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THE TALOS CONTROL SYSTEM

The Talos autopilot was specifically designed to steer the ramjet missile with minimum angles of attack and to stabilize the missile in roll during the boost, midcourse, and terminal phases. The autopilot system evolved from late World War II designs by using such new components and system concepts as the hydraulic amplifying servo valve and the Sensitivity Feedback Autopilot developed by the Bumblebee Program.

The Talos wing control system was a powerful electromechanical-hydraulic system. It rotated the missile's wing surfaces to control the airframe in response to commands from the guidance system and automatically compensated for changes in aerodynamic sensitivity and stability associated with the considerable changes in missile speed (low subsonic to more than twice the speed of sound), altitude (sea level to more than 70,000 feet), and center of gravity (resulting from fuel consumption).

Talos was controlled by four independently movable wings mounted close to the center of gravity of the missile. Opposite pairs of wings moved together to control the missile in two orthogonal control planes (see Fig. 1). The missile was accelerated laterally and/or up and down when wings were deflected since the wings provided most of the missile lift. The control surfaces were sized to produce lateral accelerations that exceeded 14 g for altitudes up to 40,000 feet, above which the maximum attainable acceleration decreased. The wings were moved differentially to produce torque about the missile longitudinal axis to control missile roll. Wing control, with the attendant small angles of attack, was most desirable for Talos because airflow into the ramjet engine inlet was affected adversely by large angles of attack.

The Talos control surfaces had many design virtues, one of which was the limited motion of the center of pressure with Mach number and angle of incidence allowing the selection of the axis of rotation to minimize wing hinge moment. The effectiveness of the control system was sensitive to how quickly the control surface could move to produce lift. Accordingly, the control system was designed to move the wings at a maximum rate of 170 degrees per second.

As with all missiles, Talos had body vibrational modes during flight that necessitated care in the placement of sensing instruments, in particular those used for the control system. Even then, compensation and filtering of their signals were required. Furthermore, since the control surfaces were near the center of gravity and also near a point of maximum body vibration, the control surface had to be properly mass balanced to prevent coupling or flutter.

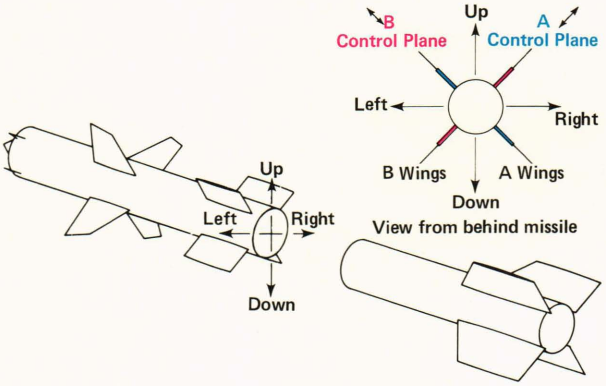

Figure 1 — The orientation of the Talos missile during all flight phases is shown. This orientation, termed "X configuration," provides maximum vertical and lateral acceleration.

The control system was functionally different for each of the three flight phases: boost, midcourse, and terminal homing. During the boost and midcourse phases, it operated as a conventional wing position system, and during the terminal phase, as an adaptive autopilot.

The servos that drove the wings were hydraulic, drawing prime power from a duct air-driven turbine. During the short early boost phase, when the air turbine was unable to supply the required hydraulic power, energy was provided by stored high-pressure nitrogen that pressurized the hydraulic system. The servos required approximately 25 horsepower.

THE BOOST-PHASE AUTOPILOT

Talos was actively stabilized during the boost phase to compensate for an aerodynamically unstable booster-missile configuration. Stabilization in the steering planes maintained the missile's orientation in space parallel to that at the time of launch. This was accomplished by command signals from a free gyroscope that had been uncaged just prior to launch. Rate gyroscopes were used in each of the two wing planes to provide damping. Figure 2 is a block diagram of the control system during the boost phase. The aerodynamic gain increased significantly during

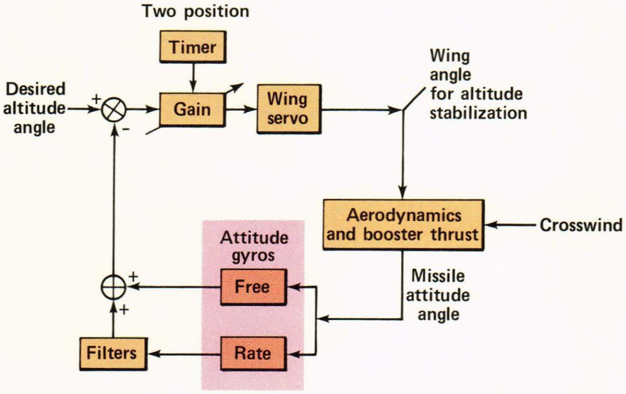

Figure 2 — The attitude control system maintained stability of the missile booster configuration during the boost phase. Two identical control channels were employed, one of which is shown. The free gyro, which was uncaged just prior to launch, provided an inertial attitude reference during the boost phase. The rate gyro was used to provide weathercock damping.

boost and, accordingly, the controller gain was reduced. This was done by a timer that reduced the gain by a factor of 2.6 at 1.75 seconds after launch. Since the effects of aerodynamic misalignments and mass unbalance, booster jet misalignment, launcher tipoff, and crosswinds during the boost phase were minimized, this boost-phase control reduced the launch dispersion and allowed the use of a relatively narrow guidance beam.

Roll control was the same for the boost phase and for the midcourse beamriding phase. Figure 3 is a block diagram of the roll system. The missile's roll position on the launcher was maintained both during the boost phase and after separation from the booster. The roll moment-of-inertia and aerodynamic characteristics during the boost phase were, of course, quite different from those during the post-separation phase. The response of the missile to roll disturbances was considerably faster after separation.

THE MIDCOURSE AUTOPILOT

Following separation from the booster, the ramjet engine was ignited. The velocity of the missile was controlled by a Mach-sensing fuel-control system, while steering was controlled by a beamrider link. During this phase, the guidance radar was programmed by target position, missile range, and previously determined parameters, all of which caused the missile to fly a trajectory that properly positioned it to begin the terminal phase.

After separation from the booster, the missile was aerodynamically stable, and control was switched from the attitude stabilization mode to a midcourse beamriding mode. An error signal, proportional to the angular off-beam error, was generated by the beamrider receiver (Fig. 4) and resolved into orthogonal components that were fed to the appropriate steering channels.

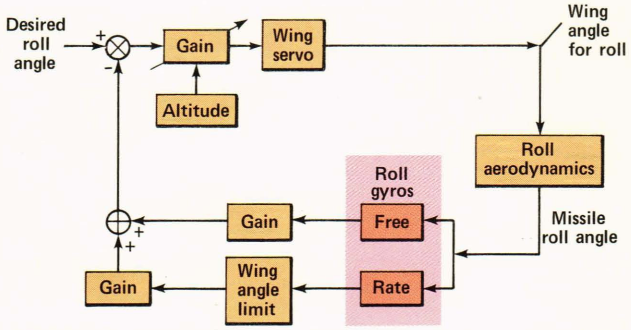

Figure 3 — Roll control was maintained during the boost and midcourse phases. The roll free gyro was uncaged at launch and provided an inertial vertical reference, while the roll rate gyro provided damping. Gain of the control loop was varied with altitude. To minimize roll-yaw-pitch coupling during the terminal phase, the roll free gyro was disconnected and a lag-lead shaping network added.

The autopilot was designed to respond to commands directing the missile to maintain its position in the guidance beam. Response was as rapid as possible without overshooting the desired position or exciting the missile's natural tendency to oscillate about its center of gravity (called weathercock oscillation). The autopilot response time varied with altitude. However, the character of the response was maintained essentially the same by programming autopilot sensitivity with altitude. Altitude was measured by a series of reliable and accurate switches that sensed the ambient static pressure. Compensation for velocity was not required since the flight Mach number was controlled. A gravity bias was used to compensate for gravity so that the missile would not fly below the center of the guidance beam as a result of gravitational force.

THE TERMINAL PHASE (HOMING)

After the midcourse phase had placed the missile into a favorable position relative to the target, a signal from the guidance transmitter activated the terminal phase of guidance. Target acquisition was normally completed soon enough after activation to permit at least 10 seconds of homing before intercept. Although 10 seconds seems a short time, it was adequate to remove missile heading errors and compensate for target maneuvers. To achieve this, the autopilot compared the requested lateral acceleration and the actual achieved acceleration produced by the control surfaces, and adjusted the internal gain of the autopilot to maintain optimum response. This ''sensitivity feedback system'' replaced the pressure-activated gain control used in midcourse. The block diagram for the terminal phase (homing) is shown in Fig. 5.

During the homing phase, it was desirable to rate-stabilize the missile in roll to eliminate roll-yaw-pitch coupling. Accordingly, the free gyro was not used, but control was referenced to a roll rate gyroscope to minimize the rate of roll.

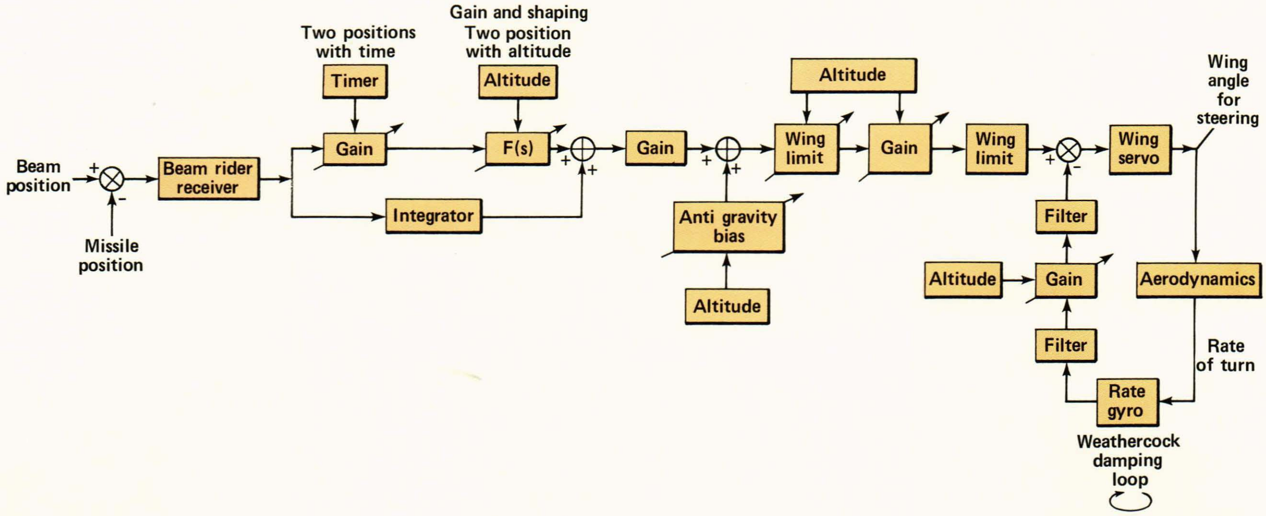

Figure 4 — Midcourse steering was controlled by a beamrider link. The beamrider receiver outputs were converted to wing commands for each control plane. These outputs were corrected for beam divergence and gravity bias by the control system. Loop gain was varied with altitude. Only one steering plane is shown.

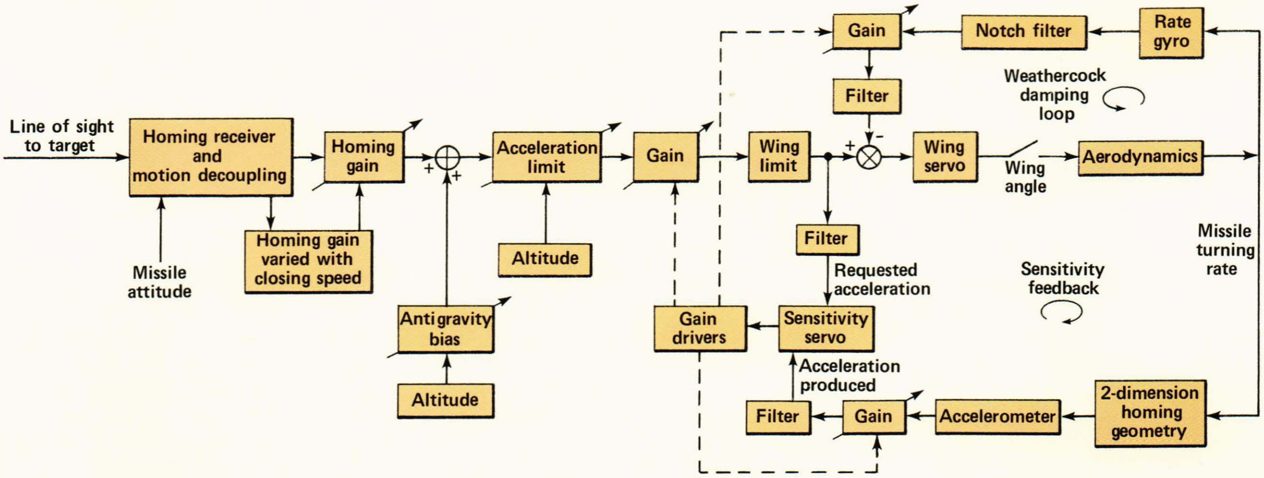

Figure 5 — Terminal steering placed the missile on a collision course by minimizing the rotation rate of the line of sight to the target. This figure shows the steering channel for one control plane. Line-of-sight rates, provided by the seeker, were converted to acceleration commands by the control system, which used the comparison of requested and achieved accelerations to adjust the gain of the autopilot and maintain optimum response. This "sensitivity feedback system" automatically compensated for changes in altitude and speed.

SUMMARY

In retrospect, the initial Talos autopilot system was an extension of World War II designs. These early systems required that the gain of the autopilot be adjusted as a function of altitude and Mach number, and programmed with time to compensate for changes in missile center of gravity as a result of fuel expenditure. The sensitivity feedback system improved the performance of the autopilot and eliminated the necessity for air density and Mach number changes to autopilot sensitivity. Talos was the first to use this sensitivity feedback design.

The outstanding performance of the Talos autopilot, despite its relative simplicity, was the result of developments in both system and component design. Many electronic, hydraulic, and electromechanical components, including end-instruments, were developed as part of the Bumblebee Program. These subsystems, components, and overall system concepts have since been used in many high-performance missiles and aircraft.