ALL-WEATHER-ATTACK SYSTEM
Report R-57
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ABSTRACT

The feasibility for an all weather interdiction by level and dive runs at terrain clearances from 1,000 to 12,000 feet against moving targets, arteries of supply and reinforcement, and isolated fixed targets has been demonstrated. The radar tracking of isolated moving targets is held to about 3 milliradians for all the runs. Ranges of target acquisition ran from 15,000 to 25,000 yards and could be extended with higher powers. The system is compatible with two-man operation. Thus, this could provide the commander with a weapon for continuing his offensive in his area of responsibility during night and bad weather against all targets on the ground compatible with radar illumination whether they are fixed or moving.
INTRODUCTION

This is a preliminary report of an experimental implementation for establishing the feasibility of the heretofore undeveloped electronics required for the All-Weather-Attack System proposed in the Control Systems Laboratory report R-28 (December, 1952).

Essentially, in order to obtain a tactical all-weather interdiction capability with high speed planes, that report proposed an integrated radar search and radar lock-on (gun-laying). With these, it proposed to achieve the four phases of attack as follows:

1. Navigation—by using the search radar for radar pilotage based on returns from fixed signals which may be augmented by any other means, such as shoran, as heretofore, until new devices such as inertial navigators and profilometers become available. It is to be noted that the lock-on radar can easily provide a profilometer for the pilot most of the time.

2. Target Detection—by either the customary fixed signal or an AMTI presentation in the center of the search display.

3. Target Acquisition—for isolated fixed targets and moving targets by the controller aiming the lock-on radar toward the target and adjusting the range for lock-on or for nonisolated fixed targets by setting up the customary range and azimuth aided tracking with the depression angle coming from the lock-on.
4. Target Destruction--by the pilot flying an attack course from the PDI (pilot's direction indicator) setup from the relative bearing of the lock-on or with the autopilot controlled by the same data. Ordnance is to be automatically released as directed by the computer.

Since the proposal did retain the heretofore customary radar data for the current bombing systems, as well as automatically providing the depression angle of the target, all of the customary bomb attacks are available to it with at least as much accuracy as presently enjoyed by the Air Force, and these were not implemented in this feasibility experiment. Rather, the implementation stressed the new feature of locking on isolated fixed targets and moving targets to permit more accurate runs than heretofore possible on any targets. Thus, a new, significant and difficult category of targets has been added. The significance of moving targets is not primarily the possible destruction of reinforcement and redeployment of the enemy forces, but because of the extraordinary ranges of detecting such targets, it becomes a prime means for high resolution detection of arteries and areas of activity and prompt destruction of these. These arteries are particularly important for any enemy blitzes during the opening phases of a war. An enemy air field that has no associated activity is not actively opposing our Air Force. Thus, the commander would have a most flexible weapon for continuing his offensive during nonvisual conditions and

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could plan and execute attacks against any fixed or moving target compatible with radar illumination in his area of responsibility.

**IMPLEMENTATION**

The implementation for these experiments was supported by Air Research and Development Command and Wright Air Development Center from the inception of the concept of a possible all-weather attack on moving targets in May, 1952.

The Aircraft Engineering Branch (WCUE) of Wright Air Development Center extensively altered B-29 number 4521852 to be the test vehicle. This included a new nose for mounting the lock-on antennas, the installation of an APS-23 antenna in place of the forward lower gun turret, a PDI scope near the pilot's panel, a scope, joy stick, and operational control panel at the navigator's station, a mounting for a servoed gun camera in the nose, and an extensive installation of relay racks and data instrumentation in the forward bomb bay, as well as sufficient inverters for the extra power load in the rear section of the aircraft. The nose radome and the gun turret radome, as well as the gun camera window, are shown in Figure 1.

The Armament Laboratory (WCLGB) of Wright Air Development Center provided extensive assistance in obtaining the required G.F.E. such as the APS-27 (XA-5) for the search radar, an E-4 gun-laying system, a "Naveye" antenna from North American Aviation and associated receivers for a
Figure 1. The Wright Air Development Center B-29 used in the AWA feasibility tests conducted by the Control Systems Laboratory, University of Illinois. The forward belly gun turret was replaced with a search antenna. The nose modification houses the lock-on radar.
monopulse lock-on, and numerous small items for maintenance and testing the performance as well as monitoring the operation.

The Control Systems Laboratory did the electronic modification of the G.F.E. equipment for operations against moving targets and the integration of these into the system flown as shown in Figure 2.

The AN/APS-27 was principally modified:

1. So that the MTI was optionally presented only in the center 60 degrees of the 180-degree search, the remaining 120 degrees showing fixed targets for navigation at all times. The center section could also optionally show fixed targets.

2. A fast, small angle scan was implemented for expediting target acquisition.

3. Markers were added to show the azimuth and range of the target locked on.

4. An eventual substitution of F.M. cancellation, after the Hughes design, for A.M. cancellation gave much more reliable performance.

The E-4 gun-laying system was extensively modified to function as a moving target lock-on (motalon) as described in Control Systems Laboratory reports R-31 and I-44.

1. An AN/APG-33 modulator and transmitter were substituted for the AN/APG-37 components since tests showed them to be adequately designed for AMTI (in having
Figure 2. In this block diagram showing the essentials of the system, the search unit presents PPI to the controller for navigation, target detection and target acquisition. The lock-on unit presents the pilot with angle steering signals, range to target, and the artificial horizon.
considerably less jitter and power hum) and 50KW peaks were more than adequate for holding any moving targets detected by the AN/APS-27.

2. The servo system was altered to respond to MTI modulation, rather than fixed echo data.

3. The computer circuits were used to provide:
   a. the range and azimuth marks for the target on the search scope,
   b. the required PDI information, as well as
   c. control for the various attack procedures (level bomb, dive and land).

4. The "joy stick" circuit was modified to control the AN/APS-27 antenna during target acquisition.

The monopulse Naveye antenna was provided with an AN/APG-33 modulator and transmitter and the hydraulic servo system was altered to serve as a motalon. (Motalon is a word coined to refer to any equipment modified to lock-on to a moving target especially through clutter.) It replaced the conical scan motalon for the second phase of the tests being reported.

The laboratory also constructed two sets of rotating corner reflectors for the ends of a runway to test the latent feasibility of extrapolating from a dive attack to a blind landing. This might be useful for emergency landing fields. Subsequently, a "handy-dandy crab corrector" was introduced in lieu of a proper computer to compensate for crosswind during landing.
INSTRUMENTATION

The instrumentation centered around three items: the pilot's station, the controller's station and that required to collect the requisite data for post flight evaluation. The pilot's station and the controller's station were designed to be a close approximation to that envisioned for an operational installation in order to evaluate the feasibility of human operation. The Flight and All Weather Section (WCT) of Wright Air Development Center provided the pilots, flight crews and the crew chief for the flight programs, while TAC Headquarters provided the military controller.

The pilot's station as shown in Figure 3 consisted of:
1. An E-4 PDI scope to the right of the pilot's panel and
2. An accelerometer just above it. Suitable displays of coarse and fine range, coarse and fine steering signals, an ordnance release and pull-out range mark, artificial horizon, and a nose-down mark for dive attacks, were put on the PDI for attack runs. Implementation of a profilometer presentation on this scope was not effected during the experiments being reported.

The controller's station as shown in Figure 4 consisted of:
1. A ten-inch AN/APS-27 PPI scope,
2. The hand control, "joy stick," for aiming the lock-on radar and the search radar at the target during acquisition,
Figure 3. This view looks forward through the pilot’s cockpit to the nose of the B-29. The pilot direction indicator scope is shown mounted slightly to the left of the aisle, to the right of the pilot’s main instrument panel.

Figure 4. The navigator’s position was converted into the radar controller’s station. His controls, pictured from left to right, are: the lock-on hand control, the dual channel headset, the attack selection box, including target range meter, fire point range adjust knob, and cameras switch, and the ten-inch PPI scope for observing either fixed or moving targets.
3. A control panel showing "range to target," "ordnance release range," and switches for selecting the mode of attack, adjusting the ordnance release range, and turning on and off the data cameras,

4. Binaural earphones for simultaneously monitoring moving target lock-on and listening on the plane's intercom system, and

5. The usual instruments showing speed, heading and altitude of the plane.

The data gathering instrumentation included not only the nose mounted gun camera mentioned above but also in the forward bomb bay:

1. Repeat PDI and PPI scopes with cameras,

2. A display panel and camera for the usual flight instruments as well as the deflection angles of the lock-on radar, and

3. A binaural magnetic tape recorder for recording the plane intercom and the butterfly lock-on signals.

The 16mm nose camera was equipped with a 6-inch telephoto lens so that between the tips of the points in the focal plane, the aperture was 32 x 52 milliradians. This camera was slaved to the lock-on antenna and, thus, recorded the firmness of the lock-on regardless of the heading or change of heading of the plane. These data can be correlated with the attitude of the plane by using the data from the instrument panel.
FLIGHT TESTS

The modified B-29 first came to Chanute Air Force Base June 15, 1953, and installation of the modified radar gear started immediately thereafter. As subsequent test showed, there had been insufficient bench testing of this gear so that the first flight was not until August 9. A series of small troubles continued to plague the installation including inadequate test equipment for the E-4 servo so that for two months most flights were concerned with establishing reliable operation. On September 21, an extensive overhaul and several changes were made, including the change from AM to FM cancellation for the AN/APS-27 and a change from lead-collision steering (Rê) to pursuit steering (ô). The latter was due to the noise in the ô channel; though, subsequent to the completion of these tests, this noise was found to be largely due to improper adjustment of the E-4 servo.

Flights were resumed October 5, and immediately, the military personnel flying the plane gained confidence in the equipment. There remained trouble with the servo and with the boresighting and tracking of the nose camera. Thus, at no time was the data sufficiently good to justify a real feasibility of hitting a target. Several observers from the Air Force visited the laboratory and flew with the equipment before this series of flights ended on November 14, 1954, with the completion of 100 hours flying,
and the plane went to Wright Patterson Air Force Base for routine maintenance.

The second series of flights started with the return of the plane to Chanute Air Force Base on January 8, 1954. For this series of flights, the equipment used was as follows:

1. The monopulse motalon was substituted for the conical scan motalon,
2. The PDI circuits had been substantially improved,
3. The APS-27 presentation had been improved,
4. The operation of the nose camera servo had been altered to remove the 28/1 gear step-up and, thus, eliminated that gear train, which had been erroneously built 26.5/1 and had been responsible for poor tracking until detection of this error after the first series of flights.
5. During this series, a circuit was introduced to permit locking-on to isolated fixed targets.

The first flight on January 11 showed accuracy and steadiness of track quite sufficient to establish a high hit probability. During this series of experiments, there were about 25 flights involving some 175 runs on targets of various sorts. A summary of these is given in the following table.
A completely correlated run refers to one where all of the data gathering devices, nose camera, PPI camera, PDI camera, instrument camera, and dual channel tape recorder were operative. Partially correlated runs are any where one, two or three of the data gathering devices were nonoperative.

The runs on highway traffic were usually taken for in-flight gear testing because of ease of locating and locking-on. Also, they were used for training members of the crew and for the first targets presented to visitors. Thus, they were often acquired at short ranges and seldom carried through to the kill.

The usual terrain clearances were about 2,000 feet for the level runs and from 4,000 feet down to 1,000 feet at 15 degrees for the dive runs. However, a few runs were made at altitudes up to 10,000 feet maximum since neither the plane nor the equipment was pressurized.

The blind landings were usually made at Chanute Field toward runways not then being used. Approximate alignment...
with the runway was usually set visually; though, it could have been done by a VHF communication from the tower of the proper runway and the controller locating the rotating reflector on his PPI. The rotator flickers on the PPI as well as giving an unmistakable wavering audio butterfly response. The need for the VHF assist could be obviated by the use of two reflectors, one at either end of the runway and that at the downwind end being slower.

The usual complement of personnel during flights consisted of Air Force pilot, copilot, engineer, scanners and either an Air Force or Control Systems Laboratory controller, as well as three Control Systems Laboratory personnel for turning on and off the set, keeping the data gathering devices loaded with tape and film, target identification from the nose, and occasional minor in-flight maintenance or adjustment. When visitors were taken, the Control Systems Laboratory personnel was reduced to one or two depending upon whether an Air Force controller was available or not.

RESULTS

In general, any completely correlated run could be reconstructed and the probable accuracy of kill evaluated. However, the breadboard nature of the modifications, the use of so much GFE with which the personnel were not entirely familiar, the marked difference in maneuverability
between a B-29 and an operational attack bomber, for example, and the avowed purpose of merely establishing a feasibility does not seem to justify this more than to verify one's visual impressions from the moving pictures.

Figure 5 shows sample frames from a completely correlated run on the laboratory truck.

Figures 6 through 9 show the controller's PPI for various types of targets.

Figures 10 through 15 show terminal frames from various runs. It is to be recalled that these were taken with a telephoto lens and the aperture between the tips of the points is 32 x 52 milliradians.

In general, one can get a fair impression of the firmness of the lock-on by viewing the nose camera moving pictures. However, an analysis was made of one of the dive runs on the laboratory milk truck and the root mean square deviation of the azimuth during the run was found to be 2.6 milliradians. This was derived from measurements of the azimuth deviation of the truck on every fourth frame of the nose camera film. At the ordnance fire point of 3,600 feet, this would give a C.E.P. of about 10 feet which in combat might well be increased an order of magnitude, to about 100 feet, to allow for dispersion of fire and errors in bringing the plane into position. Visual comparison of this run with the other runs on the truck indicates that these should be regarded as typical data.
FIGURE 5. COMPLETELY CORRELATED 15° DIVE RUN ON THE LABORATORY TRUCK STARTING AT 3000 FT.
TERRAIN CLEARANCE SHOWING PICTURES AT VARIOUS SLANT RANGES.
Figure 6. Search scope range is 11 miles. The laboratory target truck is shown (encircled) at a range of approximately 6 1/2 miles (intersection of the range and azimuth markers).

Figure 7. Search scope range is 12 miles. A train is shown (encircled) with highway traffic running parallel. Target range is approximately 8 miles.
Figure 8. Scope range is 10 miles. The rotating corner reflector is shown (encircled) at a range of approximately 4 1/2 miles. Highway traffic is proceeding diagonally across the center sector of the scope.

Figure 9. Scope range is 5 miles. A fixed target presentation of the University of Illinois Airport. Airport administration buildings appear as a "V" shaped wedge (top of circle), the runways as a complete absence of targets (lower circle area).
Figure 10. Nose and Pilot's Direction Indicator photos showing the kill point of a level bomb run on a highway truck.

Figure 11. Nose and Pilot's Direction Indicator photos showing the kill point of a level bomb run on a train.
Figure 12. Nose and Pilot's Direction Indicator photos showing the kill point of a landing run on the rotating corner reflectors (encircled).

Figure 13. Nose and Pilot's Direction Indicator photos showing the kill point of a level bomb run on the University of Illinois Airport.
Figure 14. Nose and Pilot's Direction Indicator photos showing the kill point of a dive run on highway traffic.

Figure 15. Nose and Pilot's Direction Indicator photos showing the kill point of a level bomb run on a lock and dam installation.
As expected, the lock-on slowly hunted along extended moving targets such as trains. This can be explained by realizing that the lock-on concentrates on the modulation of an adjacent ground signal such as that from an overpass bridge or building. This results in a tendency to let the main body of the train pass such a signal and then the lock-on goes over to the next large object the train is passing. These changes are always of less than two degrees and do not disturb the pilot. As the plane nears the train, the AGC acts to compensate for this so that the tendency is to move away from the rear of the train toward the center or front for trains going away from the plane and hold to the rear for trains coming toward the plane.

With extended fixed targets such as a long bridge or a complex of buildings at an airport or refinery, the lock-on slowly hunts out the center of gravity of the signal which may be that of several walls meeting to form corner reflectors.

Occasionally, the lock-on goes over from one moving target to another such as from one truck to a second either going the same or opposite direction. This is again due to the relative signal strengths and the adjacent ground pattern. It can be stopped by the incorporation of velocity memory, but due to the ratio velocities of the targets to that of the plane, such a transfer does not affect the pilot, and since the original acquisition was based on radar signals, the new target is just as desirable an aim for the artery as the first one.
The bar graphs 16 and 17 show the typical ranges for target detection, and the maximum and average ranges for target lock-on for the runs made in the second series of flight tests. It is to be noted that lock-on always comes after target detection, and thus, these graphs are limited by the search radar ranges rather than by the lock-on range capability.

Finally, these data should be discussed with regard to the purpose of these experiments, the establishment of a feasibility.

1. The ranges quoted above are considerably in excess of those required by report R-28 for a 400 knot plane.

2. The firmness of the track is well within that needed to provide the 20 milliradian combat C.E.P. assumed in R-28.

3. The average time required for target acquisition after target detection was about 4 seconds for a trained military controller.

This was greatly facilitated by processing the elevation tracking to automatically lock on ground at the intersection of the azimuth and range gates during target acquisition. Thus, the controller adjusts only azimuth and range during this phase. During the tracking phase, the elevation channel tracked either MTI or ground as desired.

4. The ease of piloting the B-29 was demonstrated several times when visiting pilots took over the controls.
Fig. 16 Average and maximum lock-on and typical PPI detection ranges for four principal target categories. (Averages based on 81 target runs.)
FIG. 17 MAXIMUM LOCK-ON AND TYPICAL PPI DETECTION RANGES FOR MOVING HIGHWAY TRAFFIC TARGETS.
after viewing a 45-minute movie film and observing the airborne operation for a few runs. The regular pilot, Lt. Ralph Bowles, relied completely on the PDI for all operations, level bomb runs, dive runs and landing runs.

**EQUIPMENT RELIABILITY**

Because the AWA circuitry was surface mounted on relay racks to facilitate adjustments and, thus, was not in accordance with JAN specifications, the ultimate reliability of a tactical system is difficult to predict and will largely depend upon the final engineering and manufacturer. However, the "breadboard" system showed a reliability far in excess of our expectations after the system was overhauled in September, 1953. During the last six months of flight tests, there were four aborted runs out of the 175, an abort being the loss of target due to equipment failure. Also, during this time, there were less than ten tube failures. To be sure, the equipment was ground checked before each flight.