UNCLASSIFIED

AD NUMBER

AD508384

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution: Further dissemination only as directed by Office of Naval Research, Washington, DC 20360, 20 FEB 1979, or higher DoD authority.

AUTHORITY

NRL Code/5309 memo dtd 20 Feb 1997

THIS PAGE IS UNCLASSIFIED

949767

[redacted]

[redacted]

SECRET

NRL Report 7044

Copy No. 21

LIBRARY
TECHNICAL REPORT SECTION
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA 93940

Over-the-Horizon Detection of Multiple Aircraft

[Unclassified Title]

FRANK UTLEY, WILLIAM C. HEADRICK, F. E. WYMAN,
DERRILL C. ROHLFS, AND JOE F. THOMASON

Radar Techniques Branch
Radar Division

February 20, 1970

[redacted]

NAVAL RESEARCH LABORATORY
Washington, D.C.

DOWNGRADED
APPROVED FOR PUBLIC RELEASE

SECRET

Downgraded at 12 year intervals;
Not automatically declassified.

In addition to security requirements which apply to this document and must be met, it may be further distributed by the holder *only* with specific prior approval of the Director, Naval Research Laboratory, Washington, D.C. 20390

[redacted]

SECRET

SECURITY

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Sections 793 and 794. The transmission or revelation of its contents in any manner to an unauthorized person is prohibited by law.

SECRET

[redacted]

~~SECRET~~

[redacted]

NRL Report 7044
Copy No.

The Over-the-Horizon Detection of the Large-Scale Strategic Air Command Penetration Exercise (Snow Time 69-1-E) of 10 October 1968

[Secret Title]

Over-the-Horizon Detection of Multiple Aircraft

[Unclassified Title]

FRANK UTLEY, WILLIAM C. HEADRICK, F. E. WYMAN,
DERRILL C. ROHLFS, AND JOE F. THOMASON

Radar Techniques Branch
Radar Division

February 20, 1970

NAVAL RESEARCH LABORATORY
Washington, D.C.

~~SECRET~~

[redacted]

[redacted]

CONTENTS

Abstract iv
Problem Status iv
Authorization iv

INTRODUCTION 1

BACKGROUND 1

- Radar System 1
- Prior Detection Results 3

OBSERVATIONAL PLAN 4

- Density Assessment of the Predicted Positions 4
- Illumination Requirement 6
- Illumination Achieved 7

TARGET DATA ANALYSIS 9

- Range-vs-Time Tracks 9
- Doppler-vs-Range Displays 12
- Procedures to Obtain Temporal Results 14
- Comparisons of Results With Postexercise Position Reports 14
- Doppler-vs-Time Processing 20
- Doppler Errors 22

REAL-TIME TRACK DEVELOPMENT USING A DIGITAL COMPUTER 23

FUTURE WORK 23

CONCLUSIONS 24

REFERENCES 24

[redacted]

ABSTRACT
(Secret)

The Naval Research Laboratory OTH radar at NRL's Chesapeake Bay Division has been used to observe a large-scale simulated air attack on the east coast of the United States. Fifty-three aircraft, including B-52's and B-58's, were deployed at various altitudes and along continuously changing penetration corridors to accomplish to coastal thrust. The OTH radar was programmed to illuminate a selected area along the inbound routes, to permit the acquisition of the largest number of aircraft echoes over the term of the exercise. Multiple real-time detections were accomplished. Subsequent analysis has permitted track identification with postexercise reported positions of 19 out of a possible 21 sorties. Definitive sorting has been accomplished with high resolution in velocity coupled with the doppler-time format of processing. Evasive maneuvers are particularly noticeable in the radar records. Such target behavior confirms sortie recognition. Analysis is continuing for aircraft detections that have as yet not been identified as a range-time track nor correlated with a particular sortie. Certain discrepancies between radar data and reported positions or maneuvers are being investigated.

PROBLEM STATUS

This is an interim report on a continuing NRL Problem.

AUTHORIZATION

NRL Problem R02-23
Project RF05-151-402-4007

Manuscript submitted December 30, 1969.

[redacted]

[redacted]

THE OVER-THE-HORIZON DETECTION OF THE LARGE-SCALE STRATEGIC AIR COMMAND PENETRATION EXERCISE (SNOW TIME 69-1-E) OF 10 OCTOBER 1968
(Secret Title)

INTRODUCTION

(S) Since the addition of a high-power amplifier (4.6 MW) and a high-gain (up to 27 dB) phased array antenna to NRL's OTH complex at the Chesapeake Bay Division (CBD), notable successes have been enjoyed in the detection and tracking of civil and military aircraft in the air corridors over the North Atlantic Ocean. This capability has been brought to the attention of SAC, in a definitive fashion, over the past couple of years, as to its influence on SAC vulnerability. During consultations at SAC Headquarters, Omaha, in June 1968, NRL and SAC personnel agreed that a worthwhile experiment would be to have NRL observe a SAC penetration exercise. Such exercises are conducted several times a year over various land-ocean and land-land boundaries. The timing was excellent to plan for an observation in October 1968. Fruitful discussions were carried out in September 1968 at NRL concerning the characteristics of the attacking force as to rendezvous area and time, flight performance, and expected spatial densities. Optimum radar system deployment was also decided upon.

(S) Arrangements were made for certain personnel of SAC to be in attendance at CBD during the exercise observation. Several SAC personnel did in fact view the real-time detections discussed in this report.

BACKGROUND

Radar System

(S) The NRL OTH radar is an experimental pulse doppler coherent MTI (moving target indicator) system which operates on frequencies in the HF band (10 to 27 MHz) and depends on ionospheric refraction of transmitted energy for the illumination of targets at remote non-line-of-sight ranges. Stationary targets (such as the earth and the sea mass) as well as moving targets scatter some of the incident energy back to the radar site via ionospheric layers. The energies returned are approximately proportional to the target area illuminated; the earth returns a large signal back to the radar receiver, and an aircraft returns a much smaller amount of energy. That the earth echo is large and the aircraft return quite small normally prevents their separation and identification on the basis of received signal amplitude. Rather, the earth return is discriminated against in the form of rejection filters for nonmoving echoes. The aircraft detection is then enhanced in a narrow-band, high-resolution velocity processor. As system dynamic range becomes greater than the earth/aircraft echo disparity, both signals can then be processed together without preliminary rejection of the earth (clutter) signal.

(S) The signal processor display formats consist of doppler vs range, range-gated doppler vs time, and amplitude vs time for selected doppler frequencies and amplitude vs doppler for a specified time. The analysis subsystem possesses flexibilities in the duration of signal storage and associated compatible analysis filter bandwidths.

[redacted]

[redacted]

(S) The development of range-vs-time tracks is at present a manual takeoff and plot technique. All the range-time data displayed in this report were prepared manually. This data preparation, however, is quite amenable to automatic (digital computer) reduction, updating, and continuous plotting. Mention will be made later concerning first efforts to have a CDC 3800 digital machine sort out the SAC exercise data points on the basis of self-consistent range and velocity criteria and plot the data as identifiable range-time tracks.

(S) Figure 1 shows the OTH facility at CBD. The large antenna near the edge of the cliff overlooking the Chesapeake Bay is the one used for North Atlantic surveillance. It is 330 feet long by 140 feet high. The frequency is 13 to 27 MHz, and the gain is 19 to 27 dB depending on frequency. The active elements consist of two rows of ten colinear dipoles, one over the other, with each row in a corner reflector. The rows may be energized singly or together in phase and out of phase. This permits a degree of vertical beam steering. Horizontally, the antenna is boresighted on 77°T, and with the use of time delay techniques the main beam can be steered over ±30 degrees from 77°T.

(S) The building behind the antenna houses the high-power amplifier (4.6 MW), the duplexer, and the receiving, processing, and display equipment. The other antenna, on

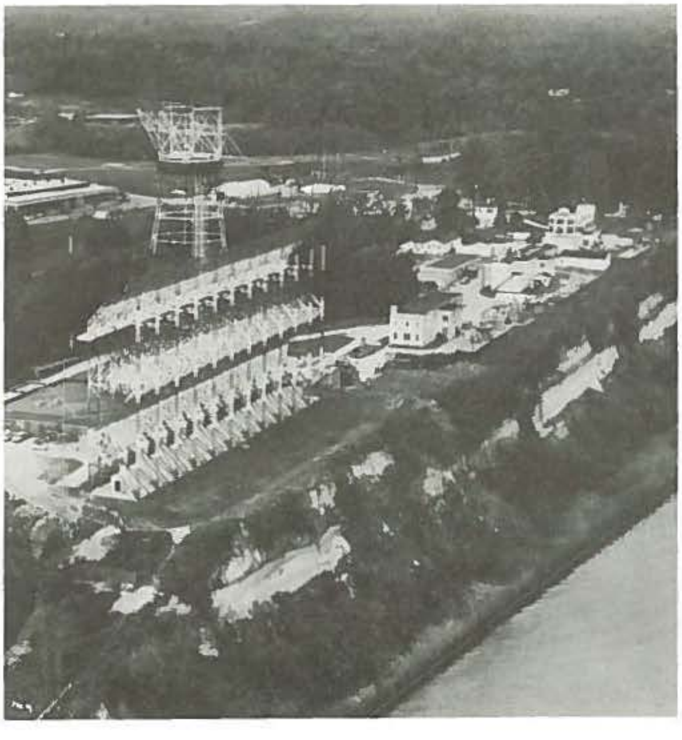


Fig. 1 - OTH facility at NRL's Chesapeake Bay Division. The building at the base and rear of the large array houses transmitter and receiving equipments.

[redacted]

the tower, consists of two colinear dipoles in a corner reflector on a rotatable pedestal (trunion). This antenna is used to monitor missile launch activity at the Air Force Eastern Test Range (AFETR), Air Force Western Test Range (AFWTR), and the White Sands Missile Range (WSMR).

Prior Detection Results

(S) Some past findings with the NRL OTH radar have a definite relationship to mass raid detection. In the following review two salient findings to be mentioned are that individual aircraft can be identified and that more than one aircraft can be detected and tracked simultaneously in the same field of view.

(S) In recent years NRL had several opportunities to view the crossing of the North Atlantic by U.S. Marine Corps fighter aircraft (F-8) groups. These aircraft were sustained in their long journey by three regular in-flight refuelings. These aircraft flew in groups of four in a rather loose formation. When scrutinizing these target echoes, all from the same range, it was noted when using the highest velocity resolution available that the individual aircraft returns could at times be singularly identified. This permitted counting the aircraft in the group. Making this possible is the random fluctuation in each aircraft's individual velocity. For velocity resolutions of 2 to 3 knots and 1% to 2% variations in aircraft velocity at 400 knots the individual spectral components become readily apparent. These results have been reported in Ref. 1.

(S) Intense surveillance was exercised over radar returns from the areas in which refueling activity would take place. KC-135 tankers were programmed to orbit the aircraft refueling points and to be in position to transfer fuel to the F-8's when they entered the area. Velocity (doppler)-vs-time processing yielded an excellent detection result in that the whole refueling operation is presented in a panorama of velocity-time tracks that can be associated with the tanker aircraft as well as the fighters. In the radar display two distinct velocity lines are seen to merge at the time of drogue hookup and are seen to separate as the fighter breaks off from the KC-135 and comes to an in-flight altitude and velocity. Thus doppler-time processing is a powerful tool in the identification of individual aircraft in an environment of peculiar speed change. This work is to be reported in a future NRL Report.

(S) Another extremely interesting experimental result in the long-range detection and tracking of aircraft is reported in Ref. 2. In this instance a P3A flown by Navy fliers out of Norfolk, Virginia, was tracked almost from his departure pattern at Lajes Air Force Base in the Azores Islands (range approximately 2200 naut mi) to a point inside of 900 naut mi from the radar, the total track exceeding 1200 naut mi. The most conspicuous feature of the flight was the sustained real-time detection of the aircraft for 350 naut mi, while it maintained a flight altitude of 100 feet. This was a cooperative flight, in that prior arrangement was made for the 100-foot altitude segment of the flight. Radio contact with the aircraft was available throughout the flight.

(S) For a part of the time while the P3A was at 100 feet altitude another aircraft of comparable performance was detected at similar ranges. It was tracked simultaneously with the cooperative P3A for 45 minutes. By reason of the velocity characteristic the second aircraft was determined to be a propeller type and probably to be at an altitude of from 15,000 to 20,000 feet. Further position information has not been forthcoming on the second aircraft. Thus it is confirmed that aircraft targets in the same field of view at dissimilar altitudes can be detected and tracked simultaneously.

(S) Even though altitude discrimination is not possible at present, NRL is endeavoring to find a correlation between an aircraft's flight altitude and its signal fading pattern. Future work is indicated.

OBSERVATIONAL PLAN

Density Assessment of the Predicted Positions

(S) In the consultations of September 1968, prior to the penetration exercise, representatives of SAC furnished NRL with maps of the sortie positions predicted for each 15-minute interval during the test. Such position readouts are called time slices. Figures 2 and 3 are the time slices for 0800 and 0815 hours GMT. The number associated with each aircraft silhouette is its sortie designation. The standard wing silhouette represents the B-52 aircraft, and the delta wing indicates the B-58 aircraft. The aircraft headings, shown by the silhouettes, were to be changed often during the penetration run. Those aircraft whose sortie number is underlined were at some time during the exercise to fly below 2000 feet.

(S) The SAC aircraft were to be deployed from rendezvous points over Northern Canada, over the North Atlantic Ocean, and near Bermuda. Only the North Atlantic grouping is in the sensitive region of phased-array illumination. Aircraft position time slices were provided every 15 minutes from 0630 to 0930 hours GMT. The coastal penetration is essentially complete by 0915 GMT. The nearest slant range (skip distance) of radar coverage anticipated was approximately 400 naut mi. All attacking aircraft would penetrate the minimum range of detection before 0900 GMT.

(S) The heavy solid lines originating on the western bank of Chesapeake Bay and extending northward past Long Island and Nova Scotia and eastward over the ocean indicate the boundaries of illumination for operation on the phased array antenna. The northern boundary is along a line of 47°T from the radar at CBD, and the boundary running eastward is 107°T from the radar. Only a fractional part of the total angle indicated can be observed at a given time, and this depends on the operating frequency (which sets the horizontal beamwidth) and on the beam steer angle.

(S) It was determined that the radar beam should be steered to a given azimuth and left there throughout the exercise. It was anticipated that a low radar frequency (below 15 MHz) would be used to achieve the desired coverage during the night of the exercise. The antenna 3-dB beamwidth expected was approximately 14 degrees. The positions in angle predicted for each sortie for each timeslice were grouped in 14-degree beamwidths for bearings 7 degrees apart. The resulting density of sorties as a function of antenna bearings would then dictate the most desirable approximate radar beam azimuth. The angle samplings and the subsequent groupings are summarized in Table 1.

(S) From Table 1 it can be seen that the antenna should be steered to an angle in the neighborhood of 60°T. Actually it was planned to radiate on an azimuth of 55° to insure illumination of North Atlantic civil aircraft for a target reference in addition to the maneuvering SAC force. It can be seen that the number of simultaneous targets expected in the radar readout would be above ten from 0745 to 0830 GMT for the azimuth bearing of 55°T. These would appear at diverse ranges and velocities and should submit to singular identification.

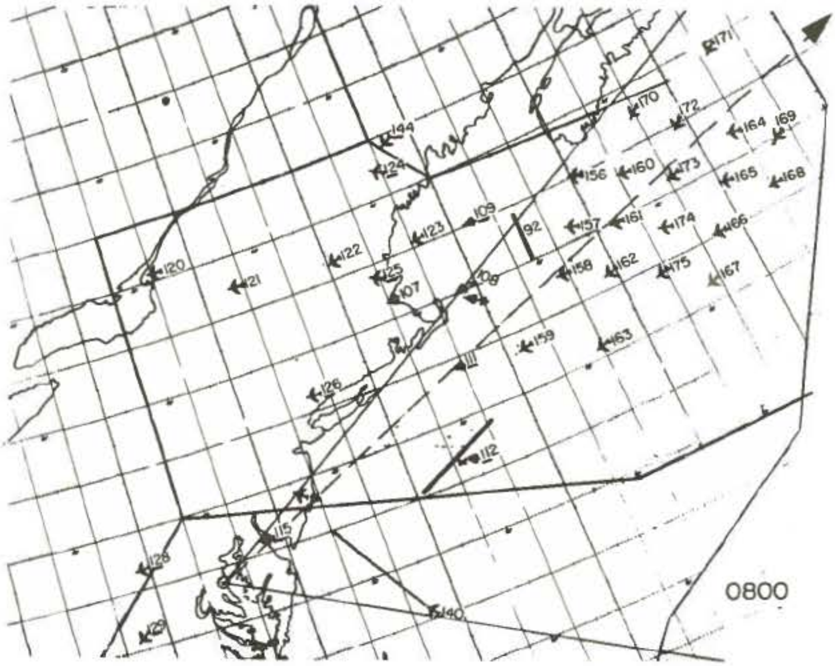


Fig. 2 - Anticipated Strategic Air Command aircraft positions for Snow Time 69-1-E penetration exercise for 0800 GMT

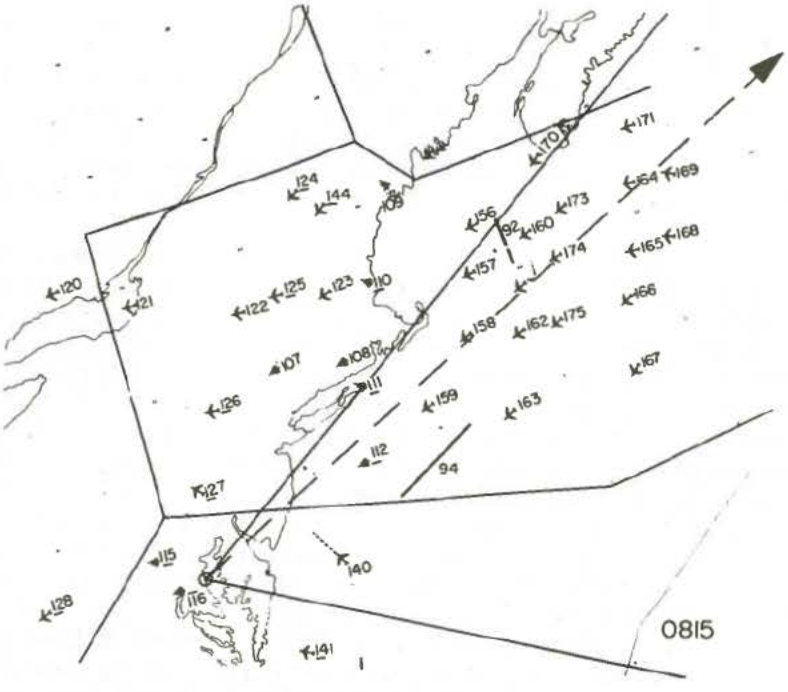


Fig. 3 - Anticipated Strategic Air Command aircraft positions for Snow Time 69-1-E penetration exercise for 0815 GMT

[redacted]

Table 1
Expected Target Appearances in 14-Degree Beamwidths With Beam-Center Bearings Spaced 7 Degrees Apart Versus Sample Times During the Snow Time Exercise (U)

Antenna Bearing (°T)	Appearances at the Different GMT Time Slices												Total Appearances
	0630	0645	0700	0715	0730	0745	0800	0815	0830	0845	0900	0915	
55	2	2	1	4	6	14	17	14	12	5	2	0	79
62	2	2	3	5	14	16	16	12	5	3	1	0	79
69	1	2	5	8	17	10	5	3	3	2	1	0	57
76	2	2	3	5	7	4	1	2	2	1	0	0	29
83	2	2	4	1	2	1	0	0	0	0	0	0	12
90	0	0	3	0	0	0	0	1	0	0	0	0	4

Illumination Requirement

(S) Early conversation with SAC personnel indicated that the aircraft would begin their penetration run from rendezvous points no more distant from CBD than 900 to 1000 naut mi. The test would be carried out during local nighttime hours, which would push radar operation to lower frequencies for the illumination of a fixed point in range, say 1000 naut mi. This is because the refractive behavior of the ionosphere depends on electron density, which in turn depends on sunlight illumination of the layer. The phased array, the most directive of the two existing antennas, cannot be operated below 13 MHz. It was expected that the normal ionospheric layer would not permit the needed propagation on 13 MHz during the early morning hours. It was determined to run a prediction for coverage based on 13 MHz operation for the necessary times of day. As anticipated the prediction showed no promise of the proper coverage via regular ionospheric layer activity. The only recourse was to hope for sporadic E layer support, which in itself is not easily predictable.

(S) The predicted coverage is shown in Fig. 4, which is a plot of those regions in slant range where an aircraft target detection might be achieved for hours of the day encompassing the expected "attack." The depth of coverage can be easily discerned. Normally F layer activity would give coverage from approximately 1500 to 2200 naut mi at 0400 GMT and from about 1880 to 2220 naut mi at 0730 GMT. The sharp transition at 0900 GMT is consistent with sunrise on the ionospheric layer being used. The effect of the sun's ionizing radiation on the layer is noted on the rapidly decreasing range between 0900 and 1000 GMT. Electron densities are greatly stimulated by solar radiation. The increase in electron density enhances the refractive behavior of the layer. The lower region in Fig. 4 is the range coverage expected if refraction were available from a sporadic E layer (100 to 110 km height). The approximate longest range that could be covered is 1260 naut mi. This is as far as a tangent ray departing the earth at the radar site might be refracted from a 100-km active layer. The nearest sensitive range expected is seen to vary from 700 naut mi at 0400 GMT to just inside 500 naut mi at 1000 GMT. From the indication in Fig. 4 of the approximate maximum slant range of SAC aircraft deployment of 1000 naut mi, it can be seen that if a sporadic layer were available as predicted, detection would be possible over a 400-naut-mi-deep range segment for times of maximum aircraft activity, say from 0700 to 0830 GMT.

[redacted]

[redacted]

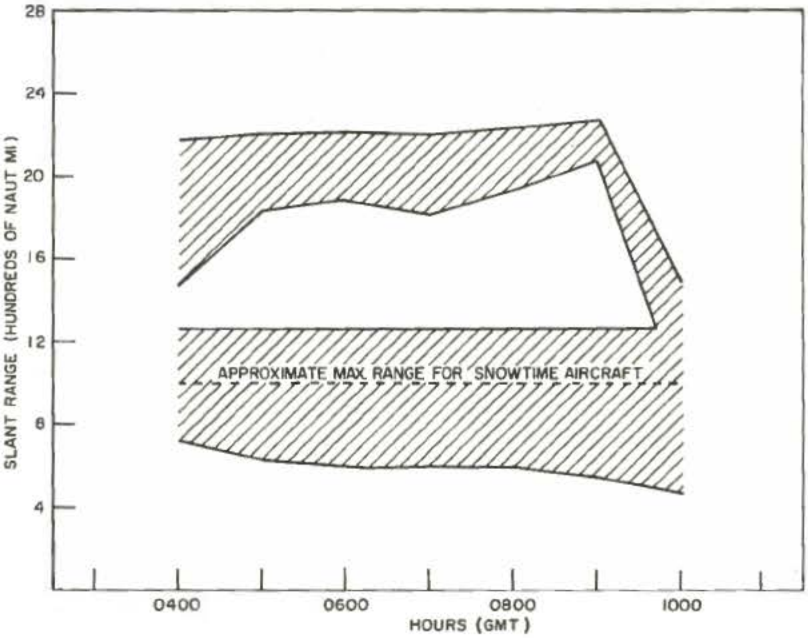


Fig. 4 - Predicted backscatter coverage for October 1968 for an antenna bearing of 55°T and an operating frequency of 13 MHz

Illumination Achieved

(S) In an effort to assess the actual propagation to be expected on a 13-MHz frequency during the predawn hours NRL researchers performed a dry run on October 8, 1968, from 0620 to 0825 GMT. The results of the backscatter soundings taken are plotted as coverage data (hatched) in Fig. 5. At the onset of the backscatter soundings it can be seen that the normal F-layer coverage and the sporadic E-layer coverage merge at 1200 naut mi. The F-layer coverage is 700 naut mi deep at 0620 GMT but continues to shrink in depth until it is only 250 naut mi deep (beginning at 2080 naut mi) at the time the soundings were terminated. The sporadic illumination evidences earth returns over approximately 200 naut mi until the path failed shortly before 0700 GMT. The sporadic layer support by virtue of its name exhibits rather unpredictable behavior.

(S) Figure 6 is a backscatter coverage plot for October 10, 1968, the actual occasion of the Snow Time exercise. It is to be noted in this instance that the sporadic layer behaved rather fortuitously and yielded illumination for several hours in the region desired. For the crucial times of 0600 to 0820 GMT the radar was sensitive to targets in the radiated beamwidth at ranges from approximately 400 naut mi out to 1000 naut mi. It can be seen that the coverage due to the two layers merged for quite a while. For a short time continuous coverage was available from 500 naut mi to 2000 naut mi. More than adequate coverage would be guaranteed if lower frequency (down to 7 MHz) operation were possible. Sporadic layers would likely not be necessary then.

[redacted] [redacted]

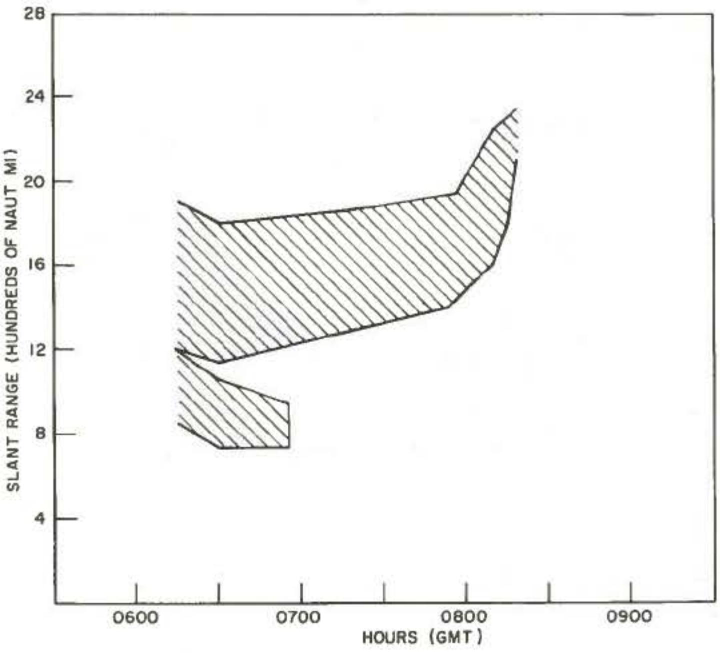


Fig. 5 - Measured backscatter coverage for October 8, 1968, for operation at a bearing of 55°T on 13 MHz nominal

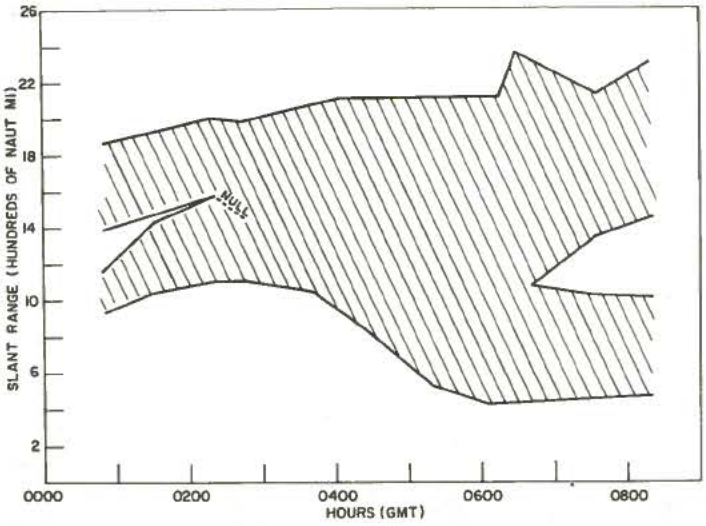


Fig. 6 - Measured backscatter coverage for October 10, 1968, for operation at a bearing of 55°T on 13.575 MHz

[redacted]

(S) the operational parameters for October 10, 1968, were as follows:

Transmitter power,	2.0 Mw peak radiated;
Pulse width,	670 μsec ($\cos^2$ shape)
Pulse repetition frequency,	60 pps, max. unambiguous range 1350 naut mi, max. unambiguous velocity 664 knots, 90 pps, max. unambiguous range 900 naut mi, max. unambiguous velocity 995 knots;
Frequency,	13.575 MHz;
Antenna,	Phased array, 55°T azimuth, both rows in phase; two-way azimuthal beamwidth, ±10 degrees at -6-dB points;
Range resolution,	20 naut mi;
Range accuracy,	±5 naut mi;
Velocity resolution,	±1 knot;
Velocity accuracy,	±2 knots.

TARGET DATA ANALYSIS

Range-vs-Time Tracks

(S) The NRL OTH radar signal processor does not as yet have the software necessary for the real-time reduction of range-velocity data points into smoothed range-time tracks. Work, however, is moving forward in the direction of implementing such a capability. Meanwhile, preliminary analysis has been completed with the manual reduction of more than half of nearly 800 range-velocity data points into approximately 40 self-consistent range-time tracks. Some of these are for outbound aircraft and some for inbound targets. Many of the original range-velocity data points have not as yet proven to be identifiable range-time tracks. Work is continuing on this facet of the problem.

(S) The radar target tracks were generated manually prior to the receipt of aircraft position data from SAC. The known position data have been machine-converted into slant-range-vs-time tracks and compared with tracks originally composed from the radar data. Many matched very well. The digital computer program also orders the computation of radial velocity for each position point. This velocity information supplies confirmation for any track identities that may be in question on the basis of slant range. This comparison in velocity and slant range has been made manually. Correlation between reported positions and radar-developed tracks appears to be excellent in most cases. Slant range determination has been based on a 100-km layer height for the sporadic-E activity. In some instances there is indeed a difference between the reported aircraft behavior and the radar data. This may be due to an error in computation or an error in position report interpretation.

[redacted]

[redacted]

(S) Figure 7 is a range-time plot showing four outbound aircraft tracks. The actual identity of any of these aircraft is at present unknown except for the long track at the greatest slant range. It has been tentatively identified as Austrian Airlines flight OOSJE flying from Montreal to Brussels. Without other position information a best-fit straight line has been drawn through the radar data points. The average deviation of the data points from the straight line is less than 4 naut mi. The three nearer tracks may be due to SAC aircraft outbound to their rendezvous points. Position information already furnished from SAC consisted only of inbound aircraft position reports. A request has been made to SAC for the high-altitude IFR clearance position records for all outbound flights. When this becomes available, these three, as well as other outbound traffic, may be identified. Records from the North Atlantic Air Traffic Control Center at Gander, Newfoundland, are being studied to identify some of the outbound tracks as Europe-bound civil flights.

(S) Figure 8 is a range-time track for outbound target tracks developed in the analysis of radar data. There are 28 tracks in the figure, of which 22 or 23 are believed to be completely independent tracks. These are the tracks that will be matched with the forthcoming SAC data on outbound positions. It is conjectured that many of these will match quite well with the outbound wave of SAC aircraft.

(S) Figure 9 is a plot similar in range-time coordinates to Fig. 8 and differing only in that it shows inbound tracks forthcoming from the radar data. Of the 24 tracks shown, 19 are believed to be independent. It is interesting to compare Fig. 8 with Fig. 9 as to the disposition of the tracks for outbound vs inbound traffic as to their distribution in the range-time space. The outbound tracks appear to be loosely scattered, whereas the inbound are much more concentrated over a narrower range extent for a shorter period of time. This latter characteristic seems consistent with "raid" activity.

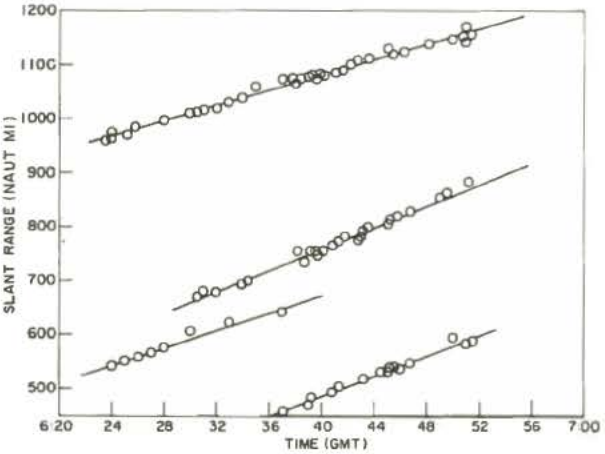
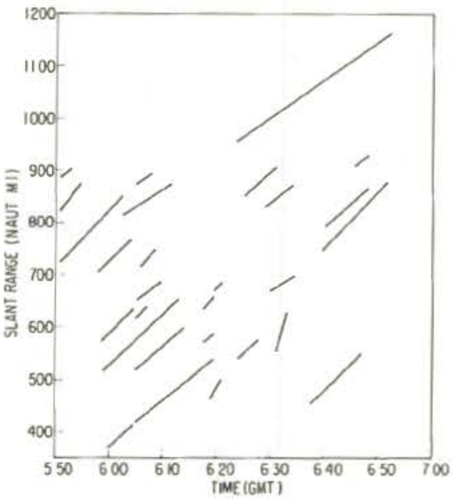


Fig. 7 - Outbound range-time tracks for four selected aircraft

[redacted]

Fig. 8 - Outbound range-time tracks for all outbound aircraft detected



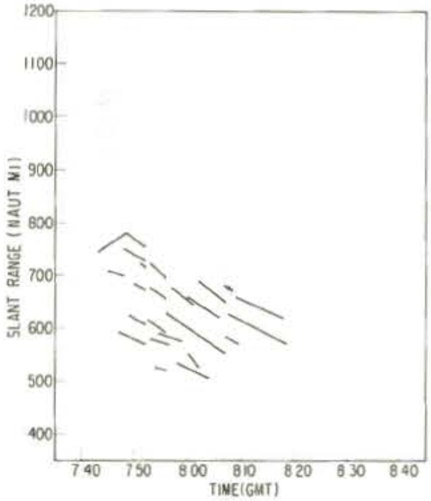


Fig. 9 - Inbound range-time tracks for all inbound aircraft detected

(S) One aircraft is seen to have turned around shortly before 0750 GMT at a slant range just less than 800 naut mi. This track is likely one of the SAC aircraft and might be either Sortie 169 or 171. Neither has been positively identified as yet for this early time. Both Sortie 169 and Sortie 171 were detected 15 minutes later.

(S) Some of the tracks are somewhat brief in time. The reasons for this are (a) the aircraft was in the radar beam only a short time, (b) a weak aircraft echo was not perceived in presence of other returns of greater strength, and (c) a particular aircraft echo was not reacquired immediately (due to signal fading) after a turning maneuver, which would give the target a different doppler frequency. An analysis to assess a reason for the brevity or lack of brevity of each individual track length will be accomplished in the near future. It was impractical to attempt such a complete analysis for this preliminary reporting.

[redacted]

(S) For the time frame shown in Fig. 9 no target tracks were developed beyond 800 naut mi, and none continued inside 500 naut mi. It is believed that no other SAC aircraft were beyond 800 naut mi at this time. It is known that a few aircraft were inside 500 naut mi. A few data points were recorded for those targets but as yet have not been assembled into substantial tracks. Concurrent auroral and meteor echoes made positive identification for the nearer targets more difficult. The auroral echo presence could have been relieved by operating the radar at a lower pulse repetition frequency. The prf used resulted in ambiguous ranges for the auroral returns. Such a change in parameters was not deemed necessary due to the high density of other targets displaced in range from the auroral returns.

Doppler-vs-Range Displays

(S) Figure 10 is a reproduction of the doppler-range display for the time 07:54:27 GMT. To the left is an actual radar display picture with a target under a doppler strobe of 15.5 Hz and a range strobe of 740 naut mi. Other targets are in view. The redrawn figure to the right in conjunction with the target table permits identification of the individual target elements. Item 1 is a spectral component due to 60-Hz spurious signal, which is a result of primary power hum being introduced through the transmitter and receiving equipments. Items 2 through 7 have been identified to be the SAC sortie numbers indicated. Items 8 and 9 are rather descriptive of undesired natural signals. Meteor echoes are nearly always present in the radar output, sometimes in large numbers, other times at a meager rate. The auroral echo is a signal which might persist at any or all doppler frequencies (depending on the intensity of auroral activity) and over a few hundred miles depth at a range of 1000 to 1300 naut mi, the distance depending on the path length from the radar to a point where the radar field and the geomagnetic field are orthogonal at ionospheric layer heights.

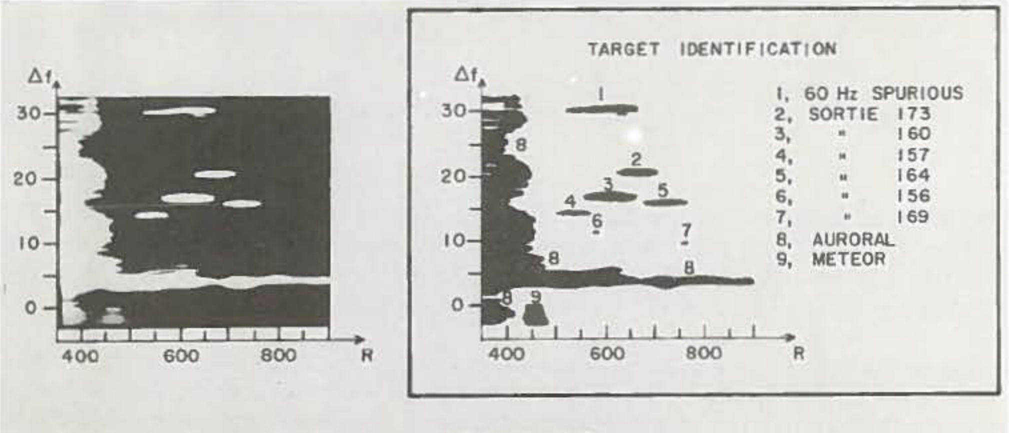


Fig. 10 - Radar doppler-range display with an associated target identification table. The ordinate Δf is the doppler frequency in hertz. The abscissa R is the slant range in nautical miles.

[redacted]

(S) Another point to mention is the varying amplitudes that the aircraft echoes exhibit. Sortie 164 (Item 5) is quite strong as compared with Sortie 169 (Item 7), which is quite weak. This is due to the incessant fading that an OTH target echo undergoes with time. In perhaps 5 to 10 seconds sorties 164 and 169 might interchange their amplitude character, the strong one becoming weak and the weak one becoming strong.

(S) Figure 11 is similar to Fig. 10 and shows radar analyzer doppler vs range with an accompanying identification table. This picture was made for a memory freeze at 07;56;30 GMT, which is about 2 minutes after the record of Fig. 10. From a comparison of the two figures several differences are obvious. Returns from Sorties 156 and 160 have completely disappeared, the return from 169 has become more intense, and a weak return from Sortie 161 not apparent in the first picture has come into view at a doppler of 20 Hz and a slant range of approximately 530 naut mi. The auroral echo also exhibits a modification in its range behavior. Mention might be made with regard to Items 8 and 9. Item 8 looks sufficiently discrete in doppler to be considered an aircraft; however to date it has not been identified with aircraft of known position histories. If the echo appeared only once in a moderately long period of time (several minutes) at similar range and doppler stations, it would be judged not an aircraft. Such could be the case with Item 8. Item 9 does not look as discrete as an aircraft signal or as wide in doppler frequency as a meteor but in fact could be either.

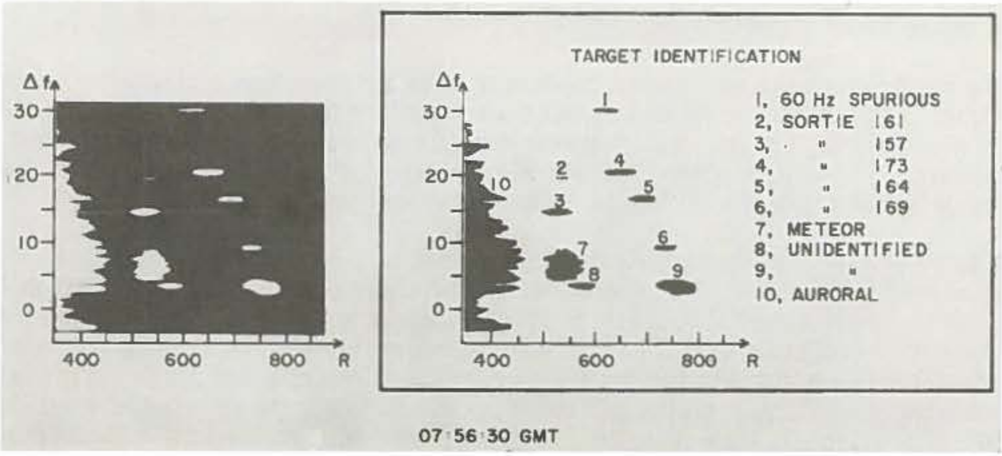


Fig. 11 - Radar doppler-range display with an associated target identification table. The ordinate Δf is the doppler frequency in hertz. The abscissa R is slant range in nautical miles.

(U) Meteoroids impinge upon the earth's atmosphere at a great rate, perhaps as many as 10^{10} per day (3). These particles enter the earth's atmosphere at velocities ranging from 10 km/sec to 70 km/sec (4). In falling through the upper regions (100 km) of the earth's atmosphere they generate, due to friction with air molecules, rather intense trails of ionization commensurate with their velocity and mass. If the radar energy impinges on the trail in the proper geometry, appreciable electromagnetic energy is reflected. This gives rise to meteor echoes in the radar output display.

(S) Often meteors present a large smear in doppler at a fixed range. The echoes normally do not last longer than a few seconds. Regardless of the duration of the meteor echo, it will always persist in the radar display for a length of time equal to the processor storage time. Sometimes the wide-band doppler smear will fade out at all doppler frequencies simultaneously, but for other meteors most of the wide band of energy will disappear, leaving a narrow-band residual which may very well look like aircraft target video and be so interpreted, if caution is not exercised.

(S) In direct contrast a turning aircraft, if under continuous and sufficiently strong illumination, can evidence a spread-doppler-type echo. This is due primarily to signal retention of the signal processor for the storage time. Longer storage times make these effects more apparent. A high-performance aircraft in a standard rate turn might well alter its radial component of velocity enough in 20 seconds to give an echo whose doppler bandwidth could well be 1.0 Hz. This would be readily discernible in the processor display.

Procedures to Obtain Temporal Results

(S) It seems extremely desirable to have a display format that would allow target doppler behavior at a given point in range to be examined coherently over a longer period of time than the normal doppler-range storage times of 5 or 10 seconds. The analysis of aircraft data points mentioned above was accomplished through the ability of freezing the memory contents in time and then recording range and velocity for the various targets. Each aggregate of stored data consisted of a 10-second sample of target echoes processed in the usual doppler-range mode.

(S) The question arises as to what the target looked like before and after a given memory time. With more information a decision might be made as to target type and as to whether maneuvering or not. The doppler-time mode of processing is introduced later in this report, and it is shown that its use renders appreciable advantage in the recognition of target types that evidence unique temporal behavior.

(S) Data were taken off by playing the digital data tape back through the 60-dB digital processor at real-time rates. The signal detections were displayed as indicated in Figs. 10 and 11. When a few targets would be presented as discernible echoes, the data memory would be locked or frozen at that time, permitting repetitive playback of the same detected targets. Each target would then be strobed in range and velocity and a record made for the given display time. After all targets were so documented, the processor would be commanded to progress in time, playing back more tape until another optimum stopping time, when additional range-velocity data points would be recorded. In the first analysis, nearly 800 data points were so recorded. The range points for all sample points have been assembled into range-time plots as seen in Figs. 7, 8, and 9.

Comparisons of Results With Postexercise Position Reports

(S) The range and velocity information has been used to identify sorties. As mentioned earlier the postexercise position reports forwarded by SAC to NRL have been used to extract actual radar parameters such as slant range from CBD and doppler in hertz corresponding to aircraft velocity. Inasmuch as the radar processor is calibrated in doppler frequency, the comparisons were made on that basis.

(S) Figures 12 through 19 make lucid the comparison technique. Each of these figures displays three parameters over the approximate time during which a given sortie was detected. The parameters are slant range, azimuth (bearing from the radar), and doppler frequency. The solid lines indicate the expected values in the three quantities as deduced from postoperation position reports. The length of the lines in time represents the anticipated in-beam time. The circles represent radar data points. Inasmuch as the radar is not capable of determining azimuthal angle, no radar data points are available for that parameter. An operational OTH system would no doubt possess a monopulse processing capability which would permit angle resolutions to within perhaps a fractional part of a degree, depending on ionospheric quietude. Such a capability would enhance target sorting and identification.

(S) Figure 12 is the comparison of reported positions for Sortie 157 with radar data. That the slant range line plotted according to position reports is not a straight line is the net effect of the several heading changes of the aircraft. There were six such changes in 36 minutes.

(S) The solid doppler line has been generated from the reported positions. When this analysis first began, the turning rates of the B-52 and B-58 aircraft were not fully appreciated. The position data indicated that a given aircraft took up a new heading as of the position report time. For this reason the doppler curve was drawn with discrete instantaneous changes in doppler. This is due to a different radial velocity that results when the aircraft changes heading. Actually the relative velocity transition does not occur over a second or two but rather over many seconds in time, perhaps as long a time interval as 100 seconds. This is due to the turning rate of the B-52 and B-58 aircraft; a 90-degree turn would require 2 minutes. Thus the transitions in doppler should be smooth, lasting finite lengths of time, commensurate with the magnitude of heading change, and not instantaneous step variations. With this in mind it should be remembered that any radar data points that fall near the ends of a step segment of predicted doppler curve and not on it, in say 30 seconds more or less before a step change and 30 seconds more or less after a step change, might in fact be very closely associated with the actual doppler frequency.

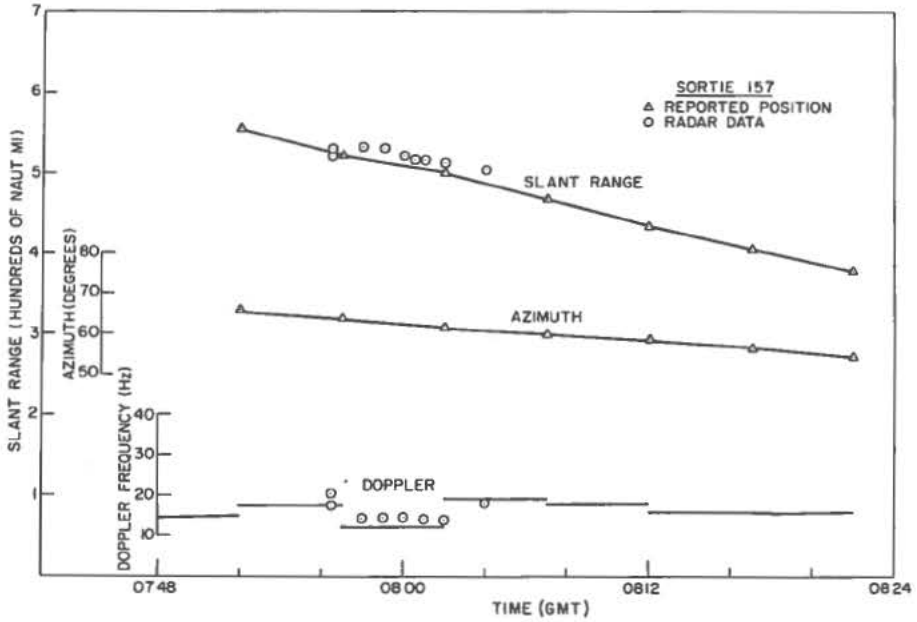


Fig. 12 - Comparison of the reported temporal behavior of Sortie 157 with radar detection data. The azimuth is from the radar.

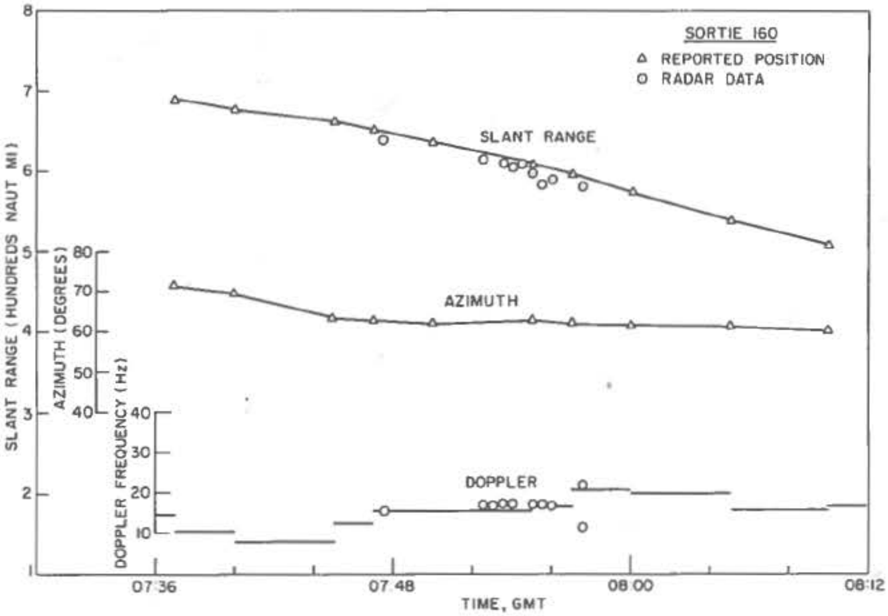


Fig. 13 - Comparison of the reported temporal behavior of Sortie 160 with radar detection data

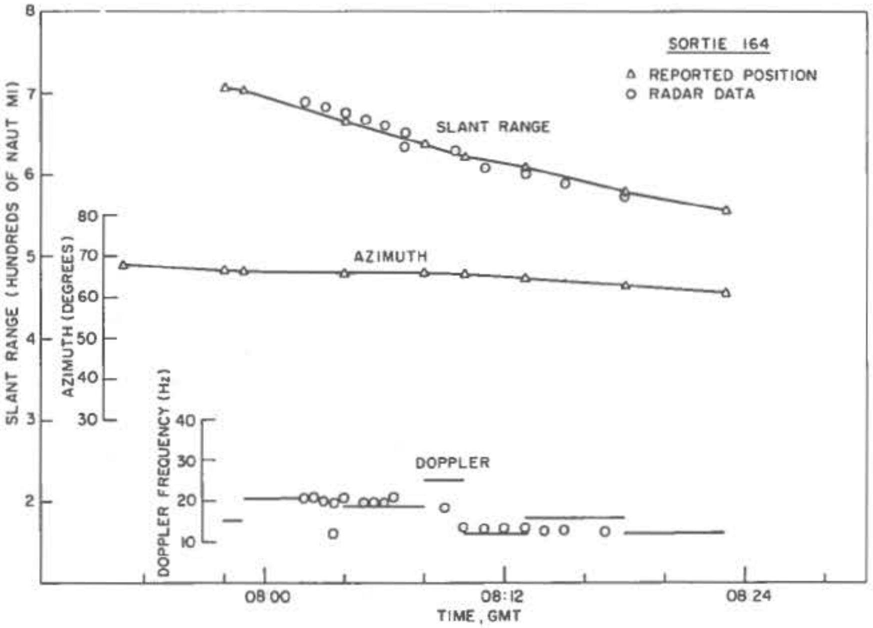


Fig. 14 - Comparison of the reported temporal behavior of Sortie 164 with radar detection data

[redacted]

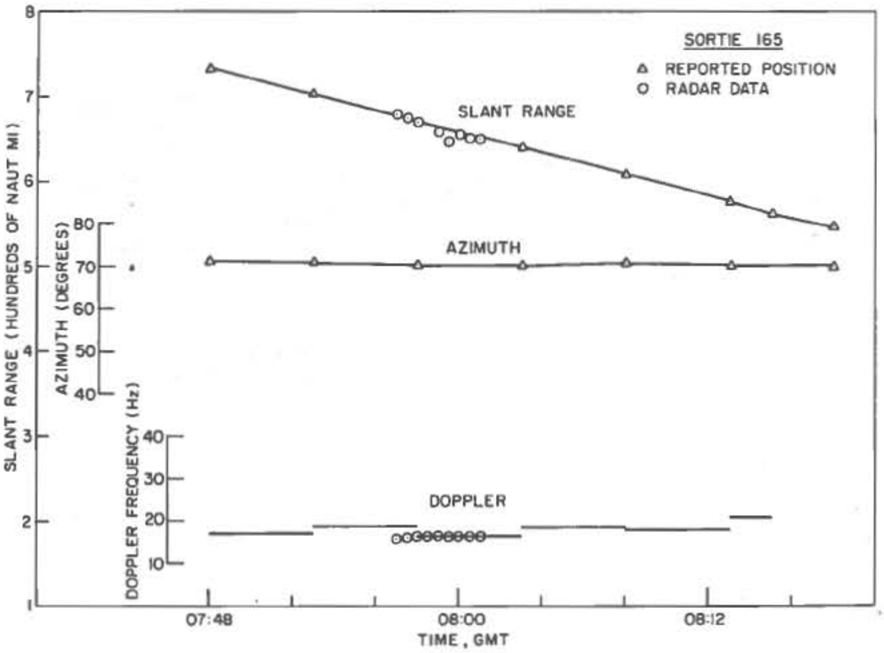


Fig. 15 - Comparison of the reported temporal behavior of Sortie 165 with radar detection data

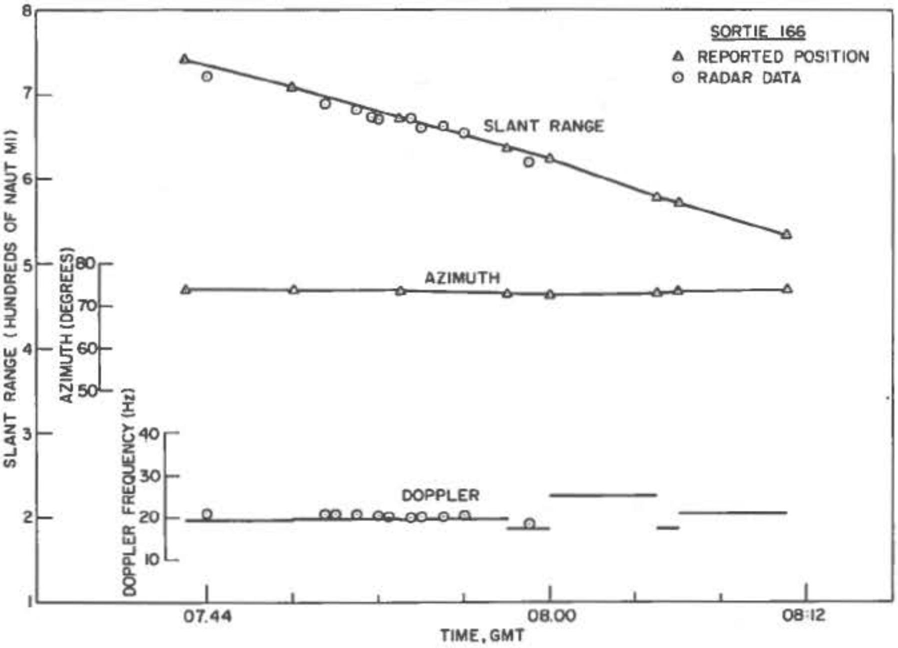


Fig. 16 - Comparison of the reported temporal behavior of Sortie 166 with radar detection data

[redacted]

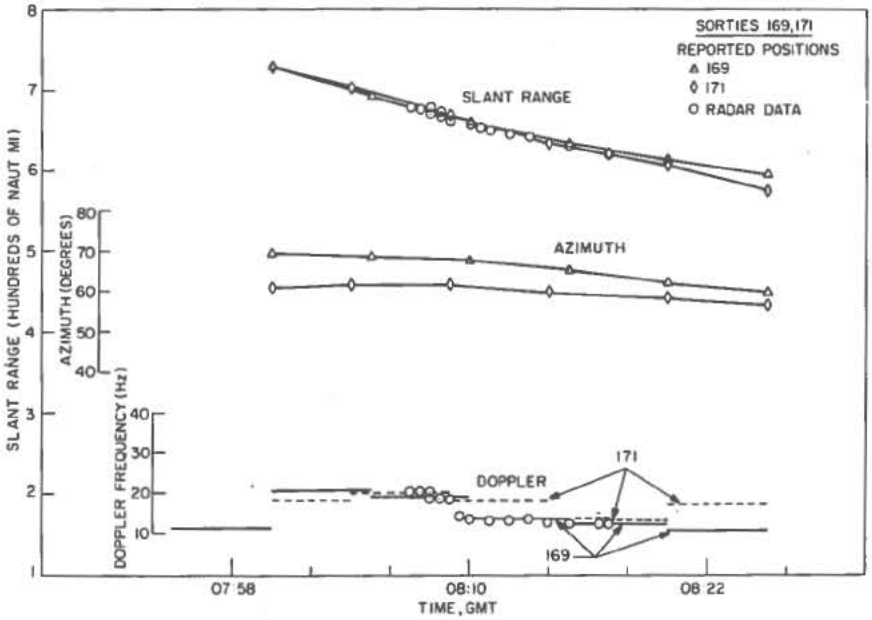


Fig. 17 - Comparison of the reported temporal behavior of Sorties 169 and 171 with radar detection data

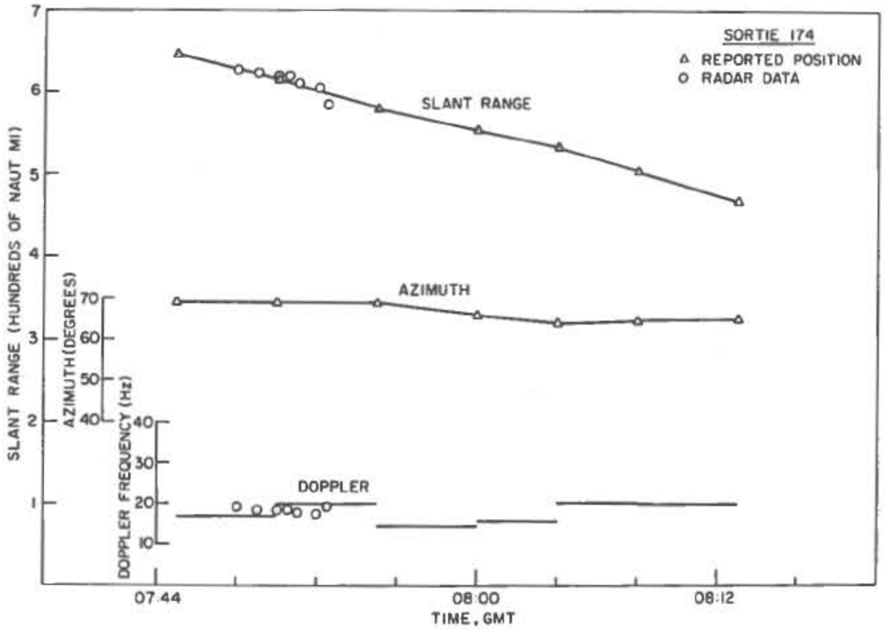


Fig. 18 - Comparison of the reported temporal behavior of Sortie 174 with radar detection data

[redacted]

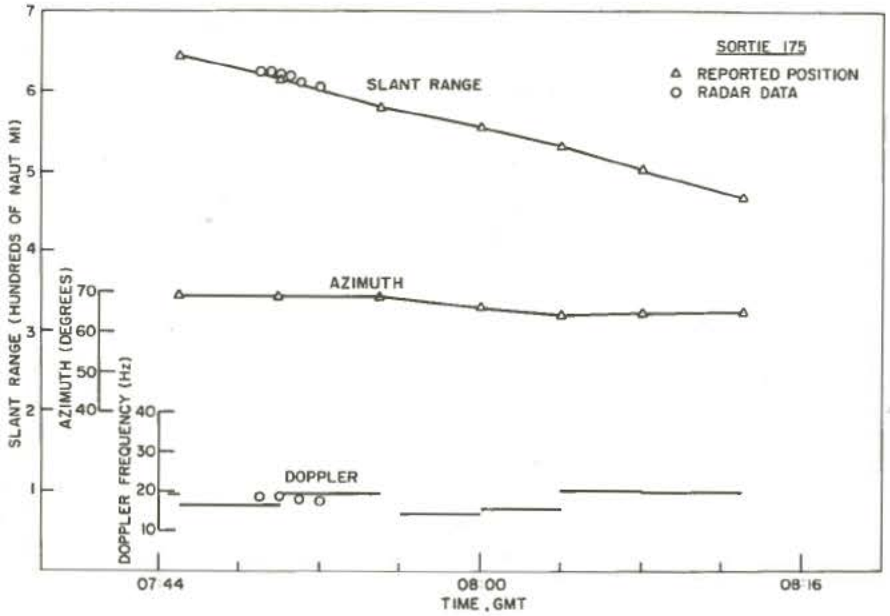


Fig. 19 - Comparison of the reported temporal behavior of Sortie 175 with radar detection data

(S) In Fig. 12 we notice modest agreement in both slant range and doppler. The two doppler points at shortly after 0756 may be due to multiple doppler glints as a result of the aircraft being in a turn. Sortie 157 seemed to be in the beamwidth from 0748 to 0824, during which it was detected from 0756 to 0804. Radar observations were terminated at 0820 GMT.

(S) Figure 13 shows the data match for Sortie 160. Most slant range points are within 7 naut mi of the reported track. The agreement in doppler is quite good. Two doppler points appear at approximately 0758 in close proximity to the reported turn time. This double data point may be due to the turn.

(S) Figure 14 gives the comparison of radar data with position report data for Sortie 164. The slant range data points agree very well with the reported track. The agreement in doppler is also quite good. The doppler data point that is removed from the track might be due to the aircraft turn. The radar track lasted approximately 15 minutes.

(S) Figure 15 shows the results of the data match for Sortie 165. The correlation in slant range is very good and in doppler is excellent. This is one of the better doppler comparisons. The two doppler points that precede the doppler track at 0758 may indicate that the aircraft had come to a new velocity at approximately 0757. For each of these records with short total tracks other data points are being tested for reconciliation, the results of which are not available for this reporting.

(S) Figure 16 shows good detection results for Sortie 166. As indicated by the azimuth plot, flight 166 was somewhat to the south of the main beam throughout the detection time. Differences in slant range probably average no more than 5 naut mi. The doppler data points compare quite favorably especially in that one data point is obtained for a new velocity shortly before 0800 GMT.

[redacted]

(S) Figure 17 is the record for Sorties 169 and 171. Even though at different azimuths, they for a good while were at the same slant range from the radar. The slant range radar data points all fall on either one or the other of the tracks. As can be seen, separation is not too readily accomplished in the slant range parameter. The doppler record however does indicate two distinct targets shortly before 0810, when the range tracks were nearly overlapping. It looks as if the radar followed the change in velocity for Sortie 169 just prior to 0810 quite well. A further search is to be made for other data points for Sortie 171. An operational radar possessing good azimuthal angle resolution, say of a few tenths of a degree, could readily separate the two targets at their minimal separation of approximately 2 or 3 degrees.

(S) Figure 18 shows the range and doppler data for Sortie 174. The slant range agreement looks good, and the doppler correlation is fair to good. From the doppler points it looks as if the aircraft did not change velocity as much as indicated. It is hoped that some of these differences will be resolved through further consultation with SAC personnel.

(S) Figure 19 gives the track results for Sortie 175. Both slant range and doppler data points match the corresponding tracks quite well. It was unfortunate that there was a shortage of data points. Further analysis may very well reveal more.

(S) Figure 20 is a consolidation of most of the individual range-time tracks into one plot with the solid line representing the actual range-time track for the indicated sortie and the circled points being the radar data points. As the title of Fig. 20 points out, those aircraft identified by track comparison were Sorties 124, 125, 156, 157, 158, 160, 161, 162, 164, 165, 166, 167, 169, 170, 171, 172, 173, 174, and 175, and those not identified were sorties 108 and 123. A track is considered identified if two or more data samples in slant range and doppler agree without question with the actual track. For the analysis completed to date of an expected 21 possible sorties to be detected, 19 have been positively identified. The reasons for Sorties 108 and 123 having not been recognized is uncertain at this time. Further investigation is indicated.

Doppler-vs-Time Processing

(S) As mentioned earlier it is indeed an advantage to process the radar signals in such a way that the doppler behavior of a given target aircraft can be studied over several minutes. Time has not allowed for many samples to be made in doppler vs time, but a few have been prepared for this reporting.

(S) Figure 21 is a three-part display showing four aircraft in a doppler-time format. For the times observed three of the aircraft are seen to modify their velocity either by a turn or a throttle change. The constant-velocity aircraft (target 3) is in view for only 25 seconds or so. Part A of Fig. 21 evidences a track of target 1 that persists for more than 3 minutes. Shortly after 0748 the aircraft increases its velocity, so that its doppler changes from 13.1 Hz to 22.3 Hz. The corresponding velocity change is shown in Table 2.

(S) In Table 2 the column marked Range Sample indicates at which point in range the radar returns were sampled. Actually double samples were taken; i.e., the received signals were sampled at two points 20 naut mi apart. The samples are then combined. Both samples fall within a radar transmitted pulse width, it being approximately 55 naut mi in duration. The maneuver onset and cessation times as well as duration are so listed. Velocities have been computed for the doppler frequency before and after the maneuver. The last column lists only tentative target identification. Additional analysis is necessary to confirm these identifications.

[redacted]

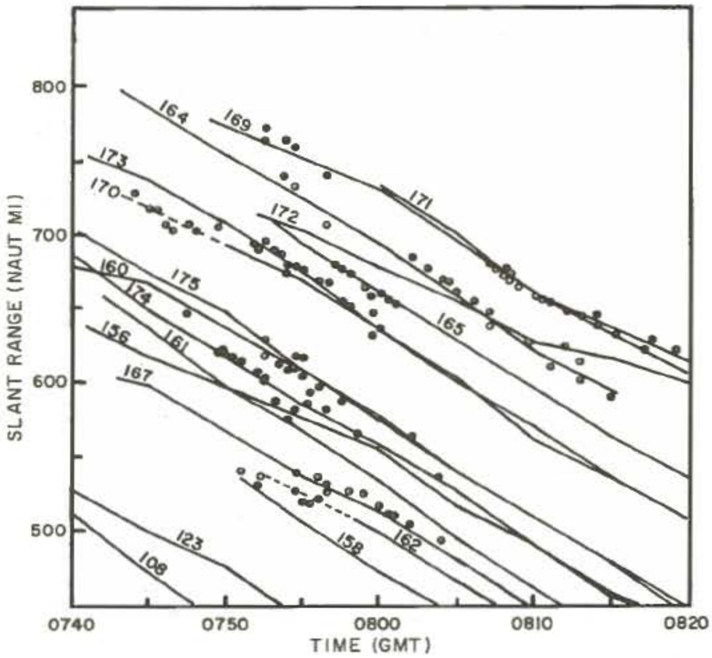


Fig. 20 - Comparison of the reported position tracks of various sorties with radar detection data. All the sorties shown were identified by track comparison except Sorties 108 and 123. Not shown are Sorties 124, 125, 157, and 166.

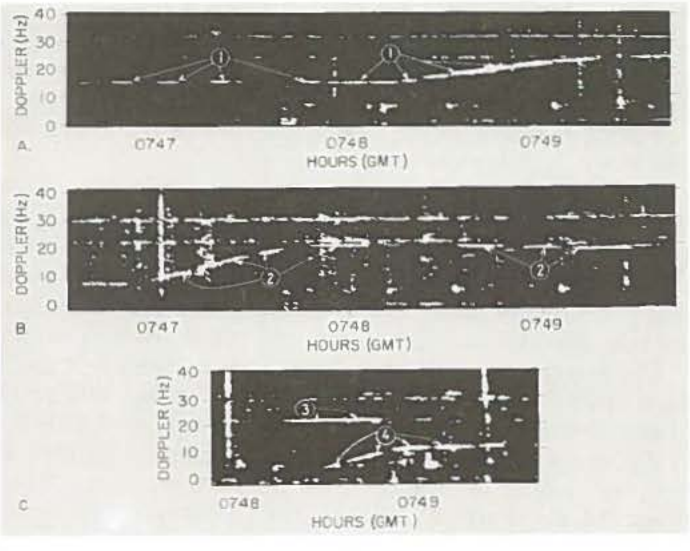


Fig. 21 - Range-gated-doppler-vs-time display reproductions depicting four aircraft doppler tracks. Three aircraft (1, 2, and 4) undergo maneuvers.

[redacted]

Table 2
Maneuver Characteristics of Targets 1 Through 4 in Fig. 21 (S)

Picture	Target	Range Sample (naut mi)	Maneuver Time			Velocity (knots)		Tentative Sortie ID
			Start	Stop	Total (sec)	Initial	Final	
A	1	685,706	074816	074920	64	290	444	160
B	2	644,665	074652	074742	50	162	438	174 or 175
C	3	766,786	★	★	★	471	471	164 or 166
C	4	766,786	074828	074904	36	89	250	169

★No maneuver

(S) For the way in which slant range and doppler frequency were extracted from the postflight records, no estimates of these parameters for Sorties 166 and 169 before 0750 is presently available. The identification of Sortie 166 with target 3 and Sortie 169 with target 4 of Fig. 21 has been accomplished only through the extrapolation of data for times later than 0750. The other identifications are also only tentative.

Doppler Errors

(S) In the comparison of radar-developed doppler-frequency data points with the doppler tracks extracted from postflight position records, an apparent lack of agreement was evident. The velocity resolution of the radar system permits the separation of targets at the same range and 0.1 Hz doppler frequency apart. Thus a difference of 0.2 to 0.3 Hz between the radar data and the position doppler track is more than one resolution bandwidth and should not be construed to be an error due to poor resolution. The errors seem to be random; good agreement might exist over a portion of the track and somewhat poorer correlation might exist over another portion.

(S) Small deviations in heading about the intended aircraft heading have been examined as to how they might in fact give rise to small differentials in processed doppler frequency. Interestingly enough, only small changes in heading, perhaps those introduced by random wind buffeting, can yield distinguishable shifts in radar doppler frequencies. As demonstrated in Table 3, certain small heading errors can result in measurable doppler frequency differences. It is appreciated that the large airframes such as the B-52 and B-58 aircraft enjoy excellent stability in heading and probably do not suffer large (more than 2 to 5 degrees) momentary deviations in heading. As noted from Table 3, a 5-degree deviation results in a 1% error in doppler, which for a target doppler of 20 Hz results in a 0.2-Hz change in doppler, which is readily detected at the radar. These doppler shifts will be pronounced when the aircraft velocity vector is directed along a radial to the radar, but off-radial velocities mitigate the doppler differentials in proportion to the angle between the radar ray and the aircraft velocity vector. It is not believed that the effect depicted in Table 3 in the sole cause of doppler discrepancy. Other causative mechanisms are being sought.

Table 3
Doppler Errors due to Possible Aircraft
Heading Errors (U)

Heading Error θ (degrees)	Cos θ	Error (%)	Error (Hz)	
			At 20.0 Hz	At 10.0 Hz
5	0.990	1.0	0.2	0.10
10	0.965	3.5	0.7	0.35
15	0.932	6.8	1.4	0.68
20	0.881	11.9	2.4	1.20

REAL-TIME TRACK DEVELOPMENT USING A DIGITAL COMPUTER

(S) NRL has in the past given thought to using a digital computer to perform track identification and inventory maintenance with continuous updating on all tracks as to their range, bearing, velocity, and heading. As a result of the analysis of the data for the Snow Time exercise, first steps have been taken to program a digital machine to synthesize aircraft tracks.

(S) For the new investigation the range and doppler data that were recorded manually in chronological order have been punched on IBM cards, which then serve as the initial computer input. The computer, having been given the necessary range and velocity criteria for track assemblage, groups those targets that bear close similarities in doppler frequency and that have range behavior consistent with that predicted. The target groups are then recognized as tracks. The digital machine will then organize the tracks and plot them in a range-time format. These data tracks can then be compared, for a common time base, directly with the tracks from the postexercise position data.

(S) Perhaps the most delicate discipline of computer analysis is the input of the proper range and velocity criteria. This has been somewhat difficult in this instance, because the turning aircraft upset narrow doppler limits in the comparison process. If the computer is looking for targets, in sequential time, that agree in doppler within ±0.2 Hz, the track for a given aircraft is dismembered when the plane changes velocity by several Hz, even though the next range data point might be consistent with the range track. This is of particular concern in a high-density environment.

FUTURE WORK

(S) Although no computer-plotted tracks have been presented in this report, work continues on computer-plotted tracks. Automated track inventory will be described in a subsequent reporting. The work anticipated in the near future is as follows:

1. Further search in radar data for unidentified aircraft.

2. Continued investigation of doppler discrepancies.

[redacted]

3. Observation, if possible, of future SAC penetration exercises.

4. Further pursuit of the goal of real-time computer track identification.

CONCLUSIONS

(S) The findings reported here demonstrate the utility of an OTH radar for the detection and characterization of a large-scale air attack. Certain deficiencies noted in the existing experimental system, particularly those of poor bearing-angle determination and lack of low-frequency operation (5 to 13 MHz), would certainly be rectified in an operational facility. This would permit the observation of all regions of interest at any hour of the day or night.

(S) The need for wide-dynamic-range narrow-band velocity processing in a high-density environment has indeed been indicated in these analyses. Doppler-vs-time processing has shown the attacking aircraft to possess unique signatures as a result of their frequent maneuvers. Additional investigations are suggested in the areas of multipath echoes from a single target and intrinsic doppler stability of OTH aircraft echoes.

(S) Early work has indicated that a large digital computer may be interfaced to the radar output to provide automatic detection and range-time track synthesis. A more dynamic target detection criterion is under development.

REFERENCES

1. Davis, J.R., Thomason, J.F., Hudnall, J.M., Boyd, F.E., and Utley, F.H., "The Spectral Characteristics and Temporal Behavior of HF Radar Echoes from Over-the-Horizon Aircraft Targets," NRL Report 6371 (Secret Report, Unclassified title), Nov. 18, 1965

2. Thomason, J.F., Hudnall, J.M., Utley, F.H., and Boyd, F.E., "Detection of Aircraft at Very Low Altitudes Using Over-the-Horizon Radar," NRL Report 6508 (Secret Report, Unclassified title), Jan. 13, 1967

3. Shapely, A.H., Harvard Circular 317, Harvard University Press, 1928

4. Manning, L.A., and Eshleman, V.R., "Meteors in the Ionosphere," Proc. IRE 47, 186-199 (Feb. 1959)

[redacted]

[redacted]

~~SECRET~~
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Naval Research Laboratory Washington, D.C. 20390	2a. REPORT SECURITY CLASSIFICATION ~~Secret~~ [redacted] 2b. GROUP 3

3. REPORT TITLE
OVER-THE-HORIZON DETECTION OF MULTIPLE AIRCRAFT (U)
THE OVER-THE-HORIZON DETECTION OF THE LARGE-SCALE STRATEGIC AIR COMMAND PENETRATION EXERCISE (SNOW TIME 69-1-E) OF OCTOBER 1968 (S)

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
An interim report on a continuing NRL Problem.

5. AUTHOR(S) *(First name, middle initial, last name)*
F.H. Utley, W.C. Headrick, F.E. Wyman, D.C. Rohlfs and J.F. Thomason

6. REPORT DATE February 20, 1970	7a. TOTAL NO. OF PAGES 28	7b. NO. OF REFS 4

8a. CONTRACT OR GRANT NO. NRL Problem R02-23 b. PROJECT NO. RF05-151-402-4007 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NRL Report 7044 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT
In addition to security requirements which apply to this document and must be met, it may be further distributed by the holder ONLY with specific prior approval of the Director, Naval Research Laboratory, Washington, D.C. 20390.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Department of the Navy, Office of Naval Research Washington, D.C. 20360

13. ABSTRACT
(Secret)

The Naval Research Laboratory OTH radar at NRL's Chesapeake Bay Division has been used to observe a large-scale simulated air attack on the east coast of the United States. Fifty-three aircraft, including B-52's and B-58's, were deployed at various altitudes and along continuously changing penetration corridors to accomplish the coastal thrust. The OTH radar was programmed to illuminate a selected area along the inbound routes, to permit the acquisition of the largest number of aircraft echoes over the term of the exercise. Multiple real-time detections were accomplished. Subsequent analysis has permitted track identification with post-exercise reported positions of 19 out of a possible 21 sorties. Definitive sorting has been accomplished with high resolution in velocity coupled with the doppler-time format of processing. Evasive maneuvers are particularly noticeable in the radar records. Such target behavior confirms sortie recognition. Analysis is continuing for aircraft detections that have as yet not been identified as a range-time track nor correlated with a particular sortie. Certain discrepancies between radar data and reported positions or maneuvers are being investigated.

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6801

~~SECRET~~ [redacted]
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Radar						
Over the horizon						
Analysis						
Target signatures						
Aircraft flight						
Multiple targets						
Ionosphere						

[redacted]

~~SECRET~~

DOWNGRADED
APPROVED FOR PUBLIC RELEASE

[redacted]

~~SECRET~~