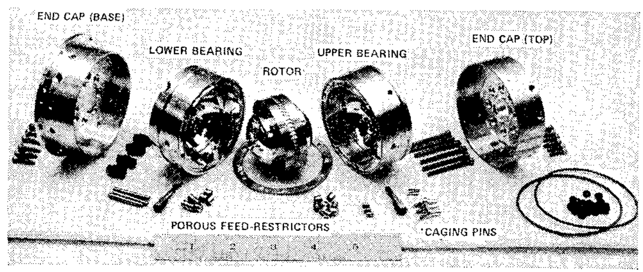

Fig. 5 Free-rotor gas-bearing gyro.

dyne-cm was found to be compatible with the design goals.

The fluidic control circuits (Fig. 3) were implemented as three stacks of etched wafers, one each for roll, pitch, and yaw, as shown in Fig. 4.

The platform was used as testbed for several fluidic gyros. Figure 5 shows a fluidic gyro dissembled that can meet the design goals of the platform. It is also shown in an assembled view (Fig. 4) as part of the fluidic inertial platform assembly. This gyro utilizes a spherical gas-bearing to support a spherical rotor with flywheel. It has spinup turbine buckets machined into the flywheel and employs slot-type analog fluidic pickoffs similar to those used in the platform.

This project demonstrated that a fluidic inertial platform of the selected design is feasible and that it appears practical for the intended application from both a cost and a performance point of view. Platform gas-bearing load capability proved to be adequate. Dimensional stability did not present a problem after proper heat treatment of the aluminum gas-bearing parts. Turbine torques were acceptably low. Performance of the reaction-jet control system met design requirements; tests verified computer-predicted data.