NOTS TP 2751

COPY 33

PROJECT CYCLOPS

An Experiment in Hurricane Modification

by

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ABSTRACT. Cloud seeding has been tried for some years, but with negligible results. In 1961, NOTS scientists and engineers developed a new method of generating silver iodide nuclei and a new means of dissemination. The new device, Cyclops, was used for the first time in a seeding operation on Hurricane Esther in September 1961. The operation was carried out in cooperation with the Weather Bureau from the U. S. Naval Station, Roosevelt Roads, Puerto Rico. The first day's operation produced a dramatic and radical change in the thermodynamics of the hurricane for a space of about one and a half hours. Had more Cyclops units been available to continue the attack, far more conclusive results might have been achieved. It is hoped to continue these experiments during the West Indian hurricane season of 1962 with modified Cyclops units.

U. S. NAVAL ORDNANCE TEST STATION

China Lake, California

May 1962

U. S. NAVAL ORDNANCE TEST STATION

AN ACTIVITY OF THE BUREAU OF NAVAL WEAPONS

C. BLENMAN, JR., CAPT., USN — *Commander*

WM. B. MCLEAN, PH.D. — *Technical Director*

FOREWORD

This report sets forth the story of the contribution of the U. S. Naval Ordnance Test Station, China Lake, to Project Cyclops, assisting a Weather Bureau effort to modify hurricanes by a new method of silver iodide dispersal. The preparatory work was begun on 16 June 1961 and the operation carried out on 16 and 17 September 1961.

The project was made possible by the combined efforts of many NOTS personnel, both Navy and civilian, and by the support of many Navy people from other units. It is impossible to acknowledge individually all who gave of their several talents to make the experiment both possible and successful. The work was the fortuitous by-product of another ordnance program; and the talents available in the Navy made possible the adaptation of the basic idea to the Cyclops experiment.

While the results were not completely conclusive, and more work must be done to evaluate and develop the technique, it seems clear that a means may be at hand to modify and perhaps lessen the fury of the elements. Working on the basis of what has been learned from the experiment on Hurricane Esther in September 1961, the work will go forward to develop better units and device improved operational methods.

This article was reviewed for technical accuracy by Dr. William G. Finnegan.

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The project was funded by Task Assignment R360-FR-106/216-1/R011-01-001 and Channel 702 Technical Services.

Released by
G. J. PLAIN
Associate Head,
Research Department
11 May 1962

Under the authority of
T. E. PHIPPS, Head,
Research Department

NOTS Technical Publication 2751

Published by	Publishing Division Technical Information Department
Supersedes	TS 62-53 NOTS TP 2751 (Advance Copy)
Collation	Cover, 17 leaves, abstract cards
First printing	145 numbered copies
Security classification	UNCLASSIFIED

INITIAL DISTRIBUTION

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INTRODUCTION

Experiments have been going on for several years to determine the effectiveness of various nuclei as cloud-seeding media. One of the problems has been to establish the most effective chemical and to find a means to seed with appropriate quantities of material, suitably distributed, within the required time for any real effectiveness.

In 1957, Dr. Lohr A. Burkardt, Dr. William G. Finnegan, and Mr. Rex Smith, all of the U. S. Naval Ordnance Test Station (NOTS), China Lake, were investigating new possibilities for producing a dense, colored smoke that would be visible at high altitudes. During the experiments, it occurred to them that pyrotechnic compositions containing silver iodate would burn to give off finely divided silver iodide. The three inventors patented this concept. No immediate application was found for this process at NOTS.

In May 1961, Dr. Burkardt and Dr. Finnegan discussed this invention with Dr. Pierre Saint-Amand, Head, Earth and Planetary Sciences Division, and he was of the opinion that this compound would be most effective in a cloud-seeding experiment that he was considering to modify the storms on the Northwest Pacific Coast, with the idea of diverting some of the rain belt farther south to bring more rain to Southern California.

Dr. Saint-Amand discussed this proposal with Prof. Louis Battan, Deputy Director, Atmospheric Physics Division, University of Arizona, who felt that the method had great promise, and suggested that the experiment be tried on hurricanes and that he discuss it with Mr. R. H. Simpson, Deputy Director of Research, Violent Storms, at the Weather Bureau in Washington, D. C. Dr. Saint-Amand met with Mr. Simpson in Washington a few days later, explained the proposal, and burned a small quantity of the compound in Mr. Simpson's office.

Mr. Simpson was extremely enthusiastic and said that he would like NOTS to perform the experiment in cooperation with the Weather Bureau during the forthcoming hurricane season in the West Indies. He stated that the Weather Bureau had tried seeding hurricanes with silver iodide but they had neither the ability to generate sufficient quantities of silver iodide nor such a method of dissemination as was proposed by NOTS.

On his return to NOTS, Dr. Saint-Amand discussed the proposal with Capt. C. Blenman, Jr., COMNOTS, Dr. Wm. B. McLean, Technical Director, NOTS, and Dr. Charles E. Waring, Head, Research Department. It was decided that Project Cyclops, as the project was then named, would be made a maximum-effort undertaking in order to meet the deadline of the start of the hurricane season.

On Capt. Blenman's orders, Capt. R. W. Calland, Senior Experimental Officer, requested from the Bureau of Naval Weapons (BuWeps) a Fleet Assist Project for Cyclops. Capt. Blenman made personal contact with RAdm. F. L. Ashworth, Assistant Chief for RDT&E, BuWeps, to ask his cooperation in expediting this FAP. Adm. Ashworth, in turn, intervened with CNO to expedite the request.

At this stage, Dr. Saint-Amand was appointed NOTS Project Manager.

PREPARATIONS

Only about 8 weeks were available, before the estimated start of the hurricane season, in which to produce and test a satisfactory unit. Therefore, there was no possibility of a sequential program of manufacture. All divisions concerned at NOTS would have to start work at once on their respective parts of the Cyclops units.

Six separate and distinct operations had to proceed hand in hand:

1. Design a propellant grain from the basic compound
2. Design a container
3. Prepare a special parachute
4. Design and test a fuze and ignition system
5. Devise telemetry equipment
6. Decide on the most suitable aircraft for the drop ship, obtain one, and modify the bomb rack

GRAIN AND MOTOR DESIGN

The basic compound was a chemical formulation of silver iodate and polymethylvinyltetrazole (PMVT). Unfortunately, PMVT was in very short supply and a castable system was desired, so an alternate had to be found. It was decided to try a Nitrasol system, and samples were made. This revealed that the available silver iodate was of so fine a particle size that it could not be used in the Nitrasol casting system.

Dr. Burkardt worked out a recrystallizing process whereby the fine-grain silver iodate could be grown into larger crystals by evaporation of an ammoniacal solution, reground to the desired size, and then mixed with the Nitrasol as an oxidizer. This mixture, when burned, would give off silver iodide, the desired nucleant.

A further problem was the difficulty of obtaining large amounts of silver iodate. The average stock of this chemical held by a commercial house is around 500 grams. NOTS required about 500 pounds. A 300-pound supply was manufactured on contract in Baton Rouge, La., but, when delivered, turned out to be of very fine particle size (unrecrystallized).

There was no possibility of having this consignment recrystallized commercially, partly because of the time element and partly because this is considered a somewhat difficult operation on a commercial basis. There was no time to design or construct any conventional equipment for this process, so the Chemistry Division at NOTS jury-rigged a large number of wooden boxes like nursery-plant flats, lined them with polyethylene sheet, and proceeded to grow crystals in every conceivable corner. When grown to suitable size, these crystals were dried in an oven, ground to 50- to 100-micron size, and then sent to the Propulsion Development Department to be made into propellant grains.

THE PROPELLANT GRAIN AND MOTOR

The original design called for an internal-burning grain, and the ignition mechanism was designed with this in mind. However, when final changes were made in the combustible, it was found that the grain burned too rapidly. The decision was made to use an end-burning grain. As the hardware was made with the exhaust ports on the forward end, it was necessary to transfer the fire through to the forward end of the unit. The propellant grain was poured into an inhibitor cylinder, turned to size, inserted, and cemented into the body of the Cyclops unit around a central micarta tube running the length of the motor. The ignition would be from the tail end, and the purpose of the micarta tube was to conduct the flame to the front end to ensure front-end burning. Many problems were encountered in the early stages because of shrinking and inhibition. But these were solved by the personnel of the Propellants Division in time to begin static ground tests on the target date.

Initial tests showed that ignition was difficult, the combustion temperature was insufficient to vaporize all of the silver iodide, the compound would not burn at much below atmospheric pressure, and an initial burning pressure of about 20 to 100 psi was required.

To solve these three problems simultaneously, three propellant modifications were made for testing with 5, 10, and 15% aluminum. It was found that 5% gave the best results in ground tests (Fig. 1 and 2).

Ignition and even combustion of a slow-burning material at high altitude has always been a problem. The Cyclops device was no exception. Because of the time element, it was decided to begin with a modified Mk 6 Mod 6 fuze. To cope with the high-altitude ignition transfer problem, the Atlantic Research Corporation (U. S. Flare Division) produced four variations of fuze train, testing them in their high-altitude chamber. The end result was the FD 30 fuze train.

This worked satisfactorily during all ground tests, but in the first live air drops there was no ignition. It was discovered in post mortem on the recovered units that the breakdown had been at the transfer point between the fuze and the ignition system. This was attributed to three factors: first, a 1/8-inch gap at the transfer point; second, the intense cold at 40,000 feet when the drop was made; and, third, a lack of gaseous products in the fuze composition, which hindered the energy transfer. The outside temperature at the time of the drop was −65°F. To solve these problems, about 1/2 gram of aluminum–potassium perchlorate with PMVT binder was added to the fuze train at the transfer point, and the gap in the fuze train was reduced to 1/32 inch. Cyclops units were then chilled to −65°F, and tests were run in the high-altitude pressure chamber at a simulated 40,000-foot altitude. The addition of the aluminum–potassium perchlorate and PMVT had added about 1,000 calories of heat, and the gas from the added compound drove the flame into the micarta tube, igniting the ignition system and the propellant grain perfectly. The next live drops gave seven out of eight successful ignitions. The one failure was due to an easily correctable mechanical difficulty.

THE CONTAINER

Simultaneously with the chemical development, a suitable container, initiator, and parachute were being designed; later, a telemetering device was introduced. On this project there was no "lead time" on any of the components. In order to meet a time scale of about 8 weeks from concept to operation, every group involved had to proceed on the basis that yesterday was delivery date. The container was designed by the Servomechanics Branch, Engineering Department, NOTS.

The container consisted of a 5 1/2-inch flare equipped for stability with fins from an HVAR (high-velocity aircraft rocket); the device was to be fired by the Mk 6 Mod 6 fuze, which, in turn, would be triggered by the line of a parachute packed into the tail of the unit.

The Irving Air Chute Co. of Glendale, Calif., was asked for 60 special ribbon parachutes on 28 June. The first 10 were delivered on 5 July, and the remaining 50 units were delivered on 14 July (Fig. 3 and 4).

TELEMETRY

There can be a vast difference between a live test drop in perfect weather over the NOTS ranges when everything can be observed by Askania cameras and even the naked eye, compared to an operational drop in the wall-cloud of a hurricane. Capt. Blenman therefore decided that the Cyclops devices must be equipped with a telemetering device, which could not be missed by either the drop or the observation aircraft, to determine whether the operational drop Cyclops units had ignited properly. They certainly could not be observed visually.

Working on the basis that existing equipment must be used, radiosonde units were modified to fit the front end of the Cyclops units. At the same time, a telemetering transmitter with audio tone at two levels and two pitches was constructed at NOTS. The first tone was activated by a pin on the bomb-release mechanism and transmitted as soon as the unit dropped from the aircraft. As soon as ignition took place, a thermal switch changed the tone, and this tone was maintained until burnout, or until the unit was out of radio range. On test drops, monitoring was done by ground recording units. On the Hurricane Esther operation, monitoring was done by the drop aircraft. Telemetry was designed by the Electronic Systems Branch and Timing and Telemetry Branch, NOTS.

THE DROP AIRCRAFT

Capt. Calland and Cdr. W. R. Eason, USN, NOTS experimental officers on the Cyclops project, were responsible for deciding on the most suitable type of aircraft and obtaining aircraft for drop tests at NOTS and for the operational drop, which would be based at the U. S. Navy Station, Roosevelt Roads, Puerto Rico.

It was decided to use an A3D Skywarrior. A special bomb-rack adapter to fit this aircraft for the project was designed and built by the Naval Air Facility (NAF), NOTS.

The drop-test A3D was provided by VAH 2 Squadron, Whidbey, Wash. The Commanding Officer of the squadron, Cdr. L. E. Kirkemo, USN, was the pilot on the first test. All other tests at NOTS were piloted by Lt. Richard Zick, USN, of the same squadron.

Lt. Frank O. Baty, USN, of NAF, NOTS, was designated bombardier-navigator for the project and to assist as necessary in all stages of construction of the device. He was also charged with the responsibility for the design and manufacture by NAF personnel of the bomb-rack adapter for the A3D. Lt. Baty made all test and operational drops of the Cyclops device.

Air-to-air photographic coverage was obtained of the test drops at NOTS by Cdr. W. L. Ennis, USN, flying an A4D equipped with underwing camera pod aimed at 90 degrees to the line of flight.

TEST DROPS

Between 31 July and 12 September 1961, 14 Cyclops units were dropped at NOTS at 40,000 feet, with the following results:

<u>31 July</u> Container, separation, and parachute test

Unit 1. No separation; parachute did not blossom

Unit 2. No separation; parachute did not blossom

Unit 3. Good separation; parachute blossomed

9 August First test of complete unit

Unit 4. Good drop, separation, and parachute; ignition failure

Unit 5. Hung up in bomb-bay by tight pin

Unit 6. Good drop, separation, and parachute; ignition failure

Post mortem on recovered units showed a breakdown of the fuze train at the transfer point. This is where aluminum–potassium perchlorate and PMVT were added.

11 September

Unit 7. Good drop and separation; smoke seen at +30 seconds; unit burned brightly until +3 minutes (Fig. 5)

Unit 8. Good drop and separation; smoke seen at +30 seconds

Unit 9. Good drop and separation; ignition failure

Unit 10. Good drop and separation; intense burnout at +50 to 60 seconds

12 September

Unit 11. Good drop, separation, and ignition; burnout at +2 1/2 minutes

Unit 12. Good drop, separation, and ignition; unit tumbled; burnout at +1 minute 10 seconds

Unit 13. Good drop, separation, and ignition; burnout at +1 minute 25 seconds

Unit 14. Good drop, separation, and ignition; burnout at +1 minute 20 seconds

Post mortem on recovered units showed that the diffusion ports on the nonpropulsive assemblies were being plugged by condensation of aluminum oxide from the burning composition. The port area was then increased by milling out the nonpropulsive assemblies.

The final tests were completed at about 1500 hours on 12 September and the results considered by the NOTS Research Board; it was decided to proceed immediately with the operation on Hurricane Esther, which was then fully formed and being tracked east of Puerto Rico.

OPERATIONAL PLANNING—HURRICANE ESTHER

On 13 September a group left NOTS for Miami by air. The group included Dr. Waring, Dr. Saint-Amand, Cdr. Eason, project experimental officer, and personnel from the Technical Information Department to record all proceedings for reports, provide still- and movie-camera coverage, and prepare any news releases for transmission to the BuWeps Public Information Officer for release.

On arrival at Miami, Dr. Waring, Dr. Saint-Amand, and Cdr. Eason went to a preliminary conference with Cdr. John Cork, USN, Officer-in-Charge, Fleet Weather Facility, Miami. The main conference convened at 1000 hours on 14 September at the Fleet Weather Facility. The chairman of the conference was Cdr. Cork, project coordinator for the Navy. Dr. Saint-Amand presented the basic philosophy of the project. Dr. Waring spoke on the chemical formula and Cdr. Eason outlined the participation of NOTS.

Mr. Simpson, of the Weather Bureau, announced that it was estimated that on 16 September Hurricane Esther would be located at about 23° N 60° W, and on 17 September, at about 24° N 64 1/2° W; it was his opinion that the estimated position on the two dates would be ideal. The afternoon was devoted to a discussion on detailed flight plans for the participating aircraft, as planned by Mr. Simpson.

SCIENTIFIC OBJECT

The scientific object was stated to be that of testing an entirely new seeding method with a new formula to discover whether the process would, by releasing latent heat in the wall-cloud, exert control of the pressure gradient or disturb the thermodynamics to such an extent that an appreciable change could be observed in the form, wind velocity, or track of the hurricane, the principle involved being that of providing freezing nuclei to turn supercooled water into ice, releasing the latent heat of fusion.

It was planned that eight Cyclops units would be dropped into the northeast quadrant of the wall-cloud at about 2,000 feet above the cloud tower to see whether this would cut a pie-shaped wedge from this quadrant. The second day's operation would be planned after observations from the first day had been evaluated.

The following aircraft were available: the Navy A3D, as drop ship; a "Willy Victor" Super Constellation weather-observation aircraft, as control ship (provided by the VW 4 Squadron at Roosevelt Roads); one B57, two DC6s, and one B26 for observation (provided by the Weather Bureau); and an Air Force U2, for high-altitude photography.

Cdr. Cork announced that he would be observing in the Willy Victor. LCdr. Harold Bryant, USN, represented COMHATWING 1, who had made available the A3D for the operation. LCdr. D. B. F. Brown, USN, Operations Officer, VAH 11, stationed at Sanford, Fla. (since, unfortunately killed in an air crash), stated that his squadron would fly a complete ground crew to Roosevelt Roads to service and maintain their A3D, as neither squadron at Roosevelt Roads was equipped with this type aircraft. Lt. John Shattuck, USN, of VAH 11, the pilot assigned to the operation, and Lt. Baty decided to return to Sanford that night and fly the A3D direct to Roosevelt Roads next day.

It was decided to brief the crews the following evening at Roosevelt Roads so that the observation ships could take off early on the morning of 16 September.

ROOSEVELT ROADS

The members of the Miami conference met again at the ready room of VW 4 Squadron at 2130 hours with Cdr. A. L. Ufer, USN, Squadron Operations Officer, who also represented Cdr. W. S. Webster, USN, Commanding Officer, VW 4 Squadron. Also present were crew members of the Willy Victor of VW 4 who would be flying during the operation. One of their aircraft was then in the hurricane, observing conditions.

For the benefit of those who had not been at the Miami conference, Dr. Waring discussed the background of Project Cyclops. Dr. Saint-Amand explained the construction of the Cyclops unit and its method of operation. He also burned a small piece of the propellant, to demonstrate the color and quantity of smoke output.

Cdr. Eason assigned the code names for such emergency situations as might arise. Three special call signs were assigned to indicate conditions found in the hurricane around drop time, which was designated T, for Tango time. X-ray indicated "conditions as indicated, only minor changes"; Yankee, "definite change, proceed at your own discretion"; Whisky, "major change, conditions dangerous, evacuate area immediately." Cdr. Cork assigned call signs and frequencies.

AIRCRAFT CONTROL AND FLIGHT PLAN

It was essential that a careful plan be made to eliminate any possibility of air collision while still maintaining the required observation of the hurricane conditions.

The Willy Victors of VW 4 Squadron had been maintaining watch on the hurricane for several days. Willy Victor 3 would be in the area during the operation and was designated as control ship. It would fly a 40-mile racetrack course at 10,000 feet in and out of the eye, making a penetration every hour (Fig. 6). Lt. (jg) Ronald Morvali, USN, was designated as the controller, and he would vector the A3D for the maximum effective course for the drop.

The Weather Bureau's DC6s would fly at 20,000 and 7,000 feet, respectively, leaving the eye at T − 2 hours and not returning until T + 2 hours, during which interval they would return to San Juan, Puerto Rico, and refuel (Fig. 7).

The B26 would fly a box course southeast of the hurricane, observing conditions in that area at 20,000 feet during the drop. It would then make a series of penetrations at 1,500, 6,000, 12,000, and, again, 1,500 feet, and then return to base (Fig. 8).

The B57 was assigned to fly at 40,000 feet and to enter the hurricane before and after the drop to observe windfield and cloud system changes in order that a comparison might be made of these factors before and after seeding (Fig. 9).

The U2 was to leave Patrick Air Force Base and take photographs over the eye of the hurricane at 60,000 feet. It was not certain that this aircraft would be available for the first day's operation.

OPERATION CYCLOPS

FIRST DAY

All time notations would be Zulu time, T-hour to be 2000 hours Zulu, 16 September 1961. All support aircraft were in position at the planned times. However, it looked at one stage as if the whole operation would have to be canceled because the A3D engines would not start. The only suitable starter unit malfunctioned. It would build up a certain number of revolutions and then cut out. The greatest credit is due to the crew chief, P. C. Delvillaggio, ADJ1, from VAH 11, who came from Sanford to take charge of maintaining and servicing the A3D. With only 10 minutes to go before cancellation would have been necessary, he located the pressure-leak in the system. He stopped the leak with his bare hand, sustaining a bad burn in the process, but he succeeded in getting both engines started. The A3D was airborne with less than 4 minutes leeway (Fig. 10).

It had been anticipated that the wall-cloud of the hurricane eye would not be more than 40,000 feet in height, and the A3D would orbit in the eye until vectored out by the control ship. It would then drop four units in the clear above the desired quadrant on the outward run, and the control ship would vector the A3D in again on a reciprocal course for a second pattern of four units.

Conditions were far from those expected. On arrival in the eye, two factors made the plan impossible. The eye turned out to be only 15 miles across; therefore the A3D could not orbit. Also the wall-cloud was some 50,000 to 60,000 feet high instead of 40,000, far above the ceiling of the A3D. Lt. Shattuck immediately dumped 6,000 pounds of fuel, to gain maximum altitude, and proceeded out of the eye in the front right quadrant.

After turning 180 degrees, he was vectored into the eye again by the command ship, and Lt. Baty released the whole load of eight Cyclops units at 5-second intervals.

It had been proposed that after the drop the A3D would orbit the outside of the center of the storm once, in case there was anything to be seen visually. Because it was necessary to dump fuel to gain altitude, this was no longer possible, and the A3D returned directly to base after the second drop run (Fig. 11).

Support aircraft continued to observe after the drop as previously planned, until the time T hour + 3.

When the WV command ship returned to base at Roosevelt Roads, the crew was debriefed, and the time-lapse films of the radarscope were immediately processed and examined by all present. These frames were taken with a 1-minute time lapse; a representative selection showing the formation of the hurricane before, during, and for periods after the drop time are shown in Fig. 12–21.

It was the unanimous opinion that a drastic change in the formation of the eye of the hurricane had taken place after the drop. As seen on radar, the wall-cloud had turned to ice, starting in the drop area, and spreading to almost 180 degrees of the hurricane eye.

In vertical formation, as seen by 10-cm radar, the eye no longer resembled a cylinder but had changed shape so that it now more closely resembled a cup. This condition was maintained for a period of about 1 1/2 hours after the drop, when the eye started to re-form, displaying for a time a figure 9 formation until the eye completely re-formed.

Cdr. Cork and Dr. C. L. Jordan, Department of Meteorology, Florida State University, had observed this phenomenon visually and were of the opinion that the change was dramatic and unprecedented.

SECOND DAY

On the second day, 17 September, the command ship changed the operational attack after the A3D was airborne because the formation of the hurricane was now changed. (On the first day, there had been an eye approximately 15 miles in diameter, compared to 7 miles on the second day.)

It had been intended to repeat the previous day's pattern of drops of four units on the outward course in the front right quadrant and four on the reciprocal course. The fact that the wall-cloud was only 3 miles thick made this unsuitable. The drop interval had been increased from 5 to 20 seconds. On instruction from the command ship, the A3D made a single pass through the right forward quadrant and released the full load of eight Cyclops units at 10-second intervals.

The preliminary assessment of the data was prepared by the Weather Bureau and presented by Mr. Simpson to the Washington D. C., Chapter of the American Meteorological Society (see DOCUMENTATION).

Unfortunately, no assessment was given by the Weather Bureau of possible error, nor were other parts of the hurricane explored during the time of the seeding and the period immediately following, so that comparison with the undisturbed portions is not possible.

The following is the substance of a portion of a report (NOTS TP 2886) being prepared by Burkardt, Finnegan, and Saint-Amand (see

DOCUMENTATION), which, in turn, uses information supplied by Mr. Simpson of the Weather Bureau.

Changes were noted in the structure of the hurricane immediately after seeding. Whether these were caused by the seeding or not is of course open to question, but the authors and the observers concurred in the opinion that the seeding produced the changes.

The most noticeable change that took place was the disappearance from view on the screen of the 10-cm radar of about one half of the wall-cloud. The 10-cm radar detects reflections from water droplets. Hence, it is reasonable to assume that this cloud was changed from a collection of supercooled water droplets to ice crystals. The changes in the form of the eye continued for at least an hour and a half. During this time, the eye oscillated and changed shape from circular to elliptical and back to circular. The eventual closure took the form of an open figure 9 and finally formed a circle again.

The changes noted visually were that the eye widened at the top, like a cup, and the clouds in the eye floor decreased and tilted downward from southwest to northeast. Cumuliform clouds were noted growing in the wall-cloud.

The seeded area rotated partially around the eye as it was blown by the wind; however, vertical wind velocities of sufficient magnitude to lift the ice crystals out removed the material from the wall-cloud in a short time.

Evidence as to the vertical velocity was given by Mr. Simpson in his talk before the American Meteorological Society. He reported that at 20,000 feet the B57 used by the Weather Bureau, flying at constant attitude and power recorded a steady rate of climb of 2,200 ft/min while penetrating the north eye wall. Upon passing into the eye, the aircraft began descending at about 2,000 ft/min (because of a downdraft), but soon reached a constant altitude. The pilots flying above the freezing level all reported heavy icing and turbulence before the seeding, but essentially none thereafter.

At 1215 local time on the 17th, eight more units were dropped at 10-second intervals on a line tangent to the wall-cloud, again in the right forward quadrant of the hurricane. During the drop the A3D lost contact with the WV 3, and observers contend that the Cyclops units missed the wall-cloud, falling largely in the eye. One plane orbiting in the eye reported a unit falling nearby. No dramatic effects were noted. This experiment should properly be classed as a null.

The track of Hurricane Esther as plotted by the Navy Meteorological Office at Roosevelt Roads is shown in Fig. 22.

DOCUMENTATION

Project Cyclops was documented from the outset on still and movie cameras by personnel of the Technical Information Department at NOTS, who also provided writing and editing services. A color motion picture, BuWeps 25-61, entitled "Cyclops I, A Study in Hurricane Modification," has been completed and is now available. NOTS TP 2822, Technical Article 16, Pyrotechnic Generation of Silver Iodide for Meteorological Applications, by Burkardt, Finnegan, and Williams, will be available very shortly. NOTS TP 2886, Pyrotechnic Generation of Silver Iodide and Other Nuclei for Meteorological Uses and Application to Hurricane Control, by Burkardt, Finnegan, and Saint-Amand, is in preparation.

"Hurricane Esther - Something Old, Something New," by R. H. Simpson, U. S. Weather Bureau, was presented to the Washington, D. C., Chapter of the American Meteorological Society, 18 October 1961.

SUMMARY AND CONCLUSIONS

The data from the first day's operation have been analyzed, and, taken with the visual observations of qualified experts such as Cdr. Cork and Dr. Jordan, it is clear that for a period of about 1 1/2 hours a radical change was produced in the thermodynamics of the hurricane.

Both visual and instrumented observations show that over a large segment of the hurricane, about 400 cubic miles of supercooled water clouds were converted into ice clouds, comprising about 20,000,000 tons of ice and releasing the energy equivalent to several atom bombs.

Spectacular results might have been obtained if more Cyclops units had been available together with more A3Ds as drop ships to maintain the attack once the initial change in the hurricane had been observed.

RECOMMENDATIONS

Whereas the Cyclops units as designed lived up to expectations, it is felt, now that the operation has been analyzed, that better results would be obtained in future operations by using smaller units dispensing about 1 kg of smoke each. This would permit wider dispersal of nucleating material per aircraft load. It is possible that the present units may grossly overseed their immediate area.

Furthermore, the A3D will only carry nine of the present units in the bomb-bay. It is also clear that the safety factor for the aircraft under these conditions is definitely marginal. An A3D was never designed to open its bomb-bay doors in a hurricane. Smaller units could be carried externally, either on the A3D or such other ship as may be found more suitable.

Proposed redesign of the Cyclops units on a smaller scale, together with experiments with other nucleants, is now under consideration at NOTS. Three units are being considered: one a 1-kg flare to be launched from a photoflash dispenser; a 10-kg drop-flare; and a long-burning fuzee to be carried on, and burned by, the seeding aircraft while in horizontal flight. Design changes are in process that will minimize particle size.

It is recommended that operations for the hurricane season of 1962 could be carried out best from an aircraft carrier. The carrier should begin operations off the Cape Verde Islands for the Caribbean hurricanes, which are spawned in this area. The carrier could operate in perfect safety about 50 miles to the left rear of a hurricane (Fig. 23).

Operating in this manner, the aircraft would have the minimum distance to fly to and from the drop area, greatly increasing the safety factor for drop and observation aircraft. Also the excellent radar on this type of ship would give maximum aircraft control and observation not only of immediate changes in the hurricane thermodynamics, but also would make possible the dropping of reflective materials into the hurricane system whereby the 3-cm radar could detect and make accurate readings of vertical and horizontal wind velocities or any unusual forms of turbulence caused by the seeding operation.

The Navy's Hurricane Hunter Willy Victor aircraft have proved very reliable, and certainly the most effective of the observation aircraft, but it is felt that quicker results in data analysis could be obtained if the instrumentation could be modified and simplified so that the data could be processed in days, instead of the months that are presently required. It is recommended that the Hurricane Hunter aircraft be equipped with instrumentation that will permit continuous recording of the following: navigational parameters, differences between aneroid altitude and true altitude, and water content of the air. This very effective air group would then be better equipped to fulfill its mission.

Navigational control could be exercised from the carrier, and the Navy would be enabled to play a more effective role in dealing with typhoons as well as hurricanes.

FIG. 1. A Burning Test of the Basic Compound With (Left) and Without (Right) the 5% Aluminum Additive Shows the Great Difference Not Only in Burning Rate but Also in Output of Silver Iodide, Indicated by the Density and Color of the Smoke.

FIG. 2. A Static Ground Test of the Cyclops Unit Shows the Heavy Iodide Output as Demonstrated by the Color of the Smoke.

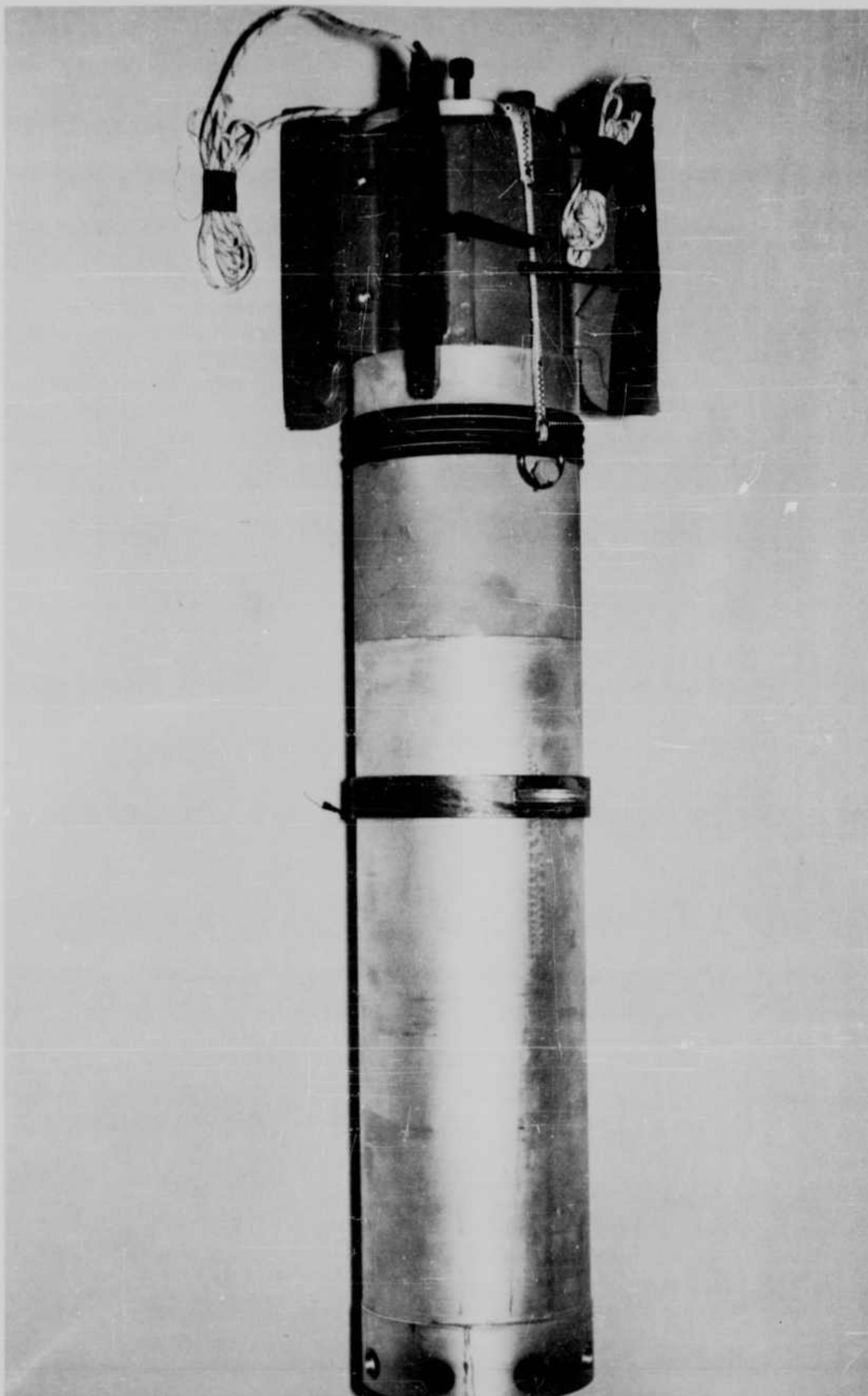

FIG. 3. The Complete Cyclops Unit Assembled, but Without Telemetry Unit.

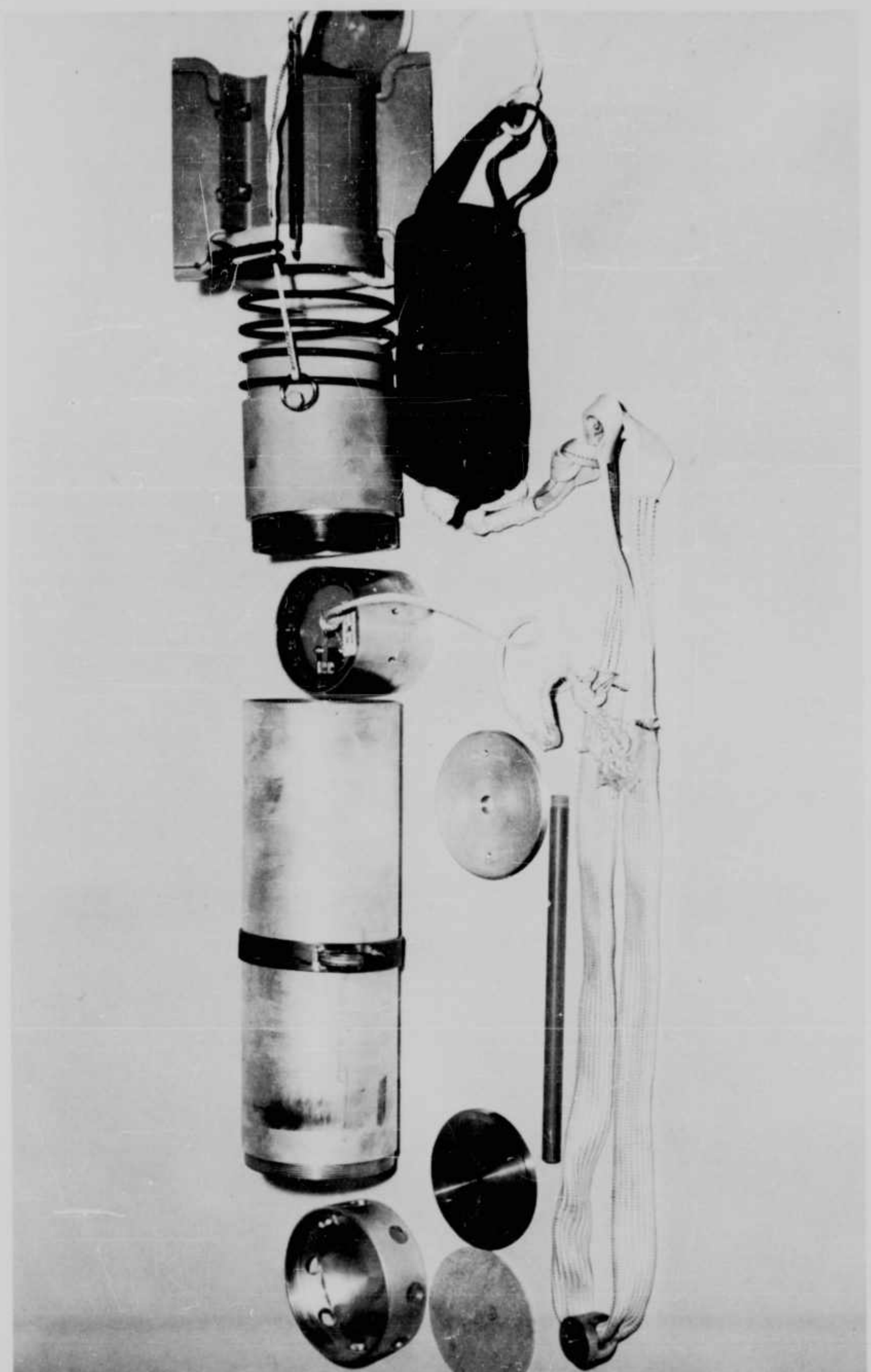

FIG. 4. The Hardware, Parachute, and Fuze Mechanism of the Cyclops Unit.

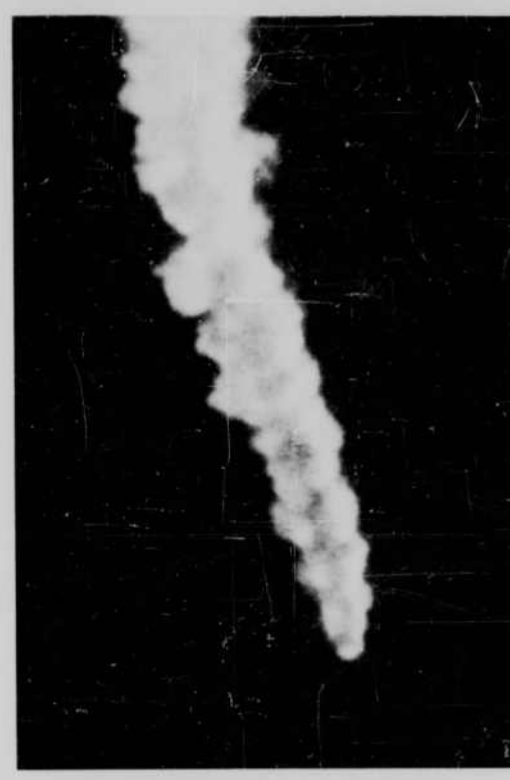

FIG. 5. A Successful Test. The drop was made over the NOTS range at 40,000 feet, and photographed by a ground Askania camera.

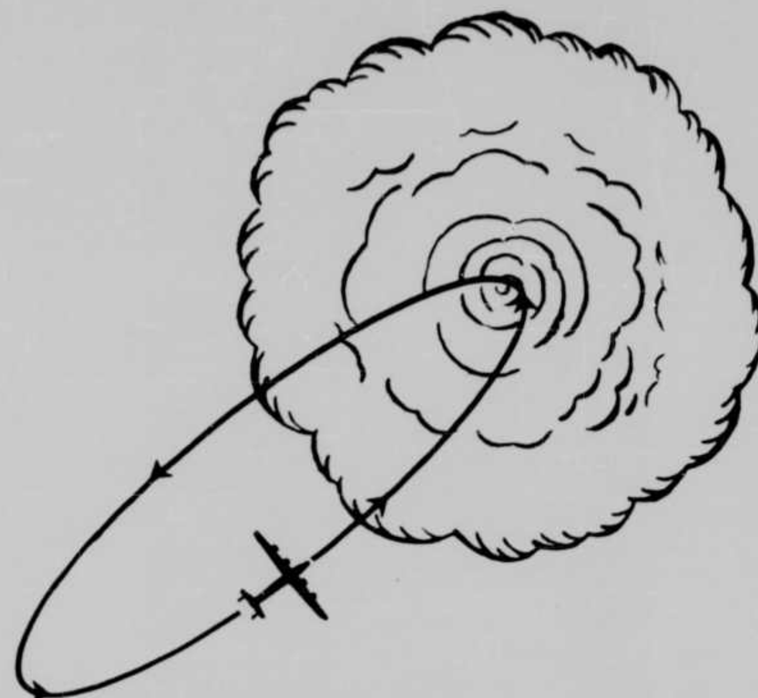

FIG. 6. Flight Pattern for the Willy Victor
Command Ship of the VW 4 Squadron.

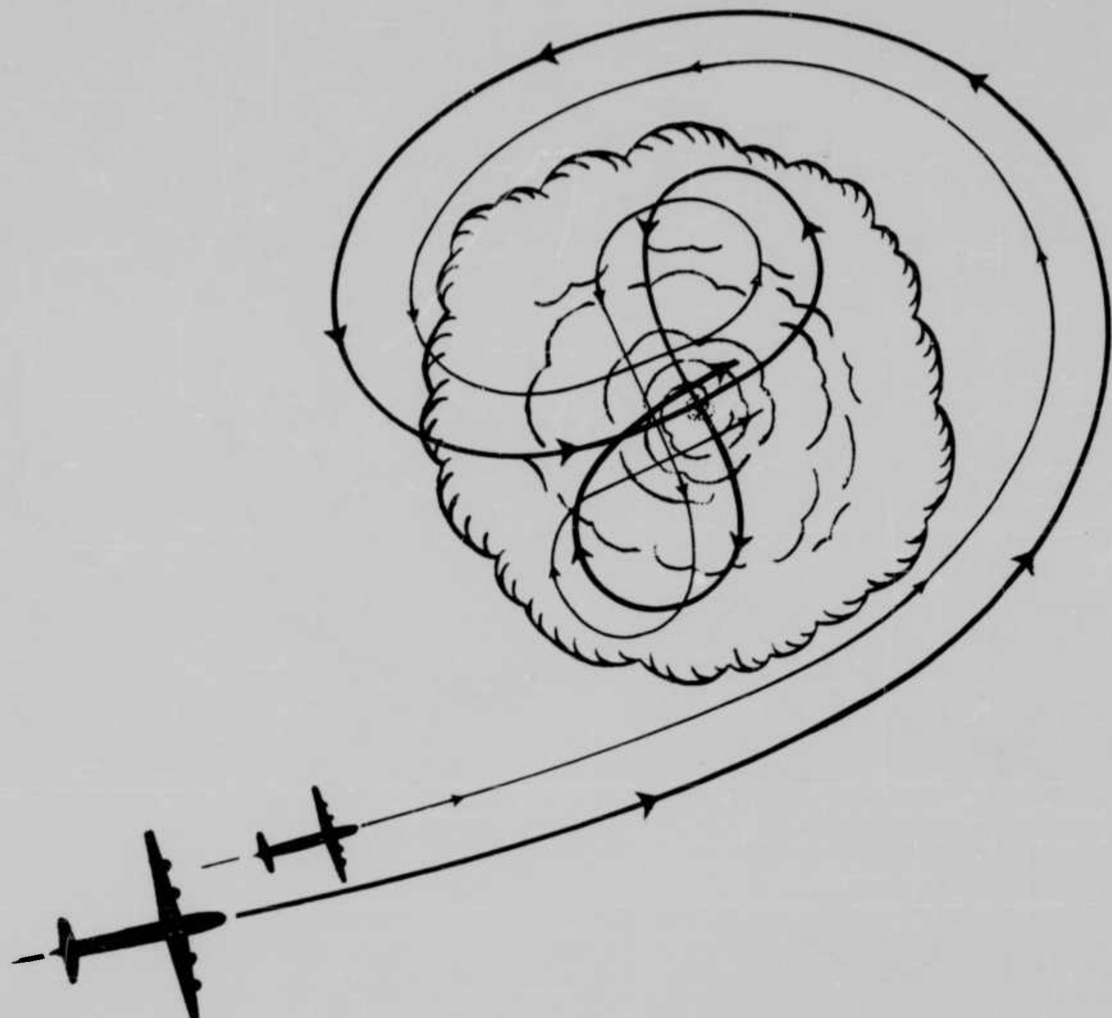

FIG. 7. Flight Pattern for the Two DC6 Aircraft Supplied by the Weather Bureau.

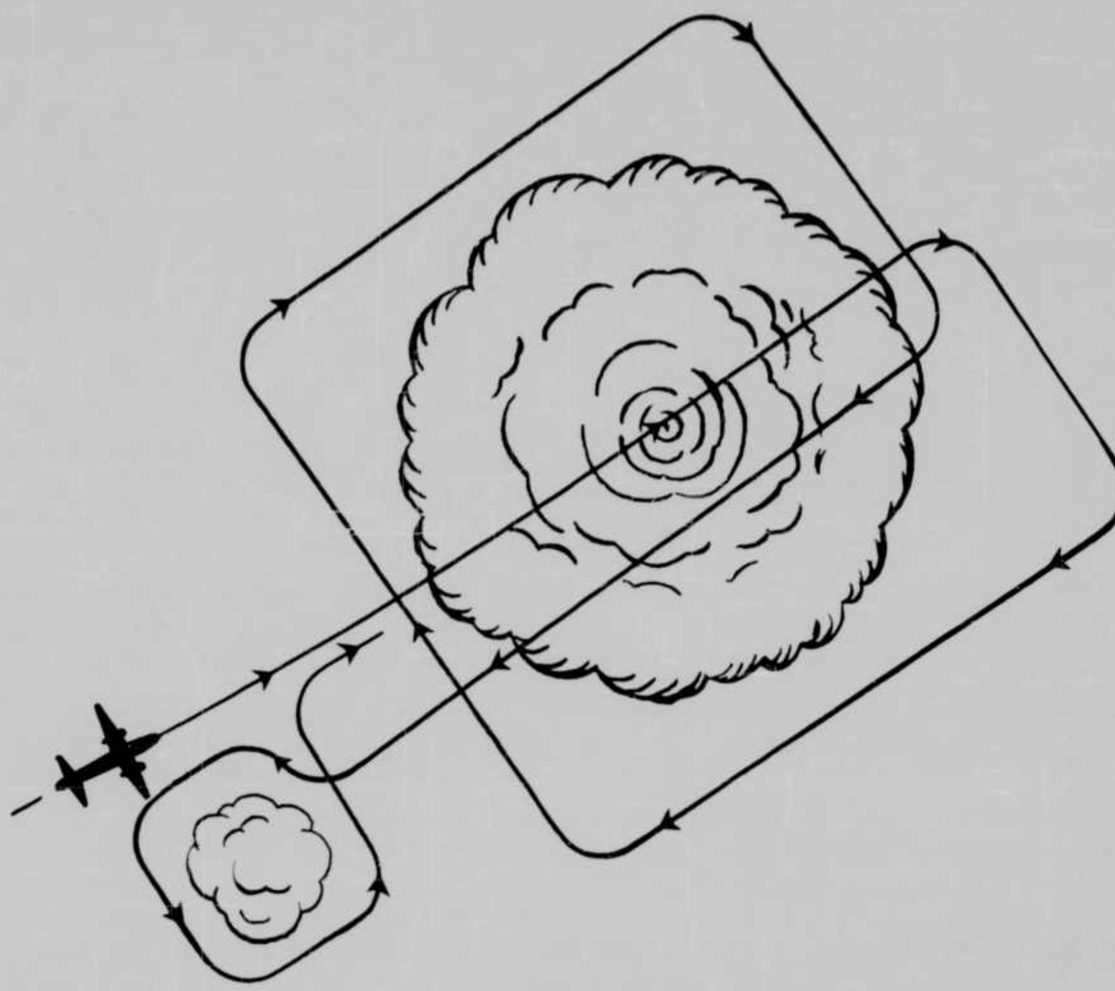

FIG. 8. Flight Pattern for the Weather Bureau's B26 Aircraft.

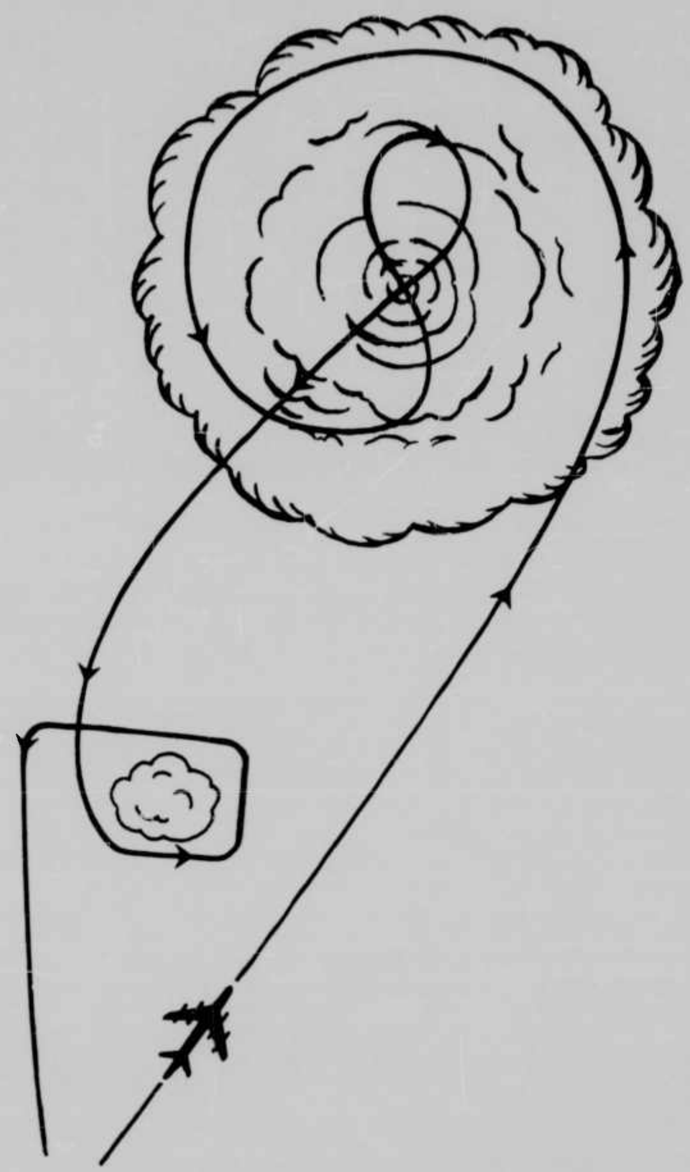

FIG. 9. Flight Pattern for the Weather Bureau's B57 Aircraft.

FIG. 10. Air and Ground Crew of A3D from HATRON 11. Left to right (rear): W. R. Williams, ADT1, J. E. Reig, AE2, P. C. Delvillaggio, ADJ1, S. E. Nees, AD2, J. J. Mancini, PR2, J. L. Dollar, AMCS; (front): Lt. John B. Shattuck, Lt(jg) Alex. R. Blunden, Donald D. Burkholder, AQ2, LCdr. Harry F. Bryant, Jr.

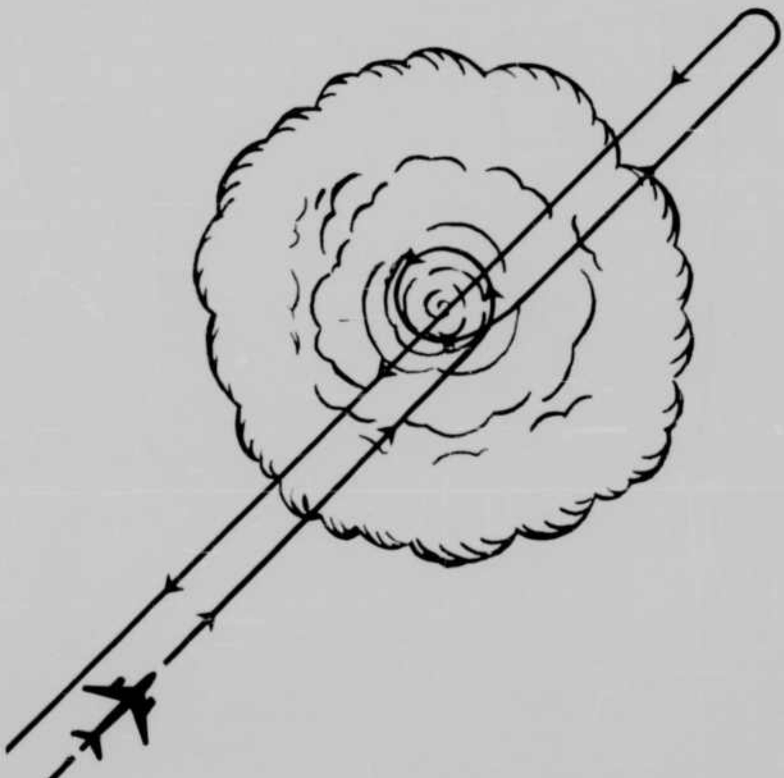

FIG. 11. Flight Pattern for the A3D Drop Ship. The aircraft was supplied by VAH 11 Squadron by permission of COMHATWING 1.

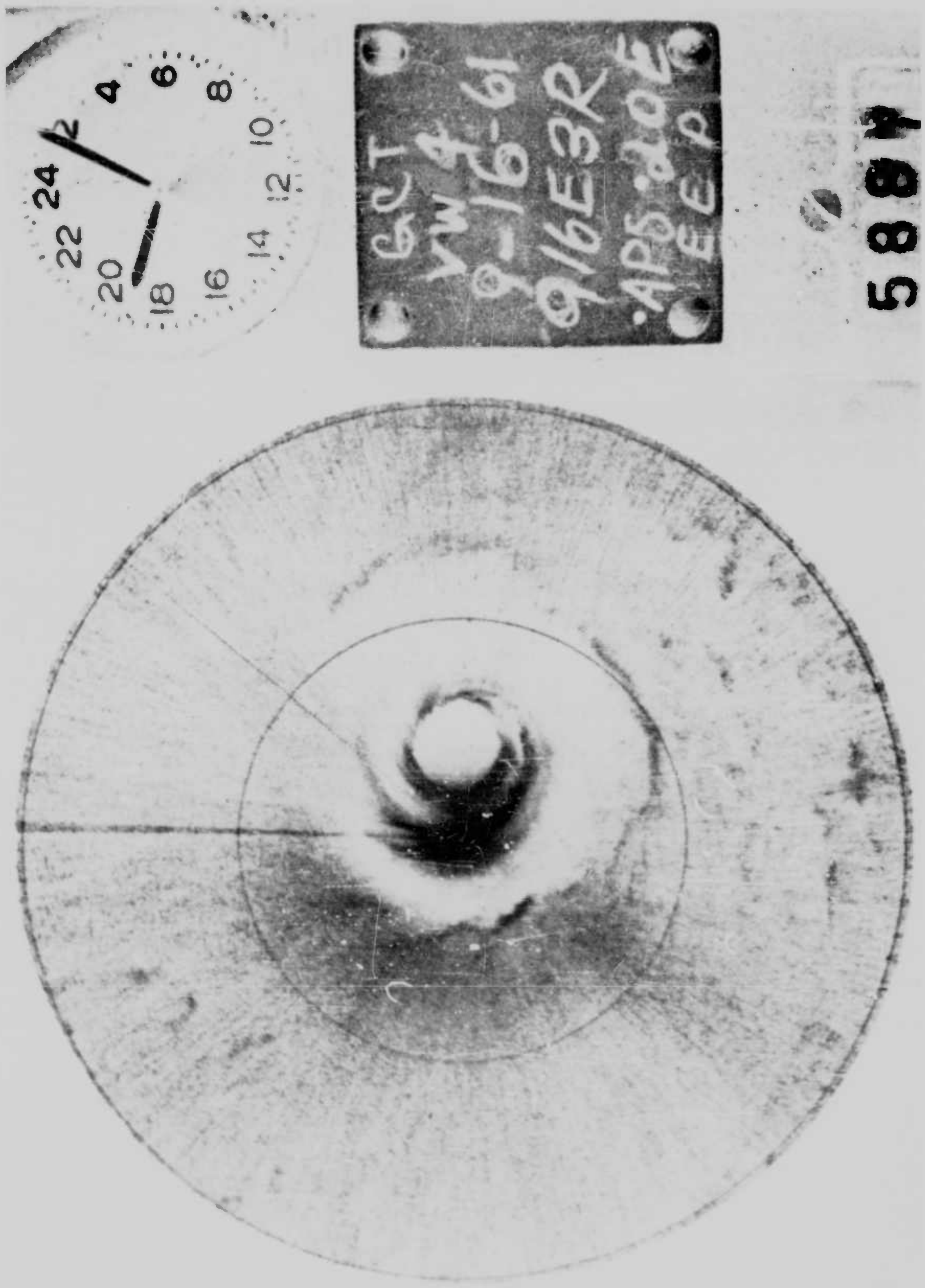

FIG. 12. Radarscope Photograph From Command Ship at T-Hour Minus 70 Minutes.

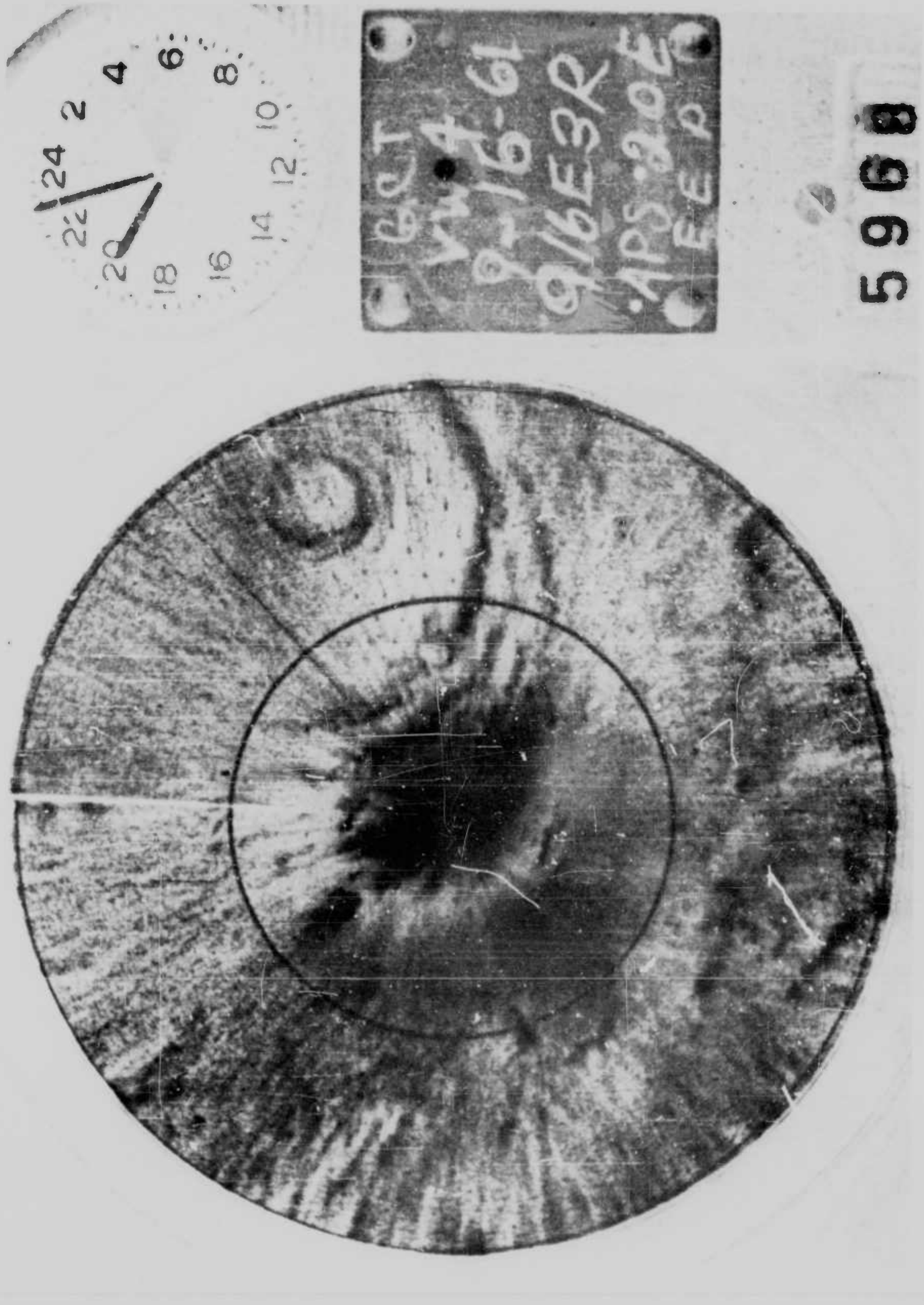

FIG. 13. Radarscope Photograph From Command Ship at T-Hour Minus 17 Minutes.

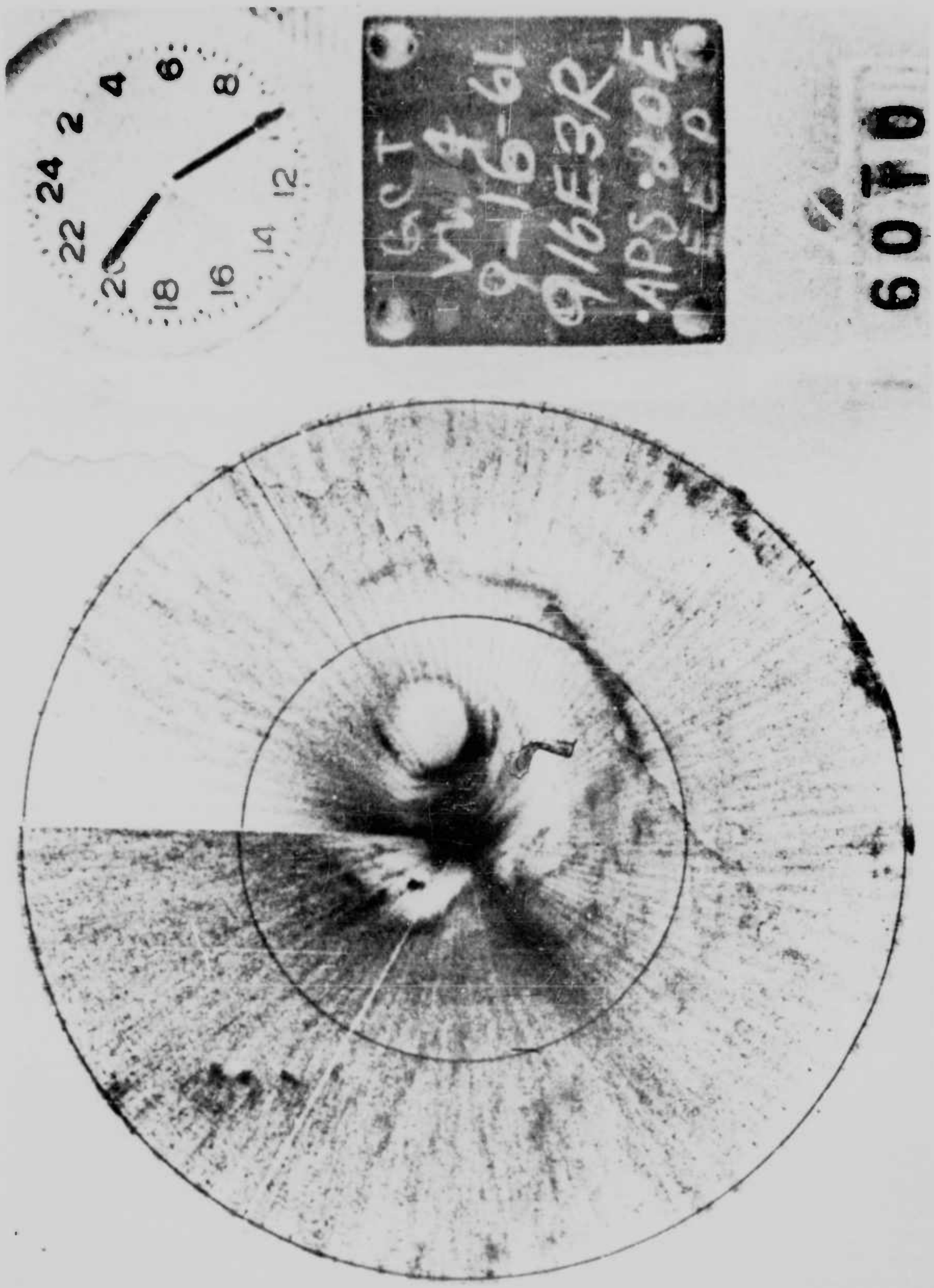

FIG. 14. Radarscope Photograph From Command Ship at T-Hour Plus 10 Minutes.

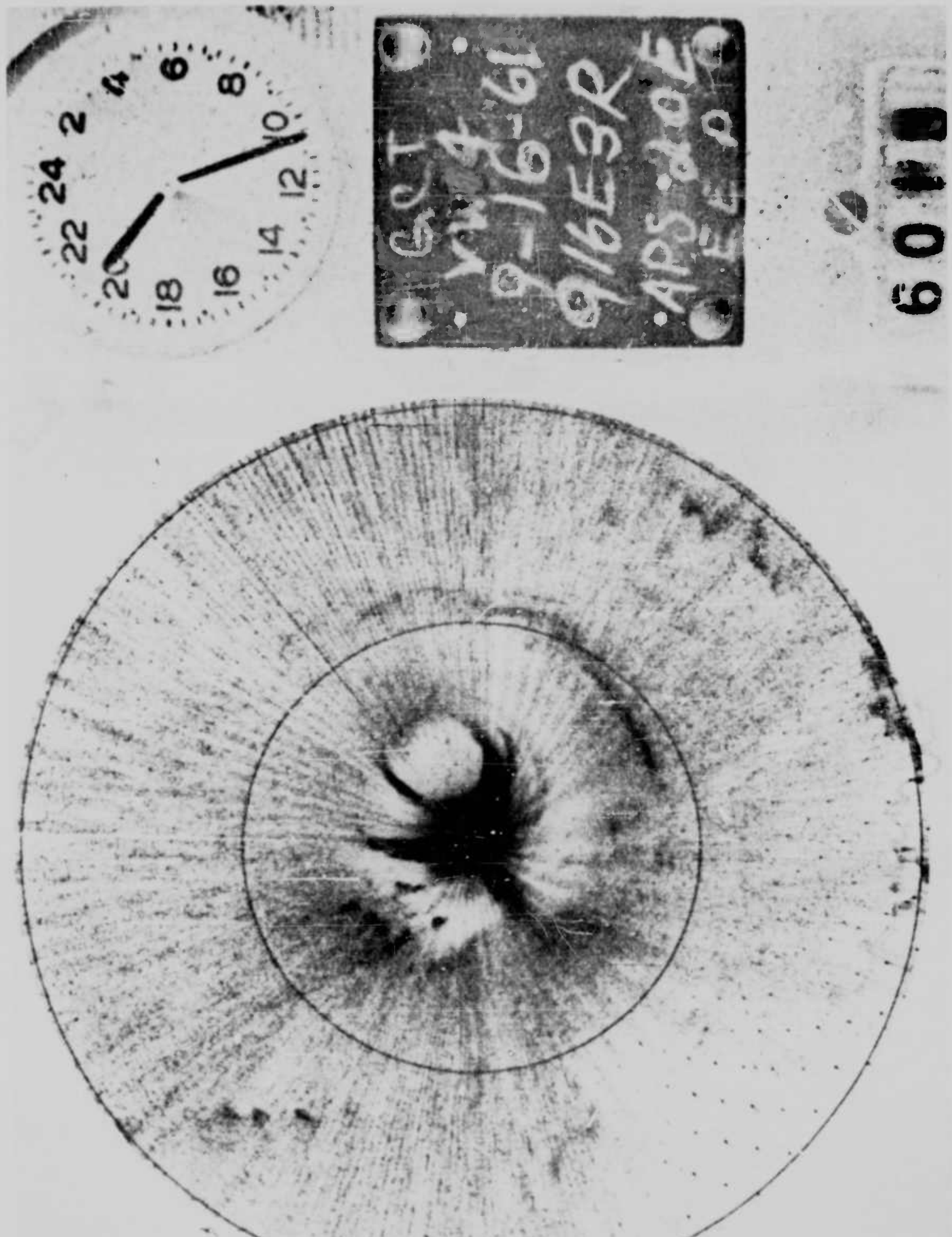

FIG. 15. Radarscope Photograph From Command Ship at T-Hour Plus 12 Minutes.

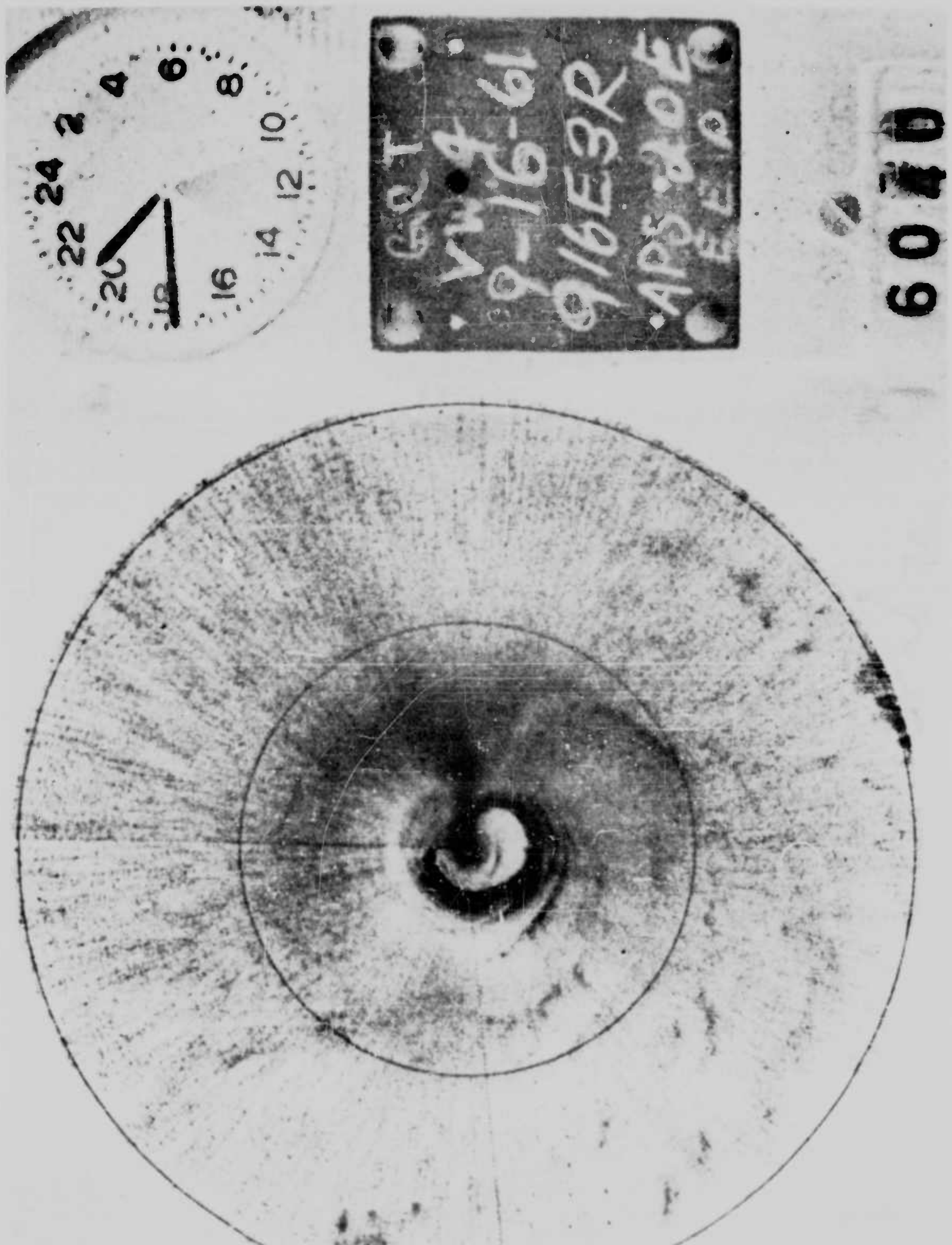

FIG. 16. Radarscope Photograph From Command Ship at T-Hour Plus 29 Minutes.

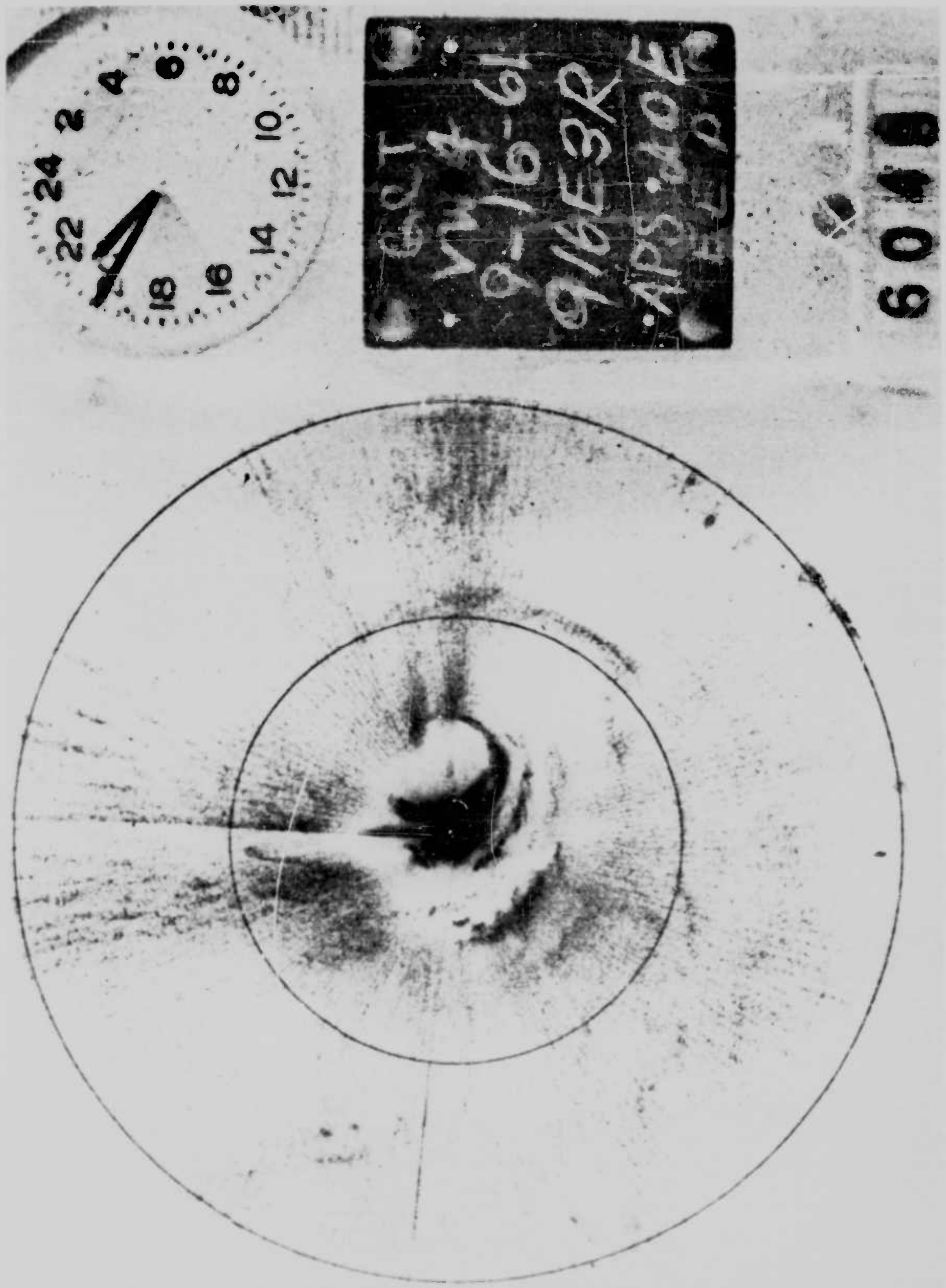

FIG. 17. Radarscope Photograph From Command Ship at T-Hour Plus 35 Minutes.

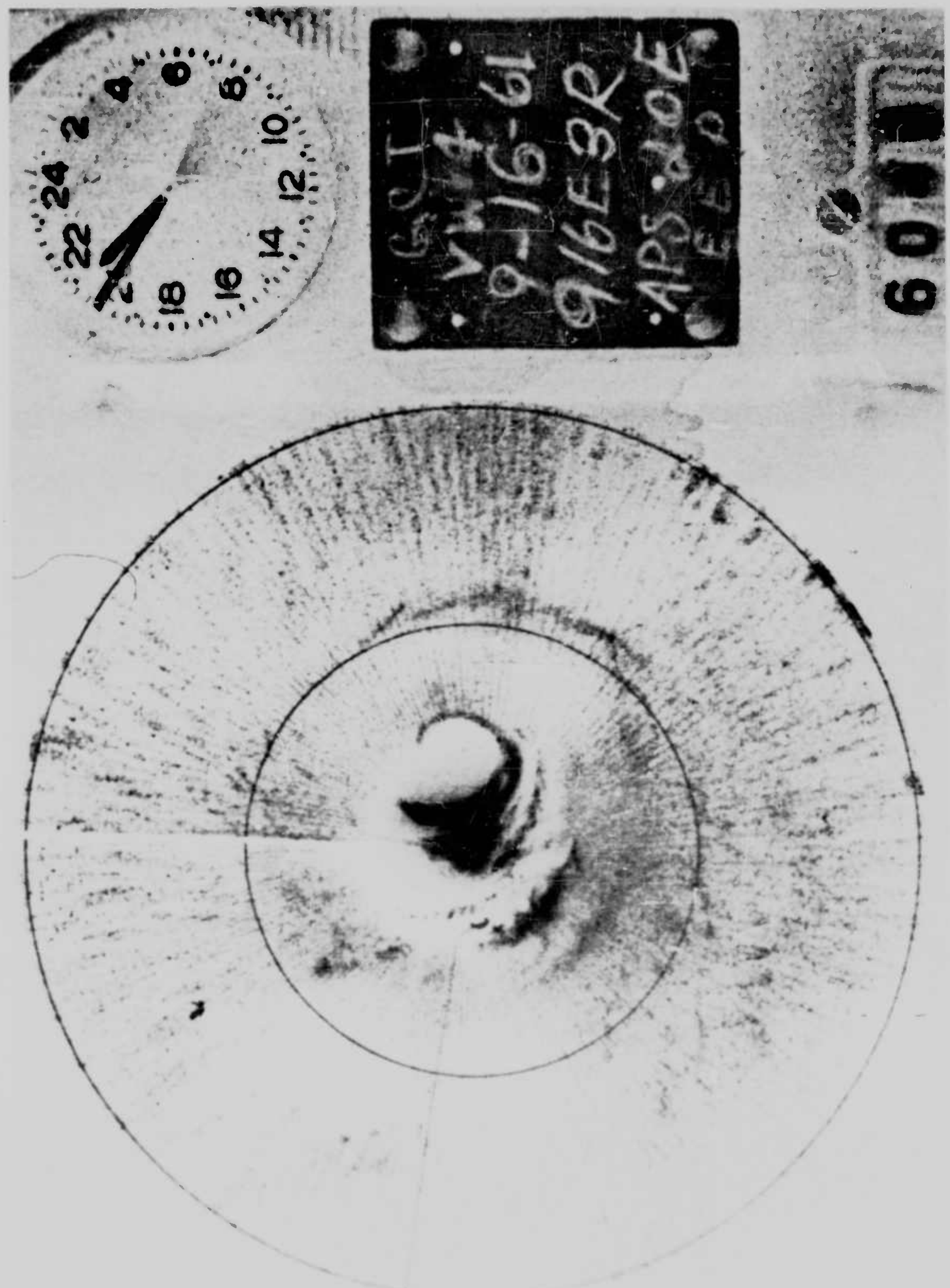

FIG. 18. Radarscope Photograph From Command Ship at T-Hour Plus 37 Minutes.

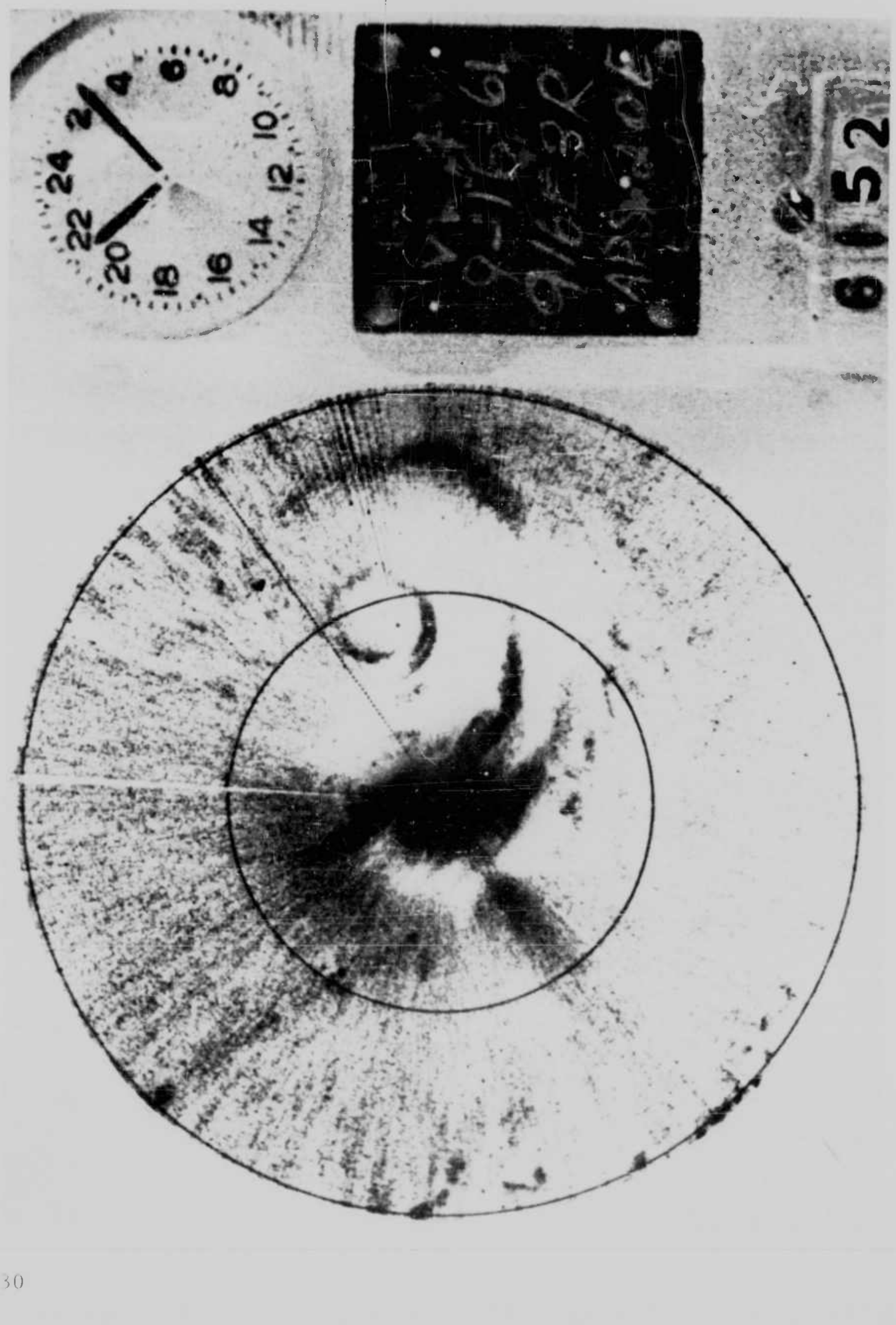

FIG. 19. Radarscope Photograph From Command Ship at T-Hour 52 Minutes.

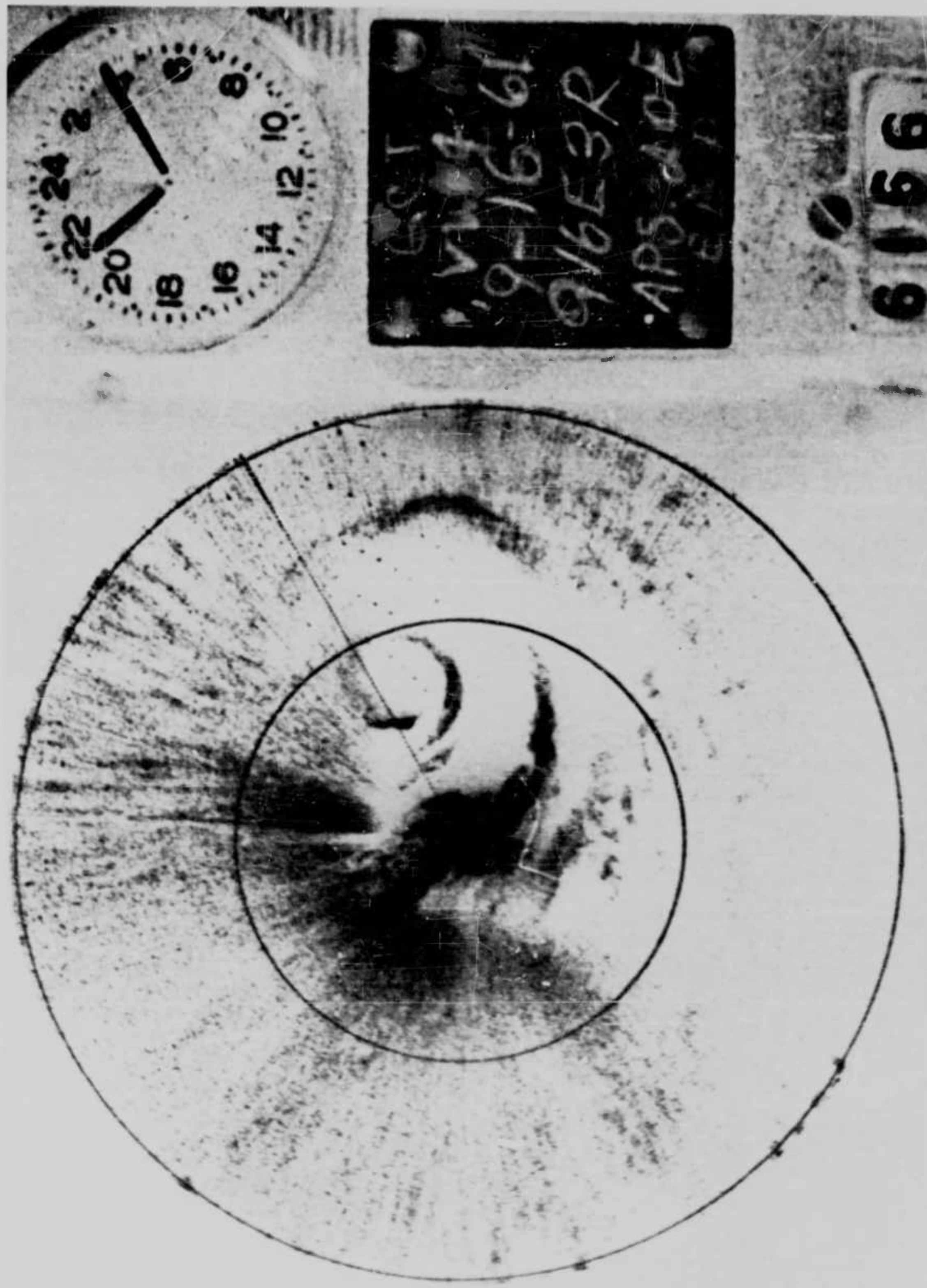

FIG. 20. Radarscope Photograph From Command Ship at T-Hour Plus 54 Minutes.

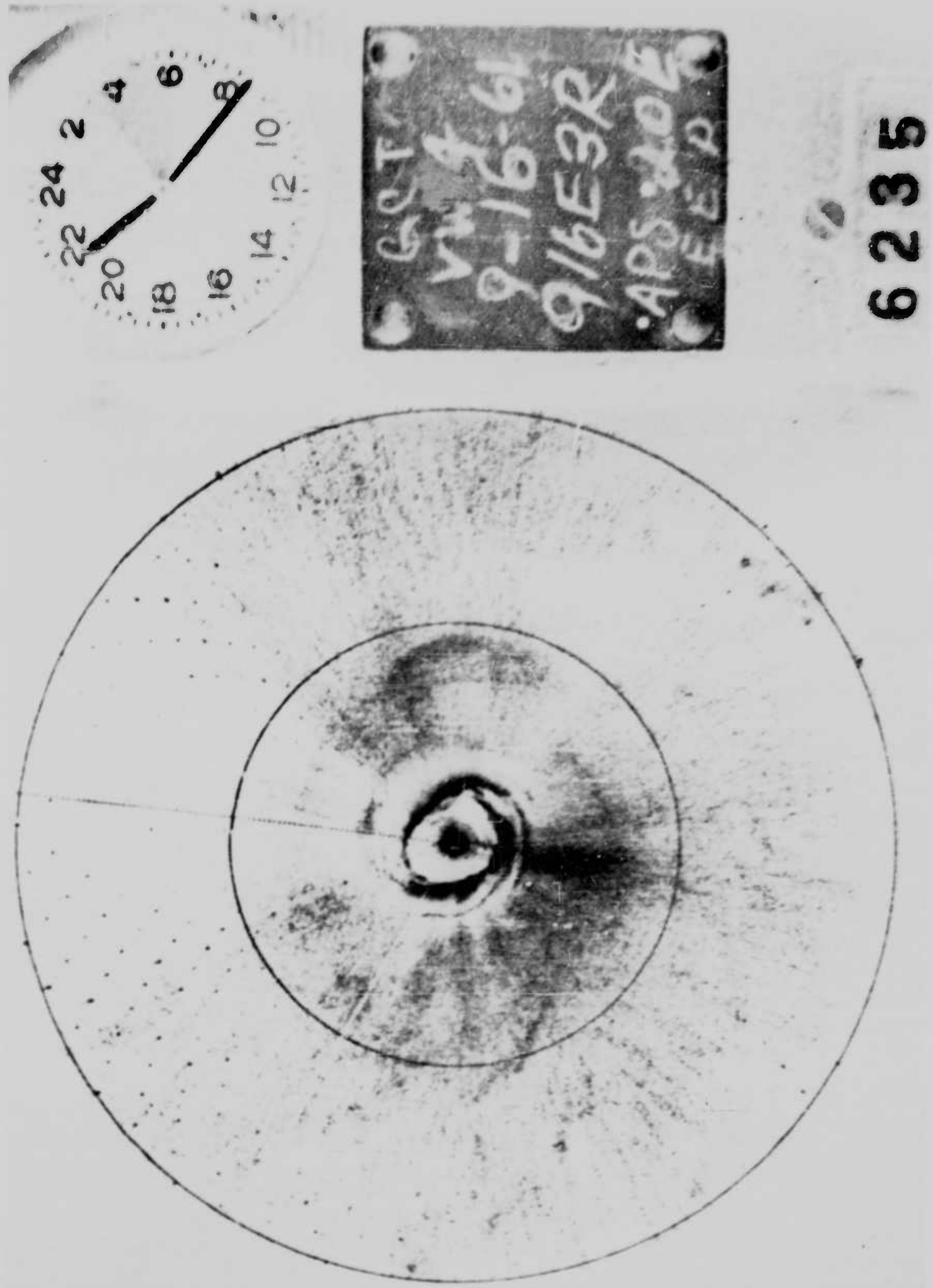

FIG. 21. Radarscope Photograph From Command Ship at T-Hour Plus 66 Minutes.

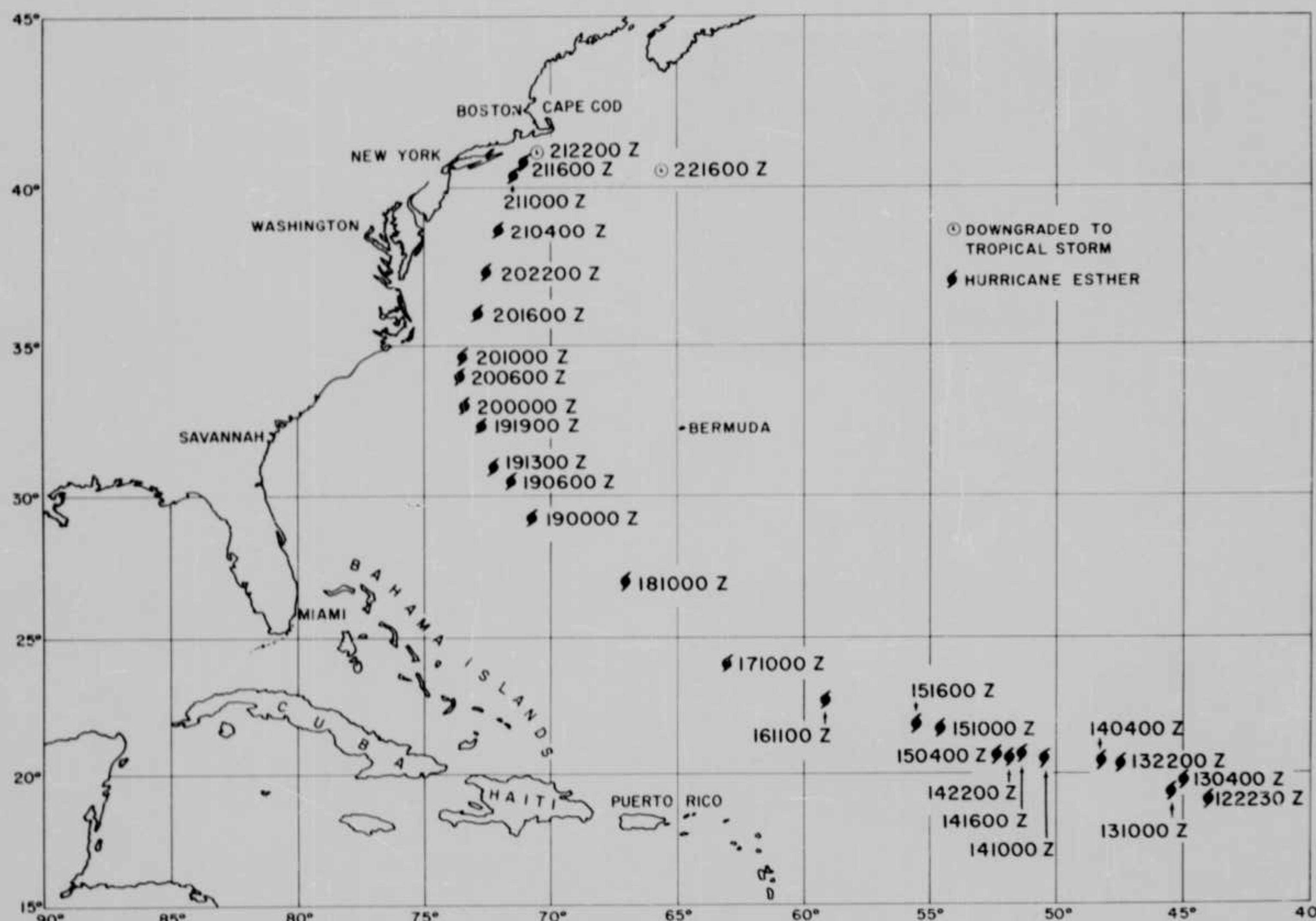

FIG. 22. The Track of Hurricane Esther as Plotted by the Navy Meteorologists at Roosevelt Roads, Puerto Rico.

FIG. 23. From Left, Lt. Frank O. Baty, USN, Dr. Wm. B. McLean, Capt. C. Blenman, Jr., USN, Dr. Lohr A. Burkardt, Dr. W. G. Finnegan, and Cdr. W. R. Eason, USN, Discuss Plans for the 1962 Hurricane Season.

ABSTRACT CARD

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ABSTRACT. Cloud seeding has been tried for some years, but with negligible results. In 1961, NOTS scientists and engineers developed a new method of generating silver iodide nuclei and a new means of dissemination. The new device, Cyclops, was used

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