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McDONNELL F4H-1 Navy interceptor is armed with four Sparrow 3 air-to-air missiles stowed in the belly and two Sparrow 3 rounds carried on wing pylons. Missile fire control system is tied to Westinghouse AN/APQ-72 radar fire control system for F4H-1.

Sparrow Keeps Pace with Target and Aircraft

By David A. Anderton

Bedford, Mass.—Raytheon Sparrow 3b, latest version in this long line of Navy air-to-air missiles, now is being tested and flown by company and Navy technicians and pilots.

The 3b version, officially designated AAM-N-6b, was designed to show performance improvement over the 3a missiles now on the McDonnell F4H-1 as primary armament. Development of the 3b, and of the 3a before it, is part of the continuing product-improvement that characterizes most contemporary weapons and their carrying aircraft.

Sparrow has been continually updated to keep it a contemporary weapon. Improvement areas have been increased range, operational altitude, and launch speeds.

Sparrow 3, which first went into service with the Navy as armament for the McDonnell F3H-2M, is a weapon designed for subsonic launching aircraft. Both the 3a and the 3b have the capability of supersonic launch.

Tailoring these performance improvements into the same airframe envelope and within the restrictions of a modest development budget is a challenge to the engineering teams assembled at the Raytheon plant here. The overriding consideration in any portion of this product-improvement program is that new weapons must be completely compatible with the ones they replace. This means no changes in configuration that would change the aerodynamics of the carrying aircraft, no demands for just a few more black boxes aboard the carrying aircraft, no major increases in weight or length of the missile itself.

Raytheon engineers, aware that there is growth potential built into the F4H-1, believe they will be able to take advantage of it to continue improvement of the Sparrow. Some of them believe the Sparrow will continue in production through this decade, and will continue to arm the Navy's supersonic interceptors during that period.

Air Force has ordered a small batch of the missiles through Navy for use during the test program on the two McDonnell F-110s now being flown by USAF pilots (AW July 30, p. 39). Future procurement depends on the results of those tests plus other factors.

Currently, the missiles are operational on the McDonnell F3H-2M, which carries four Sparrow 3 rounds externally on pylons, and on the McDonnell F4H-1, which carries four Sparrow 3a rounds in semi-submerged installations in the fuselage belly, and can carry two more on wing pylons close inboard. The Sparrow 3 has been in the fleet since June, 1958, the Sparrow 3a since last October.

Raytheon is armament integration manager for Navy on both these aircraft, responsible for tying its missile to the Hughes radar system on the F3H and Westinghouse system on the F4H.

Sparrow 3 program is centered at Raytheon's Missile and Space Division, with program management concentrated in this plant. Initial work on the program began with a research and development contract award in June, 1951. First production contract was let January, 1958, and six months later the Navy declared the Sparrow 3 operational with aircraft of the Seventh Fleet in the Pacific. Since then, the weapon also has joined the Sixth Fleet in the Atlantic.

Sparrow speed is more than Mach 3. The Navy says that it is an all-weather, all-aspect missile, which means that it can take on targets from any bearing with respect to the target and in any kind of weather that can be mastered by the carrying aircraft.

Sparrow 3 owes its current form to a basic configuration developed by Douglas Aircraft Co. for the Sperry Sparrow 1, which dates back to 1946. Sparrow has since grown in length and strength, but the basic geometry of the aerodynamic airframe remains the same.

Airframe Design

It features four cruciform wing and tail surfaces mounted on a cylindrical body tipped with an ogival nose cone. The wings span 40 in. in their present, clipped-delta form and are used to provide both lift and maneuvering

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REMOVABLE WINGS on Sparrow missile furnish directional control for the Navy weapon.

Performance

forces. A hydraulically powered servo-system moves the wings in pairs to pitch or yaw the missile in flight. Fixed tail fins supply stabilizing forces.

The body has an 8-in. diameter and is 12 ft. long. The ogival radome is made of aluminum oxide, a ceramic material, to take the high temperatures of flight at supersonic speed and to provide a window for the operational X-band frequency of the Sparrow's guidance system. Remainder of the air-frame is aluminum alloy.

Raytheon builds the missile section from the nose cone to the trailing edge of the wings, plus the tail fins and the tail cone. The rest—essentially only warhead, and rocket engine—is provided as government-furnished materiel and is sent directly to fleet units for on-site assembly with the Raytheon product.

Weight of the Sparrow 3, ready for firing, is about 400 lb.

The missile is divided into six major subassemblies for convenience:

- **Target seeker,** which includes the ceramic radomes, the radar receiver and antenna, and the necessary avionic and mechanical gear to read target data and translate it into language inputs for the autopilot.
- **Autopilot,** which includes electric power and the electronic circuitry necessary to translate the target-data input and combine it with measured data to get an output of control signals.
- **Wing hub,** which provides both structural support and control mechanisms for the wing. This hub contains the hydraulic system, whose operating fluids are carried to the wing actuators through holes drilled into the complicated hub itself rather than carried externally in tubing.
- **Warhead,** which is conventional explosive and is detonated by a proximity fuse. For test rounds, the warhead space is occupied by extensive telemetering equipment. Live rounds carry a limited amount of telemetry.
- **Rocket motor,** which is a single Aerojet-General 1.8 KS 7800 solid-propellant engine. Packaged liquid-propellant engines have been tested on the Sparrow 3 and at one point were considered as an alternate powerplant possibility. The solid unit is now standard.
- **Stabilizer assembly,** which mounts the four fixed delta fins on a tail cone attached to the rocket motor's nozzle end.

Equipment installed in the carrying aircraft is basic to the system, but has some variations between the two types—one for the F3H-2M and the other for the F4H-1—because both missile and aircraft performance are different.

Basically the system uses a large radar in the aircraft nose to perform search, acquisition, tracking and illumination of the target. Fire-control computer combines the radar data with aircraft data to produce a display for the pilot which gives him range, angle, closing speed and target altitude with respect to his aircraft.

Target Acquisition

The system also feeds data to the guidance section of the Sparrow 3 before launch so that it can acquire the target right after launching without prior acquisition. Ready status of the missile is also checked by signals coming from the fire-control computer.

There is a difference in the performance of Sparrow 3 and the 3a which is reflected in the fire-control system. In addition, the large performance difference between the two launching aircraft, and the fact that much larger and more complex radar is carried in the F4H-1, makes it possible to improve the missile weapon performance even more. The over-all F4H-1 system shows more radar range and more data-handling capacity in the computer than the system installed in the older F3H.

The F4H-1 system is built around the Aero-1A Missile Control System using a Westinghouse AN/APQ-72 X-band radar in the nose. This system has been reported able to pick up targets at ranges of more than 50 naut. mi. (AW July 30, p. 42).

Additional improvements are continually fed into the system, on both the aircraft and the missile side, through product-improvement programs.

Typical of these improvements are the performance increases that characterize the Sparrow 3a version now operational with the F4H-1, and the Sparrow 3b, which has been flown but is not yet operational. Another typical improvement in the system would be the ability to deal with future target aircraft of increased performance.

Time of engagement and target performance are two restrictions that force the Sparrow missile system into its present form. Contemporary fighter-bomber or fighter-fighter engagements are of such short duration that there is no time for fancy maneuvering. The weapon available to the intercepting pilot under these conditions must have speed range, reliability and accuracy, coupled with a powerful warhead, and an instant-launch capability. The pilot doesn't want to have to wait for the airborne equivalent of a countdown before the missile is under way. He wants the

PREFLIGHT CHECK for Sparrow 3 system readiness requires only hand cart—the AN/AWA-6 flight line maintenance unit—to supply hydraulic and electric power and cooling air. Test circuits are built into airborne gear and read in cockpit.

response from the missile that he is used to getting when he presses the trigger to fire cannon.

All-Weather Capability

He wants this capability in all-weather conditions; there's very little point in having a two-place, radar-filled airplane like the F4H-1 intercepting a target in thick cloud if the weapon available won't work in clouds, or if it's too hot, or if the sun is in the general direction of the target.

Because he may be vectored to the general area of his probable intercept, the pilot does want a missile that can fire on a collision course against a target with a heading up to 180 deg. from his own. He may not have the time or the performance for a tail chase and a rear-hemisphere attack.

Building all this capability into a missile is no mean task, and if it results in a highly effective missile, it also results in a complex and costly one. The difference between a Sparrow 3 and a Sidewinder can be measured in terms of either missile capability or missile cost. This could be one reason behind the current mix pattern being tried on the McDonnell F-110s in operational test with the USAF. These carry four Sparrows in the semi-submerged positions, and two Sidewinders on the pylons.

This gives the fighter a certain degree of flexibility and makes it possible to achieve some economy of attack. If the pilot found himself in a tail chase against a target giving him a strong infrared return, he could loose the Sidewinder and save the Sparrow for a different mission. But if he found himself on a collision course with the target flying at 90 deg. to his own heading, he would fire the Sparrow.

The intercepting pilot whose aircraft is armed with Sparrow 3s can be vectored to a prospective target or can conduct his own general search of the area. Having found and selected a target, he runs through the airborne test equipment that gives him the ready status of the missiles under his aircraft. The display in the cockpit tells him how many missiles are ready to go. He doesn't have to worry about selecting a specific missile. That is done automatically.

He monitors the radar display of the target which gives him indications of maximum and minimum range limits defining his firing point. At his option, when he crosses into the firing zone, he triggers the missile. The launch follows automatically; the pilot keeps his general heading to continue target illumination.

"The only thing left to do is avoid the debris," said one Navy pilot.

If subsequent engagements follow, or if one of the missiles develops a fault before firing, the system automatically selects the next missile in sequence ready for firing, and tells the pilot the number of operational weapons he has left to shoot.

PERIODIC SYSTEM CHECK for fault location is accomplished on Sparrow 3 with AN/AWA-8 flight line cart which is hangar-deck equipment aboard carriers. Cart is waist-high and contains automatic checkout and fault location indicators.

Sparrow uses a proportional navigational guidance system to fly the missile on a collision course with its target. With this system, the course of the missile is corrected continuously by moving the wings to apply a lateral acceleration to the Sparrow 3. The missile measures the rate of change of the line-of-sight angle between missile and target, and the closing velocity between itself and the target, and generates signals to apply an acceleration proportional to the product of those two parameters.

The Sparrow program started at Raytheon in June, 1951, when the operating division had about 600 people in the Lab 16-building here, and about 75 people on the West Coast. That contrasts with the 23,000 now in the Missile & Space Division.

Sparrow 3 was to feature a semi-active guidance system, in contrast to the two Sparrows which had been developed before it. The original was the Sperry Sparrow 1, a beam-riding air-to-air missile that became the first such missile in the U. S. arsenal arming the Douglas F3D-2M, the McDonnell F3H-2M and the Vought F7U-3M in the mid-1950s. There was also a Sparrow 2, a short-lived version featuring active guidance. Scheduled to be built in Canada as well as in the U. S., the Sparrow 2 was dropped in favor of the Sparrow 3.

At the time that Navy chose the Sparrow 3, there was competition for the job among five different missiles. Three of them were Sparrows, with Sperry, Douglas and Raytheon as prime contractors on the 1, 2 and 3 models, and the other two were the Oriole and the Meteor.

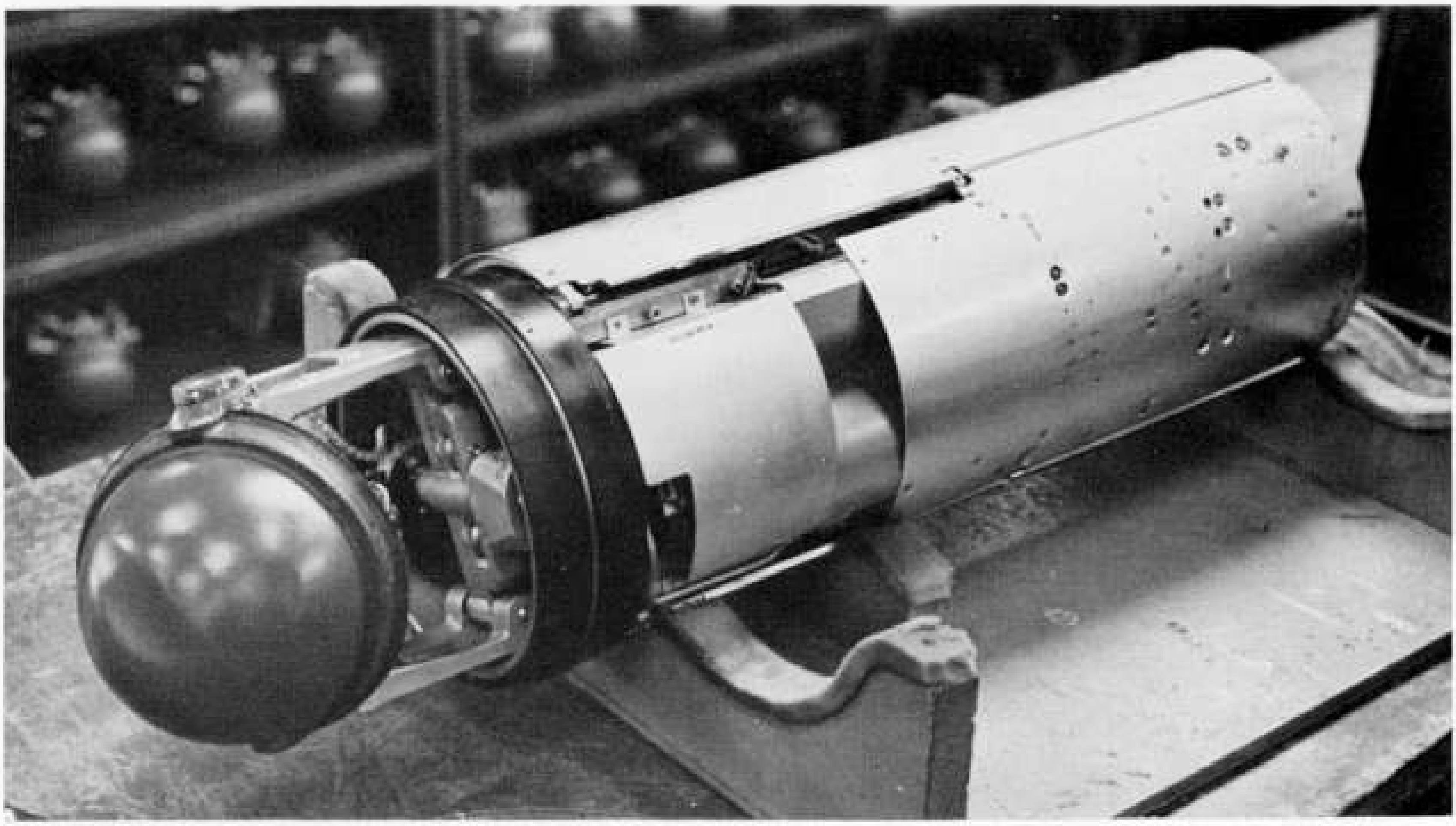
Flight test and pilot production of the Sparrow 3 began in 1953, and was followed by a build-up in production capabilities for the missile as it began to show promising test results. Sparrow 1 production, then concentrated in a Navy-owned plant in Bristol, Tenn., was phased out by 1956, and the Navy turned the plant over to the Raytheon for Sparrow 3.

Current production model, the Sparrow 3a, is being built under a fixed-price incentive contract between Raytheon Co. and the Navy's Bureau of Weapons. This is the first fixed-price contract in the Sparrow program, and Raytheon plans to bid for future production on the same basis. Cost of individual Sparrow missiles is not available, except in relative terms. One of these: Current rounds cost about one-half of the price of those in the first batch of production missiles built four years ago.

Total Raytheon work force on the Sparrow 3 is about 6,000, but the plant is backed up by a large network of suppliers and vendors.

Key Installations

Raytheon has three key installations for the Sparrow 3 program. These are its Bedford, Mass., plant for management, and research and development; its Lowell, Mass., factory supported by Navy-owned facility at Bristol, Tenn., for production, and an Oxnard, Calif.,



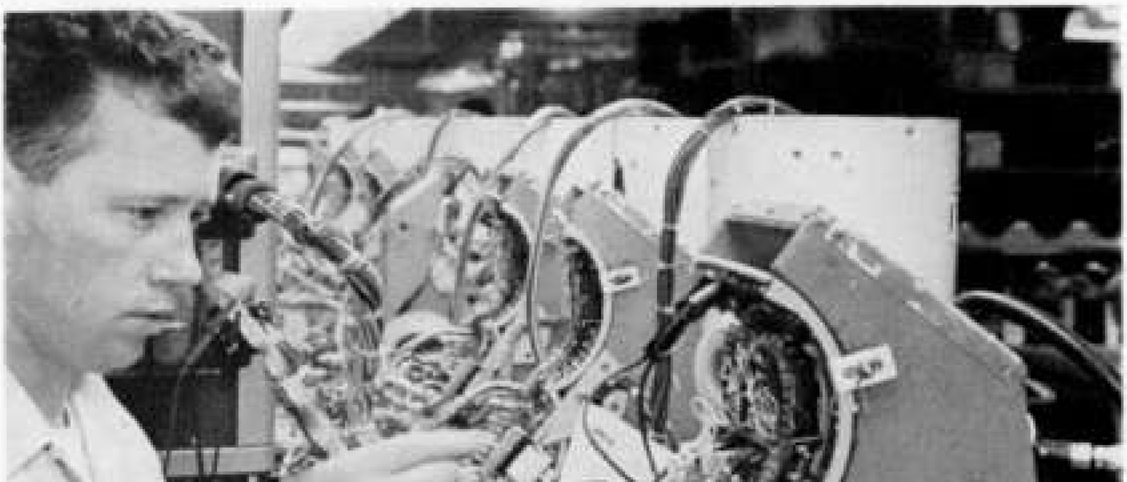
COMPLETE ELECTRO-MECHANICAL assembly of Sparrow 3 seeker head is ready for functional testing and inspection. Seeker dish is covered with protective metal cap painted red. Radome is attached later, with flanges shown at left end of this unit.

facility for flight-test and fleet support.

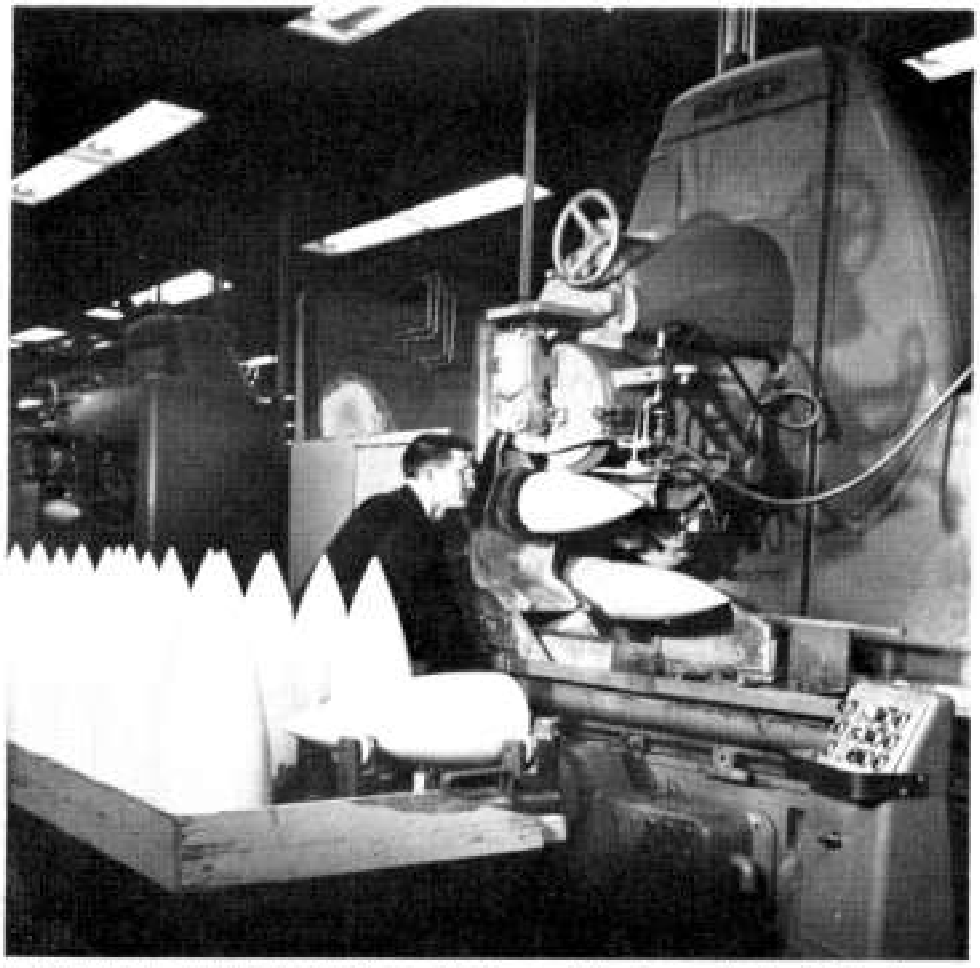
Program management is centered at Bedford, which is to become headquarters of Raytheon's Missile & Space Division in November of this year. Four technical groups at Bedford–missile, fire-control, systems engineering, and administration–manage and perform missile research, design and development. In addition, a program group and a project group work at a higher level with planning problems, future applications and other technical tasks.

For production of the Sparrow 3, Lowell is considered the lead plant, with Bristol in support. From the 400,000 sq. ft. of the Lowell facility the finished "electronic rounds"–Sparrow minus warhead and rocket motor–are delivered to the Navy. Lowell is fed by a network of vendors, supplying the myriad parts that make up the Sparrow. But by far the biggest feedline to Lowell comes from Bristol, which sends all the wings, fins, airframe shells, mechanical gimbal heads for the missiles' seekers, the electronic power units and many small components.

Oxnard, which is located near the Navy Missile Center at Pt. Mugu, works closely with that center in the developmental flight testing of Sparrow 3. Raytheon maintains a supplementary telemetry station, and does much flight-test analysis on the spot with Center personnel. In effect, the Oxnard facility serves as the contractor's proving ground. But there is more than that: Oxnard also has the responsibility for design and fabrication of test equip-



FUNCTIONAL CHECK of Sparrow 3 autopilot operation is mechanized by high-rate, high-quality production. Technician is shown connecting harness bundles.



ELECTRONIC ROUND is checked (left) in final inspection stations before acceptance by Navy. Each movable wing is checked in body connection fittings. Ceramic radome (right) is ground to final contour at Raytheon's Bristol, Tenn., plant.

ment, and for maintenance of Sparrow test rounds. Top staff at Oxnard have been with the program about 10 years.

Quality assurance and design for reliability run through the three elements of this organization like parallel themes. Mutually dependent, they are major factors behind every line drawn on paper and every test performed on a component. Raytheon engineers say that reliability has to be designed into a part at the start. For that reason, production design starts in the research and development organization. There is no design and development of prototype units which are later completely redone to make them producible.

When Sparrow 3 was chosen by the Navy, it was a test vehicle that had to make a rapid transition to a production missile. The Lowell plant established an industrial support team, made up of engineers who are knowledgeable in such production functions as quality assurance, materials, industrial and production engineering. They were to become the nucleus of the production plant, but they set up business at Bedford to inject production engineering into the design as it developed.

Early in the design of each part this team began to establish basic production structure through bills of materials, process sheets, value analysis, and the other techniques available to the production engineer. The major mission of the team was not to design the missile, but to foresee the production pitfalls and the design detours that would avoid them.

At the same time, Bedford engineers were designing for reliability at the packaging level, checking prototype performance, learning about the modes of failure. Quality assurance people worked closely with engineers in the design stages of the Sparrow 3, determining purchase specifications, and checking and questioning potential vendors of parts.

Attention Focus

All this attention to production design and quality assurance finally came to focus on specific parts coming off production lines at Raytheon and vendor plants. In Raytheon, technicians picked off parts made at company plants and checked them for conformity to specification. Their reporting of these investigations bridged the gap between the quality assurance teams in research and development on one hand and in production on the other.

Roving inspectors, assigned exclusively to determine that parts were being made according to the process sheets, had the responsibility and authority to shut down a machine or stop an operation if there were deviations.

One out of every six employes in the Lowell production plant is an inspector of one type or another. In addition to the roving teams, there are inspectors passing on the electronic assembly work every few stations along the line. These inspectors dab each connection with red paint after they have verified that the joint has been made properly and the connections are correct.

One missile out of each month's production lot is selected for a complete checkout, after each of its components and subsystems has already been signed off as inspected and working. If a fault is found, and it is apparently a random one, the missile is repaired; but if it is a type of fault that could be a general ailment, the entire batch is checked and repaired where necessary.

Navy inspectors are on the line in final assembly, where all of the missile gets one more look before acceptance. Such final inspection is performed by the company inspectors and witnessed by the Navy inspectors, standard procedure in Navy contracting.

Finally, each lot of missiles goes through a sample test which includes a complete environmental check. Then some of the missiles are proof-fired as a further quality-assurance measure.

The Lowell plant's involvement with Sparrow 3 production starts with its control over tooling for the missile. All of it is designed at Lowell, and 95% of it is made there.

Production is planned, and work centers are loaded, on the basis of units of one month's production. Raw materials are received at one end of the plant and after incoming inspection for quality are fed directly either to shears or to automatic screw machines.

Shop work centers are of two types: line production, handling large quantities of parts with a build-up to final assembly, and process production, where a number of unrelated parts receive the same kind of treatment. Example of the former is the build-up of the electronic platters that contain the seeker and autopilot; example of the latter is heat-treating.

One myth that Raytheon punctured is the old one that women can't turn out precision machine work. There are large numbers of women in the machine shop and machining process areas, working on parts whose tolerance callouts specify dimensions to within a few hundred-thousandths.

For example, the final steps in making pistons for hydraulic servo units call for grinding to close tolerances on all dimensions, near-perfect straightness of the piston, and a very fine surface finish. Raytheon tool engineers and process specialists combined the manufacture and inspection into one routine on the piston. Now women complete this operation using a fine grinder equipped with a projection-screen viewer with a dimensioned grid for guidance. The grinder head carries a probe, and is moved toward the work piece with a multiplying lever. A Precisionaire gauge gives a visual indication of the set limits for acceptable parts, and the worker can finish to an inspected dimension in one operation.

Almost all of the missile is built at Raytheon and no major subassemblies are purchased. But about 40% of the missile is bought outside in the form of raw materials, hardware, and standard components such as resistors, tubes and capacitors. Of that 40%, about two-thirds comes from small-business organizations.

Whether to make or buy a part is the subject of serious concern at Raytheon, as at other major systems contractors. The company has, and maintains, versatility in production of most of its product line, and is able to step in and produce if a vendor or subcontractor fails to meet schedules or specifications. In the Sparrow 3, such decisions are made by committee in a procedure detailed in seven pages of instructions in the company's operations manual. Basically, these instructions say that the influencing factors are management policies, optimum plant utilization, maintenance of quality levels, minimizing schedule failures and the needs of small business and businesses in labor-surplus areas. Within this framework, the final decision is expected to be that offering equivalent material at optimum cost.

Part Construction

Most of these decisions come out to make the part. So Raytheon makes most of the missile, right down to such near-standard parts as tube clips for the electronic platter assemblies, but continues to buy substantial numbers of standard parts outside.

Production at Lowell is centered on the two major avionic subassemblies of the Sparrow 3: the seeker head with its sensing and data-production system, and the computer and autopilot unit. Platters, shell framework and electronic components for these two move in steady flow through long lines of seated, soldering girls. The mechanical gimbal head for the seeker, received from Bristol, gets inspected and readied for assembly to its electronic gear.

In a separate clean area, technicians turn out hundreds of tiny gyros for the Sparrow 3 autopilot similar in design to the gyros used on the Hawk and described earlier in AVIATION WEEK (Dec. 4, 1961, p. 74).

The assembled platters, their electronics turned inside out for accessibility, then pass through separate test areas, where the seeker is checked and where the autopilot performance is measured against the simulated input of a seeker head.

Then the shells are buttoned up again, and the seeker and autopilot assemblies are joined and topped with the ceramic radome sent in from Bristol.

This essentially completes the production of the "electronic round" at Lowell. The missiles receive finishing touches in the form of decals and stenciled identifications and instructions, pass final assembly inspection, the fitting of the movable wings, and the check of igniters. The Navy accepts them, and they are trundled on their carriages into the next room for packing and shipping. There, protective covers are installed and safety-wired into place. The rounds are clamped into "coffins"—long olive-drab metal containers of about that size and shape—and loaded onto the gray freight cars waiting on the spur outside the doors.

Packed in their shipping "coffins" aboard Navy freight cars, the missiles are distributed equally to East and West Coast Naval magazines by a priority-list procedure. When a call for ship-fills is processed, the electronic rounds are sent to specific ships by routine Navy handling, and there are stored in the missile magazines.

Before loading on the carrier aircraft, the Sparrow rounds are checked, two at a time, by the DSM-32 test equipment which provides a periodic status report on missile conditions. Readout of data for one round at a time comes from the DSM-32 and forms the basis for accepting or rejecting a round.

Checked rounds then are transferred to the missile ready magazine for short-term storage. From that room they are moved to the missile assembly room, which is surrounded by warhead lockers and rocket-motor lockers. Navy missilemen assemble the complete round with warhead and motor, but without fins and wings, which are installed on the hangar deck to lessen the possibility of damage during movement of the round from the assembly area to the aircraft.

The complete round then is attached to the launching pylon or installed in the semi-submerged position, depending on the type of launching aircraft, and is checked out as ready-to-go with the equipment installed as part of the airborne fire control system.

Navy conducts all the training for the Sparrow system, as it does with all of its weapons, equipment and ships, except for some highly specialized training that might be demanded by specific changes in the Sparrow. In that case, Raytheon would conduct an in-factory training program. Navy specialists in ordnance, electronics, mechanics and in the other skills of the missileman receive extra instruction in the Sparrow system in addition to the training of their specialties.

Pilot Training

Pilot training includes some basic instruction in the use of the system, cockpit checkouts and live firings conducted during squadron exercises or air weapons competitions.

Missile failures found during checkout on ship or in launching are reported back through Navy channels to the Naval Ordnance Laboratory at Corona, Calif., where the reports are recorded and correlated.

Sparrow 3 problems are relayed to Raytheon by Corona so that the company has a running check of its own quality-assurance program by the performance of delivered rounds operated under service conditions. This link is the only official feedback from user to manufacturer in the Sparrow program. As always, there are also a number of unofficial links which also connect the Navy and Raytheon.

A realistic value for Sparrow 3 reliability could be estimated at about 95% for launched rounds, remembering that before launching, the bird has been checked three times: leaving the factory, preflight and inflight.

Sparrow 3 maintenance is based on the assumption that every missile is perfect when delivered to the Navy. But everybody accepts the reality that there will be materiel failures somewhere along the line, and that they will have to be fixed.

Maintenance Concepts

Raytheon's maintenance concepts for the Sparrow were based on the elimination of shipboard repair, and the minimizing of shipboard maintenance. Once the Sparrow 3 was delivered to the fleet, it either had to work or it was to be returned for rework. At every level of operation with the missile, where checking is involved, the Navy technician gets either a go or a no-go indication. He allows the "go" rounds to pass through his station, and sends the "no-go" rounds back through channels.

The Sparrow 3 guidance and control section, stored as one unit aboard ship, requires periodic checking on a three-month time cycle. All system elements are checked by test equipment which simulates flight problems, monitors the missile response to the problem and then locates major components which are faulty.

Test Equipment

The aircraft portion of the weapon system is designed to be checked by test equipment which can find the fault without removing the system from the carrying aircraft. Replacement of faulty units is also planned on that basis. Test and maintenance operations for the aircraft portion of the system are done at four levels:

- **Preflight,** to determine system readiness. A small hand cart, the AN/AWA-6 flight-line maintenance unit, is hauled out to the aircraft and connected to its internal systems to provide hydraulic and electrical power plus cooling air for the fire-control system. Test circuitry built into the system reads out data in the cockpit and indicates the status of the system.
- **Thirty-hour cycle,** for periodic check of the system. This test level uses a more elaborate hand cart, the AN/AWA-8 flight line cart, which supplies the required electrical and hydraulic power and cooling air, plus much automatic checking equipment and fault indicators.
- **Bench test,** to locate and correct faults. The faulty portion is removed from the aircraft, installed in a test-bench system using the complete fire-control apparatus, and repaired or replaced as necessary.
- **Depot repair,** for complete overhaul. The complete fire-control system is removed from its aircraft and run through tear-down, checking and rebuilding to production-line standards.

Basic Guidelines

For Sparrow 3 missiles, the same basic philosophies govern the maintenance and repair operations. If the missile doesn't perform correctly, back it comes. There is no teardown or overhaul of Sparrows aboard ship. Individual major components of the missile, such as the guidance unit or the seeker unit, may be replaced by another complete unit in the missile assembly process. But anything further is done at a depot level.

When a missile is returned because it was found inoperative, it is run through a production-line process which breaks the missile down into simple tasks and then provides a complete production-standard overhaul of the entire missile. Raytheon originally organized and operated the maintenance depots for Sparrow 3, to prove the concept. Now the depots are run by the Navy.

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