ARTICLE NO. 78-1261R

Copperhead Semiactive Laser Guidance System Development

Robert A. Nulk*
U.S. Army Armaments R&D Command, Picatinny Arsenal, N. J.

Harold L. Pastrick†
Office of the Undersecretary of Defense for Research and Engineering, Washington, D.C.

and

Phillip A. Morrison‡
Martin-Marietta Aerospace, Orlando, Fla.

A 155-mm cannon-launched guided projectile, named Copperhead, is currently in engineering development. The guidance and control configuration for the system employs semiactive laser terminal homing utilizing a proportional navigation guidance law (to improve effectiveness against hard-point moving targets) augmented by a bias to offset trajectory sag caused by gravity acting on the projectile in the end game encounter with the target. The system mechanization uses a laser seeker optically coupled with the reference gyro, aerodynamic tail control, roll position control, and wings to increase the projectile's lift and enhance its glide capability. Results are presented which indicated that system performance meets design objectives.

Introduction

ARMY artillery has been used as an effective weapon for saturation fire on area targets in the past; however, the artillery barrage has been lacking in capability to destroy a point target. Because the armored moving target was deemed difficult to kill and because it usually required a direct hit to demobilize it, a new weapon was developed to meet this threat. Thus, the 155-mm howitzer with laser semiactive homing guided munitions was conceived. The munition itself is now commonly called Copperhead (CLGP)—an acronym for cannon-launched guided projectile. An advanced development (AD) program was initiated in 1971 to prove that the Copperhead could be used to increase the effectiveness of standard artillery against point targets. The Copperhead system, with its precise and sensitive electro-optical components, had to be designed to withstand the same high-*g* firing environment as a standard artillery round. The system, with no information provided to the round other than that sensed by the seeker, had to acquire and guide itself to a designated target with extreme accuracy. Moreover, the system had to be compatible with the practical world of artillery—it could not be simply a delicate laboratory device. Ultimately, the system must be producible in large quantities at reasonable prices.

AD was a two-phase program in which a period of 18 months was allotted to component/subsystem development and 19 months to prototype projectile demonstration. Phase I was concerned primarily with development and implementation of the design, inspection, and test methods needed to harden previously proven guidance, control, and telemetry components and subsystems to 9000 *g* and complete projectiles to 7200 *g*. Phase II was dedicated to proving the concept through flight test evaluations. The emphasis on performance and hardening, combined with the extensive test program, had to produce a practical projectile that would meet or exceed all AD performance requirements.[1,2]

The first flight demonstrations in engineering development (ED) took place in November 1976 to evaluate roll control and roll loop stability limitations. Fully guided ED flights were initiated in March of 1977, and a total of 129 rounds had been flown as of August 1979. Hardware failures and incorrectly assumed aerodynamic characteristics[3] prevented a successful demonstration until the fifth flight. Subsequently the high-*g* capability of the components was proven. After successfully hitting a 7.7-km tank target, a series of successes followed at 16, 12,11, 7.7, 5.6, 4, and 3 km range. The accuracy of the system (Fig 1) has exceeded the requirement and all aspects of the guidance and control (G&C) loop appear

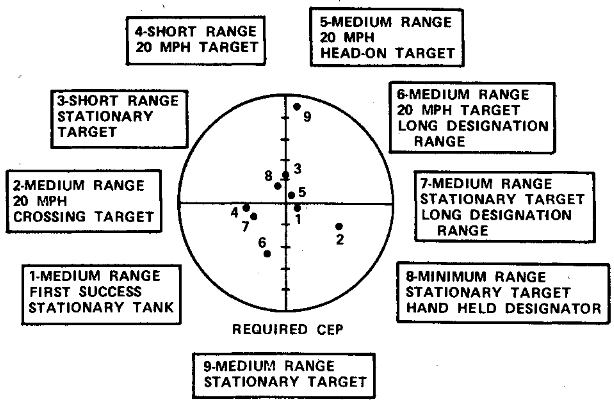

Fig. 1 Typical Copperhead guidance and control performance.

Presented as Paper 78-1261 at the AIAA Guidance and Control Conference, Palo Alto, Calif., Aug. 7, 1978; submitted Sept. 5, 1978; revision received Jan. 23, 1978. Copyright © American Institute of Aeronautics and Astronautics, Inc., 1978. All rights reserved. Reprints of this article may be ordered from AIAA Special Publications, 1290 Avenue of the Americas, New York, N.Y. 10019. Order by Article No. at top of page. Member price $2.00 each, nonmember, $3.00 each. **Remittance must accompany order.**

Index categories: LV/M Guidance; LV/M Dynamics and Control; Missile Systems.

*Product Manager, Copperhead.

†Staff Specialist. Member AIAA.

‡System Task Leader, Copperhead.

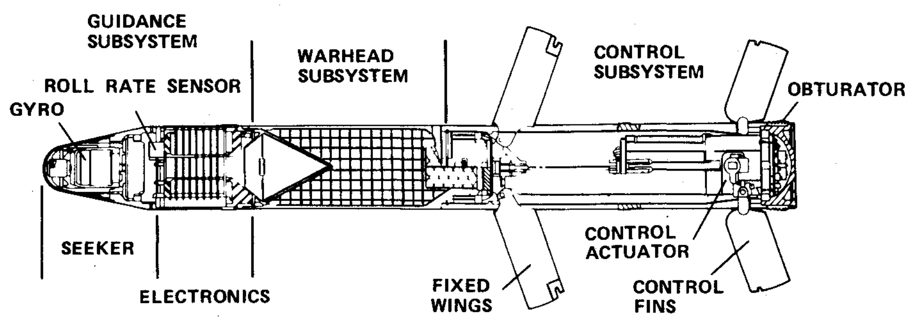

Fig. 2 Copperhead guided projectile.

exceptional. Eighty-six rounds have achieved direct hits on targets. Targets have been accurately hit while moving at speeds up to 20 mph in both crossing and head-on attitudes. Compatibility with three different types of ground designators was demonstrated.

The remainder of this paper describes the Copperhead system in general, and its guidance and control system in particular. It then describes simulation, component, and flight tests that have been used during the ED program.

Configuration Description

The Copperhead projectile (Fig. 2) is 155 mm in diameter and 4.5 ft long, and weighs 138 lb. The projectile nose is a blunted conical dome. Aft of the dome is a primary optical lens bonded to a detector assembly. The detector assembly contains other optics, a laser detector, and video preamps. The detector and primary lens assembly are attached to a coil form that contains both torquing and spin-sustain coils for the seeker gyro.

A two axis gimbaled gyro using load transfer bearings and a "gotcha" sleeve, which engages the gyro rotor during launch for launch survivability, are housed inside the coil form assembly. These items carry the large loads incurred during cannon launch and protect the gimbal bearings from brinelling. The gyro rotor has a mirror surface to reflect laser energy onto the detector and incorporates a magnetic ring that enables the gryo to be precessed or spun when the torquing or spin coils are energized. Initial spin-up for the seeker gyro is provided by a wound spring.

The projectile electronics package located behind the seeker gyro section consists of eight printed-circuit cards plugged into a motherboard assembly. The launch loads induced on the seeker gyro section and the electronics package are carried by the steel electronics housing that mechanically interfaces with the warhead subsystem. The electronics housing also incorporates a forward bourrelet, which acts as a bore rider during travel down the gun tube. An unconventional roll rate sensor is mounted on the forward bulkhead of the electronics package. Unlike conventional rate gyroscopes, this solid-state rate sensor senses inertial angular rates based on the principle of Coriolis acceleration. Contained in the sensor is a continuous laminar flow gas jet, which impinges on two hot-wire resistance sensors. The gas is pumped in a closed cycle by an electrically excited, vibrating piezo-electric diaphragm. Angular rate inputs cause the gas jet to deflect laterally, resulting in differential cooling of the two hot wires. The associated changes in resistance of the hot wires, which are connected in a bridge circuit, produce a signal proportional to the input rate. An integrated circuit amplifier converts this signal into a high-level output having low source impedance. The device has a predicted long life because there are no rotating or sliding parts. Since the laminar flow jet is submerged and neutrally buoyant within an atmosphere of the same gas, it is less sensitive to translational acceleration, vibration, and shock and therefore well suited to this application.

The steel warhead structure contains a shaped-charge warhead, warhead fuse with safe and arm (S&A) provisions and interconnecting electrical cables for interfacing the guidance subsystem with the control subsystem. During early testing, a telemetry unit having representative mass and envelope characteristics of the warhead is substituted for the warhead.

The control housing contains slots that permit the fins and fixed wings to be folded inside the structure during storage and cannon launch. Actuator electronics, thermal battery, and a cold-gas storage bottle for the controls are mounted on the control actuator unit. The actuator assembly is held in the control housing by an aft closure, which also incorporates the projectile's obturator. The control section also contains locks which hold the fins and wings inside the structure and a cam/piston mechanism which deploys the wings upon command. Secondary environment sensors are mounted in the control section to sense muzzle exit from the gun that enables arming of the warhead.

System Description

Prior to firing the projectile, three dials are set on the guidance section bourrelet which establish laser code correspondence with the appropriate forward observer designator. Next, two more dials are set to determine whether a ballistic trajectory or a fly-under fly-out (FUFO) gliding trajectory will be flown and to determine time delay for full activation of projectile components. Certain dial settings are used for ballistic trajectories and correspond to sequencer delay times taken in specific time increments. FUFO trajectories are used for long-range flights, while ballistic trajectories are employed for short-range flights. Delay times are selected to inhibit full activation of components until the target is near the acquisition envelope of the projectile.

When the code and time delay dial settings are completed, the round system is loaded, using either manual or power ramming. The proper charge is then added; the breech is closed; the howitzer is deflected and elevated to the specified firing coordinates; the primer is added; and the weapon is ready for the fire command.

At firing, the obturator on the aft end of the projectile seals the tube and shields the forward portion of the projectile from the propellant charge gases. In addition, the obturator slips circumferentially and partially decouples the projectile from rifling-induced spin, limiting the exit spin rate to less than 30 rps.

An 11-V battery is activated by the launch acceleration. When the battery reaches rated voltage, the 5-V regulators and the flight sequencer are operable. The launch acceleration also mechanically activates the warhead safe and arm. The launch acceleration releases fin retention locks; however, the acceleration also produces a moment on the fins which prevents their deployment. After the projectile has exited the tube, centrifugal force produced by projectile spin causes the four control fins to deploy. Pin stops establish the fin sweep angle at 20 deg from the normal. The fins have a roll cant that maintains a clockwise projectile spin rate higher than the body natural frequency. This prevents roll resonance from occurring during flight and permits liberal tolerances in vane fabrication. The tail fins provide aerodynamic stability during the ballistic portion of flight and aerodynamic control during guided flight.

The flight sequencer begins activating projectile components when the preset time delay (determined by the switch settings) has elapsed. After the preset delay has elapsed, the sequencer activates the 30-v sections of the thermal battery. When rated voltage is reached, all electronics within the projectiles are then operable. After the battery is activated, the sequencer fires a squib to retract the seeker gyro "gotcha." The "gotcha" holds the seeker gyro rotor during launch. The "gotcha" sleeve rotates and pulls away from the gyro. After the "gotcha" squib is fired, the roll rate sensor is activated, and the control actuator gas bottle is punctured by a cutter squib. The gas pressure from the bottle powers the control actuator and unlocks the control fins, freeing them to respond to fin position commands.

The output from the roll rate sensor is fed to the roll autopilot, which computes roll vane commands to null the roll rate. The roll commands are relayed to the control actuators, which cause the projectile to stop rolling within 1 s of any arbitrary roll orientation. The projectile is roll stabilized at this orientation for the duration of flight.

After the gas bottle is punctured and roll control is initiated, the seeker gyro is mechanically spun up by a spring-wound starter. The gyro is maintained at its operational spin rate for the duration of flight by electrical spin-sustain circuitry. After activating the seeker gyro, the wing unlock squib is fired, which frees the wings for deployment. The wing lock retains the wings inside the projectile during launch and ballistic flight. After the wing unlock squib is fired, the wings are extended by a squib-pressurized piston to a 20-deg sweep angle.

For a ballistic trajectory, the projectile will continue to fly a nonrolling ballistic trajectory until target acquisition is accomplished. If a glide (FUFO) trajectory has been selected, the seeker gyro is placed in a free mode (i.e., it acts as an inertial reference) at the same time the wing deployment command is given. Concurrently the autopilot initiates an attitude-hold mode, in which vane commands are computed to keep the projectile aligned with the gyro. In this mode the projectile will glide at an angle that is less than that established by the gyro spin axis attitude. The projectile will fly in this nonrolling glide mode until target acquisition occurs.

Target acquisition occurs when laser energy at the proper code is detected by the seeker. Upon acquisition, seeker gyro track is begun and the gyro is slewed toward the target. The guidance electronics compute torquing commands for the seeker gyro that are proportional to the line-of-sight angular error. The gyro slew mode of operation is maintained for a sufficient period of time to permit nulling of any initial pointing error; then proportional navigation guidance and gyro track are initiated and warhead electrical arming is completed. At this point the fuse arming function is complete, and the warhead will detonate upon target impact. Bias is added to the proportional navigation guidance commands to compensate for trajectory droop caused by gravity (which can result in the projectile's impacting short of the target).

Warhead detonation is triggered at target impact by either a direct impact sensor mounted inside the optical dome on the laser detector assembly or by any one of the six shock wave sensors (SWS) attached to structural bulkheads. The SWS detect shock waves caused by grazing-type impacts. The shaped charge warhead jet will penetrate the target, and the blast and fragments produced by detonation will assist in achieving the target disablement.

Guidance and Control Loop Description

The guidance and control scheme for Copperhead uses a roll-controlled airframe with biased proportional navigation guidance (PNG). Line-of-sight (LOS) rate is measured by the "optically coupled seeker gyro," and aerodynamic control is provided by tail fins, using cold-gas time-dwell-modulated actuators. This is similar to the G&C loop used during the AD phase of Copperhead, but the implementation costs were reduced and the concept refined for improved tactical applications.

Roll Loop

The roll control loop for the Copperhead guided projectile must stop an initial ballistic flight roll rate of 2-12 rps within 1 s and then maintain projectile roll attitude for the duration of the flight. During the earlier Copperhead AD program, the roll loop was implemented using a two-axis attitude reference gyro (ARG).[4] ARG gimbal outputs were used to estimate roll attitude, or more specifically, roll error relative to the vertical; roll command was generated proportional to the roll error. The airframe was rolled to a specific up orientation to allow proper direction of gravity bias compensation. (Gravity bias was always directed along the body pitch axis.) Therefore, a roll position loop was required. The present system has the ability to determine gravity bias compensation during flight by using the seeker gyro to sense the pitch over direction of the trajectory, which thereby indicates the sense of "up" in body axes. With this technique, the compensation required in the body pitch and yaw axes is determined; consequently, a rate loop would work equally well using the new gravity bias compensation scheme. A unique type of roll rate sensor was selected to implement a roll rate, rather than a position loop, since this concept reduced both cost and complexity of the AD roll loop.[5]

The objective of the roll rate loop was to prevent changes in projectile roll attitude after roll control; therefore, the major performance requirement on the roll rate sensor was the ability to sense a zero roll rate, i.e., its null offset capability. As developed for Copperhead, it was required to sense a zero roll rate or null condition to within 0.5-1.0 deg/s. Sensor proportional range was established at 125 deg/s, which provided adequate signal for establishment of roll control and sensing of roll transients. A roll rate autopilot was developed (Fig. 3) that incorporated proportional control with attitude feedback. With attitude feedback, any roll disturbances were

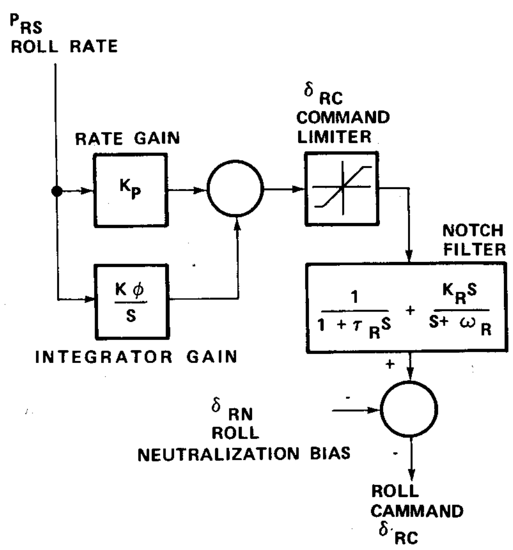

Fig. 3 Roll autopilot.

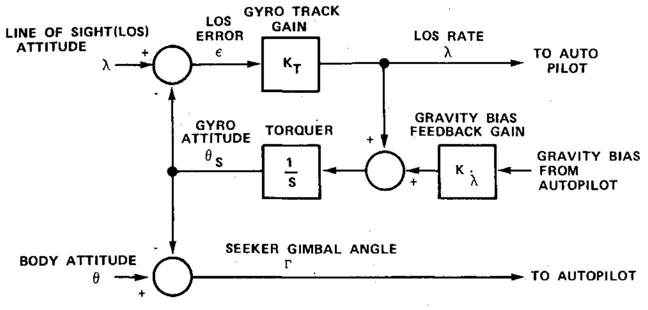

Fig. 4 Seeker and gyro loop.

	CHARGE	QUADRANT ELEVATIONS	TIME SWITCH SETTING	DELAY
BALLISTIC	XM201/ZONE 7	28.5 DEGREES	21	24.0 SECONDS
GLIDE (FUFO)	XM201/ZONE 7	23.0 DEGREES	54	19.0 SECONDS

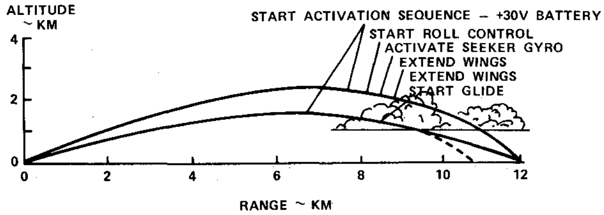

Fig. 6 Comparison of ballistic and FUFO trajectories.

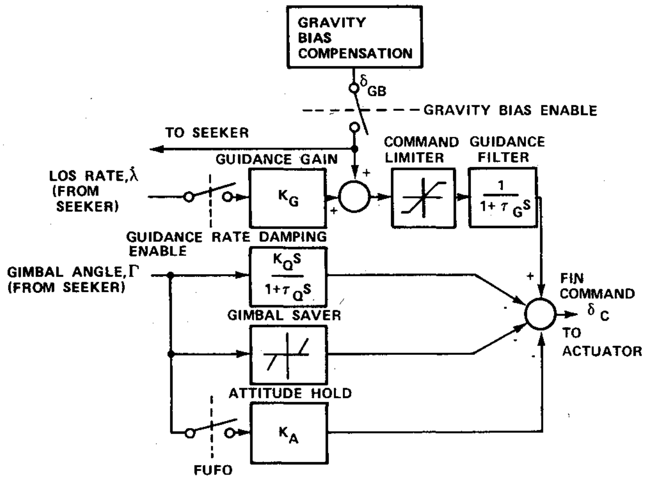

Fig. 5 Guidance autopilot loop.

integrated so that the autopilot would roll the projectile back to its original roll orientation. A notch filter was added to provide high-frequency stability without sacrificing low-frequency performance. The roll loop uses only fins one and three (yaw plane) to control roll, reducing actuator cost by eliminating the need to control fins two and four independently. The neutralization bias counteracts the fixed roll bias, which is built in all fins (causing the projectile to roll during ballistic flight). The implementation of this autopilot was accomplished at both lower cost and less complexity than the AD concept.

Seeker Loop

PNG is implemented in Copperhead using the seeker track-mode torque commands to measure the LOS angular rate (Fig. 4). As the seeker gyro is driven to track the target, the torque commands are proportional to the gyro precession rate, which approximates the LOS angular rate. Fin steering commands are then computed proportional to the torque commands. The gravity bias signal is also fed back into the tracking loop to provide trajectory shaping. The bias feedback tends to loft the trajectory and provides steeper body angles at impact, which improves warhead effectiveness against heavily armored targets.

Guidance Loop

The LOS rate commands from the 2-degree-of-freedom, gyro-stabilized seeker are inhibited by the autopilot (Fig. 5) until the pointing errors present between the gyro and target at acquisition are removed and guidance is "enabled." At this point, gravity bias commands are added to LOS-generated command by "enabling" the gravity bias circuitry, and the net signal is "limited" to prevent potential saturation of the guidance filter. The navigational gain is primarily established by the guidance gain value K_G. The guidance gain K_G is representative of the linear transfer function of velocity turn rate per unit fin deflection.

Gravity bias computed to correct for trajectory sag is added directly to the steering commands in the pitch and yaw channels. In AD the gravity bias commands were preselected prior to launch, but the ED configuration uses onboard sensors to compute the gravity bias during flight for the actual trajectory being flown. The computation logic also resolves the gravity compensation into pitch and yaw components, which are determined by the roll attitude of the projectile.

The first-order lag filter is used to attenuate disturbances due to seeker noise and laser spot motion (jitter). Seeker noise results from background noise and optical/mechanical irregularities in the seeker gyro/mirror. Spot jitter is spatial motion of the target spot resulting from designator tracking errors and beam direction fluctuations.

Most projectile and missile airframes exhibit aerodynamic damping ratios that are generally under 0.10. For Copperhead, the damping ratio is approximately 0.03 during the guided portion of the flight regime. To provide adequate airframe response and still limit the magnitude of overshoot, a first-order rate damping loop is incorporated, which increases the effective damping ratio. Body rate was approximated by differentiating the output signal of the seeker pitch and yaw gimbal potentiometers and then smoothing with a first-order filter. Because Copperhead is a nonrolling airframe, the differential of gimbal angle is a good measure of body rate.

A dead zone circuit called a "gimbal limiter" enables Copperhead to fully utilize its maneuver capabilities and fly at large angles of attack without exceeding the mechanical gimbal limits of the seeker gyro. As long as the seeker gyro gimbal angle does not exceed 10% of its maximum range, the limiter is inactive. When the gimbal angle exceeds this break point, a vane command is computed proportional to the gimbal angle excess, which acts to reduce body attitude and keep the seeker gyro from hitting its gimbal stops and tumbling.

The ED Copperhead concept also employs an additional capability over the AD concept and that is the ability to fly "constant-attitude" trajectories termed FUFO. The capability enables the attitude of the midcourse flight mode (time between completion of projectile activation and target acquisition) to be controlled, as well as providing the ability to extend the ballistic range capability of the projectile. Control of flight attitude permits shallow glide approaches at long ranges where flight path angles are typically steep (see Fig. 6). If clouds are present, the shallow approach results in the target's being visible (by the optical laser seeker) at a longer range. The longer range provides more guidance time and results in a bigger maneuver footprint and higher ef-

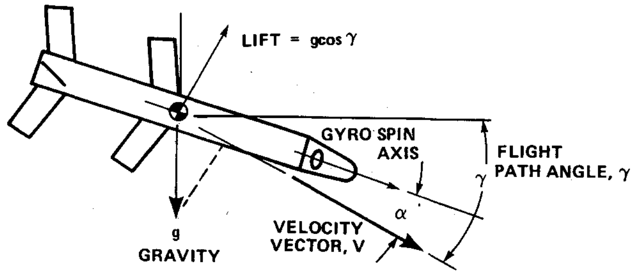

Fig. 7 Fly-under fly-out (FUFO) concept.

fectiveness. For cloud ceilings down to 3000 ft, a 20-deg glide slope provides Copperhead full effectiveness, even at long range. With this glide capability, Copperhead extends its ballistic range capability to 15 km or greater.

The FUFO trajectories are obtained by freeing the seeker gyro at an attitude 5-8 deg shallower than the desired glide attitude and closing the attitude-hold loop and later "enabling" gravity bias compensation input. The gravity bias circuit and the attitude-hold loop oppose each other until the velocity vector has achieved an attitude (the attitude-hold loop keeps the projectile aligned with the free gyro) that produces an angle of attack that offsets gravitational forces (see Fig. 7). At this point the glide attitude stabilizes and the projectile maintains this constant attitude until the target is acquired and guidance is initiated. Figure 6 illustrates use of FUFO and ballistic trajectories. When clouds are present, the FUFO trajectory provides more time once target aquisition is achieved.

When all guidance commands are combined, the pitch or yaw fin command consists of LOS error gravity bias compensation, rate damping, gimbal limiter, and if applicable, attitude hold during nonguided flight. Roll commands are added to yaw commands within the control actuator electronics.

To implement the guidance and roll commands from the autopilot, a cold-gas-control actuation system is utilized. The actuators use a carrier frequency to time-dwell modulate solenoid valves, which then operate a differential area piston. Vane position feedback is used to adjust the time-dwell-modulation duty cycle to produce the desired vane response. The actuators are similar to those used on TOW and HOBO.

Component and Subsystem Tests

The design and development objectives of the Copperhead program were to relate common launch environments to tangible design and laboratory test criteria and to prevent the recurrence of problems and failures. As was the case in the AD phase, the objectives in ED were to be met through a series of component and subsystem testing. The evolution progressed through design, laboratory test, and canister and projectile firings. Emphasis on validating the guidance and control portion of the system was evidenced through a comprehensive evaluation of the guidance subsystem at the seeker processing electronics level and at the completed guidance module level. The former was accomplished via a dozen tests that probed critical seeker characteristics. The latter was placed into a hardware-in-the-loop (HWIL) simulation to determine the miss distance characteristics under conditions representing the all-up-round flight test firings. Several of these tests will be described in the sequel. An overview of those tests that were used successfully in AD is representative of similar tests in ED. These are shown in Fig. 8.

An extensive canister test program for ruggedized subsystems was conducted. Ruggedized guidance, control, and telemetry subsystems were fabricated for 8 in. canister firing (8000 to 12,000 g) at MICOM for test and analysis. Figure 9 shows a typical mission profile of the cannon's launch. The data from these firings were instrumental in verifying the high-g hardening of major assemblies.

The HWIL simulation is performed on the MICOM Guidance and Control Analysis group's terminal homing guidance evaluation facility.[6] For HWIL operation it is necessary for the seeker to experience the projectile angular orientation and to sense the target-projectile relative translational displacements. This is achieved by mounting the hardware seeker on a three-axis flight table to enable the body-inertial Euler angles for generation in real time while sensing the laser energy projected onto a translucent screen to simulate the target. The target spot is deflected via mirror and bellow interfaces to represent the line-of-sight change between the target and projectile and include the effects of relative

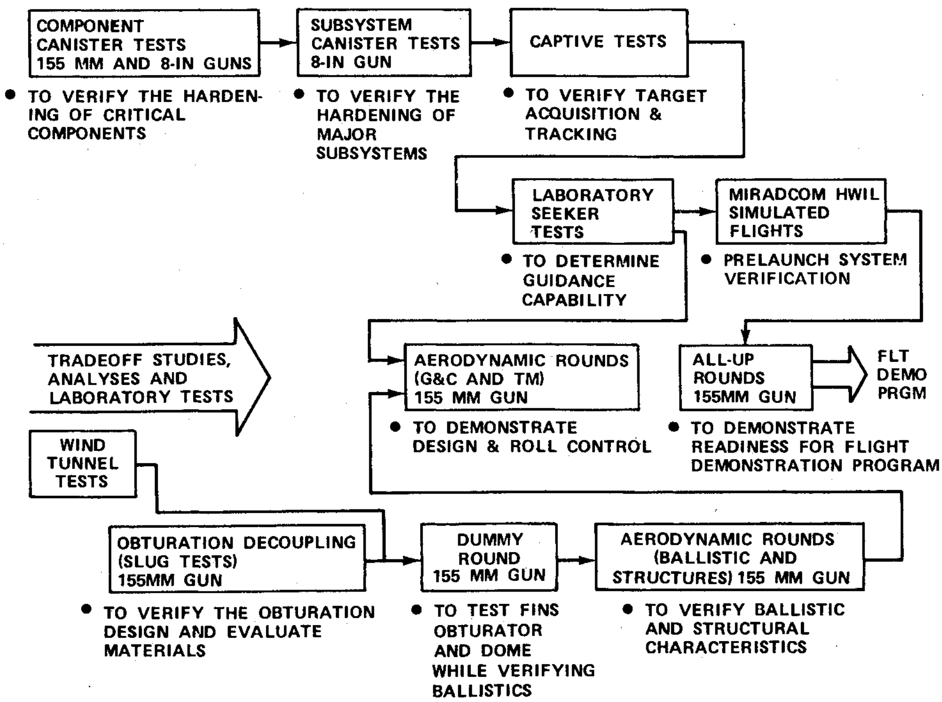

Fig. 8 Test philosophy to verify design.

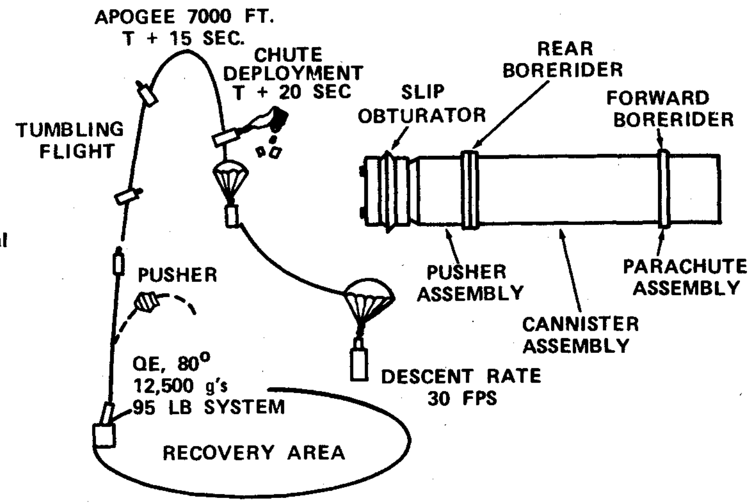

Fig. 9 MICOM soft recovery system canister and typical mission profile.

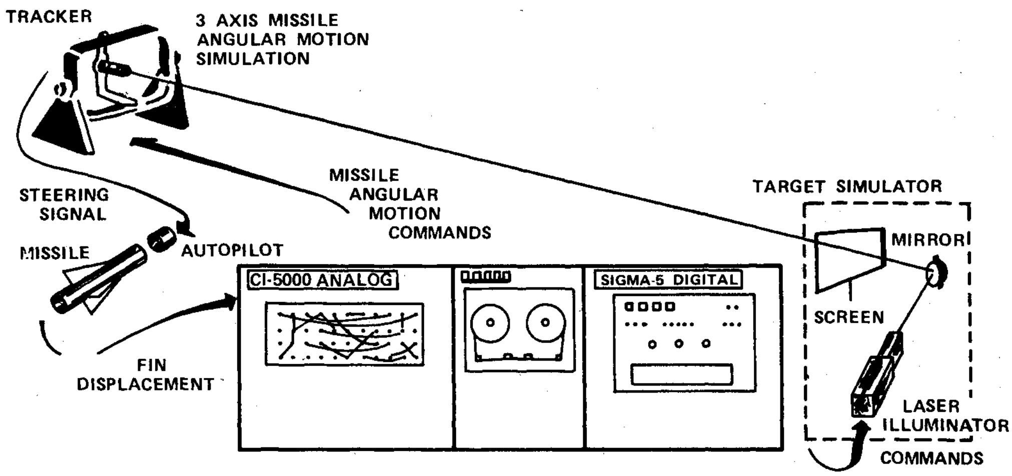

Fig. 10 Hardware-in-the-loop simulation.

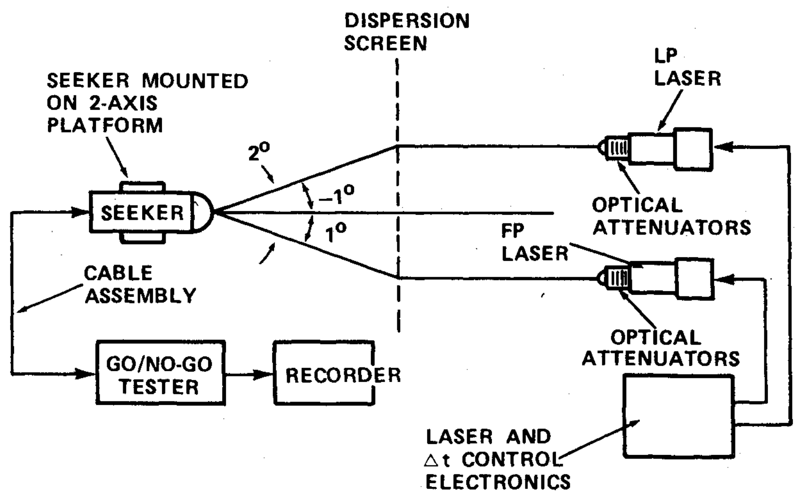

Fig. 11 Laser seeker test configuration.

range closure between them. Models of the airframe, actuator, gyro, seeker, and compensation networks are required with the mathematical generation of three flight table angles, two laser mirror angles, and aperture settings for the laser lens. Figure 10 highlights the system features.

Briefly, the test sequence consists of securing the seeker guidance module to the three-axis flight table connecting cables, to the test monitor breakout box, and to the computer's interface. Voltage levels and polarities are checked at the initial power-up condition. Simulated flights for a prescribed target are seen against a variable laser setting to simulate range closure by increasing the laser energy transmitted to the seeker via the bellows on the laser simulator. Groups of five runs each quantify the total range of the seeker from maximum range at detection (lowest energy at acquisition) to maximum energy (impact condition). Finally,

Table 1 Summary of problems and solutions

Element	Problem	Action
Hybrids	Bond and substrate failures	Pull all bond and support substrates
Actuator	Structure (flange) failure at 9000 *g*	Redesigned for 12,500 *g*
Harness	Broken wires in aerodynamic flight tests	Eliminated heat-shrinkable tubing and supported wire bundle every 6 in.
Attitude rate gyro	Bond joint released	Positive mechanical reinforcement incorporated
Roll stability	Lost roll control	Simulated failure after thorough review of aerodynamic data and modified autopilot with fix to control roll loop gain
Aft retainer ring	Ring jumped thread	Increased strength
Seeker gyro	Squib wire shorted against "gotcha" teeth	Increased squib wire to "gotcha" teeth clearance
Battery	11-V supply shorted to −30-V buss	Added fusible resistor between 11-V supply and −30-V battery initiator squib
Obturator	Inadequate roll decoupling	Changed material to polypropylene

Table 2 Summary of technology achievements

Problem	Achievement
Gyro survival in gun firing environment	Designed and tested a "gotcha" that cradles the gyro during the firing acceleration transient and later retracts and latches in milliseconds, allowing the gyro freedom to spin up and operate; load transfer bearings were also added to aid gyro survival
Roll decoupling	Designed and tested an obturator that yielded a projectile muzzle exit roll rate less than 20 rps
Fin development	Designed and proved a technique for successful fin deployment after exit fin muzzle brake without scoring the gun barrel
Hybrid substrates	Developed processes to fabricate and screen candidates for cannon environment
Detector seal	Developed technique to seal detector to base hermetically to provide long storage life
Wire survival of gun fire environment	Developed techniques to route and bundle wires to survive high-acceleration firing environment
High-strength structural design	Developed analytical models and fabrication processes that resulted in cannon firing reliability
Deliberate fin-induced roll during ballistic flight	Alleviates fin fabrication and tolerance problems and reduces ballistic dispersions

orientations of the seeker in various roll positions are made to values of 45, 90, and 180 deg. If deemed necessary to improve miss distance, vane effectiveness is improved via settings on the analog machine, and *g* bias is increased via an amplifier gain on the analog. A group of runs in each of these conditions may require 60 to 100 trails.[7] These are all oriented to maximizing performance prior to flight testing at White Sands Missile Range.

The MICOM laser seeker test facility is illustrated in Fig. 11. The seeker to be tested is mounted on a gimbaled two-axis platform. Two laser target simulators in the room provide for testing seeker performance with either single or multiple-pulse return conditions.

In addition, the HWIL simulation facility described above is used to evaluate additional seeker parameters. The seeker undergoing test is fixed to the three axis flight table located 245 in. from the diffusing screen. Data recording is done by an eight-channel strip chart recorder or X-Y plotter attached to the seeker signal processor outputs through an umbilical. The source is a low-power Q-switched laser, which accurately simulates the spectral and temporal content of the laser designators proposed for field use. The full dynamic range in intensity which the seeker would see as a result of range closure is simulated on this facility by the use of the "spot size controller" (SSC), which essentially varies the energy density in the beam as a function of time, programmable to cover six decades of dynamic range in as little as 3 s or as many as 20 s. Gimbaled mirrors located at the exit aperture of the spot size controller are used to provide X-Y motion of the laser spot on the diffusing screen. The size of the screen is such as to provide 5-deg motion of the laser spot as seen from the seeker located at the flight table. Neutral density filters located at the output of the laser in conjunction with the spot size controller provide six-decade variation in signal intensity for static measurements over the full seeker dynamic range. Calibration of the laser signal irradiance at the seeker dome is done with a Paveway radiometer, which is linear over greater than four decades of signal intensity. Calibration of the facility at the high-signal-level end is done with a set of three other calibrated radiometers.

The laser dynamic range simulation facility described above allows test engineers to subject semiactive laser (SAL) seekers to a series of combined radiometric and electronic tests which can exercise the seeker gyro/optics and signal-processing electronics to the fullest extent possible to assess its performance and compliance with technical specifications.[8] The following is a list of performance parameters that are measured to verify compliance with the specification and a description of each parameter: threshold sensitivity, real-time dynamic boresight shift over full dynamic range, proportional zone measurements in the linear region of the detector at various signal levels, instantaneous field of view (FOV) at threshold and slightly above, optical gimbal coupling, verification of code selection, gyro maximum slew rate outside the linear range of the detectors' gyro dynamics with line-of-sight change, correlation and decorrelation logic, track command rate in background, and target ambiguity discrimination.

Table 1 presents a summary of problems that were uncovered by these tests during the program. Actions taken to resolve these problems are also included.

Conclusions

All aspects of operation, i.e., obturation, fin deployment, battery activation, ballistic flight, sequence operation, gyro activation, roll rate sensor enablement, control actuator operation, roll control establishment, gravity bias compensation computation, wing deployment, target acquisition, target tracking guidance, and target impact, have been demonstrated. All performance limitations that have been uncovered during the extensive flight test program have been resolved (Table 1).

System and component testing resulted in improved ground facility test techniques for this application. In particular, the component and subsystem gun-fired canister tests with the soft recovery were uniquely developed for this program and not used before (to the knowledge of the authors). Further, flight testing efficiency was enhanced greatly by coupling it strongly with the hardware-in-the-loop simulation facility prior to and after gun-launched canister tests.

A summary of specific technical achievements already validated in the Copperhead program are shown in Table 2. Since the program is still in ED, others that relate to environmental qualification and operational evaluation, scheduled for completion in late 1979 are anticipated.

Acknowledgments

The authors appreciate the very constructive and incisive comments made by one of the reviewers, the technical editor, and S. M. Seltzer of the Control Dynamics Company.

References

[1] Huff, J. B. and Pastrick, H. L., "Performance Verification of the Cannon Launched Guided Projectile's Guidance and Control System," *Proceedings AIAA Guidance and Control Conference*, San Diego, Calif., Aug. 1976, pp. 568-574.

[2] Nulk, R. A. and Pastrick, H. L., "Flight Results and Analysis of Accurate Munitions Delivery Using CLGP with an RPV," *Proceedings NATO/AGARD Conference on Avionics, Guidance and Control For RPVs*, Italian Air War College, Florence, Italy, Oct. 1976.

[3] Morrison, P. H., "A Lesson Learned about Cannon Launched Guided Projectiles," Paper 78-1244, AIAA Guidance and Control Conference, Palo Alto, Calif. 1978.

[4] Morrison, P. H. and Amberntson, D. S., "Guidance and Control of a Cannon-Launched Guided Projectile," *Journal of Spacecraft and Rockets*, Vol. 14, June 1977, pp. 328-334.

[5] Morrison, P. H., "A New Roll Control Concept for Cannon-Launched Guided Projectiles," Paper 77-1095, AIAA Guidance and Control Conference, Hollywood, Fla., 1977.

[6] Pastrick, H. L., Will, C. M., Jolly, A. C., Hazel, L. H., and Vinson, R. J., "Hardware-in-the-Loop Simulation: A Guidance System Optimization Tool," Paper 74-929, AIAA Mechanics and Control of Flight Conference, Anaheim, Calif. Aug. 1974.

[7] Pastrick, H. L., Will, C. M., Isom, L. S., Hazel, L. H., and Vinson, R. J., "Monte Carlo Model Requirements for Hardware-in-the-Loop Missile Simulations," *Proceedings Summer Computer Simulation Conference*, Washington, D.C., July 1976, pp. 112-117.

[8] Pastrick, H. L., York, R. J., and Jolly, A. C., "System Performance Prediction by Modeling Test Data in Digital Simulations," *Journal of Spacecraft and Rockets*, Vol. 11, March 1974, pp. 133-134.

Make Nominations for an AIAA Award

THE following awards will be presented during the AIAA/SAE/ASME 16th Joint Propulsion Conference, June 30-July 2, 1980, in Hartford, Conn. If you wish to submit a nomination, please contact Roberta Shapiro, Director, Honors and Awards, AIAA, 1290 Avenue of the Americas, N.Y., N.Y. 10019 (212) 581-4300. The deadline date for submission of nominations is November 1.

Air Breathing Propulsion Award

"For meritorious accomplishments in the science or art of air breathing propulsion, including turbo-machinery or any other technical approach dependent upon atmospheric air to develop thrust or other aerodynamic forces for propulsion or other purposes for aircraft or other vehicles in the atmosphere or on land or sea."

Wyld Propulsion Award

"For outstanding achievement in the development or application of rocket propulsion systems."