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RESULTS OF THE LONG RANGE POSITION-DETERMINING SYSTEM TESTS

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ABSTRACT

The Long Range Position-Determining System (LRPDS) has been developed by the Corps of Engineers to provide the Field Army with a rapid and accurate positioning capability. The LRPDS consists of an airborne Reference Position Set (RPS), up to 30 ground based Positioning Sets (PS), and a Position Computing Central (PCC). The RPS transmits a PN modulated VHF carrier which is received by the PS units. The units measure the range changes to the RPS over a given data gathering period and transmit the range change information to the PCC via RPS sequentially. The PCC calculates the position of each PS based on the range change information provided by each Set. The positions can be relayed back to the PS again via RPS. Each PS unit contains a double oven precise crystal oscillator. The RPS contains a Hewlett-Packard Cesium Beam Standard. Frequency drifts and off-sets of the crystal oscillators are taken in account in the data reduction process. A field test program was initiated in November 1972. A total of 54 flights were made which included six flights for equipment testing and 48 flights utilizing the field test data reduction program. The four general types of PS layouts used were: Short Range; Medium Range; Long Range; Tactical Configuration. The overall RMS radial error of the unknown positions varied from about 2.3 meters for the short range to about 15 meters for the long range. The corresponding elevation RMS errors vary from about 12 meters to 37 meters.

INTRODUCTION

The Long Range Position-Determining System (LRPDS) has been developed by the U. S. Army Engineer Topographic Laboratories to provide the Field Army with a rapid and accurate positioning capability. Specific objectives of LRPDS are: (a) Provide combat survey throughout an Army Corps area; (b) Provide multiple positioning capability within a required area; (c) Accomplish survey and positioning missions in a required time frame.

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SYSTEM DESCRIPTION

The LRPDS consists of a Position Computing Central (PCC), an airborne Reference Position Set (RPS), up to 30 ground based Positioning Sets (PS), and a Maintenance Set. The PCC controls the complete mission and calculates the locations of all PS. It consists of a transmitter-receiver unit, a computer, a mission control and monitor unit, communication equipment and other auxiliary equipment. The PCC is housed in a truck mounted van. The airborne RPS consists of a transmitter-receiver unit, a data processing unit, a cesium clock (H. P. H0I-5062C), a control and monitor unit, and an altimeter. During the ranging period of a mission the RPS transmits ranging signals to the PS. During the data transmission periods of the mission the RPS receives commands from the PCC or functions as a relay between PCC and PS. The PS consists of a transmitter-receiver unit, a crystal oscillator, a data processor, a data display unit, and a battery. The PS extracts ranging data from the ranging signal, stores the ranging data, and transmits the ranging data upon completion of the ranging period to the PCC for data reduction. The Maintenance Set is housed in a truck mounted van and contains instrumentation and facilities to support field maintenance of the LRPDS equipment. The LRPDS operates on a single carrier frequency which can be tuned between 260 MHz and 440 MHz in steps of 10 MHz. The carrier is bi-phase modulated by a pseudo noise (PN) code having a code length of $2^{13}-1$ bits or 245.73 Kilometer. The RF output of the transmitter of the transmitter-receiver unit can be set for one watt or five watt. The acquisition threshold of the receiver of the transmitter-receiver units is -113 dBm and the signal acquisition time is less than 10 seconds. The receiver employs code tracking for coarse ranging and carrier tracking for fine ranging. The resolution of the system is about 12 centimeter. The overall range error caused by the equipment is less than 1.5 meter.

SYSTEM OPERATION

A typical LRPDS mission consists of five phases: (a) Preparation and initialization; (b) Ranging; (c) Data collection; (d) Data reduction; (e) Data transmission. During preparation and initialization all messages and commands necessary to execute a mission are put together in proper sequence and transmitted to the RPS and stored in the processing unit. The messages and commands are transmitted to the PS according to mission schedule. In the second phase the RPS transmits ranging signals and commands to the PS which in turn extract and store the ranging data. The ranging data are obtained by measuring the time of arrival of the ranging signals from the RPS over preselected sampling periods. The measurement M taken over one sampling period t consists of several components which are shown in Figure 1. All components of the equation shown in Figure 1 including the measurement M have the same physical quantity of length.

$$M = \Delta R + at + b\frac{t^2}{2} + N_R + N_O + P\Delta R$$

ΔR = Range Change

a = Frequency Offset

b = Frequency Drift

N_R = Receiver Noise Error

N_O = Oscillator Noise Error

P = Propagation Scale Factor

Figure 1.

ΔR is the range change between PS and RPC occurring during one sampling period. Frequency offset a and frequency drift b are considered as being constant during the ranging period and are determined and accounted for in the data reduction process. Receiver noise error and oscillator noise error are included in the overall range error caused by the equipment. The propagation scale factor takes in consideration the existence of the atmosphere. The factor is estimated and improved in the data reduction process. During the data collection phase the ranging data are transmitted in a preselected sequence from the PS to the PCC via RPS. The ranging data are processed and computed to PS location coordinates by the PCC during the data reduction phase. During the data transmission phase, messages and location coordinates are transmitted from PCC to the PS via RPS as required. Figure 2 shows a typical operational layout for LRPDS.

SYSTEM FLIGHT TESTS

The field test program was initiated in November 1972 and completed in January 1973. The primary purpose of the flight tests was to evaluate the accuracy of the system in actual field use. Four general types of Positioning Set layouts were used:

a. Short Range — Nine position sets uniformly distributed in a 30 km x 30 km area with the tenth PS located at various positions outside this area ranging from 10 km to 30 km from the perimeter.

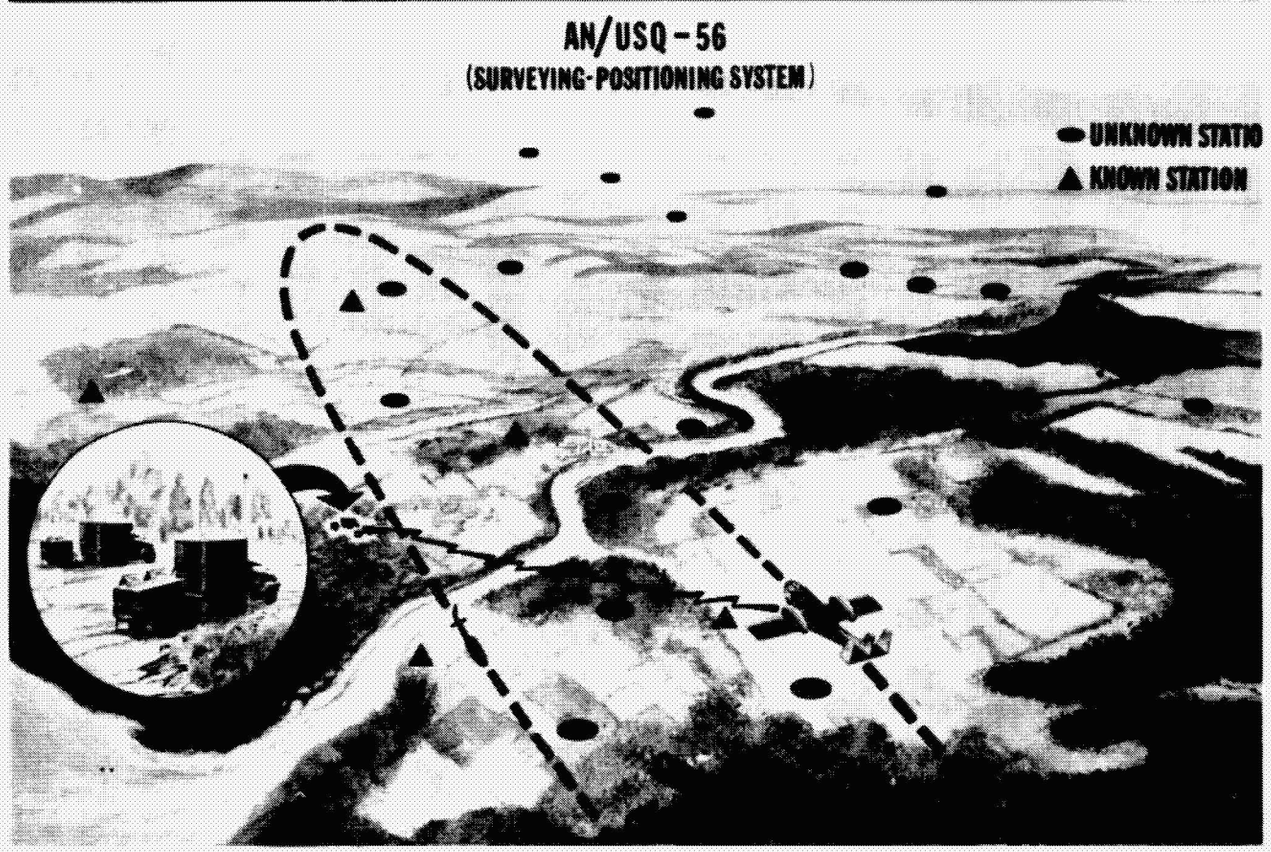
b. Medium Range — Nine to ten position sets distributed through a 60 km x 60 km area. The tenth set during some tests was located in the vicinity of the PCC.

c. Long Range — Eight to nine position sets distributed throughout a 60 km x 60 km area with one or two position sets located at positions 180 km in distance from the center of the 60 km x 60 km area.

d. Tactical Configuration — Eight to nine position sets placed in a 60 km x 60 km area with six of the sets placed in the top third of the area.

The test area used included part of the Casa Grande and Arizona Test Range. Twenty-five presurveyed sites in a 60 km x 60 km area were used as position set locations. The survey of the PS locations was accomplished by a super first order survey method which kept the survey errors of the positions down to a few centimeters. In addition to these sites, two sites located in the Yuma Test Range near Stoval were used to evaluate the long range capability. The PCC was located at the Motorola Plant in Scottsdale during all the tests. Figure 3 shows a map of the general 60 km x 60 km area with the site locations.

LRPDS OPERATIONAL SET-UP



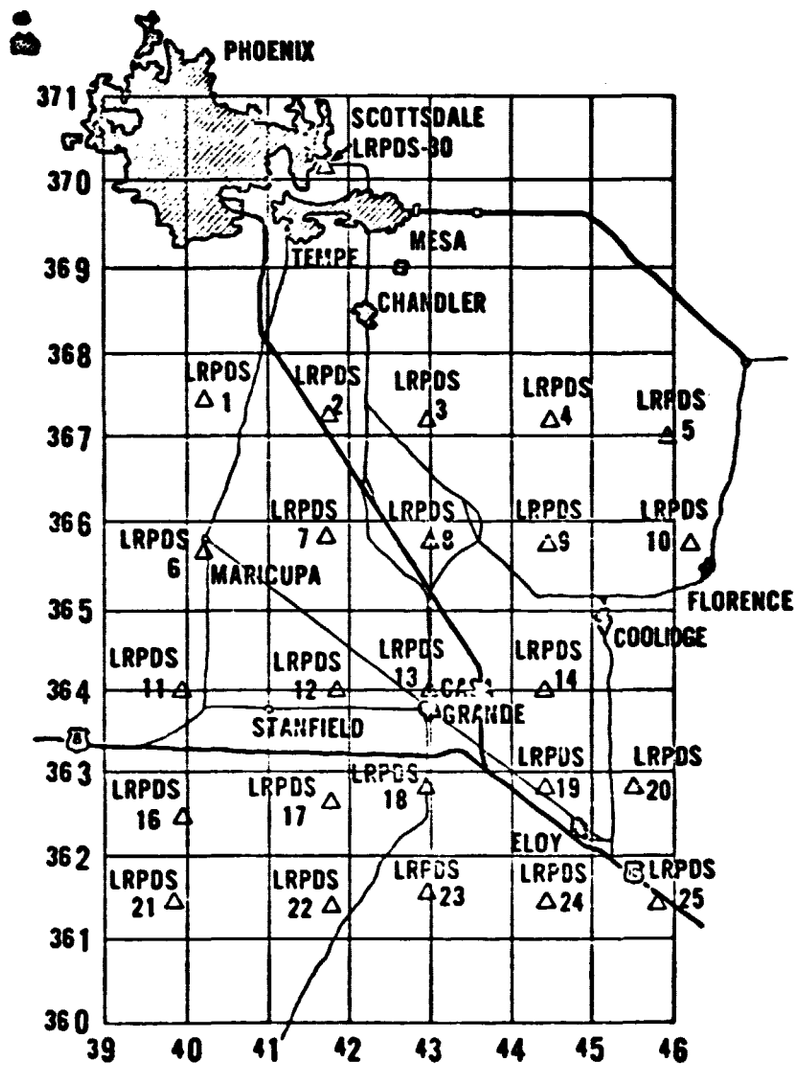


Figure 3. LRPDS Site Locations

A total of 52 flights were conducted including 62 missions for a variety of purposes. Of these, 15 missions were evaluated for Short Range Tests, 15 for the Medium Range Tests including the Tactical Configuration, and four for Long Range Tests. The other missions were devoted to Equipment Check Flight Tests.

A number of flight patterns were used throughout the tests. In each case each flight pattern generally consisted of one loop at one altitude followed by a second nearly identical to the first but at a different altitude. Figure 4 shows a flight pattern

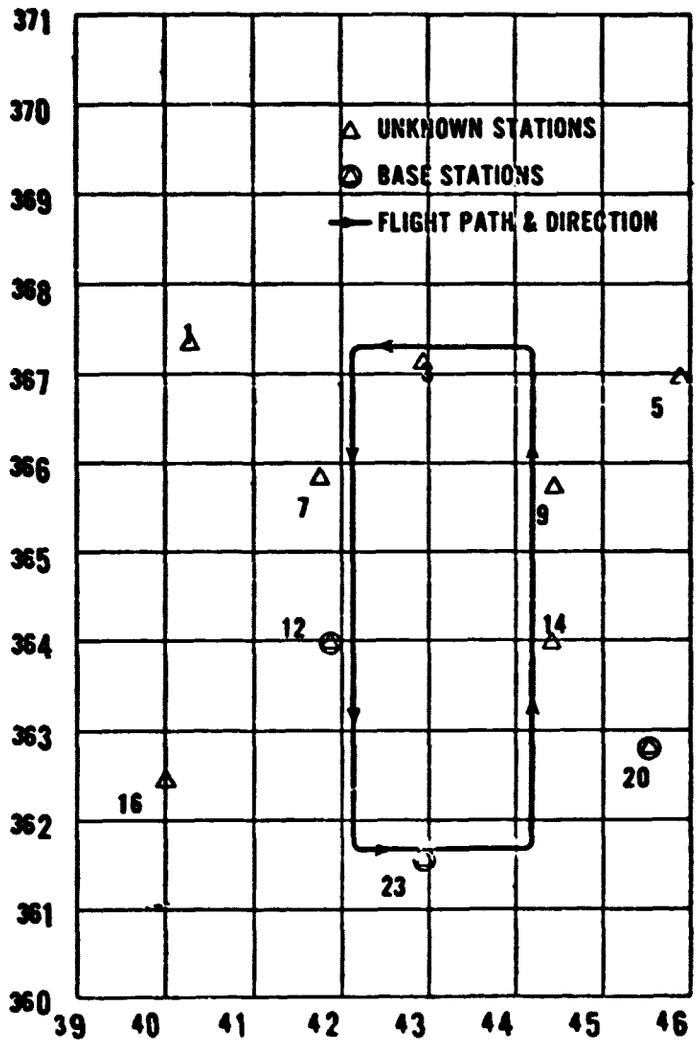


Figure 4. LRPDS Station and Flight Geometry

having a favorable geometry relative to the indicated ground stations. Figures 5 through 7 show some of the results of the Short Range Tests. The numbers in the figures are the easting, northing, and elevation errors of the positions measured by LRPDS with reference to the positions determined by survey. The positioning errors are measured in meters. Figures 8 through 10 show some of the results of the Medium Range Tests. Figure 5 through 10 show also the mean and root mean square of the errors of the individual stations.

FLT NO.	SITE NO. 2	3	6	7	12	13
7	2.9	3.1	- .8	2.1	1.0	
8	.1	1.2	.2	- .2	-1.2	.1
10	- .6	-2.9	1.0	-1.1	-2.0	-4.2
12	- .6	1.3	- .2	.4	.3	1.4
13	- .6	.0	.1	- .3	- .7	- .2
14	- .7	- .3	.0	- .3	- .2	.4
37	.1	.8	-1.4	- .0	.0	- .6
RMS	1.2	1.8	.7	.9	1.0	1.8
MEAN	.1	.5	- .2	.1	- .4	- .5

Figure 5. 30 km x 30 km Area Easting Errors

FLT NO.	SITE NO. 2	3	6	7	12	13
7	-2.2	-4.5	- .3	-2.4	.2	
8	- .1	.2	- .1	- .6	1.9	- .4
10	- .7	-1.4	- .8	- .2	.2	2.9
12	- .3	1.2	.8	.2	.5	- .7
13	-2.9	1.4	.6	.1	.9	- .6
14	-3.4	- .5	.3	- .3	- .5	- .6
37	-4.1	-4.5	1.4	.4	4.6	4.1
RMS	2.5	2.5	.7	1.0	2.0	2.1
MEAN	-2.0	-1.2	.3	- .4	1.1	.8

Figure 6. 30 km x 30 km Area Northing Errors

FLT NO.	SITE NO. 2	3	6	7	12	13
7	-20.8	-7.8	-1.9	-7.5	-7.6	
8	6.7	5.2	10.5	5.1	- .2	-4.3
10	11.5	-7.3	11.9	16.8	5.5	4.4
12	-12.3	.6	5.7	- 1.2	1.5	7.7
13	7.9	.7	.9	4.1	6.1	- .4
14	5.3	5.5	14.6	8.1	-3.0	-6.6
37	-14.2	-31.9	33.7	23.9		-26.5
RMS	12.3	13.0	15.3	12.1	4.8	11.9
MEAN	- 2.3	- 5.0	10.8	7.0	.4	- 4.3

Figure 7. 30 km x 30 km Area Elevation Errors

FLT NO.	SITE NO. 1	3	5	6	7	8	9	14
19	-5.7	1.3	-2.0		3.0		.5	- .6
20	-1.7	1.2	.6		.6		2.3	2.0
21	8.3	8.6	8.9		6.9		7.7	5.1
29	2.4	3.6	1.4	2.1		2.7		2.5
30	- .3	- .3	-4.3	.2		- .3		-1.9
32	.6	- .4	.9	1.1		- .1		
33	-1.5	2.5	5.8	4.1		1.8		
RMS	4.0	3.7	4.4	2.3	4.3	1.6	4.3	2.8
MEAN	.3	2.4	1.6	1.9	3.5	1.0	3.5	1.4

Figure 8. 60 km x 60 km Area Easting Errors

FLT NO.	SITE NO. 1	3	5	6	7	8	9	14
19	4.7	.7	- 5.1		- .1		- .3	- 2.0
20	2.2	.3	1.4		.9		1.3	1.3
21	.9	- .9	- 6.2		.7		-1.9	- 4.1
29	2.1	-1.4	- 3.9	.4		- .6		.7
30	2.4	- .8	- 5.3	- .3		- .7		- .5
32	- .8	-2.7	.1	-1.2		-2.0		
33	1.6	- .4	1.5	-3.5		- .6		
RMS	2.4	1.3	4.0	1.8	.6	1.1	1.3	2.2
MEAN	1.9	- .8	-2.5	-1.1	.5	-1.0	- .3	- .9

Figure 9. 60 km x 60 km Area Northing Errors

FLT NO.	SITE NO. 1	3	5	6	7	8	9	14
19	11.1	-2.3	26.1		.6		-27.6	-20.9
20	.2	7.7	21.5		-4.9		7.5	4.6
21	23.5	-3.3	19.5		-10.7		-13.8	-11.0
29		8.2	7.2	7.5		15.5		9.1
30		-1.8	-2.0	-4.7		2.1		11.1
32		2.9	-32.5	3.4		9.2		
33	1.7		13.9	8.8		8.8		
RMS	13.0	5.1	20.1	6.5	6.8	10.1	183	12.5
MEAN	9.1	1.9	7.7	3.8	-5.0	8.9	-11.3	- 1.3

Figure 10. 60 km x 60 km Area Elevation Errors

The horizontal errors of the positions determined by the Short Range, Medium Range, and Tactical Configuration Tests are plotted in Figures 11 through 14. Figure 11 shows the results of the Short Range Tests including 7 flights and 6 positioning sets on unknown locations. The geometry of the flight patterns of these flights with respect to the locations of the ground stations was favorable and therefore, the position errors were relatively small. The circular probable error (CEP) of the errors plotted in Figure 11 was 1.9 meter and the probable error (PE) of heights was 8.2 meter. Figure 12 shows the results of all Short Range Tests including 15 flights and 8 positioning sets on unknown locations. The 15 flights used flight patterns of various geometry. The errors were accordingly larger than the errors obtained by using good flight geometry. Figures 13 and 14 show the results of the Medium Range Tests. Figure 13 represents the results of flight patterns with good geometry and Figure 14 the results of all flights of the Medium Range Tests.

The Long Range Tests could only provide the easting and northing components of the location position. A simulation of the Long Range case had shown that the height error will always be exceedingly large because of the altitude limitation of the aircraft. The mean and the root mean square of the easting errors were 29 meter and -28 meter respectively. The mean and the root mean square of the northing were 16 meter and 13 meter respectively.

CONCLUSIONS

The LRPDS performance exceeds the stated objectives and requirements for this system. As a result, the LRPDS utility for tactical surveying is greatly enhanced.

The aircraft flight patterns were not critical to system accuracy. It is necessary to fly two normally closed loops at two relatively different altitudes to obtain best results. The flight path control and general shape did not seem to be important. Deviations of 10 to 15 km appeared to have little effect.

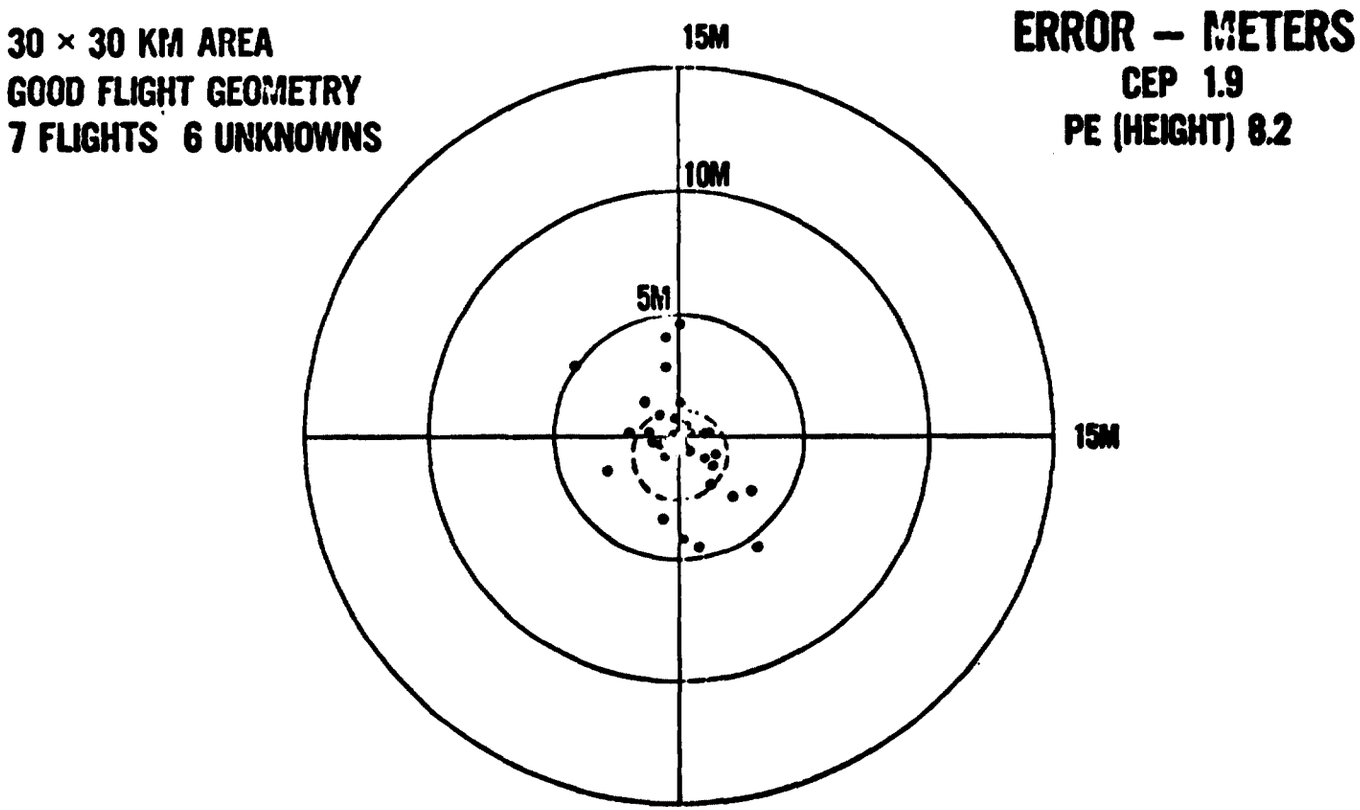

30 × 30 KM AREA
GOOD FLIGHT GEOMETRY
7 FLIGHTS 6 UNKNOWNS
ERROR – METERS
CEP 1.9
PE (HEIGHT) 8.2
15M
10M
5M
15M

Figure 11.

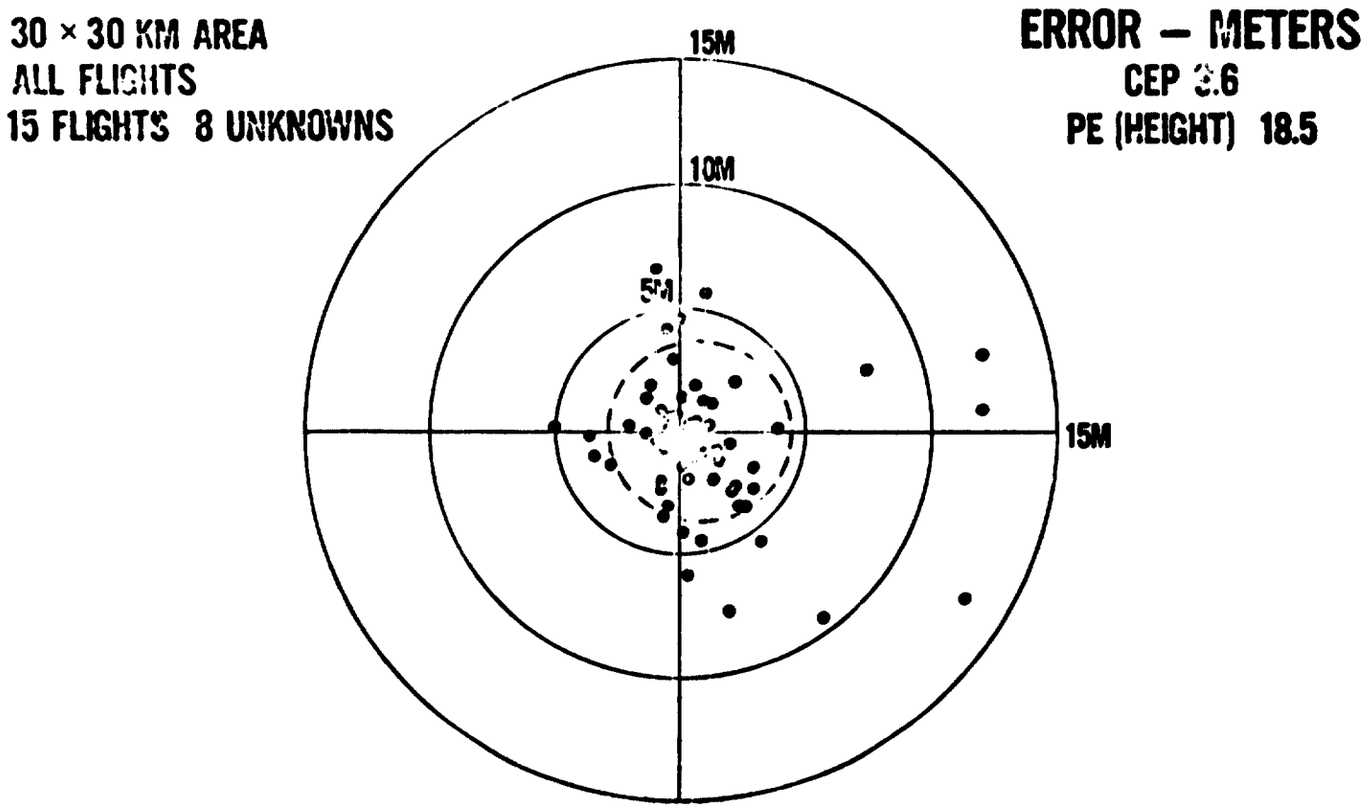

30 × 30 KM AREA
ALL FLIGHTS
15 FLIGHTS 8 UNKNOWNS
ERROR – METERS
CEP 3.6
PE (HEIGHT) 18.5
15M
10M
5M
15M

Figure 12.

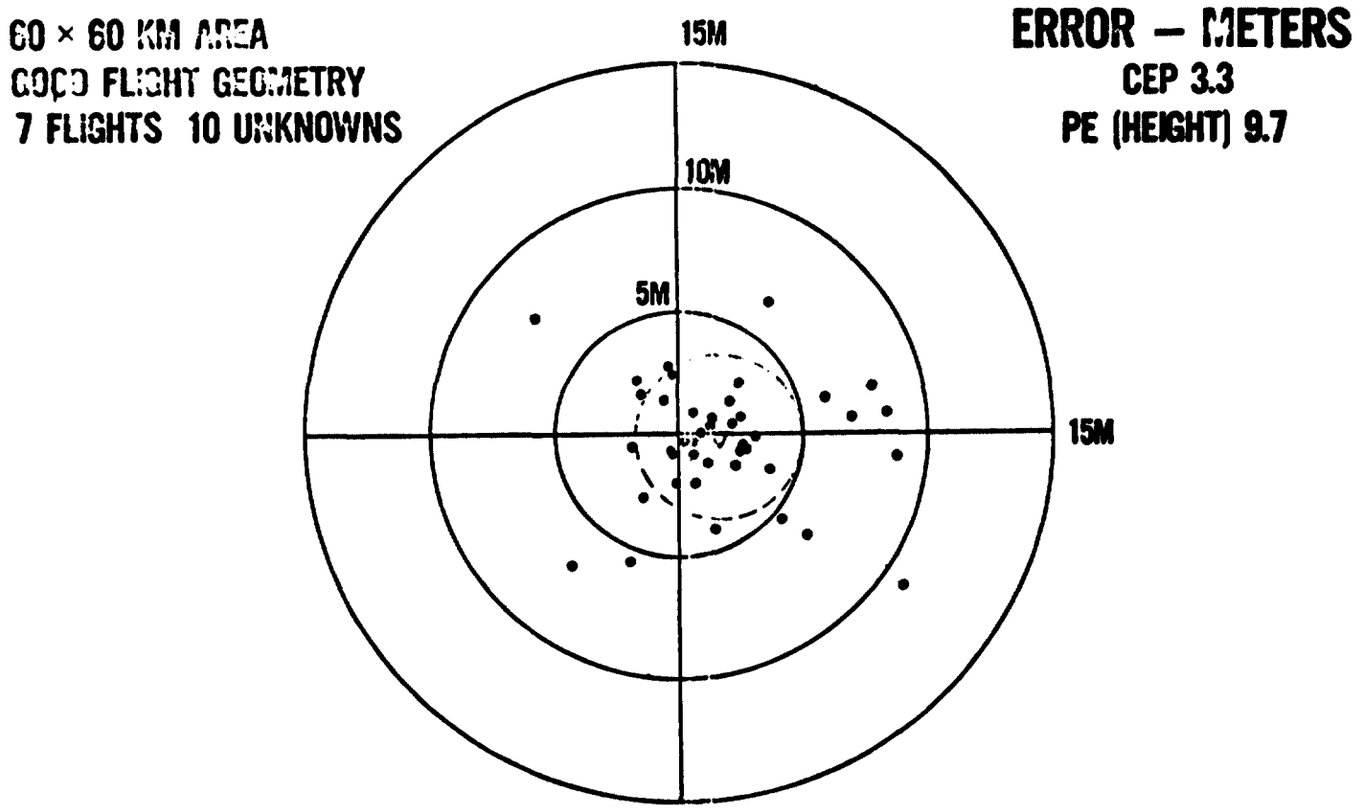

60 × 60 KM AREA
GOOD FLIGHT GEOMETRY
7 FLIGHTS 10 UNKNOWNS
15M
10M
5M
15M
ERROR – METERS
CEP 3.3
PE (HEIGHT) 9.7

Figure 13.

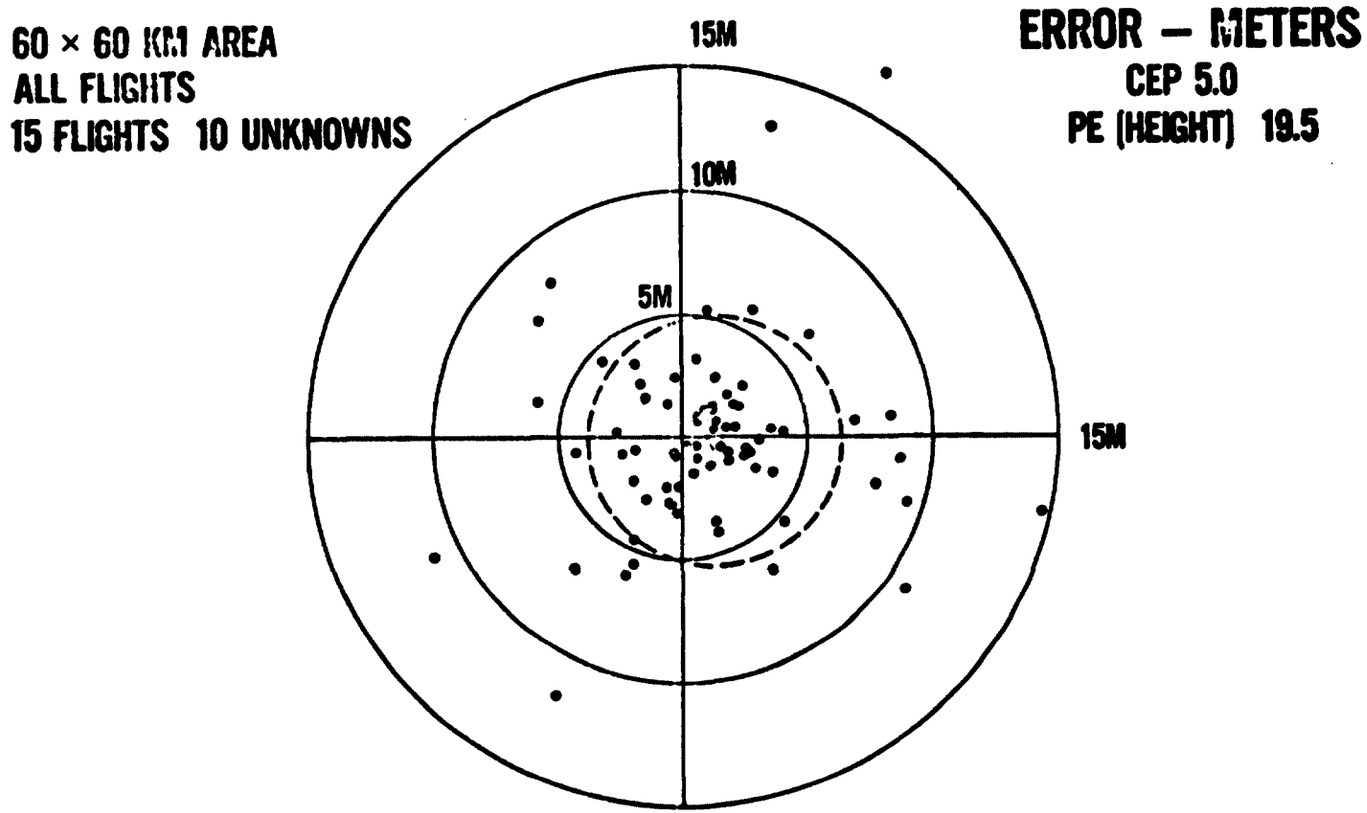

60 × 60 KM AREA
ALL FLIGHTS
15 FLIGHTS 10 UNKNOWNS
ERROR – METERS
CEP 5.0
PE (HEIGHT) 19.5
15M
10M
5M
15M

Figure 14.

QUESTION AND ANSWER PERIOD

MR. LIEBERMAN:

How do you get that field unit into enemy territory? That field unit that you showed with the helmet in it.

DR. ROHDE:

How do you get this into enemy territory?

MR. LIEBERMAN:

Yes.

DR. ROHDE:

On backpack by a soldier.

(Laughter.)

DR. ROHDE:

I mentioned in the first report on the LRPDS the weight. As a matter of fact, you need two people, because each backpack unit weighs 30 pounds, and so that two people are required to carry it.

So, I will say, this might not be a forerunner of NAVSTAR, but it shows, you know, the direction. And, of course, NAVSTAR has much tighter requirements on weight.

MR. LIEBERMAN:

Do you have a beeper in there?

DR. ROHDE:

I beg your pardon?

MR. LIEBERMAN:

Didn't you just have a beeper out in the ocean when they come down?

DR. ROHDE:

A beeper for what?

MR. LIEBERMAN:

To give the position.

DR. ROHDE:

That would be nice, but you know, you have to measure something. In order to measure something, you need some energy.

Now, I am glad to discuss this later. Maybe you have a very good idea which we could incorporate.

MR. POTTS:

Dr. Rohde, I have several questions.

On your artist's depiction of the deployment of the system, it indicated that you have three base stations in the friendly territory with your aircraft flying over friendly territory. And then your remote stations in enemy territory.

Yet your test data now showed the aircraft flying over the remote positions? Is that a valid test?

DR. ROHDE:

Now, let me see, these test data which I have shown give only the results if we would use this as a survey system.

But I have indicated in my abstract that we have actually four different areas. We have the 30 by 30 kilometer areas; we have the 60 by 60 kilometer areas; we have the long range operational area; and we have the tactical combat area.

I have not addressed the long range and the tactical combat areas.

MR. POTTS:

On several slides you indicated a circular error probability which ranged from about two to five meters, or something like that.

DR. ROHDE:

Yes.

MR. POTTS:

And then there was a height error. I guess the PE, is that probable error?

DR. ROHDE:

Probable error, yes.

MR. POTTS:

What is the significance of that? Is that an error in the location, altitude?

DR. ROHDE:

Right. Maybe I should have said that all the sites have been very carefully surveyed with conventional survey methods, and these positions were very accurate. And what we have measured with these positions sets are the deviations from these survey measurements.

DR. WINKLER:

Dr. Rohde, your system strikes me as a very straight-forward and surprisingly common sense approach to a problem which is quite general.

Now, there is one point, however, which I did not quite understand, and that is the role and the requirements of the crystal oscillators in each individual user location.

Isn't it possible by increasing the number of base stations to create the necessary redundancy so that you really don't need any high performance crystal oscillators at these stations?

I mean, this is the essential point, why is it necessary to have a high precision frequency control here in that system, when by providing redundancy you can avoid it?

DR. ROHDE:

I would say at this point we have enough problems with our data reduction, and what you suggest only would increase the data reduction on the computer, the position computer control.

DR. WINKLER:

Yes, of course.

DR. ROHDE:

And we have not entirely solved or debugged our present data reduction schemes. But we have thought about providing the base stations with cesium clocks, for instance, and then seeing if we could relax the requirements on the positioning sets.

This would be particularly interesting, perhaps, because at this time the requirement on the positioning sets is set up, and we don't move it. So, in other words, during an observation period, the positioning sets should not be moved around, because of the stability requirements.

DR. WINKLER:

Yes, but I am concerned really with the problem, how shall we strike that engineering compromise, speaking on the one hand possibly using a larger number of high precision oscillators under very strenuous conditions, or on the other hand using a little bit more computation.

In my judgement and I have considered that in many systems, the balance should always be with more computation.

DR. ROHDE:

Right, but this would require a considerably larger computer, because our present computer just barely can do the work within the allocated time. So, either we have to increase the emission time, which is undesirable from the military point of view, or we have to have a larger computer, and so far I don't know exactly what computer we could recommend. However, computer development is very fast, and we have to keep looking at these things. As a matter of fact, we have right now a test in our laboratories to re-examine the entire computer portion, which we literally underestimated. Everybody was concerned about the crystal oscillator, or the oscillator's period, but we found out that the oscillator period problems could be solved. We had many more problems with the computer system, or with the entire software and data reduction.

MR. WILSON:

I just wanted to know, what was the approximate frequency?

DR. ROHDE:

The system operates on a single frequency, and the frequency can be tuned between 240 and I guess 400 megahertz in steps of 10 megahertz, so that the number of users which are adjacent can use the system without interfering with each other.

MR. BRUHL:

Dr. Rhode, I am Keith Bruhl.

Have you, perchance, considered re-transmission of either Loran-C or three frequency Omega for this type of application?

DR. ROHDE:

One of the problems with Loran-C, and Omega, is that you have at least ground wave propagation, and I have shown you these results, in the desert of Phoenix.

If you would use the same system, maybe, in a jungle area, the results might not be as good, and in the framework of another project—I guess it is NAVSTAR—we are working on a program to determine close to ground wave propagation effects, such as foliage penetration, multi paths and so on.

But one of the problems with Loran-C, is the unknown of the propagation close to the ground. Suppose you measure a position repeatedly. If you take a standard deviation, it might be very good. Of course, I don't know if you measure this over a longer period of time, you might perhaps find out that after a rain or so, if you look for a diurnal variation, a seasonal variation, that your standard deviation will increase.

But by the same token, you may measure repeatedly, but you may measure repeatedly wrong.

MR. BRUHL:

That is, of course, true.

What you would have in your favor if you used Omega, would be that you would be retransmitting in base band on the UHF carrier to a translator and back to

the base station. This is very similar to the system that the Coast Guard is now evaluating.

DR. ROHDE:

Would you expect that you could position a point to something better than 10 meters?

MR. BRUHL:

If it was premapped, yes. If the area has been premapped before by coordinates.

DR. ROHDE:

Yes, but if you don't have the time to do that?

MR. BRUHL:

You are quite right. I think there are ways around this. In other features, it is extremely lighter in weight, and you have a lockup a lot longer, in about 30 seconds.

DR. ROHDE:

I guess one of the reasons to overcome these problems, among others, is the embarking on the NAVSTAR program where you have consistently relatively high elevation angles. Maybe next time, if we get the modulation receiver, and we make reasonable experiments, we can report about this, too.

CMDR. POTTS:

Dr. Rohde, I didn't plant Keith Bruhl back there. I am glad he opened up Loran-C. I don't want to sound like a salesman.

We had a chain, and still do have a chain over in a jungle area, and we used it for quite a number of years, and got quite a lot of data on the baseline and between stations for about 200 miles, and the users were happy and reported repeatability in the order of 60 feet.

DR. ROHDE:

Yes, I guess you want me to—oh, I am not going to interrupt you.

CMDR. POTTS:

The absolute accuracy, of course, is a function of the conductivity of the soil, the way it was propagating. There is no question about that.

In your system there, where you are talking about a 200 kilometer distance, in enemy territory, and where the Loran-C transmitter baselines could be significantly shorter, I don't think you are going to have any trouble at all getting a 10 meter accuracy. Not only that, I was struck by the vulnerability of your system, in that the users are, first of all, radiating the signals, and second of all, you have got the aircraft up there which is also vulnerable.

DR. ROHDE:

I would agree that if you go to 200 kilometers that the results which can be obtained with Loran-C may approach the results which you may obtain with LRPDS under certain conditions. We have to look, of course, at all the parameters.

I guess what you are referring to is the maps which were made for Vietnam.

MR. POTTS:

No, I was referring to the users' experiences in the studies they were doing, and most of them are in the literature.

DR. ROHDE:

Yes. We have also looked into, of course, Loran as a potential positioning system, but for survey application, techniques, field artillery surveys, the accuracy is insufficient.

You have seen the accuracy we obtained in a typical area where we were conducting surveys, which is 30 by 30 kilometers, and you have seen that the horizontal position accuracy is in the order of a few meters, better than three meters.

MR. POTTS:

I quite agree with you, without precalibration, we couldn't do that with a normal Loran-C system with long baselines.

MR. WILSON:

I was just going to make a comment on the use of Loran-C versus the 400 megacycle system. Isn't one of the big problems here jamming?

I think Loran-C would be much easier to jam than the 400 megacycles system.

DR. ROHDE:

Yes. Of course.

As far as I know, Loran-C has a CW or pulse type modulation. So, it is more easily jammed. Also the enemy should not make use of our systems.

MR. WILSON:

Loran-C is a pulsed system, that is phase-coded. As a matter of fact, about 13 years ago the Army did extensive tests on the vulnerability of the Loran-C. I can state without worrying about going to jail that it is not very vulnerable.

We are more of an interference to ourselves when we position one chain near another and are not careful of rate selection.

DR. ROHDE:

Yes, certainly maybe we could at another time discuss this in more detail. We are always open to additional suggestions.

MR. EASTON:

Thank you very much, Dr. Rohde.