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UHF AEW Radar Observations of Elevated Tradewind Ducts

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ABSTRACT

Airborne uhf (435-Mc/s) propagation paths observed during the course of a 12-month study of elevated tradewind ducts (Project TRADE-WINDS IV) varied from 240 to 1200 nautical miles (naut mi) as compared with less than 180 naut mi observed for the same system in a standard atmospheric propagation medium.

Out of 18 flights spaced over a year, 17 (94 percent) resulted in the radar detection of elevated ducts. Ten flights (55 percent) resulted in the discovery of ducts which permitted the radar detection of targets at ranges in excess of 500 naut mi.

Radar data has been obtained which shows that the elevated ducts off the southern California coast can have an extent in longitude in excess of 1200 naut mi and a latitudinal extent of greater than 1000 naut mi.

Average attenuation rates as low as 4 db/100 naut mi have been observed for pathlengths of over 1000 naut mi.

The existence of ducts off the California coast capable of sustaining long range radio-radar propagation was not limited to the summer months. On the basis of data obtained during the 12-month study, there is evidence that the occurrence, strength, and extent of the ducts does not change significantly with the seasons of the year.

The airborne uhf radar has proved to be a useful tool for the detection and observation of elevated ducts. Through the observation of ducting radar return signals, it was possible to determine the number, relative strength, height, and the thickness of elevated ducts.

PROBLEM STATUS

This is a final report on one phase of the problem; work continues on other phases.

AUTHORIZATION

NRL Problems R07-02 and R02-29
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RAV-53-R005/6521/F001-02-002

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UHF AEW RADAR OBSERVATIONS OF ELEVATED TRADEWIND DUCTS

INTRODUCTION

The Wave Propagation Branch of the Naval Research Laboratory has for the last few years been engaged in a series of experimental studies (Project TRADEWINDS) of radio propagation through the tradewind inversion (1,2,3,4). Past experiments have demonstrated that elevated transoceanic ducts are capable of trapping and propagating vhf and uhf radio signals at low loss for ranges in excess of 2000 nautical miles (naut mi) (5). The TRADEWINDS IV project, started in December 1960, had as its objective the twice a month sampling, over the period of a year, of the meteorology which existed between San Diego and Honolulu for the purpose of developing information on the character and persistency of the tradewind inversion.

The Search Radar Branch, which had been conducting studies with an experimental airborne radar, was asked to cooperate by providing information on radar propagation in the tradewind inversion. This report is a summary of the significant radar results obtained during the year of cooperative effort.

SYSTEM PARAMETERS AND FREE-SPACE RANGE

The Naval Research Laboratory (NRL) AEW Radar (6) was an experimental 435-Mc/s system capable of operating in either of two modes: the first, a coded pulse or matched filter mode, and the second, a conventional mode with a 12.8-μsec pulse length. All TRADEWINDS IV data is based on operation in the conventional pulse mode and at a reduced power level of 250-kw peak pulse power output. The pertinent radar system parameters are:

Peak pulse power output	250 kilowatts (kw)
Average power output	940 watts (w)
Pulse repetition frequency	294 pulses per second (pps)
Antenna gain on the horizon	19.8 decibels (db)
Antenna polarization	horizontal
Average azimuth beamwidth	10 degrees
Average elevation beamwidth	12 degrees
Average elevation beam tilt	- 12 degrees
Antenna scanning rate	5 rpm
Pulses per beamwidth	98
Pulse length	12.8 microseconds (μsec)
Frequency	435 megacycles/second (Mc/s)
Receiver noise figure	6.0 decibels (db)
System noise temperature	1055 degrees Kelvin
Transmission line and duplexer losses	1.0 decibel (db)
Visibility factor	-1.3 decibels (db)
Bandwidth factor	0 decibel (db)
Pattern loss factor	1.6 decibels (db)
Range for 50% blip-scan ratio for a radar cross section of 5 sq m	114 nautical miles (naut mi)

For the TRADEWINDS IV project a useful indication of radar system capability is to be found in the determination of the amount of power available at the receiver terminus of the one-way propagation path between the ground monitoring site and the aircraft.

The Navy Electronics Laboratory (NEL) at San Diego, California, cooperated on the TRADEWINDS IV project by providing personnel and ground facilities for monitoring the airborne radar transmissions. Pertinent parameters of the NEL ground station are:

Antenna site	Pt. Loma, California
Antenna gain	22 decibels
Antenna polarization	circular
Transmission line loss	1/2 decibel (assumed for purposes of calculation)
Polarization loss	3 decibels, linear to circular polarization loss.

The NEL-NRL system parameters may then be reduced to the following expression for the free-space received signal power:

$$P_r(\text{dbm}) = 34.33 \text{ db} - 20 \log R(\text{naut mi})$$

where $P_r(\text{dbm})$ is the received signal power in decibels referred to a milliwatt, and $R(\text{naut mi})$ is the range in nautical miles between the NRL transmitter and the NEL receiver.

Table 1 is a tabulation of the free-space theoretical received signal power versus range for the NEL-NRL system parameters.

Table 1
Free-Space Received Signal
Power vs Range

Range (naut mi)	Received Power (dbm)
100	-5.67
200	-11.69
300	-15.21
400	-17.69
500	-19.65
600	-21.21
800	-23.69
1000	-25.65
1200	-27.21
1600	-29.69
2000	-31.65
2260	-32.75

EXPERIMENTAL PROGRAM

The area in which the meteorological-radar measurements program was conducted is shown in Fig. 1. Aircraft flight restrictions required that the indicated rhumb line course, rather than a great circle route, be flown between the two terminals of the propagation path. Altitude restrictions, which were imposed at each terminus, limited the acquisition of ducting radar data to those portions of the flight path which lay between the points ECHO (32°N, 120°W) and WHISKEY (24°20'N, 147°30'W).

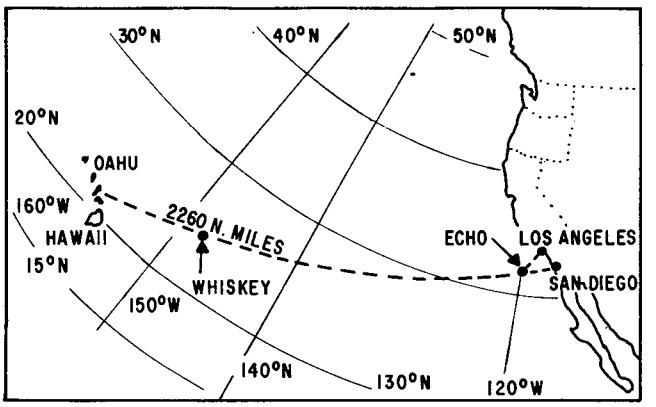

Fig. 1 - Map of the area and the flight path along which radar and meteorological ducting measurements were conducted during the period December 17, 1960, to December 2, 1961

The inversion altitude was initially determined through meteorological sounding with the radar aircraft as it proceeded to the starting point of each mission. Three times during each mission the aircraft was programmed to make meteorological soundings (to determine the number, vertical extent, and strength of the inversion layers) between 50 and 10,000 ft altitude.

The radar records made during each flight consisted of 35-mm photographs of a plan-position indicator (PPI) for each scan of the radar antenna, and Polaroid photographs of the radar A-scope and a second PPI. In addition, the aircraft was equipped with instrumentation to record external temperature, pressure, and the refractive index of the medium.

AMBIGUITY AND DISTORTION

The anomalous propagation of radio-radar signals encountered between San Diego and Honolulu was the result of superrefraction caused by the tradewind inversion layers. The extended ranges achieved with the NRL airborne radar in strong elevated ducts resulted in echoes being returned from targets at ranges of more than one repetition period from the aircraft. As a consequence, there was an ambiguous indication of range and a distortion of target shape when displayed on a conventional PPI.

Figure 2(a) contains a replica of an A-scope trace for signal returns from the radar target, Isla de Guadalupe. The range from the transmitter pulse to the target echo as indicated on the A-scope trace is 85 naut mi. Through reference to the navigational plot of the aircraft's position, it was known that the range from the aircraft to the target for this specific example was 635 naut mi. The ambiguity for this simple case is then readily resolved through a determination of the number of interpulse intervals separating the target from the aircraft. The range for a "multiple-time-around" echo (MTAE) is expressed by

$$R = R_{\text{Ind.}} + n\, R_{\text{prf}}$$

where

R = range to the target,

$R_{\text{Ind.}}$ = range indicated by PPI or A-scope,

n = the number of whole interpulse intervals between the radar and the target, and

R_{prf} = the range corresponding to an interpulse period.

The interpulse period for the radar is 3400 μsec, which corresponds to a range of 275 naut mi. As shown in Fig. 2(b), the target is in the third interpulse interval at a range of

$$R = 85 + (2)\ (275) = 635 \text{ naut mi},$$

which is in exact agreement with the aircraft navigational plot.

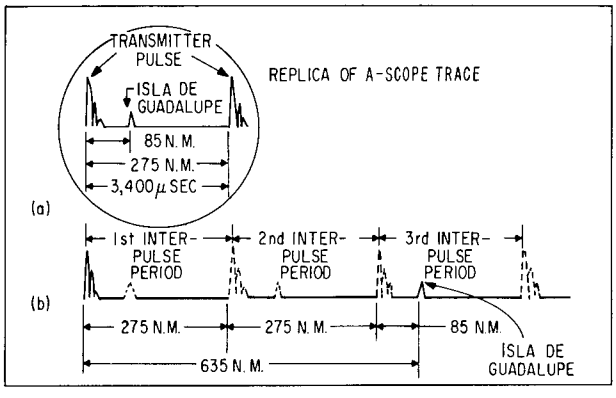

Fig. 2 - Resolution of A-scope range ambiguity for the radar target of Isla de Guadalupe, August 25, 1961

Accompanying the range ambiguity was a distortion in the display on the PPI of those targets which were at a range of greater than one interpulse interval from the aircraft. The straight-line target, line ABC in Fig. 3, in the second interpulse range interval is distorted and displayed as A'B'C' on the PPI.* The two hatched areas on the left-hand side of Fig. 3 shows the manner in which an extensive circular target area in the second interpulse interval translates into an ovate-shaped figure when displayed on a PPI.

*The polar equation for the line ABC in Fig. 3 is

$$\rho = a \sec \theta$$

where ρ is the line B'P(ρ, θ) and P(ρ, θ) is any point on line ABC with polar coordinates ρ and θ. The line BB'$(= a)$ is perpendicular to ABC. The angle BB'P is equal to θ.

The line ABC is transformed to A'B'C' whose equation is

$$\rho = a\ (\sec \theta) - b$$

where b, for this example, is equal to BB', the amount that ABC is displaced towards the pole B'. (The equation $\rho = a\ (\sec \theta) \pm b$ is Nicomedes' equation of a conchoid.)

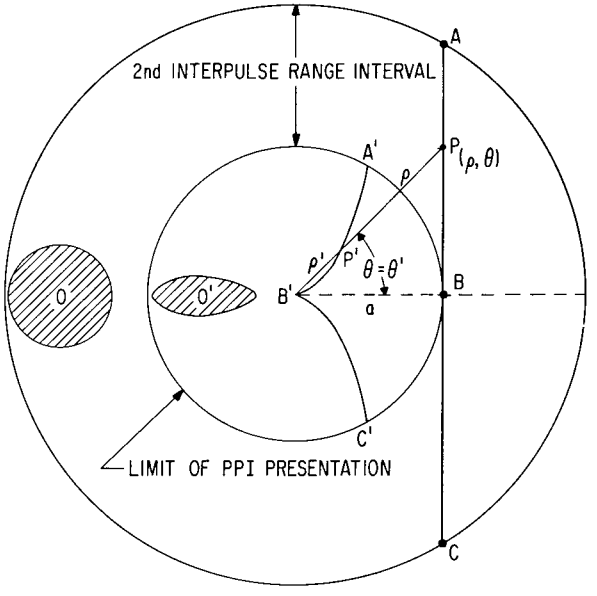

Fig. 3 - Examples of PPI distortion of targets located at ranges that are greater than the first interpulse range interval (275 naut mi)

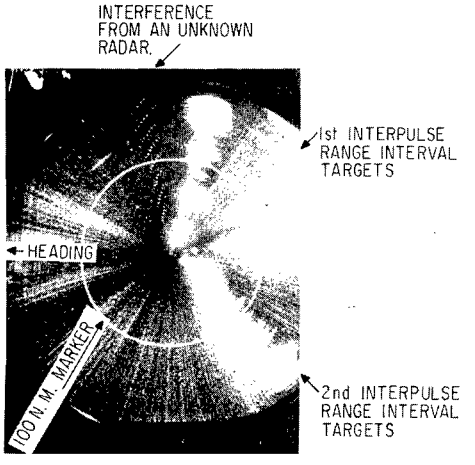

Fig. 4 - PPI record of ducting radar returns from the California coast, September 26, 1961. Aircraft at 1300 ft and 240 naut mi from San Diego; time: 16:19Z.

The characteristic "vee" or conchoid distortion illustrated in Fig. 3 was seen repeatedly on the various monthly TRADEWINDS IV flights. An example is shown on Fig. 4, where the inner vee-shaped target mass represents returns from mainland areas in the second interpulse range interval, while the outer targets in the PPI photograph are unambiguous returns from offshore islands located within the first interpulse range interval.

RESULTS

As was stated in the introduction, this report summarizes radar data for the TRADEWINDS IV project. Individual missions are cited because they are representative of other missions of a similar character, or they are cited because they are unique. A comprehensive report detailing the meteorological aspects of each TRADEWINDS IV mission is being prepared by the Wave Propagation Branch.

A total of 24 flights were made between San Diego, California, and Honolulu, Hawaii. NRL airborne radar range information is not available for six of the flights because the radar as a system was inoperative, or else radar personnel were not available due to employment on higher priority projects.

Table 2 is a chronological listing of each of the 24 flights. Odd-numbered missions are east-to-west transits and even-numbered missions are west-to-east transits. The tabulated NEL maximum detection ranges are the maximum ranges in nautical miles from the NEL, Pt. Loma, antenna site to the aircraft. The maximum airborne radar range to the mainland covers land mass targets in the general region from 20 to 38 degrees North latitude and includes the various offshore islands, as well as the coasts of California and Baja California. Maximum airborne ranges to Hawaii are the maximum ranges for detection of the islands of Hawaii and Maui.

Table 2
Chronological Listing of the 24 Flights for Which Radar Data on Tradewind Ducting was Attempted

Mission No.	Date	NEL Maximum Detection Range for 435-Mc/s AEW Signal (naut mi)	NRL Maximum Airborne Radar Range (naut mi)		Notes
			Mainland	Hawaii	
1	12-17-60	No Record	No Record	220	(a)
2	12-19-60	No Record	855	210	
3	1-17-61	No Record	No Record		
4	1-22-61	No Record	675	276	
5	2-20-61	1374	510	250	
6	2-23-61	1320	1200		(b)
7	3-14-61	700	430		
8	3-17-61	No Record	No Record		
9	4-27-61	897	700		(c)
10	4-30-61	598	980	355	
11	6-10-61	905	455		
12	6-13-61	919	475		
13	6-22-61	No Record	No Record		
14	6-26-61	No Record	No Record		
15	7-18-61	No Record	No Record		
16	7-21-61	No Record	No Record		
17	8-22-61	1153	610		
18	8-25-61	948	465		
19	9-26-61	785	800		(d)
20	9-30-61	No Record	690		(e)
21	10-10-61	1243	495		
22	10-13-61	1281	730		
23	11-28-61	735	430		
24	12-2-61	330	180		

Notes: (a) Aircraft primary power instability prevented radar operation during the initial six hours of flight. NEL did not monitor the NRL AEW signals but did track the NRL radar aircraft with their own ground-based 435-Mc/s matched filter radar to 380 naut mi.

(b) The radar range of 1200 naut mi was the greatest range recorded during the course of the 12-month TRADEWINDS IV project. The target area for this greatest radar range was the southern tip of Baja California, a region to the southeast of the AEW aircraft.

(c) Aircraft primary power instabilities required that the radar be shut down at a range of 897 naut mi from the mainland. There was no loss of radar ducting data since mainland returns were lost at a range of 700 naut mi. However, NEL monitoring data was still being recorded at the time of AEW radar shut down.

(d) A strong duct existed out to a range of 630 naut mi, at which point a thunderstorm broke up the ducting layer. NEL continued to detect signals to 785 naut mi, while radar returns from Baja California were detected to a range of 800 naut mi.

(e) On the eastern end of this flight, radar returns were detected in three separate duct layers. The 690-naut mi returns from the mainland were detected when in a duct at 3000 ft, and again at about 680 naut mi in a duct layer at 2000 ft. Radar detection of the mainland was again achieved through a third duct, a haze layer at 6000 ft, when at a range of 455 naut mi from the mainland. A change in the scheduled flight plans, plus poor communications, resulted in NEL's not being alerted to monitor this particular flight.

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Table 3
Classification of Runs and Range Extensions

No. of Runs	Range Extensions	Maximum Radar Range (naut mi)
1	none	160-180
3	small	180-275
9	moderate	275-550
9	great	550-1200

In Table 3, runs have been classified as to whether they exhibited none, a small, a moderate, or a great extension of range over that expected by scatter processes in an nonstratified atmosphere. Data related to the Hawaiian terminus are included as separate runs in Table 3.

Based on NEL-NRL measurements in a nonstratified meteorological structure (Missions No. 1 and 24), one-way propagation ranges of 380 (see note (a) of Table 2) and 330 naut mi compare favorably with the work of Rogers (7) and previous tradewind projects (8). Radar ranges in a nonstratified meteorological structure (Mission No. 24 and flights along the Atlantic seaboard) resulted in ranges of 160 to 180 naut mi. In Table 3, it is assumed that 160 to 180 naut mi represents the maximum range (for this particular system operating at altitudes comparable with those at which the tradewind inversions are encountered) when scatter processes alone are operating.

Figure 5 is a bar graph plot of the NRL maximum detection ranges for mainland coastal targets. In Table 4 the 17 NRL runs shown in Fig. 5 are averaged for comparison with 14 maximum range values obtained from the NEL radio-signal range plot. Note that since the NRL average maximum range is a radar range, the maximum propagation path-length for this system is then twice the indicated radar range.

Ranges from the aircraft to Hawaii are not shown in Table 4 because of the inability to acquire data due to the operational restriction imposed at the western terminus. From point Whiskey (Fig. 1) to Honolulu (600 naut mi), the region in which restrictions were in effect, the aircraft's proximity to any existing inversion layers was strictly a matter of chance.

One aspect of the average maximum detection radar ranges not brought out in Table 4 is a consideration of the direction of the propagation paths relative to the aircraft. The NEL data is based on the predominately west-to-east path relationship which existed between the aircraft and Pt. Loma. The NRL data reflects the experimentally encountered condition that maximum airborne radar ranges were invariably achieved against targets which were located to the southeast of the aircraft.

Insufficient data is available to perform a meaningful statistical analysis, but it is of interest to note the difference between mean and median values of detection ranges for the odd- and even-numbered missions. Odd-numbered missions (east-to-west) resulted in detection of the mainland through inversion layers which existed during local morning hours, while even-numbered missions (west-to-east) resulted in detection of the mainland through inversion layers which existed during local afternoon hours. The arithmetic mean and median detection ranges for all antemeridian ducts are 556 and 502 naut mi, respectively, while for postmeridian flights the arithmetic and median detection ranges are 695 and 690 naut mi. Also, the two greatest ranges recorded (see Table 2) were both achieved through inversion layers which existed during local afternoon hours.

Cloud diagrams, radio-signal range plots, and duct layer diagrams for six different missions are presented in Figs. 6-11. The cloud diagrams in these figures show the type

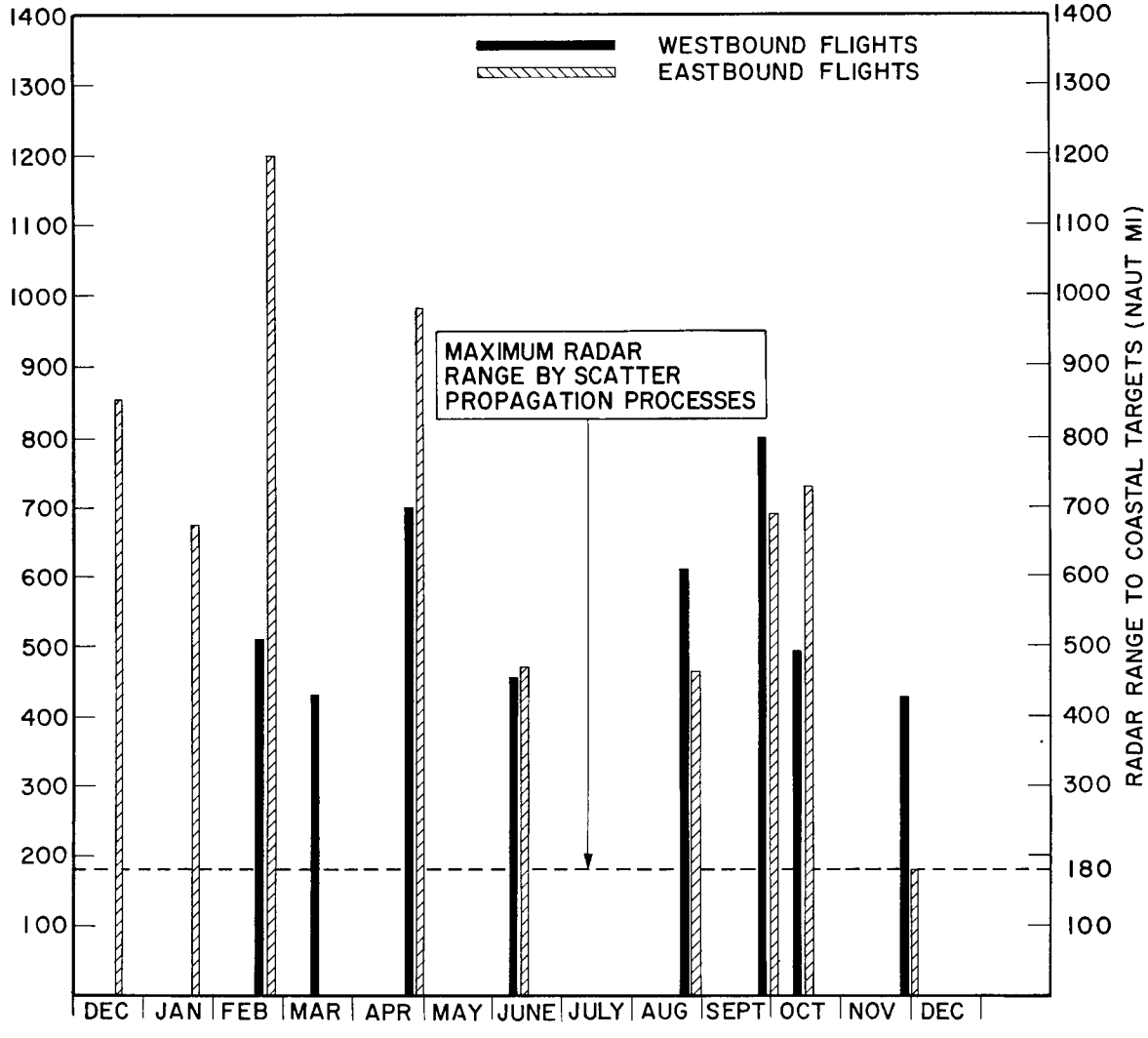

Fig. 5 - Bar graph of NRL-measured maximum ranges for airborne detection of the mainland

Table 4
NRL Average Maximum Detection Radar Ranges

Detecting Station	No. of Runs	Average Max. Range (naut mi)	Average Max. Propagation Pathlength (naut mi)
NEL	14	942	942
NRL	17	628	1256

of cloud structure encountered along the flight path. The numerical notations such as 6/10, 7/10, etc. represent the meteorological estimates of the percentage of cloud cover along the various portions of the flight path.

The section of each of these figures designated as the NRL radio-signal range plot is the NEL monitoring record of the NRL 435-Mc/s airborne radar.

The NEL record has been reduced to show the maximum and minimum signal levels for consecutive 1-minute time intervals. The reasons for breaks in the signal plot are the following: the signal loss associated with the aircraft's leaving the duct during the course of meteorological soundings; the "on" time for the NEL 435-Mc/s beacon; the tuning of equipment when the aircraft radar antenna was searchlighting towards NEL; and the radar transmitter "off" time.

The free-space reference curve on each of the radio-signal range plots is based on the data presented in Table 1.

The duct layer diagrams on the figures under discussion indicate the number, the vertical extent, and the continuity of ducts along the flight path. The altitude and vertical dimensions of the ducting layers are based primarily on refractive index measurements, though in a few cases the radar was the source of the required information. The single line passing through the circled points on the duct layer diagram represents the aircraft's pressure height. This record in turn shows where along the route the aircraft made its meteorological soundings.

Figures 6 and 7 persent meteorological and signal level information for two different missions which are representative of the flights which resulted in the best experimentally observed elevated ducts. Figure 6 is an example of the case for which the ducting layer is defined by a stratus cloud deck, which gradually rises in altitude as the observation point is moved westward from San Diego.

In Figure 7 the strong duct is the result of an extensive haze layer rather than the more commonly encountered tradewind stratus cloud deck (Fig. 6).

In both Figs. 6 and 7 the western ends of the missions are marked by the presence of haze and/or stratification of cumulus cloud tops at about 5000 ft, with the result that "patchy" ducting areas were encountered.

In Fig. 6 the average attenuation rate for the region from 350 to 1200 naut mi is approximately 2 db/100 naut mi, while in the region from 1200 to 1374 naut mi the average rate is approximately 20 db/100 naut mi.

In Fig. 7 the average attenuation rates are 2.5 db/100 naut mi for the region from 100 to 500 naut mi, 10 db/100 naut mi for the region from 500 to 1000 naut mi, and 1.5 db/100 naut mi for the region between 1000 and 1320 naut mi.

Figure 8 is an example of cloud cover, radio signal data, and ducting layer information for a mission which resulted in a "moderate" extension of radar range. The ducting layer for this mission consisted of a combination of sections of haze and stratus cloud deck. Out to about 560 naut mi the attenuation rate was approximately 5 db/100 naut mi, after which point the rate increased rapidly with the signal dropping below the minimum detectable level when at a range of 700 naut mi from San Diego.

The meteorological and signal level data for the one mission which did not result in the enhancement of maximum radar detection range is shown in Fig. 9. The cloud diagram portion of this figure does not show any stratification; rather, it shows extensive convective cumulus activity. The attenuation rate in the signal level portion of this figure is about 20 db/100 naut mi, which is in good agreement with scatter propagation rates cited in previous tradewinds projects (5).

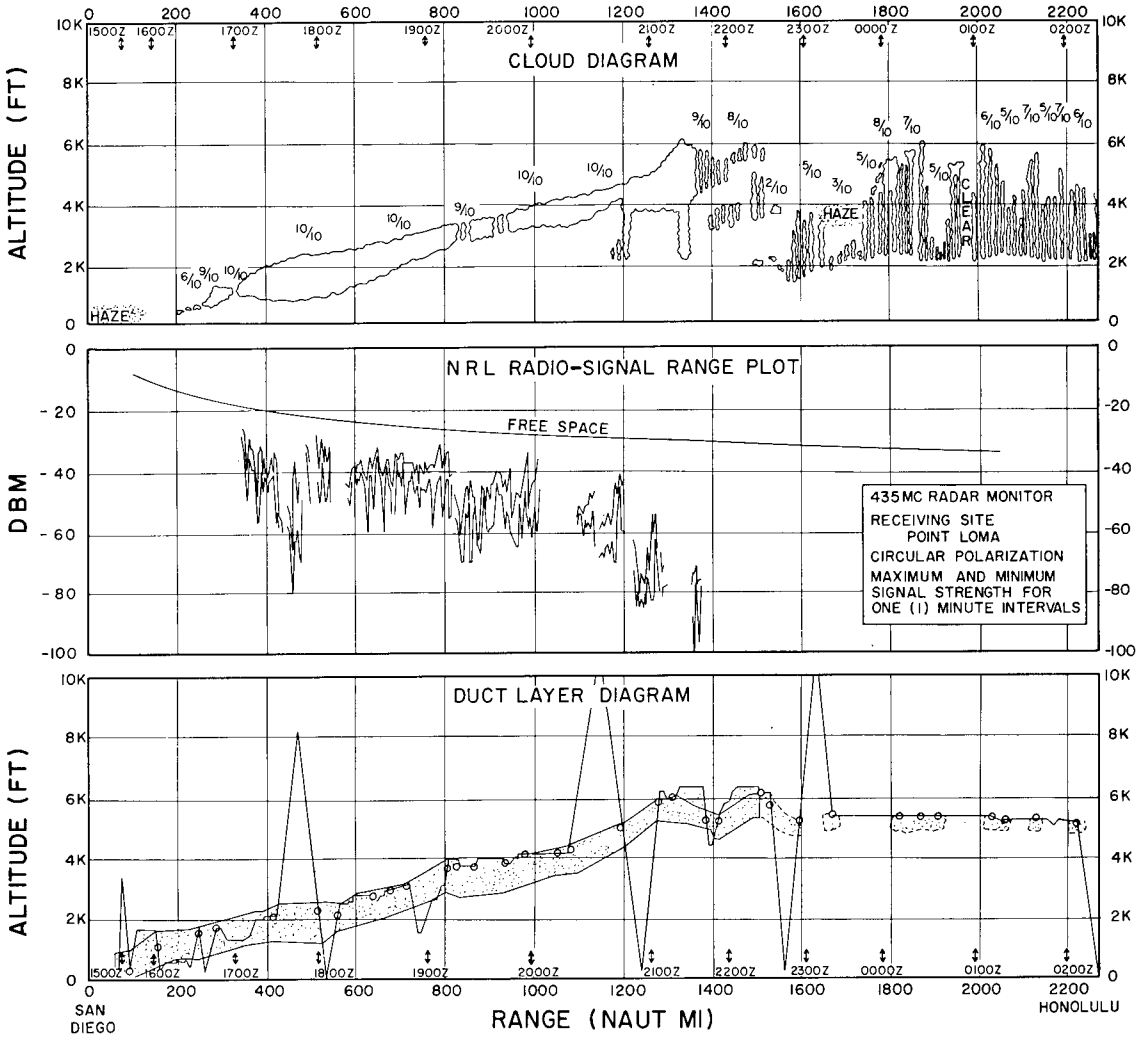

Fig. 6 - Cloud diagrams, radio-signal range plot, and duct diagram for Mission No. 5, February 20, 1961. Example of long-range ducting conditions with a stratus cloud deck.

Mission No. 19 (Fig. 10) was unique because of the severe storm encountered when at a point 630 naut mi out from San Diego. This was the only mission in which "weather" was observed with the airborne uhf radar. Based on (a) the continuity of cloud cover, (b) the signal strength as measured by NEL at San Diego, and (c) the observed airborne radar returns, the duct extended out to 985 naut mi, except for the break between 630 and 660 naut mi. Up to 785 naut mi there was sufficient signal energy to couple through the 30-naut mi break in the duct to obtain radar returns from the coastal area. The continuity of the cloud layer was such that it is probable that ducting radar returns could have been observed at a range of 985 naut mi. However, the signal was lost when the aircraft left the duct and made a meteorological sounding at 785 naut mi. Two ducting layers were observed on this flight: one was a haze layer at about 3000 ft, and the second was an initially lower stratus cloud deck which joined the haze layer at a point about 500 naut mi from San Diego.

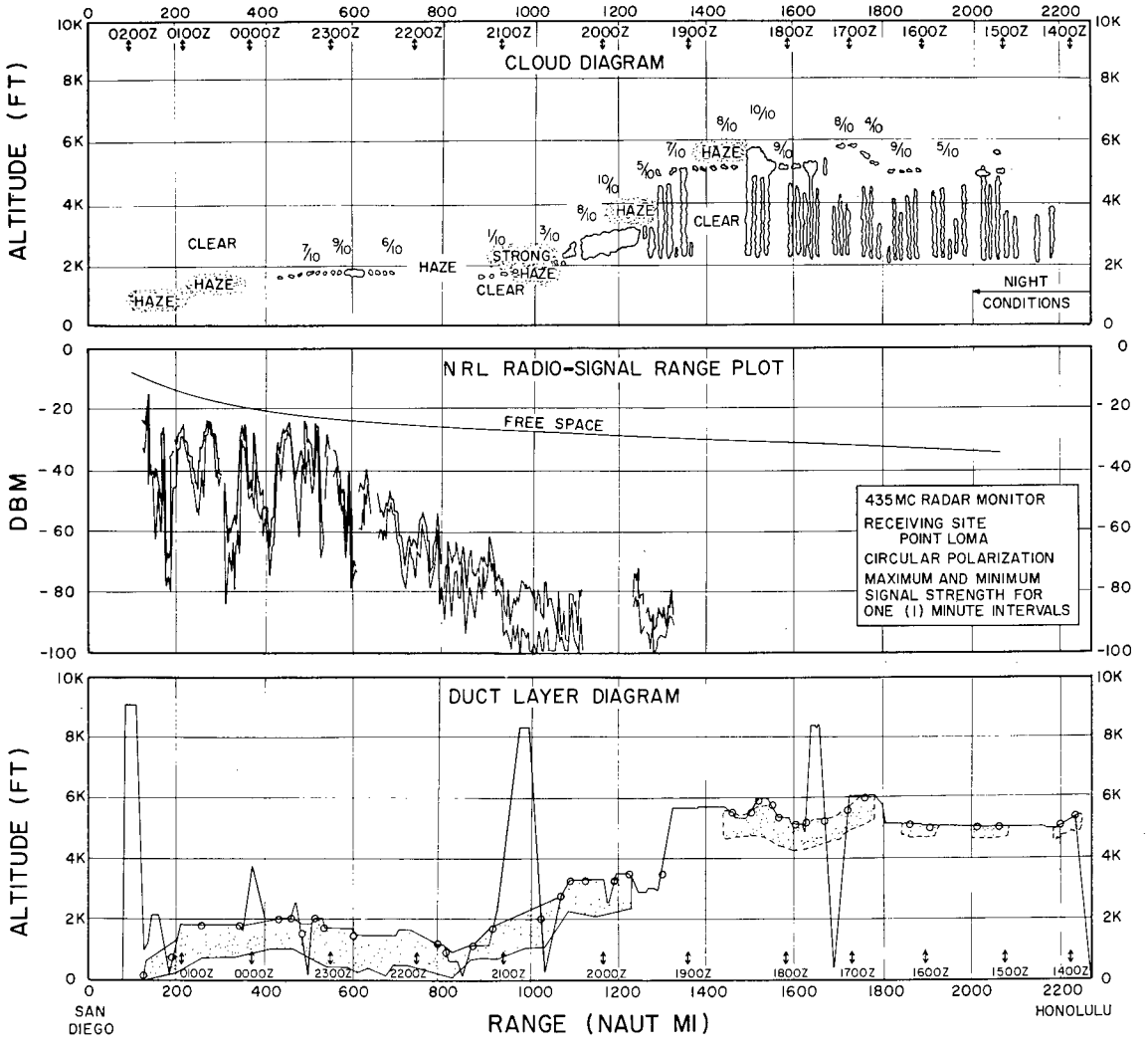

Fig. 7 - Cloud diagrams, radio-signal range plot, and duct diagram for Mission No. 6, February 23, 1961. Example of long-range ducting conditions with a haze layer.

Mission No. 20 (Fig. 11) was a second unique and noteworthy mission because of the three separate ducting layers which were encountered. The lowest layer was the regular tradewind inversion stratus deck at about 2000 ft. The two higher layers, one at about 3000 ft and the other at about 7000 ft, were haze layers. Radar returns from the mainland were obtained through each of these layers. Due to a malfunction of the airborne refractometer, the radar was the only means of verifying the presence of a continuous duct in the region from 450 naut mi to San Diego.

The radar's sensitivity to changes in aircraft altitude when operating in a ducting environment is shown in Fig. 12. These photographs show the buildup and decay of mainland ducting signal returns as the aircraft descended from 2660 to 560 ft. Based on this radar data, the duct vertical bounds are approximately 1200 to 2250 ft. The refractometer determination of duct position for this same period in time (see Fig. 7) shows the duct to

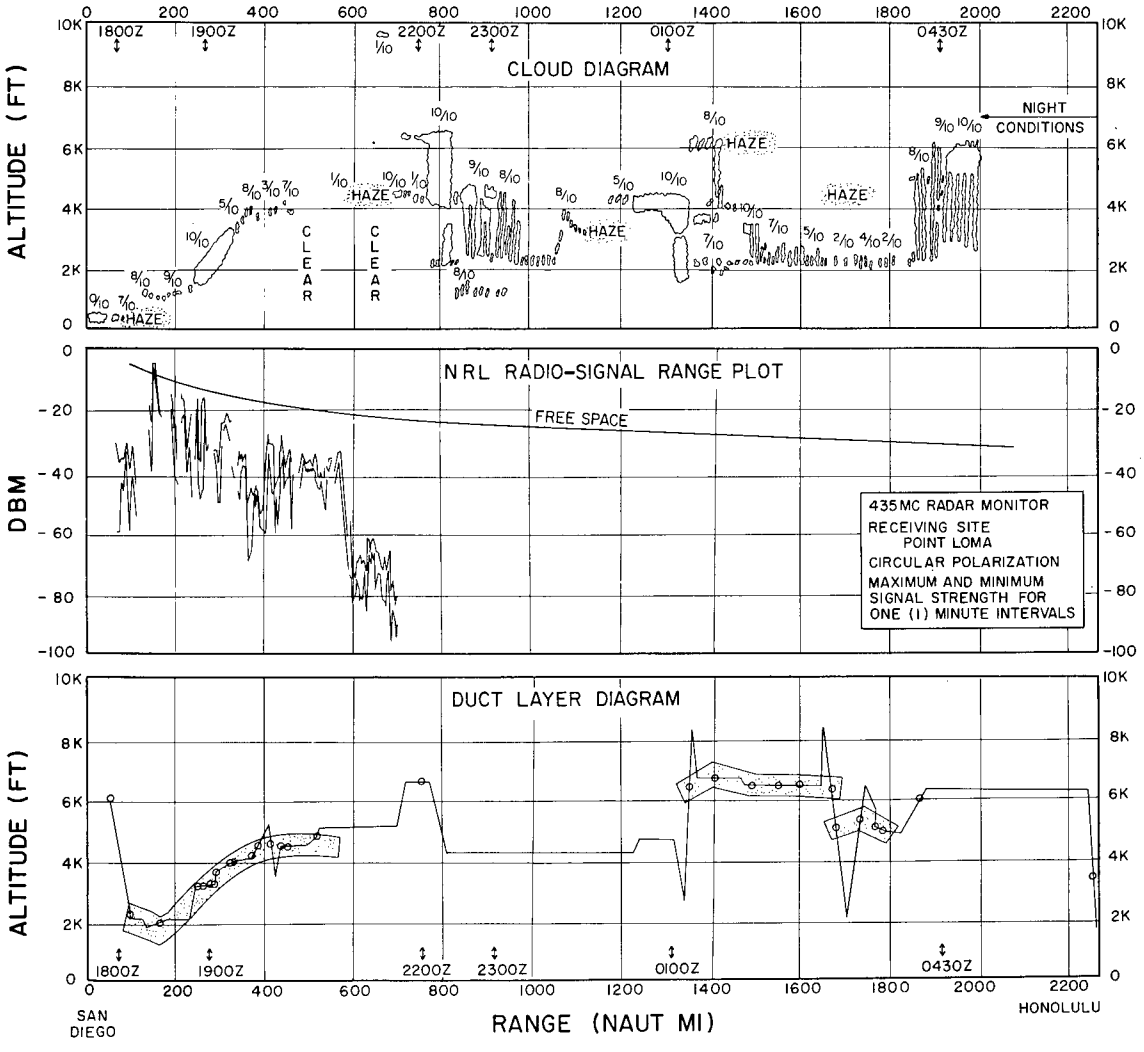

Fig. 8 - Cloud diagram, radio-signal range plot, and duct diagram for Mission No. 7, March 14, 1961. Example of moderate-range ducting conditions through haze and stratus cloud decks.

be between 700 and 1950 ft. The difference between the two determinations of duct thickness and altitude are believed to be accounted for by the approximately 12-degree downward tilt of the pattern of the airborne radar antenna.

Examples of the resolution of range ambiguities for one particular mission (Mission No. 19, Fig. 10) are shown in Fig. 13. In each of the plots in Fig. 13 the PPI records are translated to charts to show the most probable areas from which these returns were being received. The "blind zone" on the particular PPI from which the photographic records were made did not permit the viewing or recording of signal returns from all ranges.

In Fig. 13(a) the area A targets are resolved as being returns from land mass targets in the area A'. This resolution is based on agreement in bearing and range between the two areas and on the knowledge that there are not any extensive targets between the radar and area A'. Not subject to resolution is the probability that targets from the third interpulse range interval may be included in the returns shown for area A.

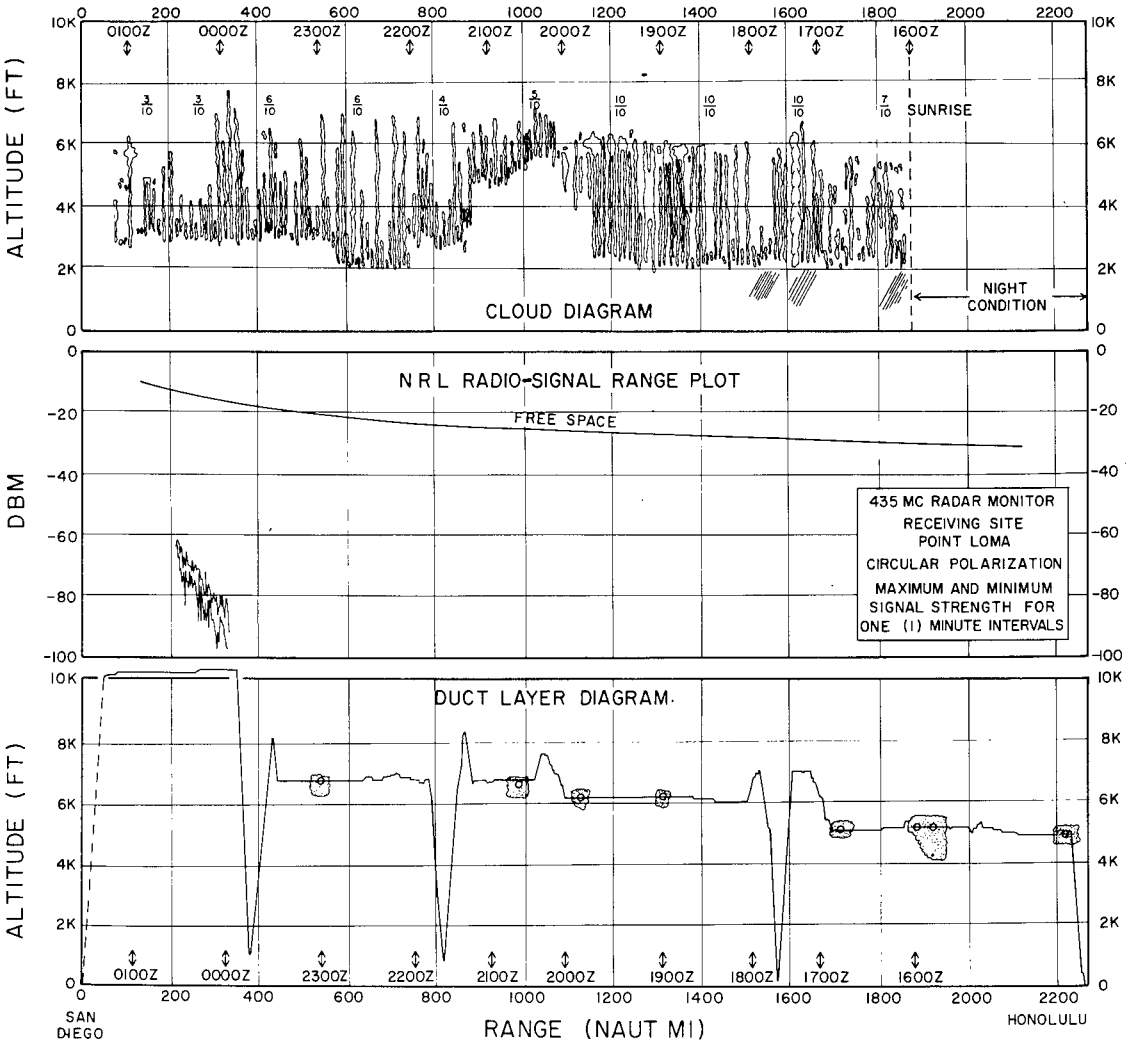

Fig. 9 - Cloud diagram, radio-signal range plot, and duct diagram for Mission No. 24, December 2, 1961. Example of conditions for which radio ducting was not encountered.

Area B targets are resolved in the same manner as the area A target returns.

Area C targets do not include any ambiguity because these are targets which had been under continuous observation and are known to have been within the first interpulse range interval.

Figure 13(b) shows the PPI record for a position 268 naut mi further from San Diego than was the case for Fig. 13(a). The area A targets are resolved as area A', a portion of Baja California.

Target B on the PPI presentation is target B', Isla de Guadalupe, an outstanding radar target which was relied upon for radar range and bearing checks in the resolution of the position of ambiguous coastal targets.

Figure 13(c) shows a replica of the PPI record for Mission No. 19 when at a range of 614 naut mi from San Diego. The target A is resolved to be the area A'. The other target

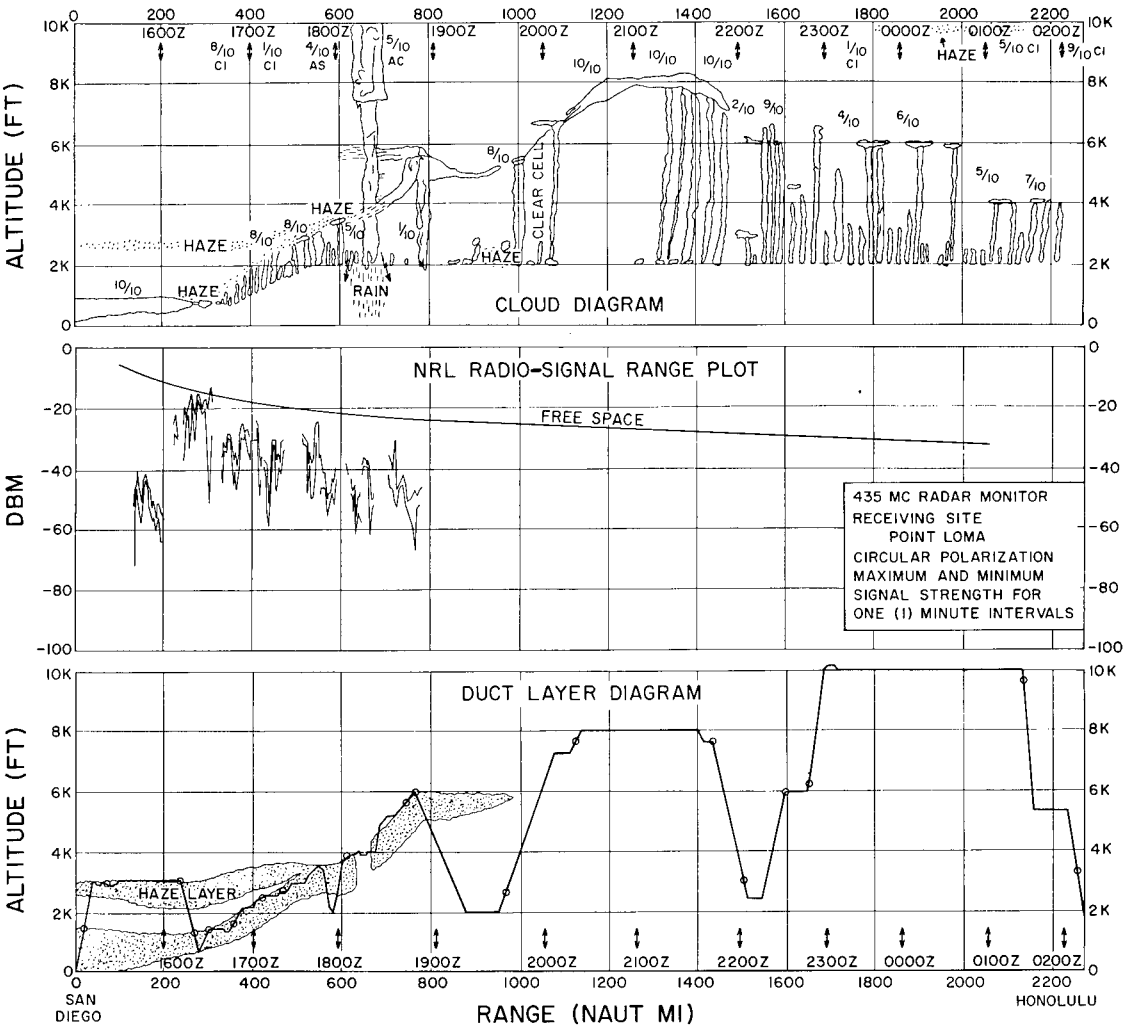

Fig. 10 - Cloud diagram, radio-signal range plot, and duct diagram for Mission No. 19, September 26, 1961. Example of multiple layer radio ducts, and a strong duct with a 30-naut mi break.

area represented on the PPI record is the return from a severe storm, which at 1808Z was approximately 15 naut mi ahead of the radar-meteorological aircraft.

Figure 14 is a composite of PPI records between 1619Z and 1808Z. The composite record shows that ducting returns were received from over 1000 naut mi away from the coast line. The radar verification of the extent of ducting area in latitude is limited to the regions swept out by radial lines drawn from the aircraft's position to the limiting azimuths of the target areas, such as are shown in Fig. 13. The gray-toned area of Fig. 14 represents the region of "anticyclonic curvature" and shows a good "fit" of radar experimental data with the theory advanced by D.L. Randall (8,9) in the meteorological prediction of radio ducting areas.

Various attenuation rates may be considered in connection with the propagation paths through elevated ducts. Average attenuation rates over periods of time involving hours have been referred to in connection with the radio-signal range plots of Fig. 6 through 11.

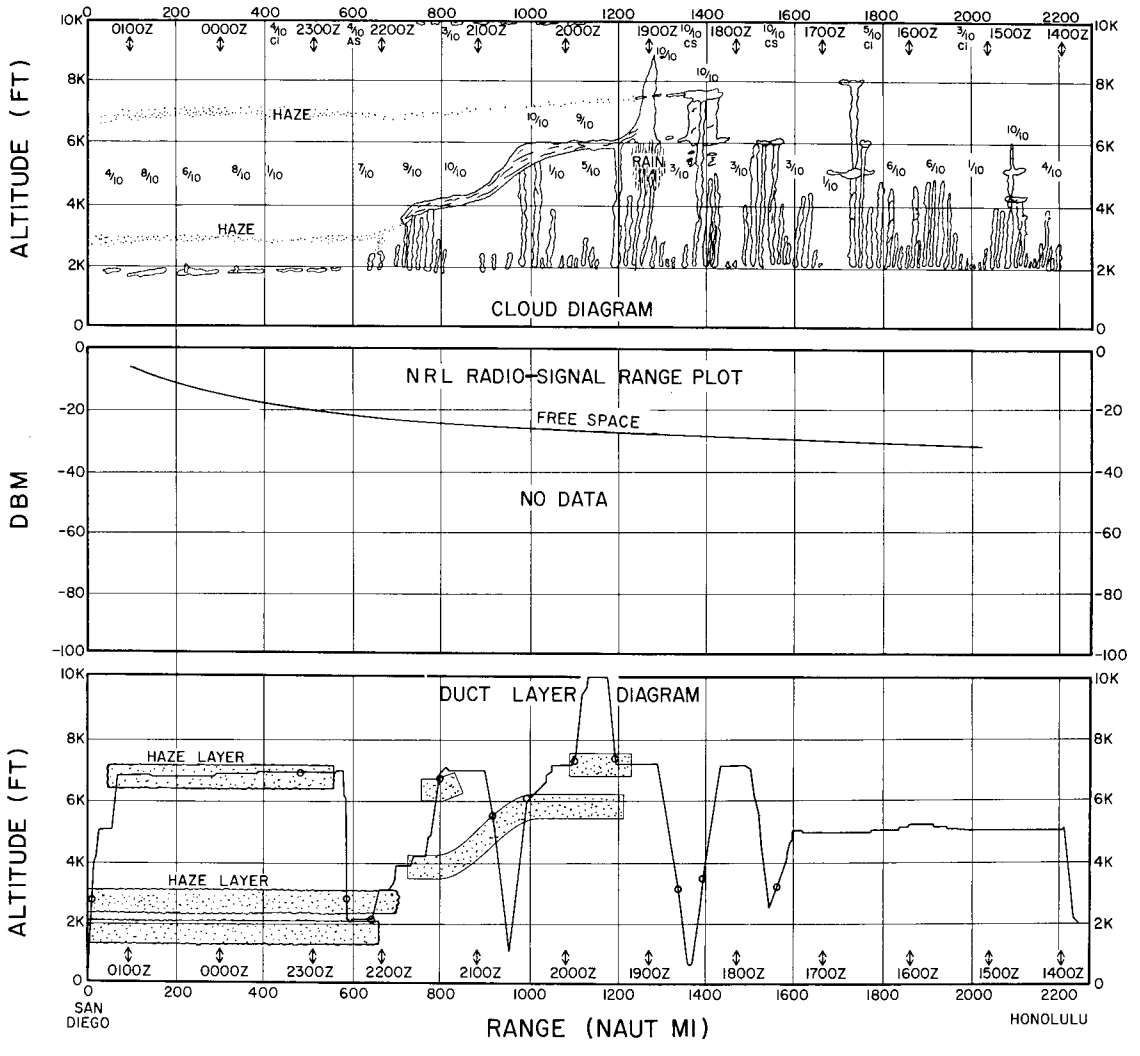

Fig. 11 - Cloud diagram, radio-signal range plot, and duct diagram for Mission No. 20, September 30, 1961. Example of multiple layer radio ducts.

In Fig. 15 a series of PPI photographs are used to illustrate the extreme, short-term fluctuations that occur sometimes in the amplitude of the received signal. These photographs, obtained during Mission No. 22 when approximately 470 naut mi from San Diego, show about 25 db variation in signal level occurring within a time interval of 12 seconds (see top two frames of Fig. 15).

POWER-LOSS MODELS

It is of interest to consider the feasibility of a long-range vhf/uhf communications system which takes advantage of the elevated ducts which are encountered between the West Coast and Hawaii. In Fig. 16 approximate models for signal loss over the one-way path from San Diego to Honolulu are shown. The transmitter and receiver power reference levels are based on the NEL-NRL parameters shown on the first page and in Table 1 of this report.

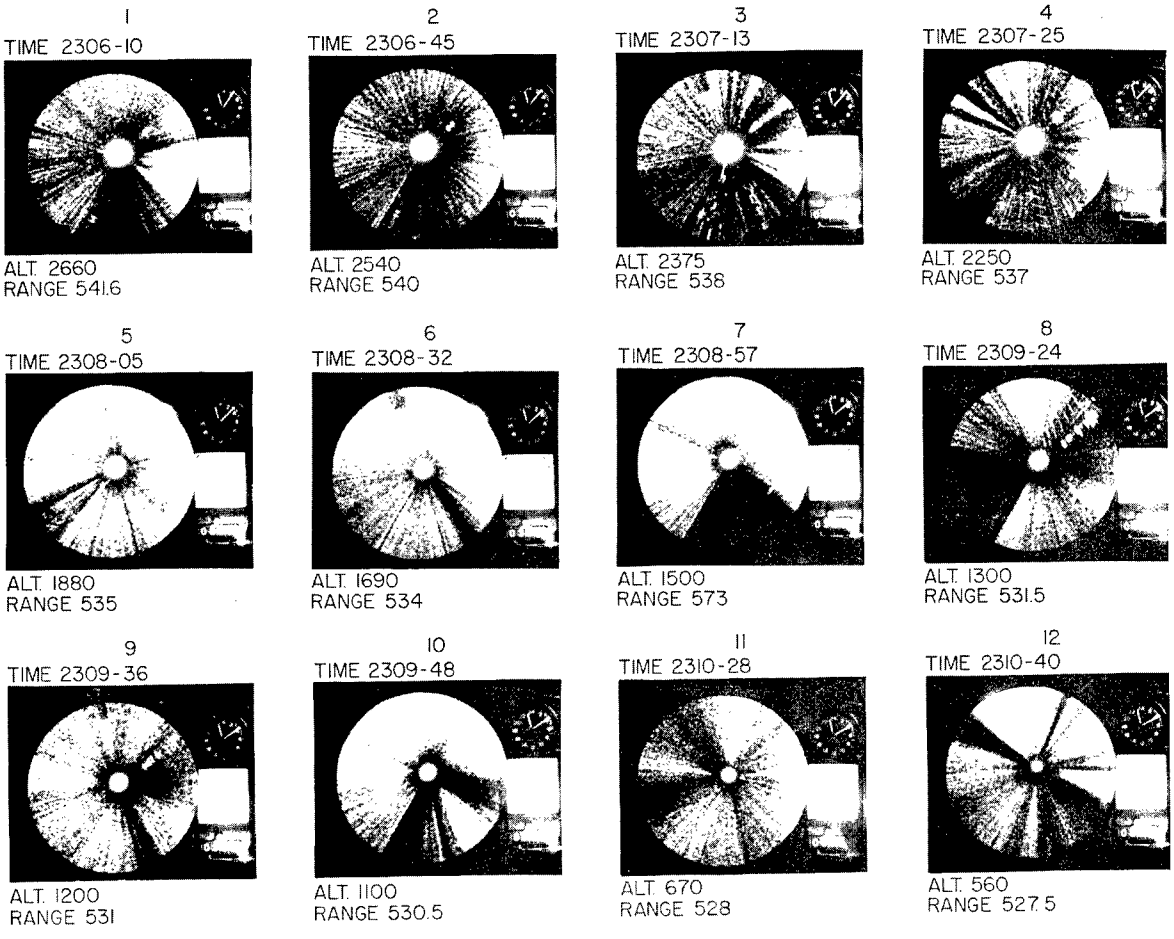

Fig. 12 - Radar PPI photographs of signal buildup and decay associated with vertical soundings through an elevated duct (Mission No. 6 of February 23, 1961)

Considering as a first model a nonstratified or featureless atmosphere for the entire 2260-naut mi path between San Diego and Honolulu, beyond the radio horizon (typically 70 to 90 naut mi for most of the TRADEWINDS IV missions) the received signal power is assigned a decay at the experimentally observed rate of 17 db/100 naut mi. At 400 naut mi the received signal approaches a minimum detectable signal (MDS) level of approximately -100 dbm. From the MDS point, a scatter loss rate of 17 db/100 naut mi is extrapolated to the end of the path, resulting in a predicted signal level of -415 dbm. The nonstratified model represents a condition encountered on one of 18 radar flights.

The second model is representative of average ducting conditions during the year of operation. At a range of 100 naut mi the received signal level is about -19 dbm. From 100 to 980 naut mi the recieved signal is attenuated at a rate of 6.5 db/100 naut mi, while from 980 to 2260 naut mi a scatter loss rate of 17 db/100 naut mi is assigned, so that at the receive terminus the predicted signal level for average conditions is -294 dbm.

The third model is that concerned with optimum ducting conditions. For this case the signal level at 100 naut mi is -17 dbm. From 100 to 1960 naut mi the received signal is attenuated at a rate of 4 db/100 naut mi, and from 1960 to 2260 naut mi the signal is attenuated at the 17 db/100 naut mi rate. Thus, for optimum ducting conditions, the

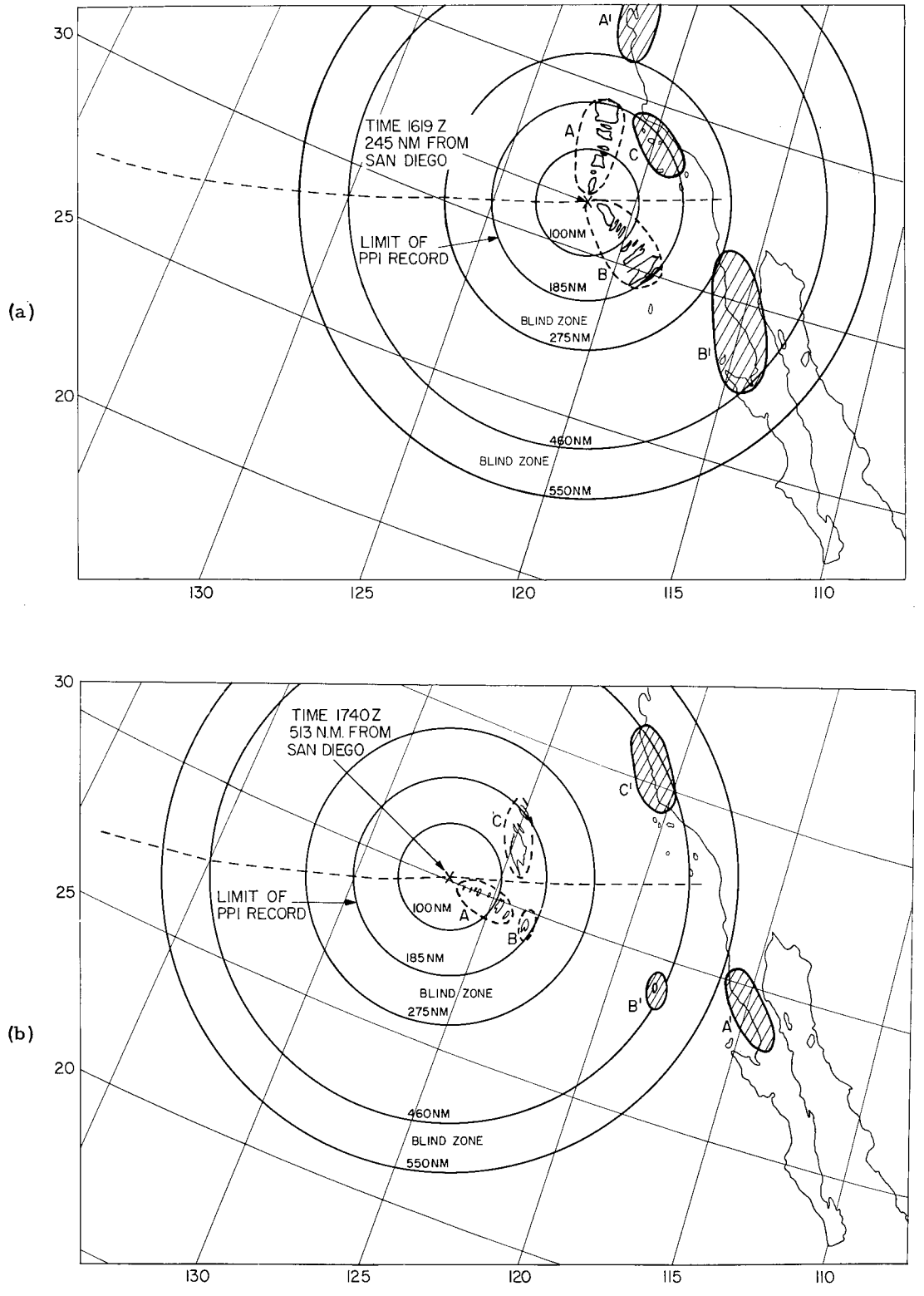

Fig. 13 - Resolution of radar target range ambiguities and areas for Mission No. 19, September 26, 1961. The data are shown for the following ranges from San Diego and times: (a) 245 naut mi and 1619Z, (b) 513 naut mi and 1740Z, and (c) 614 naut mi and 1808Z.

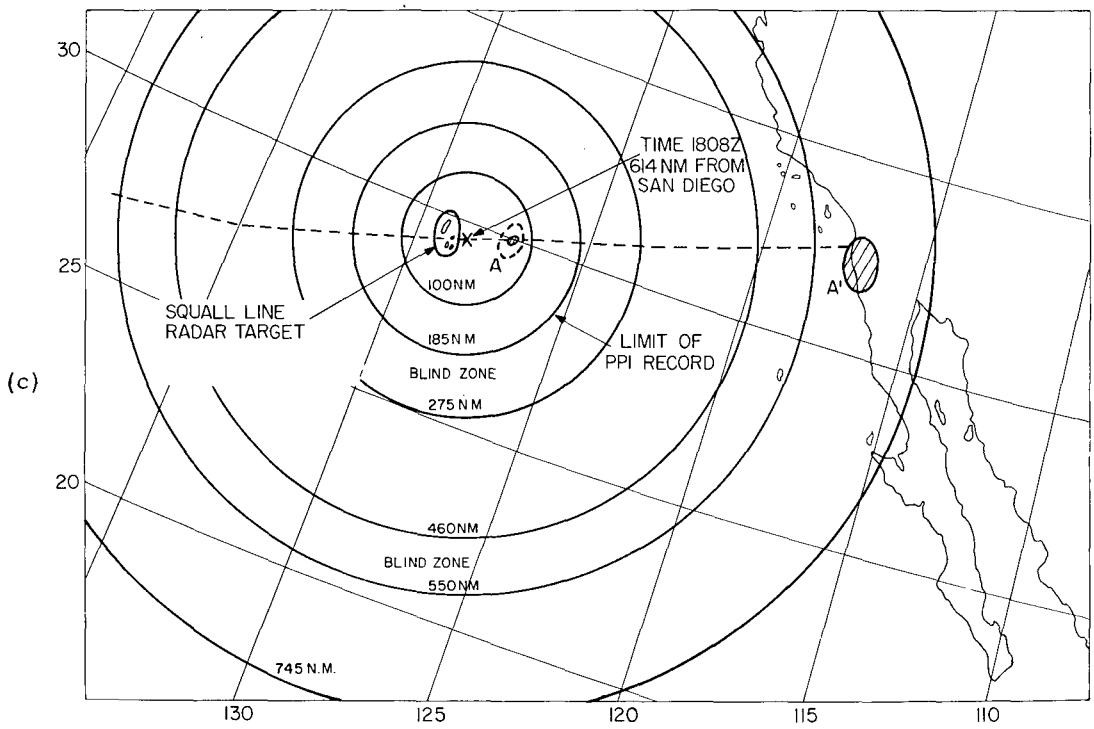

Fig. 13 (cont'd) - Resolution of radar target range ambiguities and areas for Mission No. 19, September 26, 1961. The data are shown for the following ranges from San Diego and times: (a) 245 naut mi and 1619Z, (b) 513 naut mi and 1740Z, and (c) 614 naut mi and 1808Z.

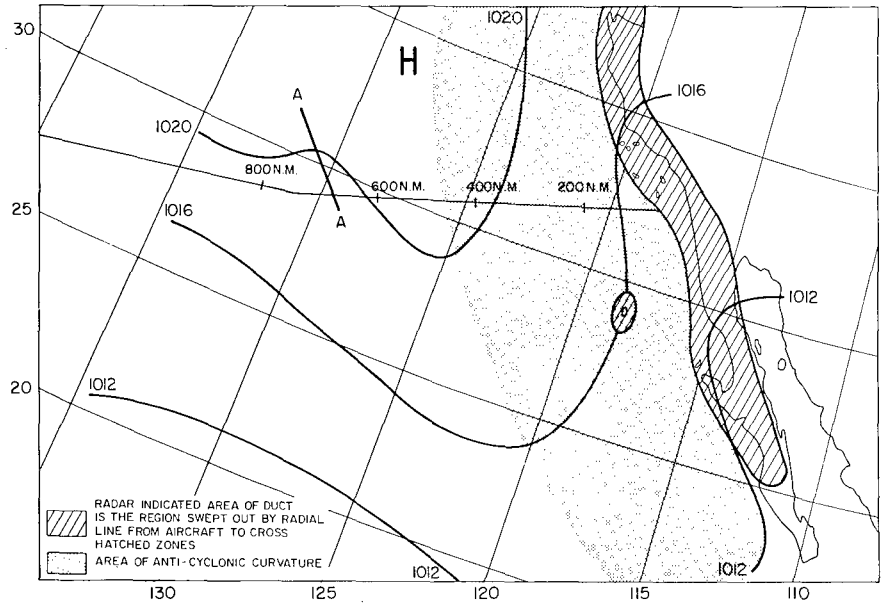

Fig. 14 - Composite of all radar returns during the interval 1619Z to 1808Z for Mission No. 19, September 26, 1961

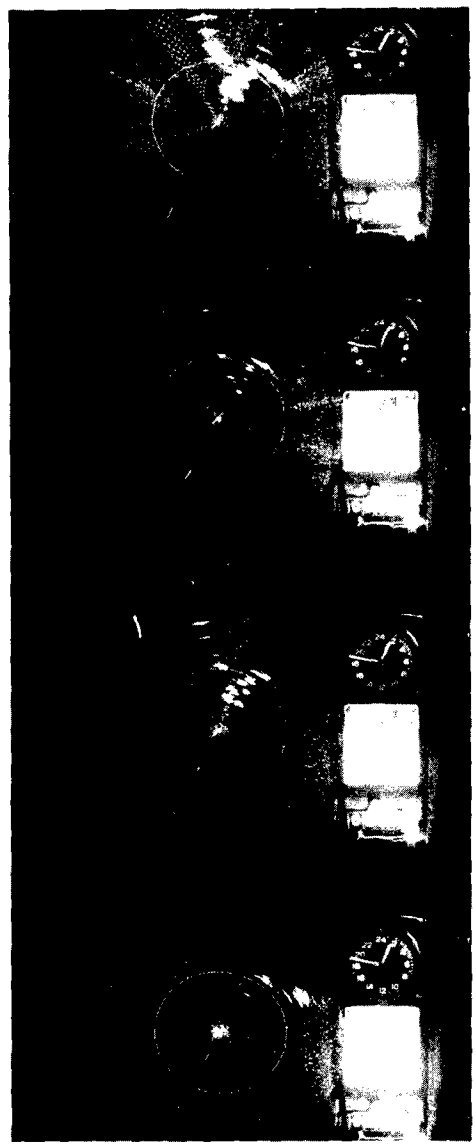

Fig. 15 - Radar PPI photographs showing successive short-term (12-second) variations that sometimes occur in received signal while in level flight within a duct (Mission No. 22, October 13, 1961, 470 naut mi from San Diego)

received signal is determined to be at a level of -142 dbm. The conditions represented in this model were approached by approximately 10 percent of the TRADEWINDS IV missions.

CONCLUSIONS

The airborne uhf radar has proved to be a useful tool for the detection and observation of elevated radio-propagation ducts. Where suitable targets are available the radar provides an instantaneous picture of the strength and extent of a ducting area in all azimuths relative to the position of the aircraft.

The radar data has shown that the ducts off the California coast, on occasions, have an extent in longitude in excess 1200 naut mi while exhibiting a latitudinal spread of greater than 1000 naut mi.

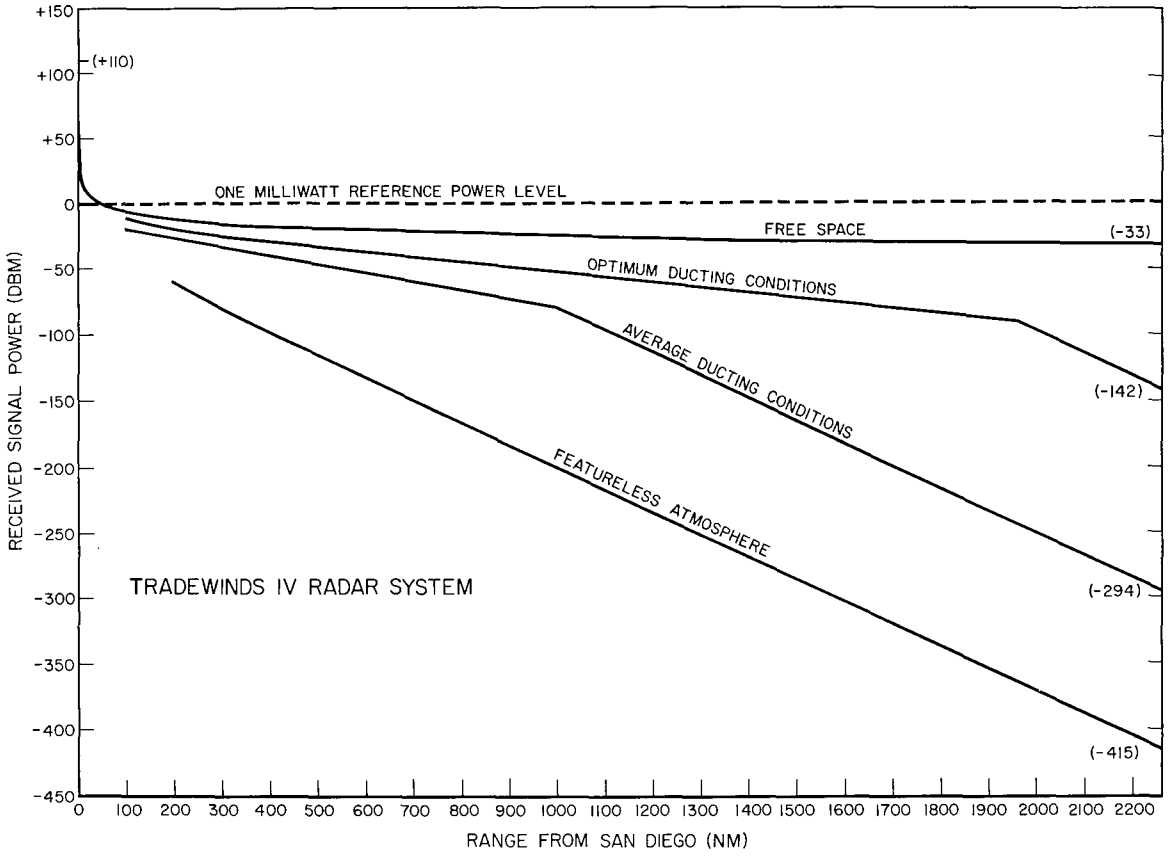

Fig. 16 - Experimental power-loss models for the San Diego to Honolulu propagation path

The attenuation rate for scatter processes of propagation is about 17 db/100 naut mi. Experimentally, in an elevated duct, average rates of 4 db/100 naut mi have been observed for radar paths of over 1000 naut mi.

The existence of elevated ducts off the southwest coast of California capable of sustaining long-range radio-radar propagation was not limited to the summer months. On the basis of data obtained during the 12-month study, there is evidence that the occurrence, strength, and extent of the ducts does not change significantly with the seasons of the year.

UNCLASSIFIED

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13. ABSTRACT

Airborne uhf (435-Mc/s) propagation paths observed during the course of a 12-month study of elevated tradewind ducts (Project TRADEWINDS IV) varied from 240 to 1200 nautical miles (naut mi) as compared with less than 180 naut mi observed for the same system in a standard atmospheric propagation medium.

Out of 18 flights spaced over a year, 17 (94 percent) resulted in the radar detection of elevated ducts. Ten flights (55 percent) resulted in the discovery of ducts which permitted the radar detection of targets at ranges in excess of 500 naut mi.

Radar data has been obtained which shows that the elevated ducts off the southern California coast can have an extent in longitude in excess of 1200 naut mi and a latitudinal extent of greater than 1000 naut mi.

Average attenuation rates as low as 4 db/100 naut mi have been observed for pathlengths of over 1000 naut mi.

The existence of ducts off the California coast capable of sustaining long range radio-radar propagation was not limited to the summer months. On the basis of data obtained during the 12-month study, there is evidence that the occurrence, strength, and extent of the ducts does not change significantly with the seasons of the year.

The airborne uhf radar has proved to be a useful tool for the detection and observation of elevated ducts. Through the observation of ducting radar return signals, it was possible to determine the number, relative strength, height, and the thickness of elevated ducts.

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