NRL Report 5923

RESEARCH USE OF INSTRUMENTED DRONES IN CLOUD PHYSICS AND METEOROLOGY

R. E. Ruskin

Atmospheric Physics Branch
Atmosphere and Astrophysics Division

June 14, 1963

U. S. NAVAL RESEARCH LABORATORY
Washington, D.C.

CONTENTS

ABSTRACT

Small drone aircraft have been evaluated by other investigators in the past for several cloud physics and meteorological research applications which are not practically solved by other means. During April and May 1962, nine flights were made in a field evaluation of the suitability of a 13-ft-wingspan standard target drone aircraft as an instrument platform for cloud physics and meteorological research. These drones, while sufficiently small to create minimum disturbance to small clouds, are designed to operate above 40,000 ft in altitude and in higher turbulence than small manned aircraft can tolerate. The evaluation indicates that this type of drone can readily be modified to incorporate 75 lb of interchangeable meteorological and cloud physics instrumentation and to telemeter to a ground receiver or mother aircraft. In future planning of large cloud physics research projects, use of drones can add to manned aircraft capabilities if the proper safety factors can be provided, particularly a flight-restricted air space.

PROBLEM STATUS

This is an interim report; work on other phases of these problems is continuing.

AUTHORIZATION

NRL Problem A03-09
Project RF 003-02-41-4252 (NRL)
and
NRL Problem A03-14
Projects RR 004-02-01 (ONR) and ARPA Order 263-62

Manuscript submitted January 23, 1963.

RESEARCH USE OF INSTRUMENTED DRONES IN CLOUD PHYSICS AND METEOROLOGY

INTRODUCTION

In cloud physics studies which involve a time history of the changes during the early stages of cloud formation, the interpretation of the observations is considerably complicated by the modifications introduced by the penetration of aircraft large enough to be manned. In some cases, large aircraft may dissipate the cloud penetrated. To assess the feasibility of using drones large enough to provide reasonable instrumentation and tracking capability yet small enough to avoid excessive disturbance to clouds penetrated, a field study has been conducted jointly by the U.S. Navy and the U.S. Weather Bureau and is reported herein.

Small drone aircraft are little known in the field of meteorology, but hold promise for performing several special purpose functions which cannot feasibly be achieved by other means. Three general types of drones have been evaluated by various investigators for meteorology and cloud physics applications.

Two types were reported by MacCready (1) in 1960. A radio controlled homing glider with a 50-inch wing span carried aloft by a balloon was evaluated for retrieving air samples or instruments less than 2-1/2 pounds. This system was designated HARP for High Altitude Retriever Probe. LARP (Low Altitude Retriever Probe) is a 5-foot powered drone which can be either command controlled or spiraled up automatically by a continuously homing type radio control. As presently being developed, LARP climbs to 10,000 feet in altitude, then glides down. This drone is planned to carry a small temperature-humidity vs altitude recorder and a 1-1/2-ounce autopilot.

The third type of drone, the KDB-1, which is one of several similar models in use by the military services for antiaircraft and missile target practice, was recently evaluated for use in cloud physics research applications and is the subject of this report.

THE KDB-1 TARGET DRONE

A series of flights was conducted using the standard Navy KDB-1 propeller-driven drones (Fig. 1) modified slightly to incorporate meteorological instruments and a radar tracking transponder. These small radio-controlled aircraft have a wingspan of 13 feet and a length of 15 feet. Their flight duration is about 1-1/4 hours at 200 mph indicated airspeed. They can reach altitudes in excess of 40,000 feet in approximately 20 minutes. The usefulness of these drones in remote field areas is enhanced by their ability to take off and land without use of a runway. They are launched by jet-assisted takeoff (jato) from a stationary launch stand and are landed by parachute. In case the radio control fails in flight, the parachute is automatically deployed after 4 seconds. The standard 55-watt transmitter controls from ground to air over a 50-mile range. In addition to the radio command control the standard drones incorporate an automatic pilot system. The automatic pilot system incorporates a vertical gyro, position and rate gyro, computer amplifier, and aileron and elevator servo actuators. This system provides stabilization of the drone in roll, yaw, and pitch, thus greatly facilitating the control, particularly when the drone is far enough away so that the controller has difficulty in observing small

Fig. 1 - Standard target drone modified to expose meteorological sensors on wing pods. Telemetry and radar transponder antennas are visible near the rear of the fuselage.

attitude changes. Another aid in checking the control system during flight and permitting easier visual identification of the drone is provided by a smoke trail achieved by a radio command to introduce oil into the engine exhaust.

DRONE INSTRUMENTATION

These drones are normally equipped with fiberglass wing-tip pods which incorporate corner reflectors to enhance the radar cross-section for better tracking capability. These pods are easily removed, and each provides mounting space approximately 10 inches in diameter and 3 feet long for instrumentation. Some additional space is available inside the main fuselage of the drone - approximately a 1-foot cube in the largest compartment and several smaller spaces. On the standard drone approximately 75 pounds of extra instrumentation can be added, including the weight of batteries.

As a first attempt to determine the feasibility of using instrumented drones of this type, one wing-tip pod was modified as shown in Fig. 2 (with cover removed) to incorporate a cloud particle sampling instrument. This instrument was an NRL drone adaptation of the instrument described by Todd (2) in which a Formvar-coated blank movie film is run through a solvent and then exposed to the slipstream of the aircraft during flight to collect replicas of droplets or ice crystals present in clouds penetrated. The Formvar solvent is evaporated and the film is continuously rewound on a film reel during flight.

The other wing tip pod (Fig. 3) was instrumented by a Weather Bureau contractor to measure the following: free-air temperature by use of the axial-flow vortex thermometer (3), vertical draft velocities by use of a variometer, indicated air speed, and altitude. The desired aerodynamic exposure for the sensors on both pods was provided by mounting probes outside the pod at points which provided the desired characteristics of static pressure, straight line air flow, or pitot pressure. On the second pod, provision was made for digitally telemetering the instrument information. The electrical signal was conditioned as necessary by preamplifiers in the pod, then fed to a modulator and transmitter unit mounted in the main fuselage of the drone. The four channels of information were simultaneously telemetered on one radio-frequency carrier using four standard FM subcarrier frequencies of the Inter-Range Instrumentation Group specifications (4).

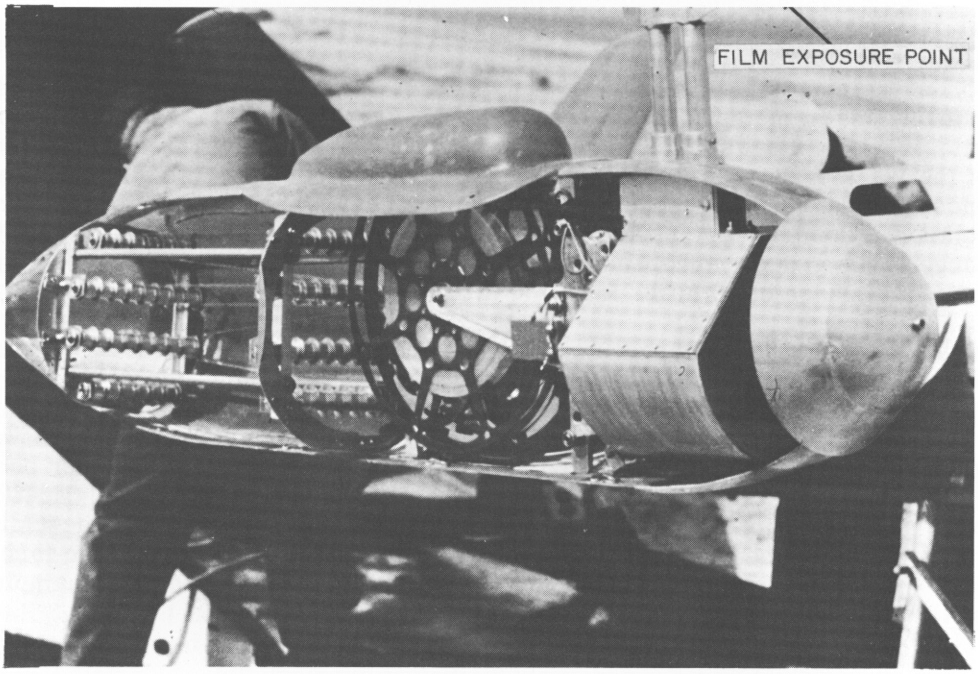


Fig. 2 - Continuous film sampler for cloud droplets and ice crystals. The pod nose is covered with a hail shield.

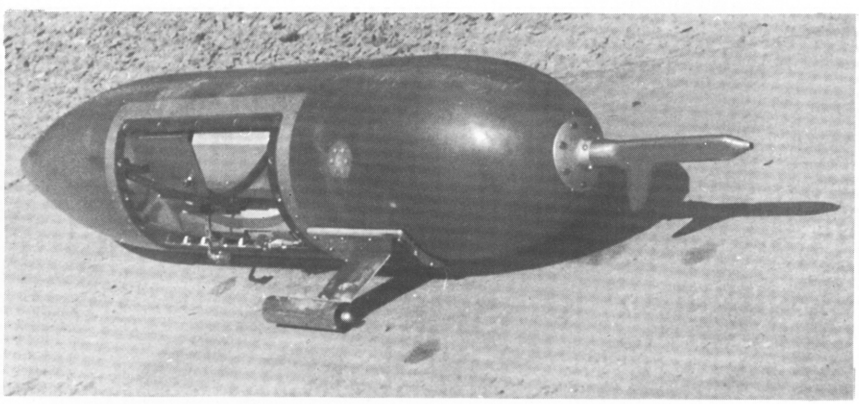


Fig. 3 - Meteorological instrumentation pod incorporating aerodynamic probes and signal-conditioning preamplifiers

The standard Navy version of this drone aircraft includes provision for a radar transponder beacon. Since plans for this field operation included evaluation of the use of these instrumented drones for penetration of clouds and severe storms over civilian territory, the radar transponder was replaced by an air traffic control (ATC) transponder beacon which was compatible with existing airline traffic control center equipment.

TELEMETRY READOUT ON A MOTHER PLANE

In order to include in this project, evaluation of a wide range of operational possibilities for drone use in meteorological research and, if possible, obtain severe storm measurements, provisions were made to receive the instrument telemetry signal aboard a DC-6 of the Weather Bureau Research Flight Facility. Provision was also made to track the drones by radar and transponder interrogation aboard the DC-6 and to transfer command control of the drone from the ground to this mother plane for flights beyond the radio range of the ground-control transmitters. Control from the mother plane was achieved at a distance of 50 miles from the drone.

Since this aircraft was already equipped with a high-speed digital coding and recording system described by Reber (5) for monitoring 50 channels of meteorological information aboard the aircraft, a comparatively simple system was developed and installed aboard this aircraft to receive the drone vhf telemetry signal. The four subcarrier frequencies between 14 and 55 kilocycles are separated by filters, each tuned to the proper subcarrier center frequency. The signal of each of these channels is used to operate a flip-flop circuit, code the information into binary format, and store this information to be available upon interrogation by the digital timing and recording system. This magnetic tape recording system can handle ten complete data samples per second with each data sample composed of 150 characters.

THE FIELD OPERATIONS

The type of target drone system evaluated in this project is designed to permit field deployment as a self-contained unit, including the drone aircraft, spare parts, repair equipment and facilities, radio control transmitter, and mobile launch stands (which also serve as retrieval dollies). This type of ground support system was furnished by Navy Utility Squadron Six at Norfolk Naval Air Station for this field operation. Nine flights of modified drones were made, the first three at Dam Neck, Virginia, near the Norfolk Naval Air Station, and the last six at Fort Sill, Oklahoma, as a part of the program of the National Severe Storms Project (NSSP).

In the course of these nine flights, drones were launched and flown visually under control of the ground controller. Command control on two flights was transferred from ground controller to the aircraft controller, who continued to fly the drone using information from the fire control tracking radar located near the launch site. Control was transferred back to the ground controller to maneuver the drone to proper position for parachute recovery near the launch site.

The principal problems encountered in this operation were due to the short time schedule imposed by the necessity for selecting a period with high probability of encountering severe storms, since this application was included in the types of feasibility planned to be studied. Considerable effort was expended between flights in overcoming difficulties in the radar interrogation system and in the telemetry digitizing system, which was installed as a developmental model and required several changes in the field simultaneously with the conducting of the operation.

Flights at Norfolk, Virginia

The first three drone flights were made at the Navy FAAWTC restricted flight area near Norfolk, Virginia, on April 5 and 6, 1962. The objectives of these flights were:

1. To gain experience in the modification and instrumentation of the standard KDB-1 target drone;

2. To determine the effectiveness of the experimental telemetering instrumentation from the drone to the mother aircraft, using the Weather Bureau digital system;

3. To determine what problems might be associated with use of the NRL cloud droplet sampler equipment installed on one wing tip in a pod;

4. To determine the effect on flight characteristics and launch characteristics due to the change of center of gravity and weight distribution of the drone resulting from the modifications installed;

5. To determine the feasibility of transferring drone control from the ground to a DC-6 mother aircraft, check the relative plane and drone attitudes in which the antenna radiation patterns would provide sufficient signal to insure uninterrupted command control signal, and to determine the range at which command control signal would be reliable;

6. To determine effectiveness of radar tracking of the drone by use of the APS-20E radar aboard the DC-6;

7. To verify operation of the ATC-beacon transponder aboard the drone both when used with the APS-7 interrogator aboard the DC-6 and when used with the MPX-7 radar interrogator stationed on the ground;

8. To determine the extent of damage to be expected on the various instrumentation and electronic equipment aboard the drone due to the parachute landing impact.

On the first flight, a standard drone was modified by the addition of ballast in accordance with the weight distribution in the wing-tip pods and fuselage that was equivalent to the loadings due to the instrumentation modifications which would be used in future flights. The drone jato launch carriage assembly was modified slightly to correct the jato thrust line for the new location of the drone center of gravity, as modified by the distribution of weight of the instrumentation.

After the drone had been launched and had climbed to 5000 feet in altitude under control of the ground controller, the ground-based gun fire control radar was used to follow the course of the drone and relay information by radio to a drone controller aboard the DC-6 mother plane. Command control was then transferred from the ground to the airborne controller, who satisfactorily demonstrated the feasibility of flying an excellently controlled pattern within the restricted area, using the ground radar information on altitude, azimuth, range, and closing rate.

On this flight the tracking beacon was not installed, and attempts to locate the target drone by use of the APS-20E radar aboard the DC-6 were not successful. After about 1/2 hour of airborne control, the command control was transferred back to the ground controller, who made a normal landing recovery of the drone over the beach area after a total flight of 54 minutes.

The second flight used the instrumented drone equipped as described under "Drone Instrumentation" above both during ground-to-air and air-to-air checkouts. The instrumentation telemetering was not received satisfactorily aboard the DC-6. The contractor made several modifications to the DC-6 telemetry receiving equipment during the flight but was unsuccessful in receiving more than occasional weak signals through the system. Ground checks indicated the drone transmitter was emitting at a satisfactory signal level. It was later decided that the system aboard the DC-6 required a preamplifier ahead of the receiver, APR-4Y (which had been procured from government surplus), and also required modifications to the counter system to make the circuit more immune to stray noise. These changes were incorporated later, before the Oklahoma tests. The air traffic control transponder installed aboard the drone appeared to have good emission when interrogated by the MPX-7 portable ground-based radar interrogator located 1/2 mile from the launch site. On drone takeoff the MPX-7 received this transponder at a high level, such that the return appeared on the PPI scope of the MPX-7 all the way around the azimuth for a short time. This signal was not picked up by the APX-7 interrogator equipment working into the APS-20E radar aboard the DC-6. During this flight, tracking information was again provided by the ground-based fire control radar. Command control was again satisfactorily transferred to the DC-6 airborne controller, who flew patterns keeping the drone within the restricted area, then returned control to the ground controller.

When it had been ascertained that the telemetering problem could not be resolved aboard the DC-6 during this flight, the flight was terminated after 47 minutes, while fuel still remained, since a prime objective of this flight was to retrieve the instrumentation on the drone with minimum chance of landing in the water. The drone was brought back over the beach by the ground controller and parachuted to the ground. During this land recovery the parachute system malfunctioned to the extent that the normal transfer of load from the drone's tail forward to the center of gravity (to permit level attitude of the drone on landing) failed to operate due to an open fuze in the squib circuit. Therefore, the drone impacted nose down and was tossed onto its back by the wind. The shear bolts used for attaching the instrumented pods to the wing tips released the pods on impact, thus preventing major damage to the instrumentation in these pods. The NRL cloud droplet sampler sustained damage primarily in the breaking loose of the external probe portion. These damages were repaired before the drone flight the following day.

On this first instrumented flight, all added equipment was operated from a single additional standard drone battery of the silver cell type having 27-1/2 volts and a 7.5-ampere-hour capacity. Tests of this battery after the flight still indicated a full 27-1/2 volts under a 5-ampere load, indicating that the capacity of this battery is satisfactory to maintain the approximately 5-ampere total load of all the extra equipment.

The third flight had the primary objective of determining what flight patterns of the DC-6 could be made while still maintaining satisfactory radio command control of the drone without loss of signal due to changes of antenna patterns of both the drone and the DC-6 during the various combinations of turns and banks which might be required in Oklahoma when directing the drone through a storm. Flight plans were made for maintaining relative positions such that the control transmitter antenna on top of the DC-6 would have a nearly unobstructed line-of-sight to the drone by virtue of the DC-6 flying a figure-8 pattern, banking in sharp turns toward the drone and shallow turns away from it. This type of maneuver was also considered to permit the radar to operate within its antenna tilt limits most of the time while still permitting an unobstructed view of the storm from the pilot's windows. A second objective of this flight was to determine the maximum range at which satisfactory and uninterrupted radio command control could be maintained while making the necessary flight maneuvers. It had been feared that, at certain distances of separation between the two airborne vehicles, interference and fading of the signal might occur due to multiple paths (one direct and the other via reflection from the ground to the drone). The DC-6 was flown away from the drone while maintaining control of the drone over the restricted area up to a distance of 49.5 miles over land. It was found that the control signal was not lost at any time during this test. A normal land recovery was again made under control of the ground controller after completing a 58-minute flight. These three checkout flights preliminary to the main field operations in

Oklahoma provided considerable information both as to unexpected problems and elimination of what had been anticipated to be some of the troublesome problems.

Flights at Fort Sill, Oklahoma

Preparatory to the flight program at Fort Sill, Oklahoma, arrangements were made by NRL and the National Severe Storms Project personnel for support facilities under cognizance of the U.S. Army Artillery and Missile Center, Fort Sill, Oklahoma. A vacant garage building about 40 by 100 feet was provided by the Army for use as a drone preparation area, instrument repair shop, and office. A drone launch area on high ground between two artillery firing ranges provided a flight radius of 2 to 4 miles on all sides within the flight restricted area of the Fort Sill reservation. The Naval Ammunition Depot at McAllister, Oklahoma, provided two electric power plants and a semitrailer van which was used at the launch site to house telephone and radio communications equipment, the MPX-7 radar interrogator PPI scope, and miscellaneous support equipment. A 30-foot antenna mast, 28-volt electric plant, and the MPX-7 radar truck were also located at the launch site. On some flights the Army also provided tracking radars at the launch site.

The drones were launched from a mobile handling and launching dolly which was anchored in various locations such as to provide a launching direction into the wind while preventing the jato blast or dust from the blast from entering the personnel area in the vicinity of the van and equipment.

In addition to determining the technical readiness of the drone instrumentation, mother plane telemetering link, and other necessary equipment, the following items were also checked prior to each launching:

1. Early morning weather forecasts to ensure at least 300 feet ceiling and 2 miles visibility for the time period of the anticipated flight;

2. Winds aloft up to 30,000 feet for computation of drift distance of the drone during parachute descent from various possible altitudes;

3. Notification of the Army Operations Office cognizant of military flights over the local reservation;

4. Coordination with flights of National Severe Storms Project at Will Rogers Field, Oklahoma City;

5. NSSP notification of FAA, Oklahoma City, and Air Force Regional Office, New Orleans, of the time and location of the proposed drone flight for the day as well as the best estimate each day concerning future schedules.

The first drone flight (scheduled for April 23, 1962) was postponed because the telemetry from the drone was not received aboard the DC-6 flying nearby during the ground-to-air check. The ATC transponder also was not received by the APX-7 on the DC-6. The DC-6 was landed at Post Field, Fort Sill. The ATC transponder and antenna were mounted on the NRL truck which was equipped with a 28-volt dc power supply. Cross checks between the MPX-7 radar interrogator at the launch site, the DC-6, and the ATC beacon on the truck indicated deficiency in the APX-7 interrogator system aboard the DC-6. This difficulty was later traced to the coaxial cable from the APX-7 equipment to the antenna. This cable had deteriorated and had developed a high loss.

After three flight attempts, telemetered signal information was received and the drone was launched on April 26. While this flight lasted only 30 seconds, a great deal of information was obtained. The ATC transponder was tracked by the MPX-7 ground equipment but not by the APX-7 aboard the DC-6. During this short flight the Army MPQ-29 radar tracked the drone to 425 feet above the terrain. This short calibration of the altitude telemetry indicated a major discrepancy in the telemetered information. The cause of the early abort on this flight was twofold: (a) A wind shift occurred too late in the pre-launch procedure to permit rearranging the launch site area to prevent a considerable crosswind component on the drone at launch, and (b) the jato harness used had not been modified to move the thrust line closer to the drone's center of gravity. The combination of crosswind and slightly too steep climb prevented adequate air speed for control. The decision was then made to modify the jato harness on all future flights where the instrumentation caused a change in the normal center-of-gravity location.

After considerable troubleshooting of the telemetering system, the second launch was made on May 3. This was the first day of the operation on which clouds were present. Therefore, the cloud particle sampling instrument pod was installed, along with a separate battery, in order to prevent possible reduction of reliability of the battery supply of the telemetry system. A malfunction of the jato caused a launch delay during which the engine overheated somewhat. After 7 minutes of flight (and before reaching cloud height) the engine failed and the drone made a dive from 3600 feet with insufficient time available to complete deployment of its parachute. The resultant crash landing did considerable damage to all of the instrumentation with the exception of the telemetering transmitter and the ATC beacon. The impact was sufficient to tear the beacon transponder loose from its shock mounting base; however, no malfunction of the beacon occurred as a result of this impact. The data telemetry signal was received aboard the DC-6 even after impact; however, the values were at no time representative of the measurements being made. Apparently the subcarrier frequency of the receiver's locking oscillator did not lock in to the frequency being received. The frequency recorded after drone impact was the same as that during flight, and was about equal to the center of the subcarrier frequency band.

The third flight was made on May 4 and achieved an accurate cross-check of the altitude data as telemetered and that determined by ground control approach radar located at Post Field about 5 miles from the drone area. This flight of 24 minutes reached 20,000 feet in altitude. It automatically terminated at that altitude because a short circuit in the fitting of the coaxial line from the control transmitter to the antenna caused loss of control signal to the drone, so that the drone unexpectedly parachuted. (Interruption of command transmitter signal for 4 seconds causes automatic termination.)

During 14 minutes of descent on the chute, the drone drifted as previously calculated by use of the winds-aloft data. The drone and chute were followed by the DC-6 and later by a small Army observation aircraft which circled the area of landing 1 mile off the reservation until the Navy truck arrived to retrieve the drone. The point of landing was about 100 yards from a farmhouse and narrowly missed a power line, emphasizing some of the safety aspects to be considered in planning a drone operation.

During this flight, it was determined that the MPX-7 PPI scope presentation of the ATC transponder return covered too great an azimuth angle on the scope to be usable for out-of-sight control of the drone, particularly when the elevation angle to the drone was high. The limitation is caused by the mode of operation of the MPX-7. The antenna operates in a horizontal (azimuth) search mode using a narrow fan beam extending from the horizon to zenith. When the target is nearly overhead, the antenna pattern overlaps the zenith enough to pick up a target throughout the horizontal rotation of the antenna. In this case, as the antenna and scope sweep rotate, the target is continuously presented on the scope in the form of a circle with its radius representing the slant range to the target. Reduction of radar receiver gain may eliminate most of this circle except when the target is directly overhead. In this case the drone's altitude can be determined as being equal to the range represented by the minimum circle radius on the scope. The scope was calibrated by following the ATC transponder mounted on the truck and driven to the restricted area boundary. The radar slant range was found to be 2-1/2 miles. At 30,000 feet in altitude the slant range to the boundary is increased to 5-1/2 miles. In order to facilitate continuous determination of the drone location relative to the boundary, lines were drawn on the scope face to represent the boundary at each of three altitudes. Even at 3000 feet in altitude, the usability of the scope presentation was marginal, and at 30,000 feet the scope distance at the station boundary was less than 3/16 inch greater than the circle representing slant range to the target when directly overhead. In this case an altitude change of 3000 feet moved the position on the scope as much as 2-1/2-mile horizontal travel from overhead to the boundary. This limitation is a problem only for close range. The MPX-7 at Oklahoma City (70 air miles away) required no correction for altitude changes of the target.

The fourth flight on May 7 automatically parachuted after 14 minutes of flight. Termination was apparently due to a low voltage on the battery, combined with probable malfunction of the control transmitter due to coaxial cable defects caused by considerable use and by foot traffic over the coaxial cable.

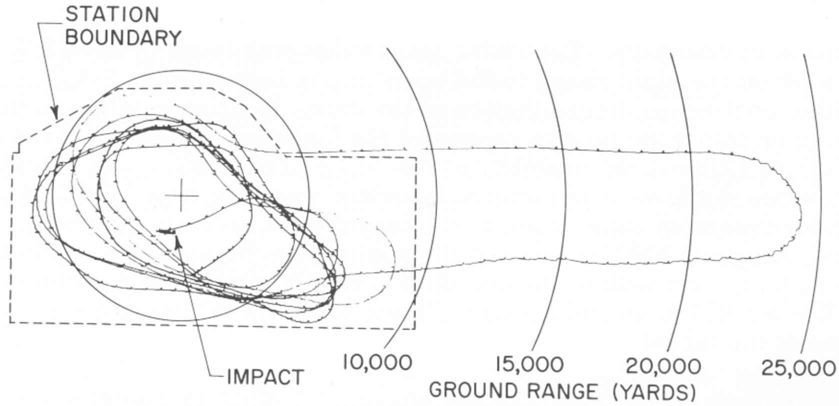
During this flight the MPX-7 interrogator was operated much more satisfactorily than previously by virtue of a remote gain attenuator which had been installed at the scope console. The scope pattern still was spread too much in azimuth to be usable whenever the drone was at close range. The gain changes required with changes of the drone range were too rapid to permit satisfactory use for blind controlling of the drone when it was closer than about 2 miles, particularly at altitudes higher than 3000 feet.

This flight furnished additional information on telemetry problems. The altitude signal was received, but a shift in calibration had occurred. The transponder was also received by the DC-6 APX-7 and provided a satisfactory presentation on the airborne radar scope.

The fifth flight on May 9 completed 45 minutes of controlled flight and controlled recovery. This flight was tracked by two modified M-33 fire control radars stationed at the launch site by the Missile Systems Evaluation Group at Fort Sill. The ground controller followed the drone and its command control responses by following the plotted altitudes and trajectories on the radar automatic plotting boards. The boundaries of the restricted air space were drawn on the plotting board so that the relative position of the drone was always apparent. In Fig. 4 are shown the altitude and trajectory plots. For good plotting accuracy the total altitude range of the 14-inch-high altitude plotting board was set up to be 14,000 feet. When the drone reached 14,000 feet, therefore, an offset of 13,000 feet was made in order to plot the 27,000-foot-altitude portion of the flight. This portion of the flight extended 9 miles off the reservation and return. The original ground-range scale on the plotting boards was 1:25,000, large enough for accurate measurements and direct comparison to a station map underlay at the same scale.

The ATC transponder beacon was tracked almost continuously by the MPX-7 at the launch site, by the APX-7 aboard the DC-6, and by the MPX-7 at the National Severe Storms Project headquarters at Oklahoma City. On this flight an attempt was made to calibrate the indicated airspeed telemetry channel. A satisfactory signal level was received, but the values were erratic as compared to the speeds determined from the 5-second timing marks on the radar plots.

Prior to this flight scattered cumulus clouds were present. Therefore, the second model of the cloud particle sampler wing-tip pod was installed (replacing the previously damaged instrument). The launch was delayed 2 hours because of emergency repairs to the DC-6 before takeoff. During the flight no clouds came within range; hence no cloud data could be obtained. The mechanical operation of the sampler was satisfactory; no electrical interference was indicated in either the telemetering or command control systems; and the instrument was recovered without damage after parachute impact.



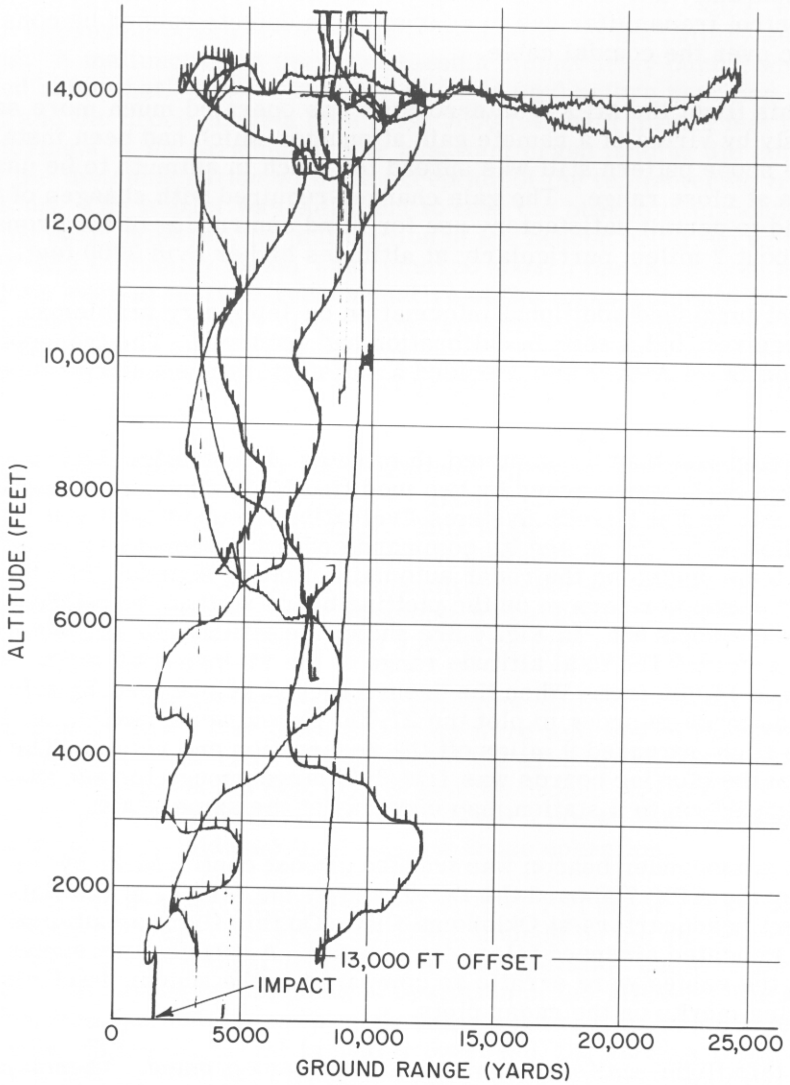


Fig. 4 - Radar plots of the fifth drone flight at Fort Sill, Oklahoma. The trajectory is not shown for first few minutes of flight until radar locked onto the target. The timing marks represent 5-second intervals. The altitude plot includes an offset of 13,000 feet so that the climb to 27,000 feet and the retrace on descent could be plotted within the 14,000-foot range of the plotting board.

This flight was the first one in which sufficient tracking and altitude information was obtained for safe transfer of control to the DC-6.

Launch of a second drone for airborne control planned for the same day was postponed because of the lateness of completing this first flight.

Before the next flight a recheck of the telemetry system indicated that several of the components had been damaged in the series of landings, so that only one channel could be made operable in the short time available. It was decided that altitude information would be the most necessary for blind control from the DC-6 in case of possible loss of communications or tracking by the ground radar. The altitude channel was reactivated and calibrated by use of the pressure calibrating instruments at Will Rogers Field, with the drone pod transmitting to the DC-6 on the ramp.

On May 11 the DC-6 landed at Fort Sill and picked up personnel for drone control from the plane. Ground-to-DC-6 flight checks indicated satisfactory operation of the altitude telemetry and the DC-6 APX-7 interrogation of the drone ATC transponder beacon. The sixth and final flight of this series was again tracked by the M-33 radar. Altitude telemetry checked with the M-33 plot. After the drone had climbed to an altitude of 27,000 feet, the ATC transponder signal faded simultaneously on the DC-6, the MPX-7 at Oklahoma City, and at the launch site. The scheduled transfer of command control to the DC-6 was canceled because of a malfunction of the control box associated with the command transmitter on the DC-6. The flight was continued under ground control with the M-33 radar tracking for 30 minutes at 27,000 feet over the restricted area.

During descent the transponder beacon signal returned weakly at 18,000 feet and approximately full strength about a minute later at 15,000 feet, again being received on the DC-6, at the launch site, and at Oklahoma City. The temperature at the DC-6 altitude of 20,000 feet was -15°C. While the ATC transponder was rated for operation only down to -10°C, the unit used on this flight operated to -15°C or slightly lower. The second unit, used on the preceding flight, operated for 1/2 hour at -20°C with no apparent reduction of signal.

The flight was terminated by command after 63 minutes of flight. Because of high wind gusts on landing the lateral velocity of the drone coming in on the parachute caused damage to the wing and fuselage requiring repairs beyond the field shop capability. On two of the previous landings the damage had been of a similar degree (in addition to the drone expended on the second flight because of high-speed impact). In operations over the ocean or in other areas where less reliability could be tolerated, sufficiently good repairs could have been made to permit reflying some of the drones which, on this operation, were returned to the overhaul base. On more extended field operations, more complete repair facilities would be justified, permitting a larger percentage of drone reuse.

CONCLUSIONS ON OPERATIONAL CONSIDERATIONS

Operational considerations which became apparent in the course of this project include the following:

1. A restricted air space must be available with a sufficiently large area to permit conducting all operations within its boundaries on all flights which are less than 25,000 feet in altitude.

2. Before making any flights (which must be at or above 25,000 feet) penetrating civil air space, NOTAMS must be arranged well in advance; and prior to each flight, coordination must be achieved with air traffic control centers and military jet operation centers within aircraft range.

3. For any flights off the restricted area, the value of the flight must be carefully weighed against the odds of possible hazard, considering the location and conditions of the particular flight.

4. Wind drift of the parachuting drone should be calculated before flight for all flight altitudes in order to assist the controller in maintaining positions which will reduce the likelihood of damage to property in landing.

5. Flights in which a control or telemetry aircraft is involved are many times more difficult to coordinate than flights entirely controlled, tracked, and telemetered on the ground. This problem is further increased as the distance to the aircraft base is increased.

6. Provision must be made for repairs on both the instrumentation and the drones after each flight. It must also be expected that frequently the drone and occasionally a complete set of equipment will be damaged beyond field repair, requiring availability of spare equipment.

7. An important planning item for a drone operation is adequate tracking and communications equipment including backups of all critical items. Communications become less critical if all operations are conducted from the ground than if aircraft must be coordinated simultaneously. However, successful recovery chances are improved by communications from the tracking site to a four-wheel-drive vehicle which can immediately start toward the expected impact area in case of an unanticipated parachute deployment at a considerable distance from the launch site.

8. Visual tracking of the drone from the aircraft was not possible at any time during these tests. For safety in flight planning, the drone must be kept at some distance from the mother plane, particularly when the speed of the drone is faster than that of the mother plane (so that the distances are continually changing). A minimum separation of 3000 feet in altitude was maintained at all times except when the drone was 5 miles or more to the side of the mother plane and its position relative to the plane was reliably known. At these distances the drone cannot be seen. Flight planning must provide for the complete operation being conducted without visual sighting of the drone except when the drone is flown near the ground launch area.

9. The drones must be launched with visibility good enough to permit visual tracking for distances of about 1000 yards. Visual control can be maintained for 2 or 3 miles on a clear day. For longer distances or under hazy conditions, it is necessary to provide a fire-control-type radar to provide tracking information to the controller, both as to altitude and position of the drone. Attempts to use the ATC radar transponder signal displayed on a PPI radarscope proved extremely difficult for controlling and impossible to use at high elevation angles such that the slant range to the drone was nearly equal to its altitude. Slant range and altitude must be continuously converted to position information in order to be of value to a controller. Automatic plotting is almost necessary in order to provide a continuity of information as to the drone's maneuvers and speed. (An M-33 radar with automatic position and altitude plotting boards was used with a flight made at 27,000 feet in altitude following accurately a planned flight pattern to a point 15 miles from the launch site and return.)

10. The transponder presentation on the PPI scope of the radar aboard the mother aircraft is suitable for use in controlling the drone when the two craft are flying in positions such that the altitude difference is small compared to the horizontal distance between the drone and plane. In the Oklahoma tests the radar transponder aboard the drone was simultaneously tracked from the Fort Sill launch site, from the mother plane, and, whenever the drone was above 5000 feet in altitude, by an air traffic control monitor at the NSSP Headquarters at Oklahoma City, 70 air miles away. This transponder,

transmitting at 500 watts peak power, is rated as being capable of interrogation and tracking within line-of-sight up to 200 miles. A limitation found for this transponder one one flight is the requirement that the transponder be kept warmer than about -10°C. The signal, after a short time at 27,000 feet in altitude (-20°C) became extremely weak and was not readable until the drone descended to about 15,000 feet (-12°C).

11. In planning an operation involving drones, consideration must be made for the requirement that approximately six to ten men are needed for preflight maintenance and launching of the drones in addition to personnel required for tracking, scientific coordination, and other technical problems inherent in any field operation. Since a rather large investment of manpower and equipment is required, it is desirable to plan an operation to include a variety of uses which can be substituted for the main mission of the operation, depending on what weather conditions prevail each day as the operation progresses.

SUMMARY OF METEOROLOGICAL CAPABILITIES AND LIMITATIONS

Many capabilities, as well as several limitations, of target drone use in cloud physics and meteorological research were determined:

1. Meteorological measurements can be telemetered satisfactorily to either a mother aircraft or a ground station within radio range. The use of several simultaneous channels for data transmission is highly desirable due to the rapid changes in some weather variables at the high speed of the drone. The instrumentation and telemetering for the drone must be designed to withstand high shock loads, both during launch and landing. Electric power is limited on the drone to that which can be carried in batteries. Two silver cell drone batteries were added for the meteorological instrumentation. Each battery is capable of supplying about 5 amperes at 28 volts dc for the duration of a flight (about 1-1/4 hours maximum).

2. Cloud droplet sampling instrumentation was operated on some flights, including operation after the shock from a previous landing.

3. Since no severe weather was within range during this operation, further work must be done before the capabilities or limitations of drones for use in severe weather penetrations can be determined. Much of this information may be obtained without actual drone penetrations of storms. Particularly, information must be obtained on the effects of high electric field and lightning upon command control radio equipment, the effects on the drones of high liquid water content conditions, and the performance of parachute loads in thunderstorm turbulence conditions. While it is known that this type of drone can tolerate quite high turbulence, the extent to which the control gyros can operate in a severe thunderstorm may be a limiting factor.

4. Future modifications incorporated in drones which are to be procured primarily for a meteorological research application can improve the capabilities of the drone somewhat beyond those available in the standard Navy operational target drone. Either wind-driven or engine-driven generators may be used to provide for heavier electrical power loads or longer duration flights. A larger wing area can permit operation at lower power levels and lower speeds with longer duration at the sacrifice of the present high resistance to turbulence.

Drone aircraft, while not a general purpose tool, are probably the best means for performing a number of special purpose operations of cloud physics and meteorological research. The altitude capability in excess of 40,000 feet is not obtainable on many types of manned aircraft. As further development is accomplished on various types of small drones, greater utilization will be feasible. For a particular operation, all factors must be weighed to determine whether the drone or manned aircraft or other vehicles may be most suitable to achieve the goals involved.

Future planning of cloud physics research field facility sites should include consideration of the necessity of restricted air space, not only for safety during cloud penetrations by manned research aircraft, but also for possible use of small drone aircraft to augment data-gathering capabilities.

ACKNOWLEDGMENTS

The joint efforts of Dr. R. H. Simpson, Office of Meteorological Research, U.S. Weather Bureau, and the NRL personnel were responsible for establishing and carrying out this project. In addition to the many personnel of the Weather Bureau, particularly in the National Severe Storms Project and Research Flight Facility, and the many Navy personnel, particularly in Utility Squadron Six, especially appreciated are the efforts by the U.S. Army Artillery and Missile Center, Fort Sill, Oklahoma, who provided the launch area, restricted air space, personnel operating army tracking radars, and many facilities to expedite this operation. Beech Aircraft technicians and controllers added much to the success of this study. Engineers of Ess-Gee Corporation were instrumental in setting up this project; in developing the digital telemetry, they cooperated wholeheartedly in overcoming the problems of converting an engineering model to an operational system while flying it. Wilcox Electric Company consigned two units of their developmental model ATC transponder for use of the study.

REFERENCES

1. MacCready, P. B., "Automatic Retrieval of Stratospheric Research Equipment," Instrument Soc. of Amer. Preprint NY60-3, Fall Instrumentation-Automation Conference and Exhibit, Sept. 1960

2. Todd, C.J., "A Study of Cloud Composition," Proc. 9th Weather Radar Conference, pp. 280-285, 1961

3. Ruskin, R.E., Schecter, R.M., Merrill, R.D., and Dinger, J.E., "Axial-Flow Vortex Thermometers for True Air Temperature Measurements in Flight," Proc. Instr. Soc. Amer. 7:308-310 (1952)

4. "IRIG Telemetry Standards," Inter-Range Instrumentation Group of the Range Commanders' Conference, White Sands Missile Range, New Mexico, IRIG Doc. 106-60, 1961

5. Reber, C.M., "The Airplane as a Meteorological Instrument Platform," Proc. 2nd Technical Conference on Hurricanes, Part I, U.S. Dept. of Commerce, NHRP Report 50, pp. 149-155, 1962