INFLIGHT WORLDWIDE VLF EXPERIENCE USING GLOBAL NAVIGATION GNS-500

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ABSTRACT

Throughout five years and thousands of hours of operation, many of the advantages and disadvantages originally envisioned for VLF navigation were borne out by practical experience with commercially available equipment utilizing both VLF Communications and OMEGA Navigation stations. Global Navigation Incorporated proved it possible to design, manufacture and market reliable low-cost equipment which is low in weight and power input requirements. The equipment exhibits excellent long term accuracy with reception unaffected by altitude or terrain. Expected disadvantages to VLF navigation have been experienced as well, and can be grouped into five major areas: reception, signal ambiguity, propagation anomalies, station network geometry, and transmitter reliability. This paper remarks on the positive aspects and details the gravity of the negative aspects as they have proven inflight to be a problem, along with methods used to minimize their detrimental effects. Prospects for truly redundant worldwide signal coverage utilizing either the present VLF Communications Network or the proposed fully implemented OMEGA Navigation chain are analyzed independently, based on both actual experience and computer generated predictions. It is suggested that a combination VLF Comm/OMEGA system is one way to achieve the degree of coverage required.

INTRODUCTION

In 1970, flight testing began on what was to become the first commercially available navigation system based on a worldwide VLF Communications network. This prototype system proved the feasibility of such a base for navigation, and was developed into the Model GNS-200 by

Global Navigation Incorporated. The GNS-200 gained acceptance in many parts of the world but was hampered by the need for increased capability and a computer to ease pilot operating workload. Nevertheless, the operational experience gained in navigating on the VLF Comm signals and OMEGA unique frequencies with this system proved invaluable in developing the next generation system, GNS-500. During and after this time, hundreds of thousands of flight hours have shed more light on the problems which must be dealt with in the development of any VLF Comm or OMEGA navigation system. This paper begins with the GNS-500, as much has been published about the Model 200.

GNS-500 DESCRIPTION

Theory of Operation

The GNS-500 derives navigation information from VLF signals by a phase measurement technique. As all the Comm signals and OMEGA unique frequencies are transmitted on different frequencies, receiver boards must be provided for each of the stations to be received, but decommutation is not necessary. That is, if only these two types of inputs are used, the fact that they are all on different frequencies automatically tells the computer which station just sent which signal. These various frequencies are measured simultaneously and then converted to a common frequency for comparison and processing. As there are so many frequencies being received, position fixing in the OMEGA sense is impossible because signal processing ratios become too complicated.

The GNS-500 is a Rho-Rho system rather than hyperbolic, meaning that lines of constant phase are circles instead of hyperbolas. Each receiver must be initialized and calibrated at the time it first phase locks with a reliable signal. Five times each second the computer measures the phase angle and calculates the distance to each station (whether received or not). These changes in phase angle are accumulated and converted to a change in latitude and longitude from the last computed position. The accuracy of this fix is based solely on the accuracy of the position inserted by the pilot before flight, and any error accumulation after that time.

Use of Frequency Standards

The phase of each received signal is compared with a stable frequency reference carried in the GNS-500. If this reference is of sufficient stability, navigation can be conducted with only two stations being received (assuming a reasonable angle at the receiver position). If the standard is not stable enough for the degree of accuracy required, a third station is necessary to navigate, it in effect acting to stabilize the onboard standard.

The GNS-500 includes both a highly stable Rubidium Atomic Frequency Standard (about one part in ten to the tenth) and a separate quartz crystal local oscillator. Under normal operation, the Efratom FRK Rubidium Standard is used solely to stabilize the less accurate local oscillator and thus allow for navigation on as few as two received signals. This design philosophy of including two types of standards was chosen to allow for navigation before the Atomic Standard has warmed up, or to allow navigation to continue in the Rho-Rho mode despite a failure of the Atomic Frequency reference, provided three suitable signals are present in these cases. This scheme takes maximum benefit from the Rubidium Standard in areas where good navigation depends on it, and in effect releases the system from this dependence when enough signals are otherwise available.

Equipment Description

The GNS-500 is made up of four main boxes. These include:

1. The Control Display Unit (Figure 1) includes the numeric displays, data input keyboard, data selector switch, power and operating mode controls. Physical dimensions of this unit were made to conform with Arinc specifications, and operation of the unit was designed to closely match that of popular inertial navigation systems.

2. The Receiver Computer Unit (RCU) is the heart of the system, containing all of the VLF Comm and OMEGA receivers, the entire microprocessor and memory, boards for interfacing inputs from outside sources and formatting outputs to the aircraft into standard forms, the quartz crystal local oscillator, and the system power supply. The RCU comprises a 3/4 ATR

short box mating with standard Arinc rack and connector.

3. The Optional Equipment Unit (OEU) contains the Rubidium Atomic Frequency Standard and a battery pack to sustain the entire system in the event of short power input loss.

4. The Antenna (Figure 2) is a high speed blade design E-field type which includes a preamplifier in the base. It was chosen as the standard system antenna in lieu of a loop because of higher gain and ease of determining a location for mounting. Although a loop antenna is preferable in conditions producing precipitation static, it is more susceptible to aircraft-generated disturbances, many time necessitating a skin-mapping of the aircraft before installation. In some cases an ADF sense antenna has been used successfully with the GNS-500 through a signal splitter.

The entire system described above weighs 36 pounds and requires 3.7 amps of 28 volts DC, with no requirement for AC power. It is certified for operation to 45,000 feet unpressurized, through a normal operating temperature range of -54 to +55 degrees Centigrade, and for installation in an explosive environment.

VLF STATIONS AND THEIR CHARACTERISTICS

VLF Communications Stations - General

Table 1 - VLF Communications Stations

Ident	Location	Abbrev. on Fig. 3	Frequency kHz
NSS	Annapolis, Maryland	A	21.4
NAA	Cutler, Maine	M	17.8
NBA	Balboa, Panama Canal Zone	P	24.0
NLK	Jim Creek, Washington	W	18.6
NPM	Lualualei, Hawaii	L	23.4
NWC	Northwest Cape, Australia	S	22.3
GBR	Rugby, England	G	16.0
NDT	Yosami, Japan	J	17.4
JXN	Helgeland, Norway	O	16.4
GQD	Anthorne, England	R	19.0

Although the primary mission of the VLF Comm stations is communication, the signals which they radiate are well-suited for navigation as well. Operating between 16 and 24 kHz, they are phase stable to one part in ten to the twelfth or better, and radiate up to 1000 kilowatts of power, many times that of the OMEGA signals. Communication is carried out on these frequencies by frequency shift keying with the transmitter "on frequency" about 50% of the time. The combination of this high density duty cycle and tremendous radiated power provides extremely long reception range and a strong signal-to-noise ratio at the receiver. Even in high-speed maneuvering aircraft, the receiver need not be rate-aided, as the signals received from the Comm stations are effectively continuous.

With all the apparent advantages to navigation on Comm signals come some disadvantages, too. One of the most evident is the weekly maintenance schedule which puts each station off the air for about four to six hours per week. Two of the stations shut down daily (Table 2).

Table 2 - VLF Station Maintenance Schedule

Ident	Day	Time (GMT)
NAA (M)	Monday	1400-1800
NPM (L)	Monday-Tuesday	1700-0200
GBR (G)	Tuesday	1000-1400
NBA (P)	Tuesday	1200-1800
NWC (S)	Wednesday	0000-0400
NSS (A)	Wednesday	1300-1900
NLK (W)	Thursday (1st and 3rd of month)	1700-2200
NDT (J)	Daily	2300-0750
JXN (O)	Daily	0400-0500
		1000-1100
		1600-1700

In addition to scheduled maintenance, some of the Comm stations shut down or shift off frequency for a few minutes every other hour just prior to the even GMT hours (e.g., 0954Z, 1557Z, etc.). Almost all of the Comm stations do this within ten minutes prior to midnight GMT.

OMEGA Navigation Stations - General

One of the most comforting aspects of the OMEGA Network is the peace of mind which comes from knowing one is using stations dedicated to navigation. Although they were dreadfully slow in coming on the air, there are five transmitting today with reasonable regularity.

OMEGA stations transmit 10 kilowatts of power when fully commissioned. Presumably, this level is kept low to limit transmission distance and avoid confusing a receiver which might otherwise pick up the same station from several pathways around the globe.

OMEGA is a time-shared phase system using three different frequencies in a commutation pattern to fix position, and their processing ratios to expand positional ambiguity. It is not possible to utilize any of the three regular navigation frequencies in a pure phase measurement machine such as the GNS-500 without commutation of the signals to figure out which station just sent that last burst of signal. For this reason, the only part of the OMEGA signals which have previously been utilized have been the unique frequencies transmitted for three or five segments out of eight segments from Hawaii, North Dakota, and formerly from Trinidad and Norway. (The newly released Model GNS-500A does commutate the OMEGA navigation signals before phase comparison.)

In our experience using unique frequencies, transmission for three segments of every eight segments seems to be about the minimum acceptable duty cycle density for a non-rate-aided receiver doing phase measurement in a high speed aircraft. The remaining empty segments can be thought of as pure noise during which time the receiver must calculate a phase angle in anticipation of the next signal burst. This tracking task is aggravated in a noisy environment such as precipitation static conditions so that the first stations to drop out are usually the OMEGAs, before the higher power and longer duty cycle Comm stations.

Nevertheless, the capability of utilizing stations which have no regularly scheduled maintenance periods or bi-hourly outages would seem to be a nice supplement to a pure VLF Comm system, if only to sustain navigation during these outage periods in areas where necessary. Unfortunately, even the fully commissioned OMEGA stations must be maintained. This is exemplified by the one month outages for antenna maintenance of both North Dakota and Japan beginning on 2 September and 15 October, respectively. Fortunately, these periods did not overlap.

VLF Comm and OMEGA Signal Reliability

A study was done by the Collins Radio Company to determine signal availability and signal failure duration for both the VLF Comm and OMEGA stations. Data was compiled from all the "Daily Phase Values and Time Differences" bulletins (TSA-4) issued by the U.S. Naval Observatory during one year, beginning September, 1973. The analysis was directed at answering the following two significant questions:

1. What is the probability of having usable transmitted signals for flights of various time duration?
2. When a station fails, how long and with what probability will it stay off the air?

Results of the analysis of actual VLF Comm and OMEGA operating data are summarized below:

Table 3
Probability of Signal Availability (percent)

Flight Time (hours)	2	4	6	8	10
VLF Comm	98.9	98.0	97.2	96.3	95.5
OMEGA	98.2	96.6	95.2	93.8	92.5

Table 4
Probability of Failure Duration (percent)

Failure Duration (minutes)	2	5	10	60
VLF Comm	91.9	75.8	55.9	6.4
OMEGA	92.1	36.3	17.4	4.5

Table 3 shows that 98.0 percent of all four hour long flights will be completed with complete VLF Comm coverage. On the remaining 2.0 percent of four hour flights, when signal outage does occur, 75.8 percent of the time it will last for five minutes or more. Similarly, for OMEGA navigation, signals were available for 96.6 percent of all four hour flights, with 36.3 percent of the outages lasting five minutes or more. (This is the interpretation made by Collins of their data, but it is not clear what minimum number of signals are required by the represented VLF Comm or OMEGA equipment to retain defined "signal availability".)

VLF NAVIGATION CHARACTERISTICS AND PHENOMENA

To produce a truly useful system, OMEGA and Comm navigation system designers must understand and cope with characteristics sometimes peculiar to VLF navigation alone. Those noted inflight to be significant include the following:

A. Antipodal or multipath susceptibility.
B. Signal ambiguities and operation without signals - dead reckoning.
C. Reception geometry dependence.
D. Diurnal phase shift error.
E. Sources of signal attenuation.
F. VLF Comm and OMEGA signal coverage.

Antipodal or Multipath Susceptibility

An example of carrying a good thing too far is the problem which exists when VLF signals reach around the world from different directions. Propagational antipoles are created which are areas of confusion from the receivers' point of view. Figure 4 depicts regions where receivers have been adversely affected by this phenomenon, and the particular Comm stations involved. It has also been noted that these areas change position between night and day. Other areas probably exist in addition, but have not been confirmed in the field. The GNS-500 protects itself from this occurrence by disregarding the position determination from a station which is separated from the receiver by a given maximum distance.

Areas can also exist far from the geographic antipoles where multipath signals will be received under certain conditions. The inherent ability of the receiver to determine the dominant mode plays a part in safeguarding against a detrimental effect on the system. When this safeguard breaks down and an erroneous phase is locked by the receiver, the computer must become involved in ferreting out the guilty signal. As multipath signals normally reveal themselves in the receiver as very high rates of change of position, the GNS-500 computer disregards the input from any station which claims the aircraft has an unreasonable groundspeed, i.e., over a given maximum limit.

Signal Ambiguity and Operation Without Signals - Dead Reckoning

Signal ambiguity is present in a radio frequency carrier primarily because one signal cycle is identical to the next. However, positional ambiguity is resolved up to a 72 mile lane size with three frequency OMEGA by processing the ratios between these frequencies. Indeed, one of the most attractive capabilities of the OMEGA system is its ability to reposition itself in a lane following a signal outage, provided the aircraft remains within the lane. Severe ambiguities occurring in a multi-frequency phase system make minimum signal retention of prime importance to designers. Nevertheless, signal loss can occur (the GNS-500 requires a minimum of two suitable inputs), and position must then depend on a sophisticated form of dead reckoning in order to reacquire a correct position after the return of signals.

Dead reckoning in the GNS-500 employs magnetic heading from the aircraft compass and True Airspeed input either from an air data system or manually inserted by the pilot on the CDU keyboard. These are used together with the last computed wind direction and speed to navigate during periods of signal loss. As these periods are usually of short duration and the dead reckoning reasonable, error accumulated is normally quite acceptable.

There are two conditions most likely to cause dead reckoning. They are heavy precipitation static where the signals are lost in noise, and operation in areas of marginal VLF Comm or OMEGA coverage, usually aggravated by poor station geometry and transmitter shutdowns.

Reception Geometry Dependence

The number of stations received by a VLF Comm or OMEGA navigation system is of importance only if the direction of reception is considered as well. From the Saudi Arabian peninsula, for example, the Comm stations in Great Britain (2), Norway, Maine, Annapolis, Panama, and Washington are all received within a 23 degree angle at the receiver position. This multitude of stations is little better than two transmitters forming the same angle, and the result (assuming there are no other inputs) is minimum acceptable navigation. Figure 5 shows a similar occurrence with OMEGA stations where the area included within the 22.5 degree angle in the Southeast United States is unnavigable with an OMEGA system requiring three stations, even when Japan, North Dakota, and Hawaii are on the air. For OMEGA systems capable of Rho-Rho navigation on two stations, this area is unnavigable with only Japan and North Dakota transmitting.

Diurnal Phase Shift Error

VLF signals are propagated in a waveguide formed by the earth and the ionosphere, so changes in the earth or ionosphere will result in changes in signal parameters such as phase velocity. Diurnal phase shift is the most pronounced variation affecting the signals, being caused by the rise and fall of the reflecting layer. Because this shift is essentially repeatable and predictable, corrections are applied by an analytical model in the computer. The pilot inserts Greenwich Mean Time and the date on the keyboard which are converted to the sun zenith angle, to continuously compute the light and dark portion of the path between the receivers and each station.

Correction in OMEGA systems is more critical than VLF Comm systems because of the lower frequencies used by OMEGA. An error shift of one cycle at 10 kHz involves twice the distance as one cycle at 20 kHz. This frequency dependence is true also of sudden ionic disturbances (SIDS) and other unpredictable changes.

Sources of Signal Attenuation

The usable range of VLF Comm and OMEGA signals is affected by physical factors. A signal will have greater range when traveling over salt water, in an Easterly direction, or on a pathway in darkness. Attenuation of signals occurs over large land masses or frozen areas, in a Westerly direction, and on daylight pathways.

One of the most striking sources of signal attenuation is the island of Greenland. This mass of nonconducting fresh water ice which exceeds 10,000 feet of thickness in the center attenuates all VLF signals crossing it, creating shadows on the opposite side from the transmitter. These shadows have surprisingly well-defined borders as shown in Figure 6 for the Comm stations in Great Britain, Japan, and Australia.

VLF Comm and OMEGA Signal Coverage

Actual results of Comm station usability measured and flown around the world over the last six years are shown in Figure 7. Station symbols depicted in capital letters over an area are considered prime navigable stations. Those shown in small case are weaker secondary stations which are of benefit at night or of limited use midday. It should be noted that at this time (November, 1975) Hawaii Comm (L) is off the air for maintenance and Annapolis (A) is transmitting on a special format, removing them from the picture at present. (A modified Annapolis receiver has been made to track the minimal shift keying format now being experimented with, but is not at present in the field.)

Figure 7 shows, for most areas of the world, more than minimum Comm coverage even during station maintenance. In fact, this has been the experience of the GNS-200 and GNS-500 and one reason for their commercial success. It has been proven beyond a doubt that navigation is easier on signals which are available, although not dedicated to navigation, than with stations not yet commissioned.

"Omega 10.2 kHz Signal Coverage: Local Noon", Figure 8, comes from a report entitled "OMEGA Signal Coverage Prediction" written by representatives of the Analytic Sciences Corporation of Reading, Massachusetts, and the OMEGA Navigation System Operations Detail of the U.S. Coast Guard. The figure is a composite diagram on which all the -20 dB signal-to-noise ratio contours are plotted for the planned full OMEGA network.

Several assumptions were made. OMEGA coverage was defined to exist where the signal-to-noise ratio is -20 dB or better in a 100 Hz bandwidth. Under these conditions, a well designed receiver is capable of making an accurate phase measurement, and in fact, the experience gained by OMEGA tracking of the GNS-500A affirms many of these contours. Each coverage limit line is labeled by the appropriate station with an arrow in the direction of the usable signal.

Figure 9 depicts world areas to expect three OMEGA station reception, this diagram being simply a compilation of the information contained in Figure 8. As three stations is the minimum number of signals that some OMEGA systems are designed to operate with, and this study has assumed that all eight of the stations are operating, it is seen that areas of the world will be lacking if any one station is shut down.

The next figure shows areas to expect two OMEGA station reception with all eight at full power. These will be areas of minimum acceptable navigation for those systems capable of Rho-Rho fixing from only two stations, and will be areas of dead reckoning for systems requiring three stations. Given the assumptions that Liberia and La Reunion come up as scheduled, that the South Pacific station finds a home and begins transmitting, that none of the eight stations ever leave the air for maintenance as have North Dakota and Japan recently, then Figures 9 and 10 should be the best OMEGA coverage situation that the world should expect.

CONCLUSIONS

The U.S. Navy and Department of Defense seem to lack the desire to accept a dual mission for their VLF Comm stations to include navigation. The signals are on the air as they have been for years, they are high powered, phase stable, and suitable for navigation. The DOD has at least stated recently that they do not intend to shut down the Comm stations, but offers no blessing to users or the FAA. Even so, the free availability of such signals should be considered a valuable national resource, and treated as such.

Navigation on VLF Comm or OMEGA has advantages and disadvantages. Figure 11 shows the VLF Comm signals usable in areas of two and three station OMEGA reception. The OMEGA Network is just what the doctor ordered for supplementing VLF Comm navigation, or it can be said that the Comm stations can provide help where the OMEGA is lacking. There are many methods open to system designers, many ways to place emphasis. Through the experiences gained in all types of VLF navigation with the GNS-200 and GNS-500, the Model GNS-500A has evolved as Global Navigation's answer, and the first VLF system to receive up to sixteen stations.

33480 N
118200 W
LEG CHG
01
1
WPT DEF
VLF DR
FR TO
DIS/ETE
DA/GS
BRG/VAR
TK/TKD
WPT
XTK/SX
POS
/IND
GMT/DATE
TAS
OFF
A
C
ENTER
GLOBAL NAVIGATION INC.
VLF·OMEGA
L 1
N 2
R 3
W 4
5
E 6
7
S 8
9
0
BACK

Figure 1

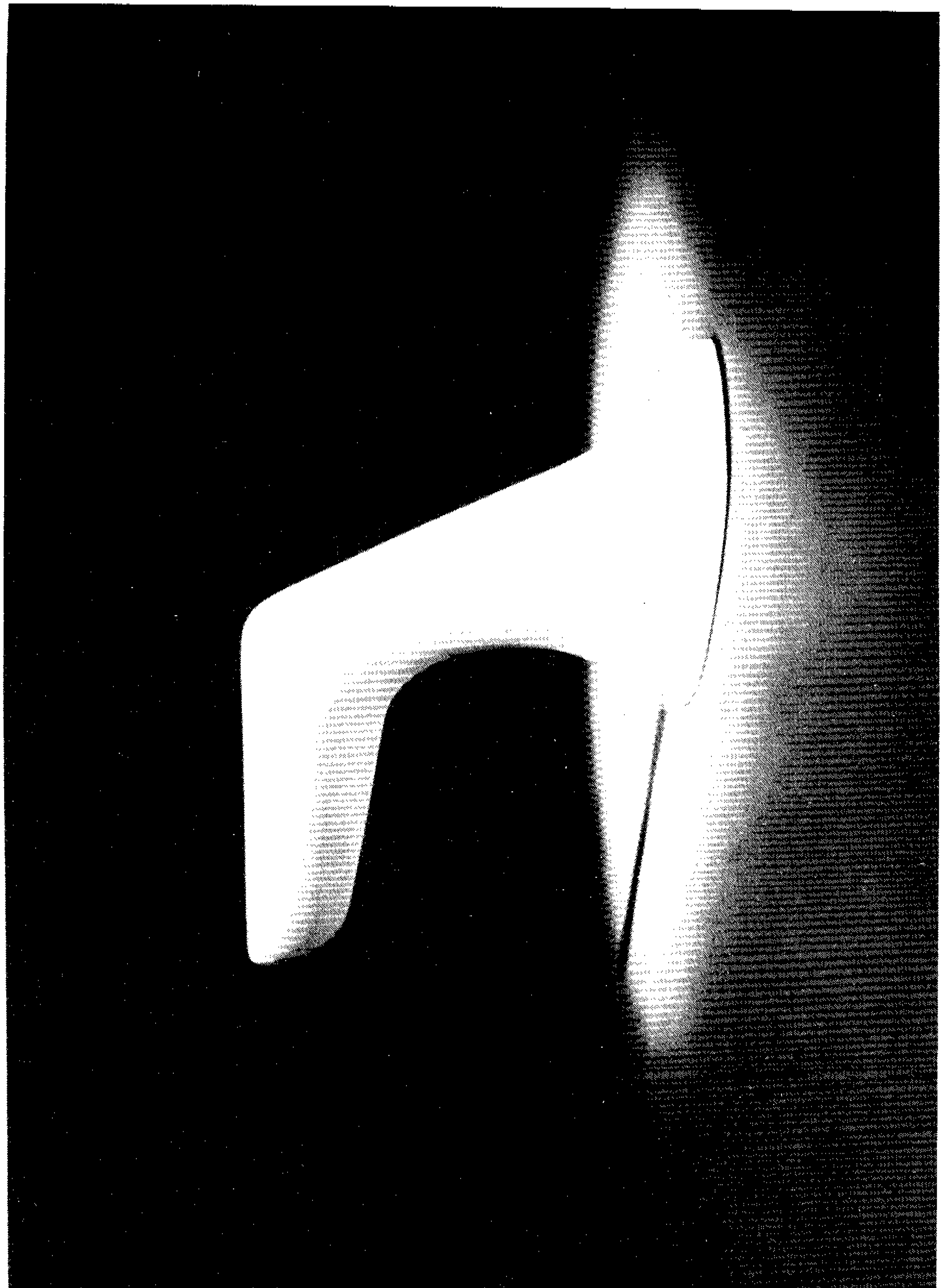
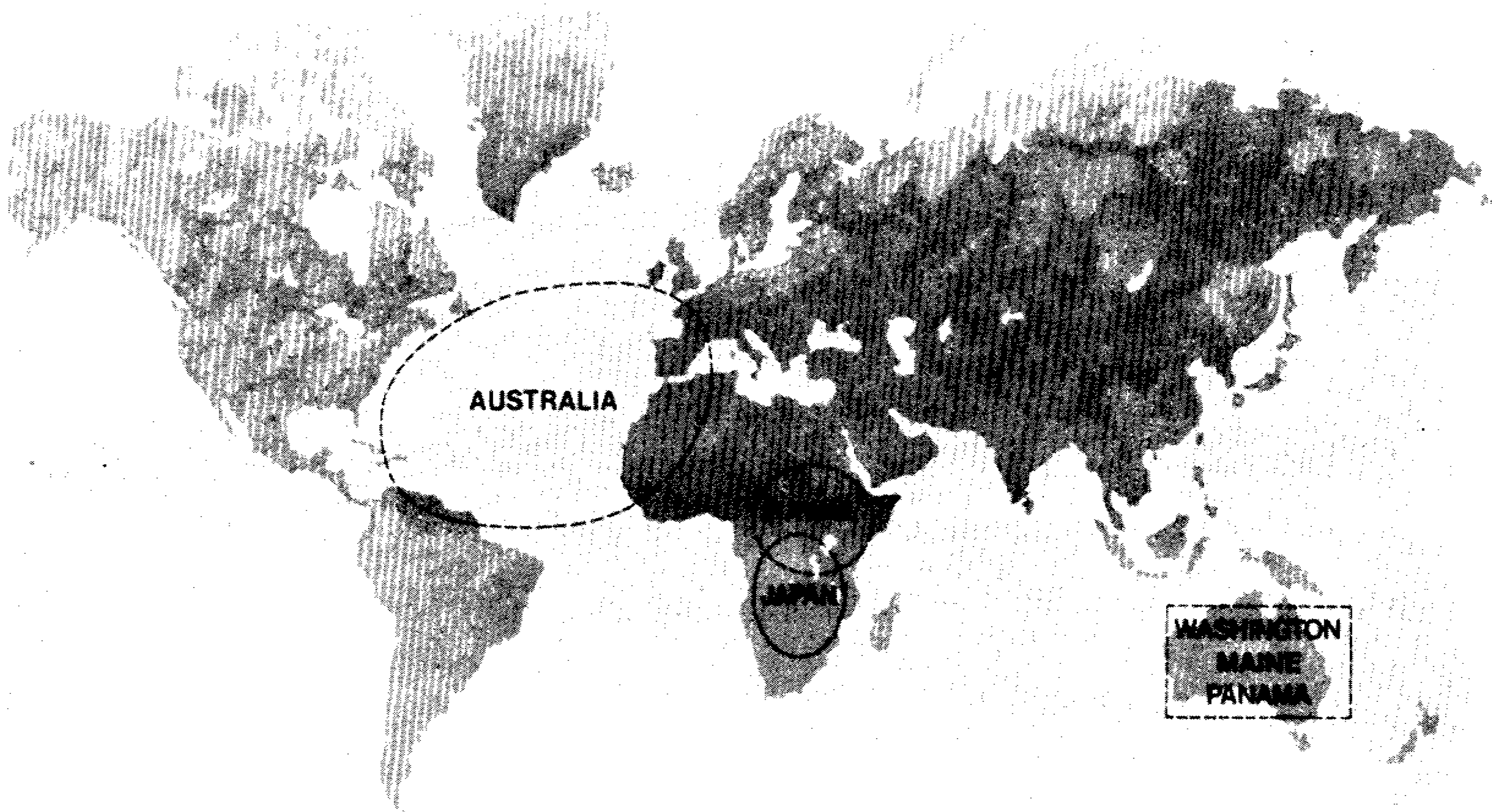


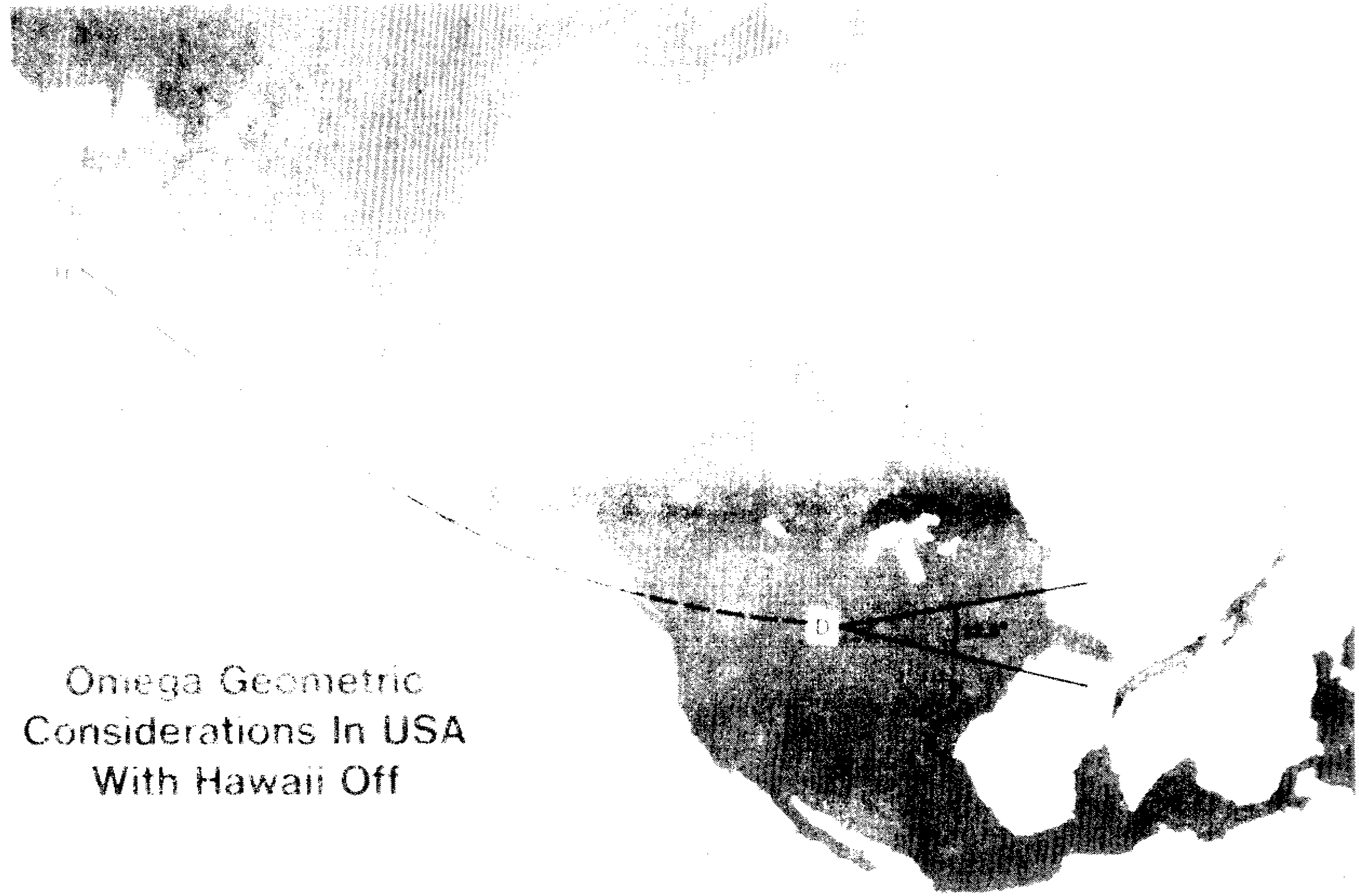
Figure 2

Worldwide VLF Comm Omega Network Used by GNS-500A

Figure 3

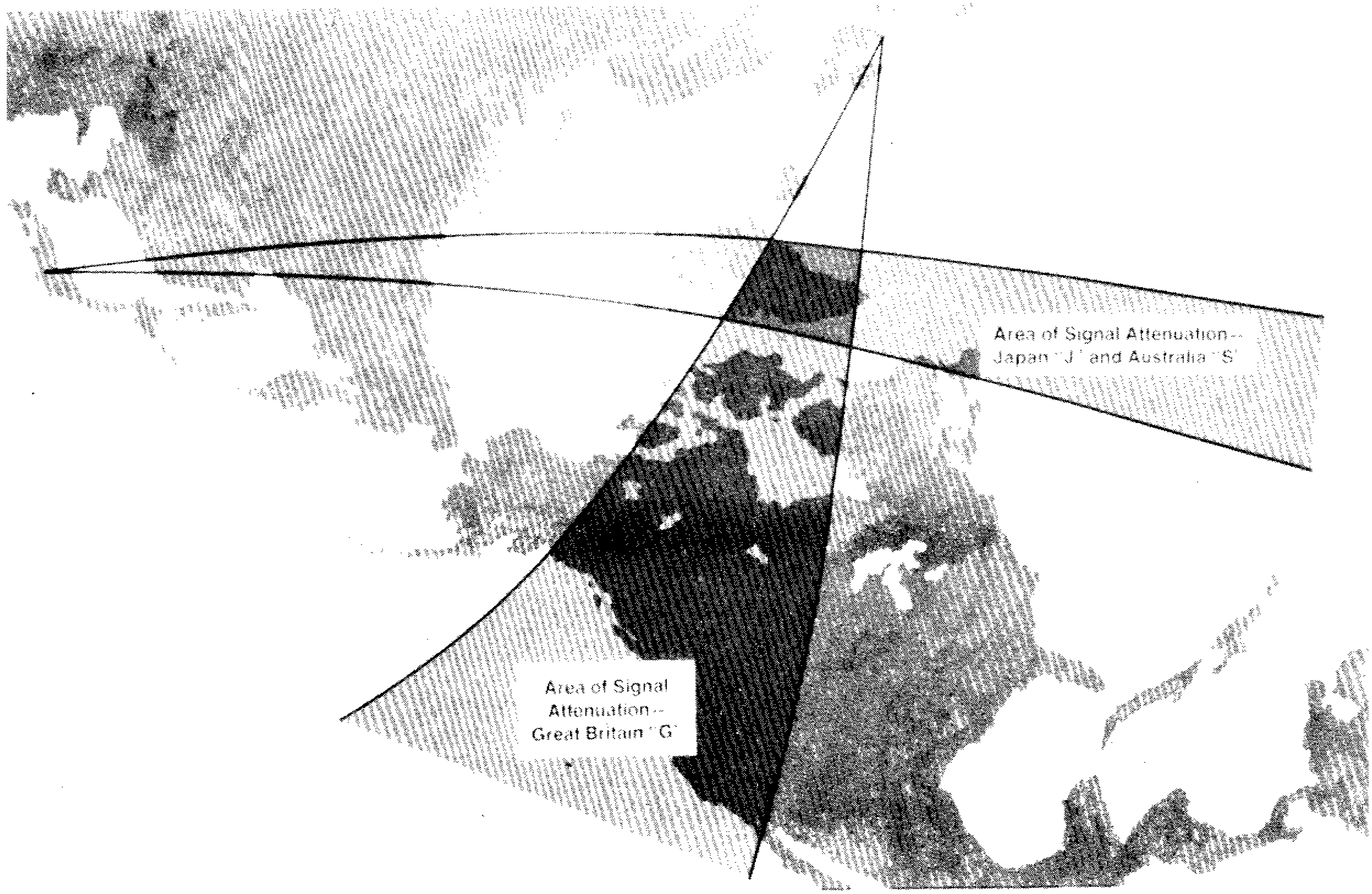


Areas Where Antipodal Or Multipath Activity
Has Been Experienced Inflight



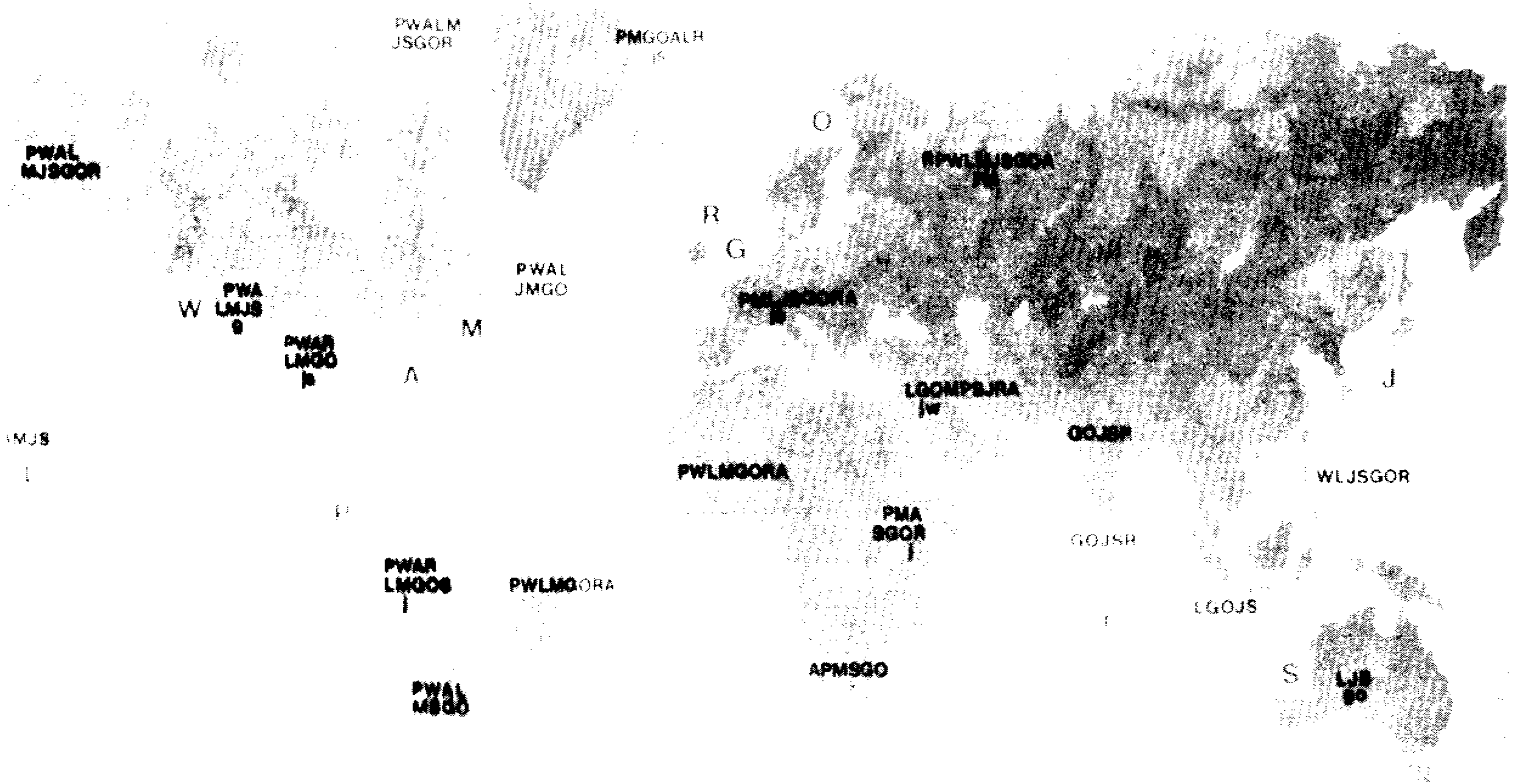
Omega Geometric
Considerations In USA
With Hawaii Off

OFF



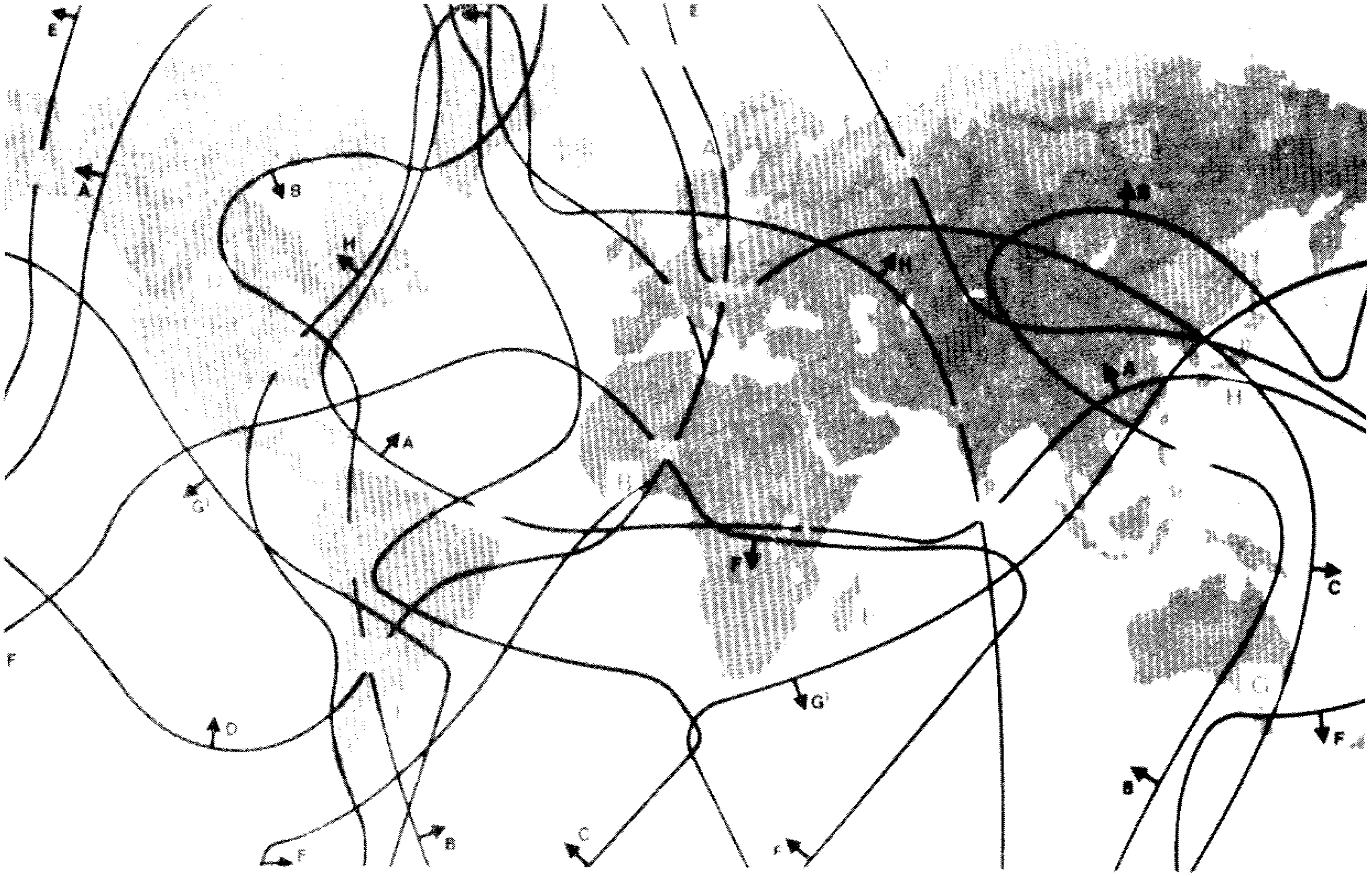
Effect Of Greenland On VLF Propagation

Figure 6



Primary Secondary VLF Comm Usability

Figure 7

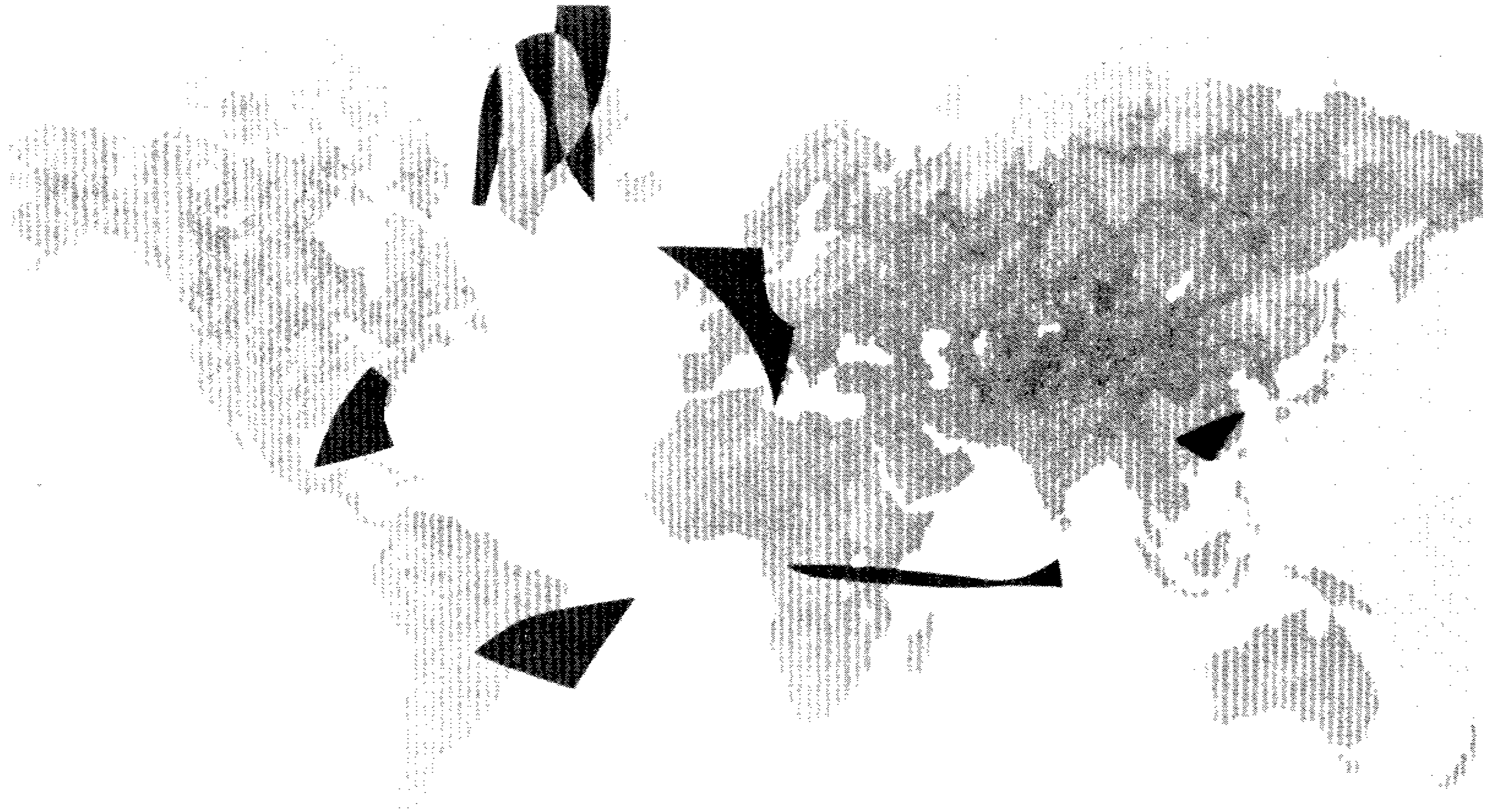


Omega 10.2 KHz Signal Coverage Local Noon

Figure 8

World Areas To Expect Three Omega Stations At Local Noon Assuming All Eight Operating

Figure 9



World Areas To Expect Two Omega Stations At Local Noon
Assuming All Eight Operating

Figure 10

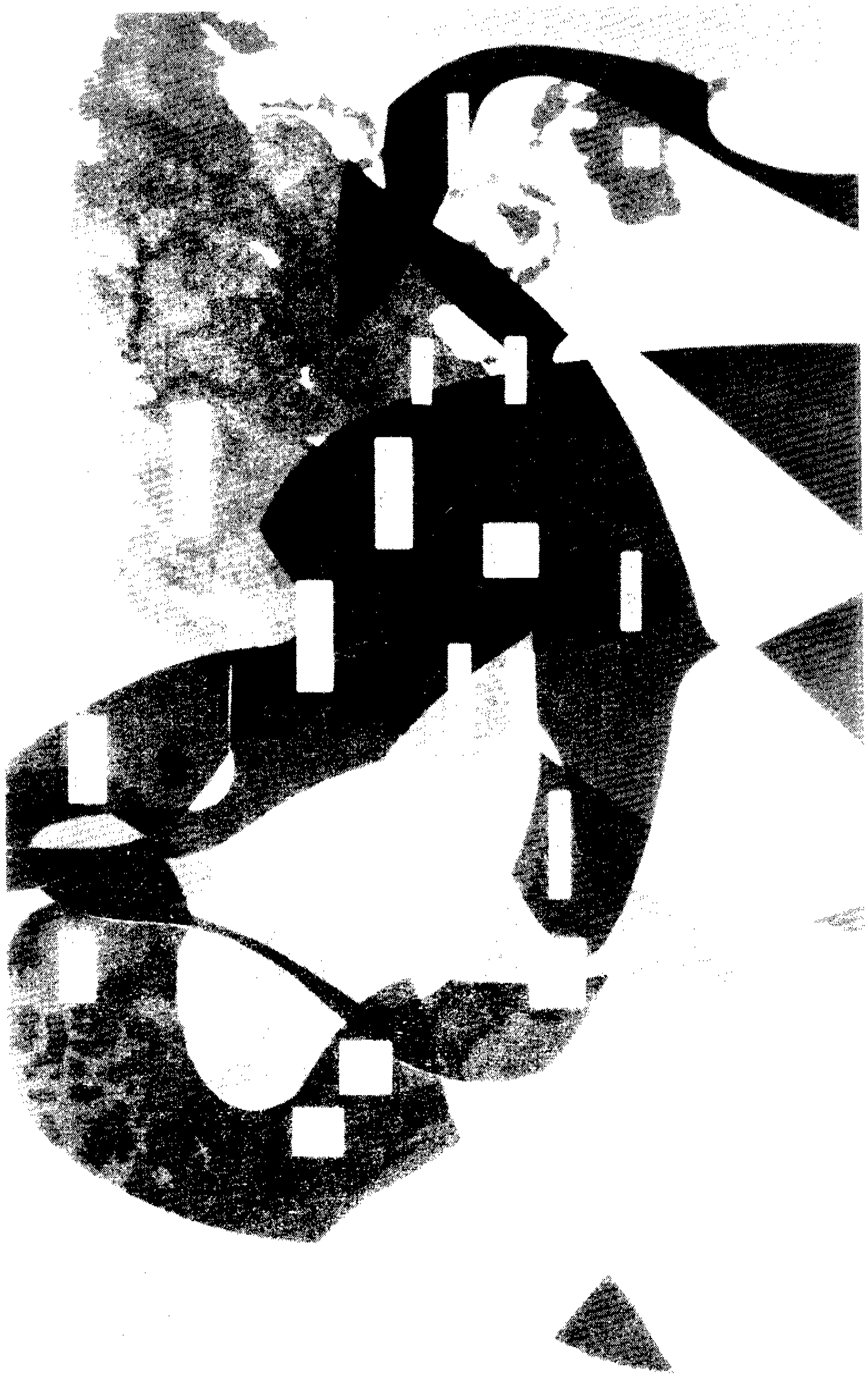


Figure 11

QUESTION AND ANSWER PERIOD

MR. STONESTREET:

Bill Stonestreet, Draper Laboratory.

You mentioned that you have a commutator in the Omega receiver or in your VLF receiver, that commutates or synchronizes to the Omega transmission. Would you care to expand on that?

MR. TYMCZYSZYN:

What we do is, we use a 10.2 frequency, and it takes the computer about three minutes in the beginning after you switch it on to commutate if you are receiving at least two stations, including 10.2. Then it uses the 13.6 phase angles actually to navigate with.

MR. STONESTREET:

Is it an amplitude correlation or is it done in phase?

MR. TYMCZYSZYN:

I am sorry. I can't answer that. I don't know.

MR. STONESTREET:

Okay, fine. I would also like to say that I like your test pattern.

MR. BARSZCZEWSKI:

Barszczewski, National Research Council.

I would just like to make a comment. First of all, all VLF Omega navigation systems are only 99.5 or whatever proof, because you have other anomalies like sudden disturbances and polar cap absorption, whatever gives, that makes sometimes the data quite unreliable, and as far as the coverage, I think there is some excellent publication by NRL quite recently by a gentleman named Houser, that gives excellent predictions: signal-to-noise ratio and signal strength for VLF stations worldwide, and this particular thing is very useful to me. We have spotchecked a couple of times, and it verifies very nicely.

MR. TYMCZYSZYN:

I would like to see that report. I in my own experience have found that a few of those lines have matched the ability of our receivers to receive the Omega. Of course, anytime besides local noon, I have had better results. In fact, on a flight recently in California, I was receiving 13 stations. That was 8 Comm stations and 5 Omega stations, but we have to assume that some of our customers want to fly at local noon.

DR. REDER:

There are two areas according to our experience with VLF monitoring which are a big problem no matter what the prediction says. One is the area around Australia because of the problem of Omega signals from Haiku, due to mode interference; and No. 2 is the area around the Indian Ocean and Madagascar. The reason there, is antipolar inter ference. For instance, Japan Omega to Madagascar is very heavily contaminated by antipolar interference.

It is interesting to note that NDT, which is in the link, Japan-to-Madagascar, is mixed with antipolar signals, but the same signal over the same pathlinks, just with the slightest different angle going down towards La Reunion -- that is a French Island a little further south -- is not mixed. So it just shows how important the angles in the magnetic field are.

DR. WINKLER:

Unless somebody else has something to say to the question of why the Navy does not want to sanction or bless the use of the VLF communication signals for navigation; I would like to clarify that. There are a variety of reasons why the communications service cannot accept responsibility for the consequences of the use of these signals other than communication. However, I can assure you that there is a sufficient interest in the department of defense to assist any user as much as possible with this information, and it is for that reason that the Observatory Bulletins and also messages and the telephone service, which is an answering service, will provide improved information on the availability of these signals and down times as much as it can.

One of the reasons why a responsibility for navigational use cannot be accepted is that indeed, as has been mentioned before, some of the stations will begin testing with other modes of operations, and minimum shift keying is one of them. Also, in view of the use of these stations for priority communications, there is a possibility of rather short notice on frequency changes or unannounced frequency changes, but if you look at the record over the last ten years, these have been less so than any other service.

MR. TYMCZYSZYN:

If I might make a comment, we have had excellent relations with the Navy. They have been very good at giving these reports, not only to us, but to our customers, and we have had a little more trouble with the Department of Defense. In fact, one of our customers wrote a letter to the Department of Defense, a general inquiry, saying I am using your system and on and on, just to put in another point for us. He got a very stern letter back, and he called us up and read us this letter, and said, "Boy, the Department of Defense doesn't seem to be on your side. By the way, I would like two more GNS Systems next month."

DR. REDER:

But, Mr. Tymczyszyn, don't you know that the Navy is a part of the Department of Defense?

Well, isn't it really that they don't want to bind themselves, because they cannot guarantee that they won't go off the air? I think that is the most important thing.

DR. WINKLER:

I am not disputing anything which has been said, but the requirements for the communications are practically identical. Communication signals must stay on the air, and every possible measure is taken to assure that. I think the real reason is one of keeping one's liberty to make changes in an emergency must be preserved, but fortunately that has never been used in the past, not yet.

DR. REDER:

Before we go to the next paper, I just would like to mention one thing. We had oodles and oodles of VLF phase and amplitude recording at Fort Monmouth. Dr. Winkler has the same amount, almost, of VLF phase recordings in Washington. If you need any information, please contact us. The stuff is all available.

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One more comment to what was mentioned about the PCA's of polar cap absorptions, I think the PCA problem is probably the least worrisome, for the simple reason that protons are very bad, but they have one very nice feature -- they come in such a mass that actually phase stability during the PCA is rather good on this northern path, and it is one that has started, more or less predictable of what will happen in the next couple of days, which you cannot say for solar x-ray flares. The worst things are solar x-ray flares No.1; and No. 2, in certain areas, electron precipitation from the belts.

Fortunately, this area is rather limited, but this is the worst, because they are very poorly predictable.