"I WAS THERE"

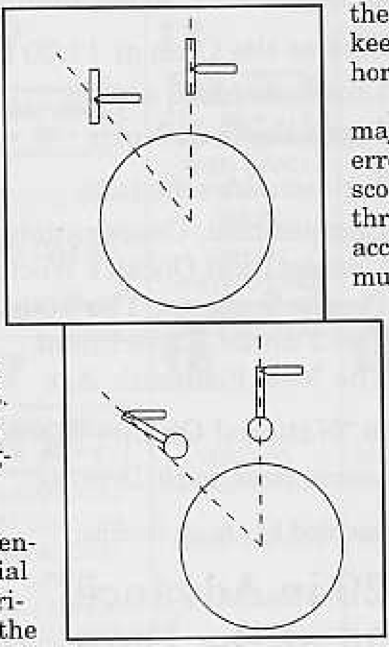
The Beginnings of Inertial Navigation

Joe Martino

Today, airliners and military aircraft, submarines and even ICBMs depend upon inertial navigation to steer their way from origin to destination. This technology was first developed for military aircraft in the late 1950s, and has seen dramatic improvement since then. How did it all start?

In 1955, as a second lieutenant, I was assigned to the Weapons Guidance Laboratory, forerunner of today's Avionics Directorate, at WPAFB. I had just completed a Master's Degree in automatic controls and was assigned to a section dealing with inertial navigation.

First, what is inertial navigation? The basic idea can be illustrated by two thought experiments. Suppose you have a long, thin rod which is supported so it can rotate freely about its center of mass. Begin with this rod initially vertical, as shown in the top portion of the figure. Now imagine accelerating the support tangentially to the earth. Because the rod is supported at its center of mass, it remains fixed in inertial space, always parallel to its initial orientation. As seen by an observer on the earth, however, the lower portion would appear to swing forward about the support. Next, suppose you have a short pendulum with a massive bob. Begin with this pendulum vertical, as shown in the lower portion of the figure. Now, imagine accelerating the support tangentially to the earth. The bob will appear to swing backward, rotating about the support. Thus, as seen by an observer on the earth, the "infinite period pendulum" represented by the rod supported at its center of mass will appear to "lean back" when accelerated. The short period pendulum will appear to "lean forward" when accelerated. The implication of this thought experiment is that a pendulum can be found with an intermediate period such that it will remain vertical when accelerated tangentially to the earth, leaning neither forward nor back.



In practice, it is impossible to construct such a "Schuler pendulum," named after the originator of the idea. However, such a pendulum can be simulated with a system of accelerometers and gyroscopes mounted on a gimbaled platform, and connected in an electronic feedback system. The accelerometers measure horizontal acceleration; this is integrated to calculate velocity; velocity is converted to angular velocity about the earth's center; the gyroscopes are used to rotate the platform at that angular velocity so the accelerometers remain horizontal; velocity is again integrated to obtain distance traveled. In addition, the gyroscopes measure rotation of the vehicle (e.g., roll or pitch of the aircraft). This rotation is added to the computed rotation of the vertical, thus keeping the platform with the accelerometers horizontal despite vehicle maneuvers.

When I joined the Armament Lab, the major problems we had to deal with were errors in the accelerometers and the gyroscopes. Accelerometers were nonlinear, had a threshold below which they could not measure acceleration, and their dynamic range (minimum to maximum acceleration) was limited. Gyroscopes "drifted," that is, did not accurately measure vehicle maneuvers nor the computed angle through which the accelerometers were to be measured. Moreover, gyroscopes had an additional error proportional to the square of the acceleration imposed on them (this was particularly significant for ballistic missiles). The result was that a cumulative error built up in the calculated position of the vehicle, and the magnitude of this error oscillated at the "Schuler period" of 84 minutes.

Much of my work was focused on improving accelerometers and gyros. This involved better bearings, tighter manufacturing tolerances, and similar approaches to making a mechanical device more precise. One such project involved improving the gyros in the Thor missiles. These were the missiles which John F. Kennedy later removed from Turkey in return for the Soviets removing their missiles from Cuba. Ironically, I was transferred out of the lab in 1958, just before the project was finished. It wasn't until 1994 that I came across a Thor guidance system in the Air Force Museum. This was the first time I'd seen "my" gyros.

However, part of my work involved trying to find alternatives to mechanical gyros and accelerometers. Under my direction, contractors investigated tuning forks, masses suspended on piano wires, and dust particles suspended by electrostatic forces, all without success. One researcher brought to my attention the "Sagnac Effect." Years before, it had been demonstrated that an interferometer with two

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I Was There ...

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counter-rotating light paths would exhibit fringe shifts if it were rotated. This demonstration was done on a ship making a tight turn. However, we calculated that for a Sagnac-effect gyro to detect the range of angular rates we needed, it would either require an extremely long light path, or use very short wavelengths such as X-rays. The first was impractical in an aircraft; the second would require detectors much more sensitive than any then available. The interesting thing is that today's inertial systems use Sagnac-effect gyros, achieving a long light path through a multi-turn coil of optical fiber. That was something we couldn't imagine in the 1950s.

Today's inertial navigation systems, utilizing fiber-optic gyros, digital computers, and other refinements, represent major improvements over the systems of the 1950s. However, the basic principles remain the same as they were when I was "in at the beginning."