Pigeons in a Pelican

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This is the history of a crackpot idea, born on the wrong side of the tracks intellectually speaking, but eventually vindicated in a sort of middle-class respectability. It is the story of a proposal to use living organisms to guide missiles-of a research program during World War II called "Project Pigeon" and a peacetime continuation at the Naval Research Laboratory called "ORCON" from the words "organic control." Both of these programs have now been declassified.

Man has always made use of the sensory capacities of animals, either because they are more acute than his own or *more* convenient. The watchdog probably hears better than his master and, in any case, listens while his master sleeps. As a detecting *system* the dog's ear comes supplied with an alarm (the dog need not be taught to announce the presence of an intruder), but special forms of reporting are sometimes set up. The tracking behavior of the bloodhound and the pointing of the hunting dog are usually modified to make them more useful. Training is sometimes quite explicit. It is said that sea gulls were used to detect submarines in the English Channel during World War I. The British sent their own submarines through the Channel releasing food to the surface. Gulls could see the submarines from the air and learned to follow them, whether they were British or German. A flock of gulls, spotted from the shore, took on special significance. In the seeing-eye dog the repertoire of artificial signaling responses is so elaborate that it has the conventional character of the verbal interchange between man and man.

The detecting and signaling systems of lower organisms have a special advantage when used with explosive devices which can be guided toward the objects they are to destroy, whether by land, sea, or air. Homing systems for guided missiles have now been developed which sense and signal the position of a target by responding to visible or invisible radiation, noise, radar reflections, and so on. These have not always been available, and in any case a living organism has certain advantages. It is almost certainly cheaper and more compact and, in particular, is especially good at responding to patterns and those classes of patterns called "concepts." The lower organism is not used because it is more sensitive than man-after all, the kamikaze did very well-but because it is readily expendable.

Project Pelican

The ethical question of our right to convert a lower creature into an unwitting hero is a peacetime luxury. There were bigger questions to be answered in the late thirties. A group of men had *come* into power who promised, and eventually accomplished, the greatest mass murder in history. In 1939 the city of Warsaw was laid waste in an unprovoked bombing, and the airplane emerged as a new and horrible instrument of war against which only the feeblest defenses were available. Project Pigeon was conceived against that background. It began as a search for a homing device to be used in a surface-to-air guided missile as a defense against aircraft. As the balance between offensive and defensive weapons shifted, the direction was reversed, and the system was to be tested first in an air-to-ground missile called the "Pelican." Its name is a useful reminder of the state of the missile art in America at that time. Its detecting and servomechanisms took up so much space that there was no room for explosives: hence the resemblance to the pelican "whose beak can hold more than its belly can." My title is perhaps now clear. Figure 1 shows the pigeons, jacketed for duty. Figure 2 shows the beak of the Pelican.

At the University of Minnesota in the spring of 1940 the capacity of the pigeon to steer toward a target was tested with a moving hoist. The pigeon, held in a jacket and harnessed to a block, was immobilized except for its neck and head. It could eat grain from a dish and operate a control system by moving its head in appropriate directions. Movement of the head operated the motors of the hoist. The bird could ascend by lifting its head, descend by lowering it, and travel from side to side by moving appropriately. The whole system, mounted on wheels, was pushed across a room toward a bull's-eye on the far wail. During the approach the pigeon raised or lowered itself and moved from side to side in such a way as to reach the wall in position to eat grain from the center of the bull's-eye The pigeon learned to reach any target within reach of the hoist, no matter what the starting position and during fairly rapid approaches.

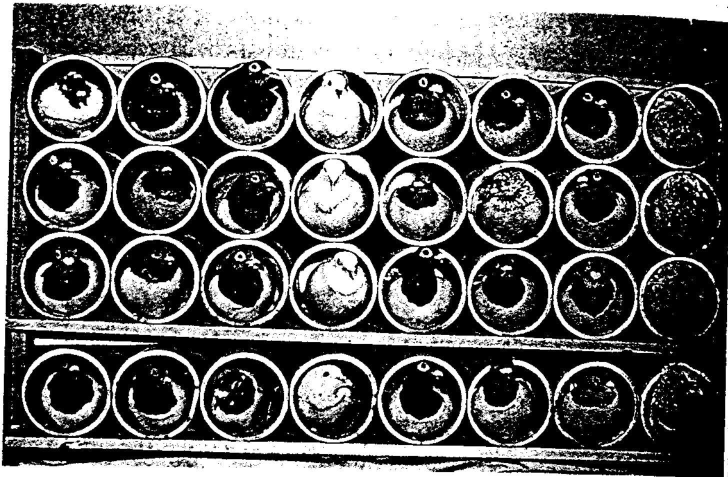

FIG. I. Thirty-two pigeons, jacketed for testing,

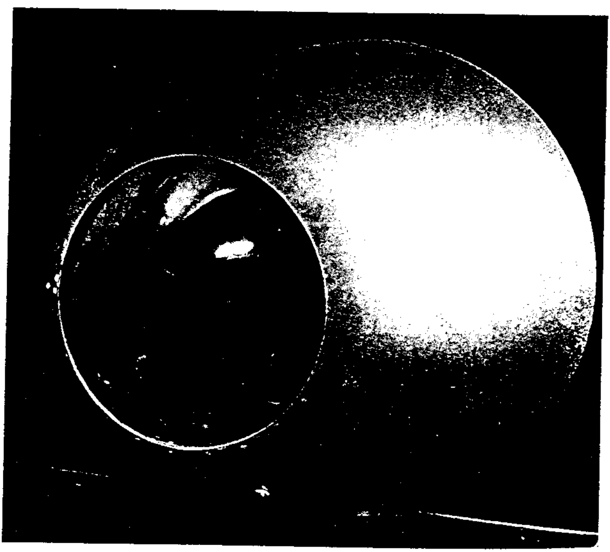

FIG. 2. Nose of the Pelican, showing lenses.

The experiment was shown to John T. Tate, a physicist, then Dean of the Graduate School at the University of Minnesota, who brought it to the attention of R. C. Tolman, one of a group of scientists engaged in early defense activities. The result was the first of a long series of rejections The proposal "did not warrant further development at the time." The project was accordingly allowed to lapse. On December 7, 1941, the situation was suddenly restructured; and, on the following day, with the help of Keller Breland, then a graduate student at Minnesota, further work was planned. A simpler harnessing system could be used if the bomb were to rotate slowly during its descent, when the pigeon would need to steer in only one dimension: from side to side. We built an apparatus in which a harnessed pigeon was lowered toward a large revolving turntable across which a target was driven according to contacts made by the bird during its descent. It was not difficult to train a pigeon to "hit" small ship models during fairty rapid descents. We made a demonstration film showing hits on various kinds of targets, and two psychologists then engaged in the war effort in Washington, Charles Bray and Leonard Carmichael, undertook to look for government support. Tolman, then at the Office of Scientific Research and Development, again felt that the project did not warrant support, in part because the United States had at that time no missile capable of being guided toward a target. Commander (now Admiral) Luis de Florez, then in the Special Devices Section of the Navy, took a sympathetic view, He dismissed the objection that there was no available vehicle by suggesting that the pigeon be connected with an automatic pilot mounted in a small plane loaded with explosives. But he was unable to take *on* the project because of other commitments and because, as he explained, he had recently bet on one or two other equally long shots which had not come in.

The project lapsed again and would probably have been abandoned if it had not been for a young man whose last name I have ungratefully forgotten, but whose first name--Victor--we hailed as a propitious sign. His subsequent history led us to refer to him as Vanquished; and this, as it turned out, was a more reliable omen. Victor walked into the Department of Psychology at Minnesota one day in the summer of 1942 looking for an animal psychologist. He had a scheme for installing dogs in antisubmarine torpedoes. The dogs were to respond to faint acoustic signals from the submarine and to steer the torpedo toward its goal He wanted a statement from an animal psychologist as to its feasibility He was understandably surprised to learn of our work with pigeons but seized upon it eagerly; citing it in support of his contention that dogs could be trained to steer torpedoes, he went to a number of companies in Minneapolis His project

was rejected by everyone he approached; but one company, General Mills, Inc., asked for more information about our work with pigeons. We described the project and presented the available data to Arthur D. Hyde, Vice-President in Charge of Research. The company was not looking for new products, but Hyde thought that it might, as a public service, develop the pigeon system to the point at which a governmental agency could be persuaded to take ***over.***

Breland and I moved into the top floor of a flour mill in Minneapolis and with the help of Norman Gunman, who had joined the project, set to work on further improvements. It had been difficult to induce the pigeon to respond to the small angular displacement of a distant target. It would start working dangerously late in the descent. Its natural pursuit behavior was not appropriate to the characteristics of a likely missile. A new system was therefore designed. An image of the target was projected on a translucent screen as in a camera obscura. The pigeon, held near the screen, was reinforced for pecking at the image on the screen. The **guiding** signal was to be picked up from the point of contact of screen and beak.

In an early arrangement the screen was a translucent plastic plate forming the larger end of a truncated cone bearing a lens at the smaller end. The cone was mounted, lens down, in a gimbal bearing. An object within range threw its image on the translucent screen; and the pigeon, held vertically just above the plate, pecked the image. When a target was moved about within range of the lens, the cone continued to point to it. In another apparatus a translucent disk, free to tilt slightly on gimbal bearings, closed contacts operating motors which altered the position of a large field beneath the apparatus. Small cutouts of ships and other objects were placed on the field. The field was constantly in motion, and a target would go out of range unless the pigeon continued to control it. With this apparatus we began to study the pigeon's reactions to various patterns and to develop sustained steady rates of responding through the use of appropriate schedules of reinforcement, the reinforcement being a few grains occasionally released onto the plate. By building up large extinction curves a target could be tracked continuously for a matter of minutes without reinforcement. We trained pigeons to follow a variety of land and sea targets, to neglect large patches intended to represent clouds or flak, to concentrate on one target while another was in view, and so on. We found that a pigeon could hold the missile on a particular street intersection in an aerial map of a city. The map which came most easily to hand was of a city which, in the interests of international relations, need not be identified. Through appropriate schedules of reinforcement it was possible to maintain longer uninterrupted runs than could conceivably be required by a missile.

We also undertook a more serious study of the pigeon's behavior- with the help of W. K. Estes and Marion Breland, who joined the project at this time. We ascertained optimal conditions of deprivation, investigated other kinds of deprivations, studied the effect of special reinforcement5 (for example, pigeons were said to find hemp seed particularly delectable), tested the effects of energizing drugs and increased oxygen pressures, and so on. We differentially reinforced the force of the pecking response and found that pigeons could be induced to peck so energetically that the base of the beak became inflamed. We investigated the effects of extremes of temperature, of changes in atmospheric pressure, of accelerations produced by an improvised centrifuge, of increased carbon dioxide pressure, of increased and prolonged vibration, and of noises such as pistol shots. (The birds could, of course, have been deafened to eliminate auditory distractions, but we found it easy to maintain steady behavior in spite of intense noises and many other distracting conditions using the simple process of adaptation,) We investigated optimal conditions for the quick development of discriminations and began to study the pigeon's reactions to patterns, testing for induction from a test figure to the same figure inverted, to figures of different sizes and colors, and to figures against different grounds. A simple device using carbon paper to record the points at which a pigeon pecks a figure showed a promise which has never been properly exploited.

We made another demonstration film and renewed our contact with the Office of Scientific Research and Development. An observer was sent to Minneapolis, and on the strength of his report we were given an opportunity to present our case in Washington in February, 1943. At that time we were offering a homing device capable of reporting with an on-off signal the orientation of a missile toward various visual patterns. The capacity to respond to pattern was, we felt, our strongest argument, but the fact that the device used only visible radiation (the same form of information available to the human bombardier) made it superior to the radio-controlled missiles then under development because it was resistant to jamming. Our film had some effect. Other observers were sent to Minneapolis to see the demonstration itself. The pigeons, as usual, behaved beautifully. One of them held the supposed missile on a particular intersection of streets in the aerial map for five minutes although the target would have been lost if the pigeon had paused for a second or two The observers returned to Washington, and two weeks later we were asked to supply data on (*a*) the population of pigeons in the United States (fortunately, the census bureau had some figures) and (*b*) the accuracy with which pigeons struck a point on a plate. There were many arbitrary conditions to be taken into account in measuring the latter, but we supplied possibly relevant data. At long last, in June, 1943, the Office of Scientific Research and Development awarded a modest contract to General Mills, Inc. to "develop a homing device."

At that time we were given some information about the missile the pigeons were to steer. The Pelican was a wing-steered glider, still under development and not yet successfully steered by any homing device. It was being tested on a target in New Jersey consisting of a stirrup-shaped pattern bulldozed out of the sandy soil near the coast. The white lines of the target stood out clearly against brown and green cover. Colored photographs were taken from various distances and at various angles, and the verisimilitude of the reproduction was checked by flying over the target and looking at its image in a portable camera obscura.

Because of security restrictions we were given only very rough specifications of the signal to be supplied to the controlling system in the Pelican. It was no longer to be simply on-off; if the missile was badly off target, an especially strong correcting signal was needed. This meant that the quadrant-contact system would no longer suffice. But further requirements were left mainly to our imagination. The General Mills engineers were equal to this difficult assignment. With what now seems like unbelievable speed, they designed and constructed a pneumatic pickup system giving a graded signal. A lens in the nose of the missile threw an image on a translucent plate within reach of the pigeon in a pressure-sealed chamber. Four air valves resting against the edges of the plate were jarred open momentarily as the pigeon pecked. The valves at the right and left admitted air to chambers on opposite sides of one tambour, while the valves at the top and bottom admitted air to opposite sides of another. Air on all sides was exhausted by a Venturi cone on the side of the missile. When the missile was on target, the pigeon pecked the center of the plate, all valves admitted equal amounts of air, and the tambours remained in neutral positions. But if the image moved as little as a quarter of an inch off-center, corresponding to a very small angular displacement of the target, more air was admitted by the valves on one side, and the resulting displacement of the tambours sent appropriate correcting orders directly to the servosystem.

The device required no materials in short supply, was relatively foolproof, and delivered a graded signal It had another advantage By this time we had begun to realize that a pigeon was more easily controlled than a physical scientist serving on a committee It was very difficult to convince the latter that the former was an orderly system We therefore multiplied the probability of success by designing a multiple-bird unit There was adequate space in the nose of the Pelican for three pigeons, each with its own lens and plate. A net signal could easily be generated The majority vote of three pigeons offered an excellent guarantee against momentary pauses and aberrations (We later worked out a system in which the majority took on a more characteristically democratic function. When a missile is falling toward *two* ships at sea, for example, there is no guarantee that all three pigeons will steer toward the same ship. But at least two must agree, and the third can then be punished for his minority opinion. Under proper contingencies of reinforcement a punished bird will shift immediately to the majority view. When all three are working on one ship, any defection is immediateiy punished and corrected.)

The arrangement in the nose of the Pelican is shown in Figure 3. Three systems of lenses and mirrors, shown at the left, throw images of the target area on the three translucent plates shown in the center. The ballistic valves resting against the edges of these plates and the tubes connecting them with

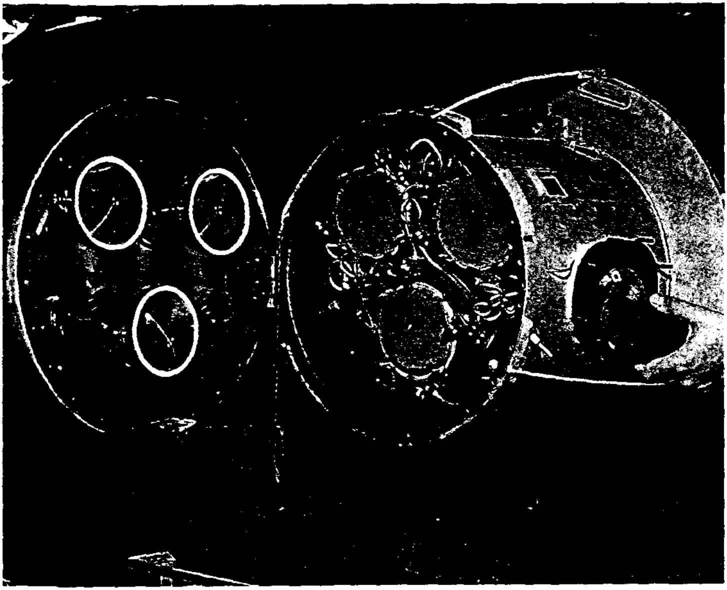

FIG. 3. Demonstration model of the three-pigeon guidance system.

the manifolds leading to the controlling tambours may be seen. A pigeon is being placed in the pressurized chamber at the right.

The General Mills engineers also built a simulator (Figure 4)—a sort of

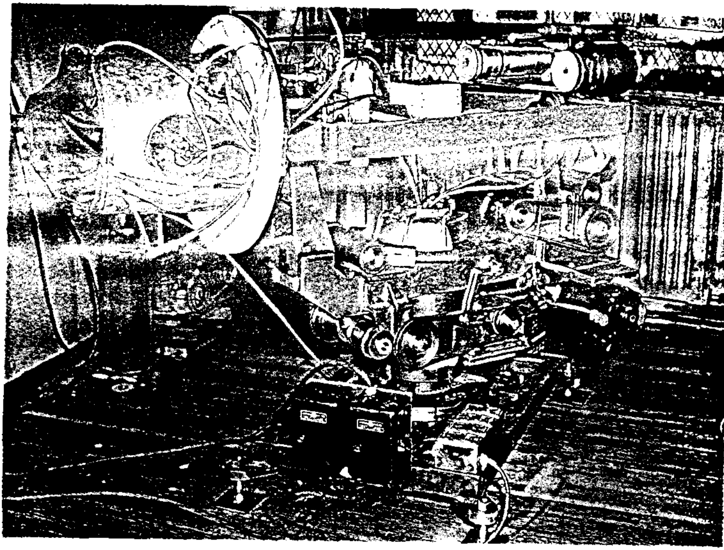

FIG. 4. Simulator for testing the adequacy of the pigeon signal.

Link trainer for pigeons-designed to have the steering characteristics of the Pelican, in so far as these had been communicated to us. Like the wing-steered Pelican, the simulator tilted and turned from side to side. When the three-bird nose was attached to it, the pigeons could be put in full control -the "loop could be closed"-and the adequacy of the signal tested under pursuit conditions. Targets were moved back and forth across the far wall of a room at prescribed speeds and in given patterns of oscillation, and the tracking response of the whole unit was studied quantitatively.

Meanwhile we continued our intensive study of the behavior of the pigeon. Looking ahead to combat use we designed methods for the mass production of trained birds and for handling large groups of trained subjects We were proposing to train certain birds for certain *classes* of targets, such as ships at sea, while special squads were to be trained on special targets, photographs of which were to be obtained through reconnaissance. A large crew of pigeons would then be waiting for assignment, but we developed harnessing and training techniques which should have solved such problems quite easily.

A multiple-unit trainer is shown in Figure 5. Each box contained a jack-

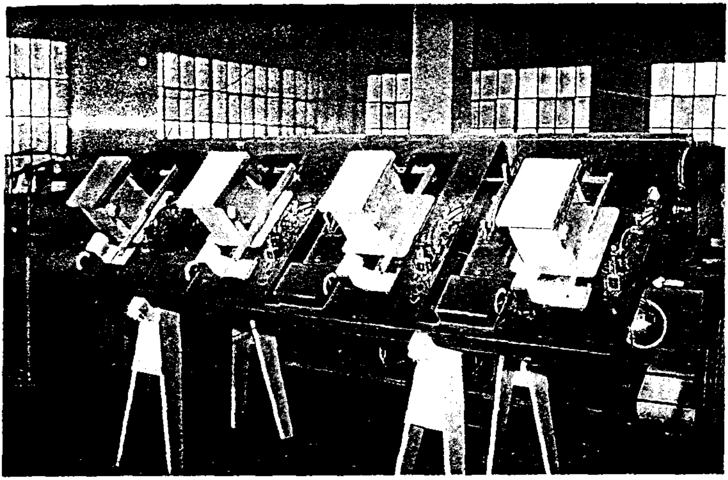

FIG. 5. A trainer for four pigeons.

eted pigeon held at an angle of 45° to the horizontal and perpendicular to an 8" x 8" translucent screen. A target area is projected on each screen. Two beams of light intersect at the point to be struck. All on-target responses of the pigeon are reported by the interruption of the crossed beams and by contact with the translucent screen. Only a four-inch, disk-shaped portion of the field is visible to the pigeon at any time, but the boxes move slowly about the field, giving the pigeon an opportunity to respond to the target in all positions. The positions of all reinforcements are recorded to reveal any weak areas. A variable-ratio schedule is used to build sustained, rapid responding.

By December, 1943, less than six months after the contract was awarded, we were ready to report to the Office of Scientific Research and Development. Observers visited the laboratory and watched the simulator follow a target about a room under the control of a team of three birds. They also reviewed our tracking data. The only questions which arose were the inevitable consequence of our lack of information about the signal required