

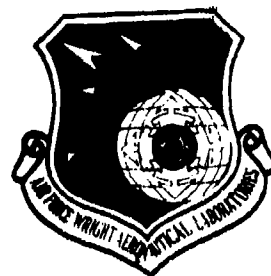
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LEVEL ^{II} ②



GLOBAL POSITIONING SYSTEM
SATELLITE SELECTION

Edward C. Dudzinski
Reference Systems Branch
System Avionics Division

2 March 1981

TECHNICAL REPORT AFWAL-TR-81-1051
Final Report for Period 1 October 1979 - 30 November 1980

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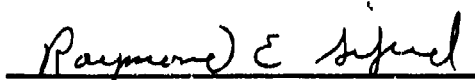


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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes an investigation of whether GPS satellite selection algorithms that consider jammer-to-signal ratio as well as Geometric Dilution of Precision can provide better navigation performance than an algorithm which discriminates on the basis of GDOP alone. The study was done with a comput- erized Monte Carlo simulation of aircraft trajectories over parametric jammer layouts with both the 18 and 24 satellite constellations. OVER			

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20. Abstract (Continued)

The report contains tables and graphs which characterize both constellations in terms of satellite visibility at varying latitudes with a range of mask angles. It details the GDOP alternatives available, and tracks both GDOP and J/S during simulated missions.

Lastly, some qualified conclusions are drawn about the comparative performance of an algorithm that considers GDOP only and one that includes consideration of J/S.

FOREWORD

This report was written by the Project Engineer, Edward C. Dudzinski of the Reference Systems Branch, System Avionics Division, Avionics Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson AFB, Ohio.

The work documented herein was carried out under Project Work Unit 60951410 during the period October 1979 to November 1980.

The author would like to acknowledge four people for their assistance in this project. William E. Shephard, Group Leader of the Reference Systems Software Group, was responsible for the initial definition of the project and provided both general direction and technical guidance during its course. Major Robert M. Edwards wrote much of the simulation software that was used, and provided constant technical advice. Lt John W. Weiser is responsible for the material on the mathematical definition of GDOP and researched the altered GPS constellation in order to change the simulation model appropriately. Lt Weiser also produced some of the plots in Attachments 1 and 7. Shirley A. Suttman patiently typed two interim memos, a draft final report, and this Technical Report.

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SECTION I

INTRODUCTION

The Global Positioning System (GPS) has been designed to meet the future navigation needs of military and civilian users. It consists of satellites orbiting the earth and broadcasting information that can be decoded by complementary receiver equipment. Two separate signals providing different levels of navigation accuracy are broadcast. Each signal requires its own decoding scheme, so general civilian access to the low-quality broadcast is possible while still restricting usage of the high-accuracy segment.

In order for either type of user to determine a 3-dimensional position fix using GPS, signals must be received from 4 different satellites. The specific satellites chosen for position fixing from those visible has a significant impact on the accuracy of the position solution. The geometric relationship of the satellites and the user affects this solution, and is characterized by a measurement called the Geometric Dilution of Precision (GDOP). Another influencing factor when directional antennas are used is jammer interference with the satellite signal, measured by the jammer-to-signal ratio (J/S).

This report describes an investigation of whether GPS satellite selection algorithms that consider J/S as well as GDOP can provide better navigation performance than an algorithm which discriminates on the basis of GDOP alone. The intent of this investigation was not to evaluate any specific algorithm, but to determine the potential benefit of general J/S consideration. The chosen method of analysis was a computerized

simulation of aircraft flying typical mission scenarios over parametric jammer fields and accessing satellites in the GPS constellation.

Three sections in addition to the Introduction comprise this report. Section II begins with descriptions of the Global Positioning System, the calculation of the Geometric Dilution of Precision (GDOP), and the use of GDOP to govern satellite selection. The goal of the project is stated and the stages of the investigation detailed. Specifics of the simulation programs and parameters are also included.

Results are presented in Section III. Visibility statistics and GDOP alternatives from the preliminary stages of the study are described first. Then simulation snapshots that track the entire Close Air Support mission are presented. Lastly, a criterion of navigation performance is described and final results based on that criterion are tabulated. These tables give percentages of navigation performance improvement that could be achieved by inclusion of J/S consideration in the satellite selection algorithm.

Some qualified conclusions are drawn in the final section about the comparative performance of an algorithm that considers GDOP only and one that includes consideration of J/S.

Seven attachments contain the detailed results that are described in the report body.

SECTION II

BACKGROUND

1. GLOBAL POSITIONING SYSTEM

The Global Positioning System was originally envisioned as 24 satellites with 12-hour orbits uniformly distributed in 3 circular orbital planes about the earth. The 3 planes will be equidistant from each other and inclined at a 55° angle to the equatorial plane. Interorbital phasing of 15° will result in 8-hour periodicity of the constellation at any point on the earth.

Budgetary considerations have changed this original constellation from a 24 to an 18-satellite configuration. The new model is a nonuniform arrangement achieved by removing 2 adjacent satellites from each of the 3 orbital planes of the original constellation, leaving other characteristics unchanged. Paul Jorgensen of the Aerospace Corporation has published a paper describing which satellites to delete. This new constellation also has an 8-hour period.

GPS user equipment can receive signals from any satellites that are above the local radio horizon and not obscured by the receiver's mask angle. This mask is a measurement of the sector of sky immediately above the horizon in which satellites are effectively invisible. Traversing the sky from horizon to zenith defines 90° of view. An antenna restricted by a 20° mask angle cannot receive signals from satellites in the lower 20° of that prospect. Masking is caused by airframe interference, the elevation of surrounding terrain, and the inherent limitations of beam-pointing antennas.

By analyzing signals from any 4 of the visible satellites, it is possible to precisely fix the position of a signal receiver. This is accomplished with pseudo-range measurements calculated from satellite clock signals and a knowledge of the signal propagation velocity. Navigation accuracy using this technique is heavily influenced by the relative geometry between the user and satellites. This geometry is characterized by measurement of the geometric dilution of precision (GDOP). GDOP is calculated by first constructing the matrix A.

$$A = \begin{bmatrix} \alpha_{1x} & \alpha_{1y} & \alpha_{1z} & 1 \\ \alpha_{2x} & \alpha_{2y} & \alpha_{2z} & 1 \\ \alpha_{3x} & \alpha_{3y} & \alpha_{3z} & 1 \\ \alpha_{4x} & \alpha_{4y} & \alpha_{4z} & 1 \end{bmatrix}$$

where α_{ix} is the direction cosine of the angle between the X-axis and the line-of-sight to the i th satellite. Finally,

$$GDOP = \sqrt{\text{Trace} \left[(A^T A)^{-1} \right]}$$

Low GDOP indicates a favorable user-satellite geometry and reduced sensitivity to measurement noise. Currently, the set of 4 satellites chosen from those visible is the set with minimum GDOP.

In the circumstance where the user has an antenna capable of directional discrimination and jammers are operating in the vicinity, the jammer interference as measured by the jammer-to-signal ratio (J/S) will differ for each satellite in view,

and GDOP might no longer exactly correlate with precision of navigation. In this situation a better position fix might be achieved by choosing a set of satellites with a higher GDOP but lower J/S. The present selection algorithm does not allow for this choice.

2. PURPOSE

The overall task objective of WU 60951410 was to conduct a preliminary evaluation by analysis and simulation of the possible advantages of an alternative, more complicated satellite selection algorithm that considers J/S as well as GDOP. Three logical phases made up this investigation.

Before suggesting improvement of the current satellite selection algorithm, it had to be determined whether the algorithm was useful in any form. Since it is exercised only when 5 or more satellites are visible, statistics were gathered on the percent of time that more than one possible set of four satellites were in view at varying latitudes and mask angles.

These visibility statistics demonstrated that alternative satellite sets were in view during a significant portion of the constellation's period, and justified proceeding to the second phase of the project.

In this part of the analysis, the goal was to determine whether GDOP characterizations of the satellite sets eliminated any choice in their use. If in almost all cases the GDOP measurement was prohibitively high for all but a single set of visible GPS satellites, the current selection algorithm would be sufficient and J/S consideration would be pointless.

Based on our simulation, viable GDOP alternatives were available and J/S discrimination was feasible. Detailed results from these first two project phases were published in two previous memos for both the original 24-satellite constellation and the modified 18-satellite configuration. Some of the statistical results are reproduced in this report; they are described under Preliminary Results.

The final phase of this project was to determine the percent of time that a dual criterion algorithm (GDOP and J/S) could provide navigation performance improvement in parametric jamming situations while flying typical mission scenarios. The directive receiving antenna simulated was the High Performance Antenna Assembly modeled by The Analytic Sciences Corporation under AFAL contract. The purpose of this report is to describe these final results.

3. METHODS

Simulation of GPS satellite views, mission trajectories and jammer interference was done with a time-driven FORTRAN software package. Initial satellite positions were assumed at time zero with a satellite directly above the equator. These positions were extrapolated to any given time using straight-forward trigonometry in an Earth-Centered-Earth-Fixed coordinate system. Position coordinates were then rotated into an East-North-Up system with origin at the user-input latitude and longitude. Individual satellite coordinates were converted into view angles (declination and aspect) from this user position.

Five different mission scenarios supplied by SAMSO were used. The trajectories were treated as straight-line segments of specified speed and direction, completely defined by the information in Tables 1 through 5 of Attachment 1.

Simulated jammers broadcasting at 1 kilowatt were located on the ground paralleling FEBA. Ten rows of them extended 80 kilometers into enemy territory, and they stretched along FEBA beyond the aircraft line-of-sight in both directions.

Figures 1 through 5 of Attachment 1 describe the X-Y trajectory of the missions, showing FEBA and the central area of the jammer field.

Simulations were run on the dual CDC CYBER 750/CYBER 175 system. The DISSPLA graphics package was used to chart some of the results.

SECTION III

RESULTS

1. PRELIMINARY RESULTS

The plots and tables referenced below make up Attachments 2, 3 and 4. Results are included for both the original 24-satellite configuration and the reduced 18-satellite system.

Figures 1 and 2 of Attachment 2 plot the average number of visible satellites observed at all latitudes with the indicated mask angles. The averages were determined over the entire 8 hour period of the two constellations.

In Attachment 3, six tables contain detailed information describing how often a choice of alternative satellite sets exist, and how wide a choice that is. Each table represents the entire period of the indicated constellation at one of the three chosen latitudes. For each of 8 mask angles, these tables show the percent of time that at least a given number of satellites are visible. For example, Table 4 shows that at 0° latitude, constricted by a 20° mask angle, users viewing the 18-satellite constellation will see 6 satellites 20% of the time. With six satellites visible, 15 alternative satellite sets are available. Exactly 5 satellites, providing 5 choices, are visible 29% of the time (49% minus 20%). Four satellites, comprising a single available set, are visible 18.3% of the constellation's period. During the remaining 32.7% of the time, exactly 3 satellites can be seen.

Lastly, Figures 1 through 6 of Attachment 4 plot the averages of the 3 best available GDOP's at all latitudes and 3 different mask angles. Each point on the curves represents an average over 8 hours, the constellation's period.

It is important to note that GDOP alternatives shown in these latter 6 figures were calculated only for those times when 5 or more satellites were visible. These figures indicate the average GDOP selection when a choice exists. The six previous tables must be consulted to determine how often the user has a choice. For example, figure 6 shows an average choice between the two lowest GDOP's of roughly 5.0 and 6.0 at 0° latitude. By consulting Table 4 of Attachment 3 we see that with a 20° mask angle at 0° latitude, 49% of the time there are at least 5 satellites visible, hence during the remaining 51% of the time only 3 or 4 satellites can be seen. Thus our example GDOP alternatives characterize only 49% of the constellation's period, with no choice available the rest of the time.

In the course of the simulation, an incidental numerical problem was encountered. When four satellites are configured so that they lie on or very near the surface of a cone with its apex at the user, the geometric configuration is unfavorable for navigation and GDOP is indeterminate. This occurs because the matrix A referenced in this paper's introduction becomes singular. When A is singular, so is the product $[A^T A]$. This product must be inverted to calculate GDOP, but the singularity makes that impossible.

This situation occurred most frequently at the poles, where a great deal of symmetry occurs in the satellite constellation. GPS user software should be protected from any catastrophic results of attempting to invert a singular matrix.

2. SIMULATION DATA

Attachment 5 presents simulation snapshots of the Close Air Support mission at 5 minute intervals, assuming an antenna mask angle of 10° . Each snapshot gives aircraft position, view angles to each visible satellite, J/S for each visible satellite, and GDOP values for all possible sets of 4 satellites.

Aircraft coordinates are in kilometers, the reference frame is that shown in the mission description figures of Attachment 1. "X" represents downrange, "Y" corresponds to crossrange, and "Z" is the altitude. The (0,0,0) point of our figures is located at ground level, 48.6° latitude, 7° longitude, centered in Western Europe. J/S is calculated in db's. Space vehicles are identified by orbit plane (1 to 3) and satellite number (1 to 8). Theta and phinrth represent satellite view angles, declination and aspect respectively. The aspect angle, phinrth, is standardized as the angle off the right wing of an aircraft bearing due north. Therefore the true aspect angle is determined by adding the actual aircraft heading angle to phinrth.

This mission was run with the original 24-satellite constellation. Under the 18-satellite version, the following space vehicles would be eliminated:

<u>Satellite</u>	<u>Orbit</u>
4	1
5	1
1	2
2	2
6	3
7	3

3. FINAL RESULTS

As stated previously, the project was intended to determine the percent of time that a dual criterion algorithm (GDOP and J/S) could provide navigation performance improvement for an aircraft in a parametric jamming environment flying typical mission scenarios. The last section of this report will describe the method of analysis used to determine those percentages and present the results.

Our comparison of the current approach (GDOP alone) with a selection algorithm that also considers J/S depends on threshold values of J/S and GDOP to determine the acceptability of a satellite signal or a 4-satellite set respectively. If a satellite's J/S exceeds 70.0 db, we consider the signal to be unusable. Similarly, if the GDOP value for a 4-satellite set is over 5.0, that satellite set is judged unacceptable.

We define the occurrence of navigation performance improvement as that situation where the minimal GDOP set is eliminated due to J/S considerations, and an acceptable alternative satellite set can be acquired.

More specifically, our simulation snapshots present one of three possible situations. First, the satellite set with the lowest GDOP can be composed entirely of satellites with J/S less than 70.0 db. Secondly, one or more satellites in the optimal set can exceed the J/S threshold when no acceptable alternative (all J/S < 70 and GDOP < 5.0) exists. These first two cases include all situations where 4 or fewer satellites are visible to the user (we can think of a 3-satellite set as exceeding the GDOP threshold). Lastly, we have the possibility of the optimal GDOP set containing one or more satellites that

exceed the 70.0 db J/S threshold while an alternative set exists which has a GDOP below 5.0 and which includes no satellites having J/S greater than 70.0. This last situation is the one in which we judge navigation performance improvement to be achieved due to J/S consideration.

We have not constructed a measure to discriminate navigation performance when J/S is below 70.0 db. If navigation performance can be improved by using an alternative to the optimal GDOP set when both these sets have no satellites exceeding the J/S limit, then we have overlooked some instances where J/S consideration would have been justified. In any case, by basing our figures on upper-level cutoffs, we have arrived at what is probably a pessimistic forecast of the navigation improvement possible.

The percentages shown in the tables of attachment 6 were determined by running simulations of our 5 mission scenarios as described in Attachment 1. Based on the assumptions above, a count was kept of those simulation snapshots where navigation performance improvement was achieved, as well as a count of the instances in which J/S values exceeded 70 db for any of the satellites. This latter count indicated the number of times the J/S criterion was exercised. Percentages were calculated by dividing these two counts by the total number of snapshots in each mission simulation.

Snapshots were taken at 60 second intervals. Each of the missions was run repeatedly until simulation time reached 8 hours, so that the entire period of the GPS constellation would be considered in the analysis. Due to the difference in mission lengths, this meant that the IST scenario was flown twice, HELO seven times, and the other three missions four times apiece.

The table values for adjusted navigation performance improvement combine the J/S elimination and overall performance improvement figures in order to normalize the mission results. One of the mission profiles was flown almost entirely within the jammer field's influence, while the other missions include varying periods of flight time at a distance from the jammer field. Since our performance measure is a percentage of total mission time, and since time spent beyond the jammers' influence cannot result in performance improvement due to J/S considerations, this difference in mission profiles causes an artificial difference in navigation performance improvement. Therefore the adjusted navigation performance improvement is a percentage not of total mission time, but of only that time spent in the jammer field's influence as indicated by the occurrence of J/S elimination.

Figures 1 through 20 of Attachment 7 graph the GDOP's that result from two different selection algorithms during a single simulation of each mission. The reference baseline simply chooses the set of satellites giving lowest GDOP. The other curve traces the minimal GDOP achieved when satellites above the J/S threshold (70 db) are eliminated from consideration. Results are included for both the original 24-satellite constellation and the revised 18-satellite configuration. Each mission was run twice, restricted by 10^0 and 20^0 mask angles respectively.

Any GDOP's exceeding 10.0 were graphed on these figures as 10.0, because for the purpose of this analysis all GDOP's > 5.0 are equivalent. Also "topped-out" at this GDOP value of 10.0 are all situations where fewer than 4 satellites are available.

When the two curves are coincident, the optimal GDOP set contains no satellites exceeding the J/S threshold and we gain nothing by considering J/S. When they diverge, J/S exceeds 70.0 db for at least one satellite in the optimal GDOP set. Whether we gain by considering J/S in this case depends on whether the GDOP value achievable from the remaining satellites is below the 5.0 threshold.

SECTION IV

CONCLUSION

The goal of this study was to evaluate payback in terms of navigation performance improvement for including J/S consideration in the GPS satellite selection algorithm. Conclusions drawn in pursuit of that goal must recognize the parametric nature of the simulated jammer layout and jammer power. Additionally, the reported percentages of navigation improvement must be evaluated in light of the performance criterion described in Section III.

Results for the 24 satellite constellation are encouraging, particularly the adjusted navigation improvement percentages which focus on the mission realm of interest. Average performance improvements across all 5 missions of 42% for the 10^0 mask and 15% for the 20^0 mask might be enough to justify the additional complexity of a dual-criterion algorithm.

Less optimistic are the figures characterizing the 18 satellite constellation. The number of alternative satellite sets increases factorially with the number of visible satellites ($n! / ((n-4)! 4!)$, where n is the number of visible satellites). For example, 8 visible satellites present 70 alternative sets, 7 visible satellites give only 35, 6 give 15 and 5 visible satellites result in a choice of 5 alternative sets. Thus a small decrease in the number of visible satellites is felt dramatically. The change from a 24 to an 18 satellite constellation greatly reduces the choice of satellite sets, and correspondingly reduces the possibility for a good geometric configuration between user and satellite.

When the view of this reduced constellation is restricted by a mask angle of 10° or 20° , the result is a virtual elimination of choice in satellite sets. This is the reason for the small percentages of navigation performance improvement reported in Attachment 6 for the 18 satellite constellation. Specifically, mission averages of adjusted navigation performance improvement were only 15% and 3% for 10° and 20° mask angles respectively. With so few satellites to choose from, the payback for a satellite selection algorithm that considers J/S as well as GDOP appears to be very low.

ATTACHMENTS

1. Mission Profiles
2. Average Satellite Visibility
3. Detailed Visibility Tables
4. Average GDOP
5. CAS Simulation
6. Navigation Performance Improvement
7. J/S Impact on GDOP

ATTACHMENT 1

MISSION PROFILES

Table 1. CAS Flight Profile

SEGMENT	DURATION (MIN)	VELOCITY (M/SEC)			POSITION (KM)		ALTITUDE (M)
		X	Y	Z	X	Y	
1	15	0.0	0.0	0.0	-185.3	-278.0	0.0
2	5	123.5	92.7	30.5	-148.3	-250.2	9144.0
3	30	41.2	190.5	0.0	-74.1	92.7	9144.0
4	15	20.6	0.0	0.0	-55.6	92.7	9144.0
5	2	231.6	0.0	0.0	-27.8	92.7	9144.0
6	2	231.6	-154.4	-75.9	0.0	74.1	30.5
7	1	154.4	0.0	0.0	9.3	74.1	30.5
8	5	123.5	-185.3	0.0	46.3	18.5	30.5
9	10	108.1	108.1	0.1	111.2	83.4	91.4
10	5	-216.2	-154.4	0.7	46.3	37.1	304.8
11	10	-185.3	61.8	12.2	-64.9	74.1	7620.0
12	25	-55.6	-216.2	0.0	-148.3	-250.2	7620.0
13	10	-61.8	-46.3	-12.7	-185.3	-278.0	0.0

Table 2. EI Flight Profile

SEGMENT	DURATION (MIN)	VELOCITY (M/SEC)			POSITION (KM)		ALTITUDE (M)
		X	Y	Z	X	Y	
1	20	0.0	0.0	0.0	-185.3	-222.4	0.0
2	5	123.5	61.8	25.4	-148.3	-203.9	7620.0
3	15	0.0	164.7	1.7	-148.3	-55.6	9144.0
4	12	205.9	77.2	-2.1	0.0	0.0	7620.0
5	18	223.1	0.0	0.0	240.9	0.0	7620.0
6	3	205.9	103.0	8.5	278.0	18.5	9144.0
7	4	0.0	0.0	-12.7	278.0	18.5	6096.0
8	3	-205.9	103.0	-8.5	240.9	37.1	4572.0
9	7	-225.0	-30.9	-10.8	146.4	24.1	30.5
10	13	-223.3	-30.9	0.0	-27.8	0.0	30.5
11	7	-220.6	-172.1	29.0	-120.5	-72.3	12192.0
12	13	-35.6	-168.7	0.0	-148.3	-203.9	12192.0
13	10	-61.8	-30.9	-20.3	-185.3	-222.4	0.0

Table 3. HELO Flight Profile

SEGMENT	DURATION (MIN)	VELOCITY (M/SEC)			POSITION (KM)		ALTITUDE (M)
		X	Y	Z	X	Y	
1	5	0.0	0.0	0.0	-9.3	0.0	0.0
2	15	65.9	0.0	.01	50.0	0.0	9.1
3	5	18.5	0.0	0.0	55.6	0.0	9.1
4	5	55.6	0.0	0.0	72.3	0.0	9.1
5	5	18.5	0.0	0.0	77.8	0.0	9.1
6	5	61.8	0.0	0.0	96.4	0.0	9.1
7	5	18.5	0.0	0.0	101.9	0.0	9.1
8	5	-61.8	61.8	.02	83.4	18.5	15.2
9	15	-82.4	0.0	0.0	9.3	18.5	15.2
10	5	-61.8	-61.8	-.05	-9.3	0.0	0.0

Table 4. PPS Flight Profile

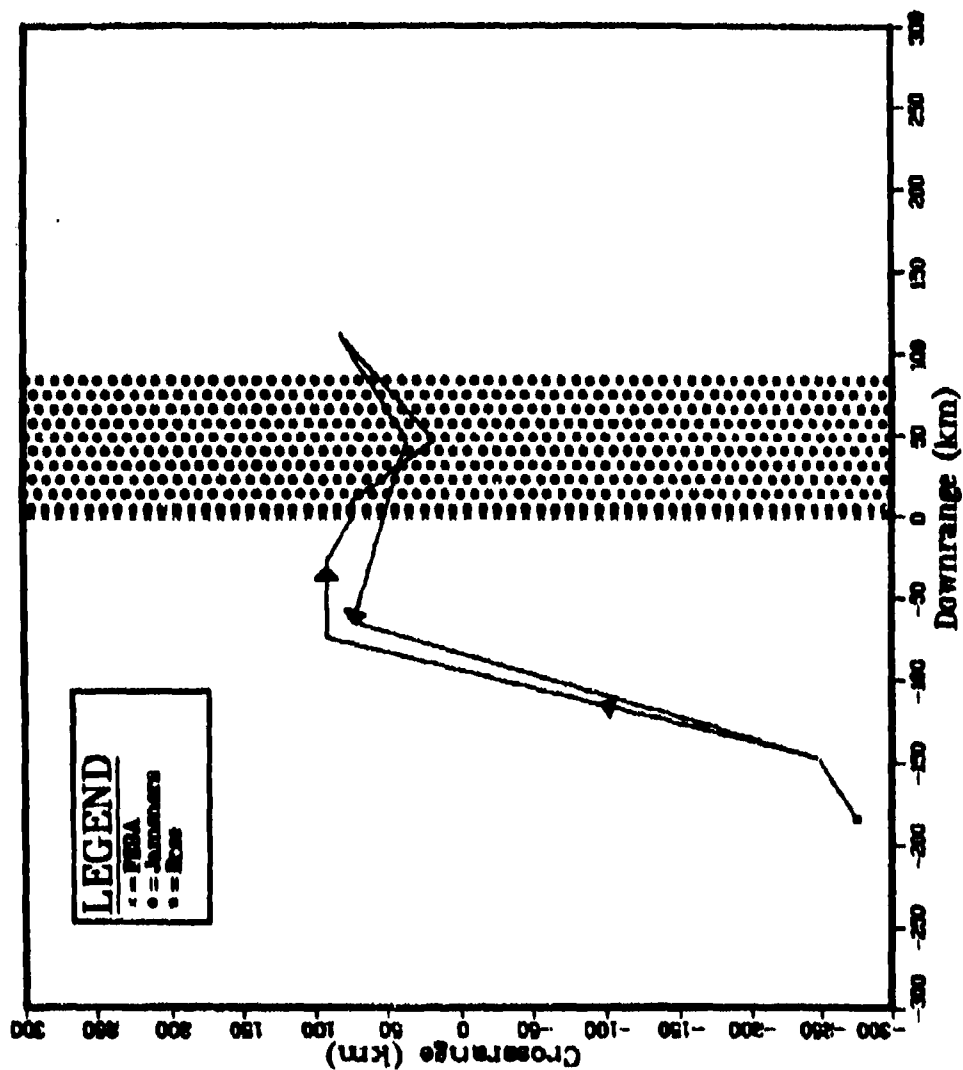
SEGMENT	DURATION (MIN)	VELOCITY (M/SEC)			POSITION (KM)		ALTITUDE (M)
		X	Y	Z	X	Y	
1	20	0.0	0.0	0.0	-185.3	-111.2	0.0
2	10	46.3	139.0	10.2	-157.5	-27.8	6096.0
3	5	0.0	185.3	5.1	-157.5	27.8	7620.0
4	10	169.9	-46.3	0.0	-55.6	0.0	7620.0
5	10	61.8	169.9	-12.4	-18.5	101.9	152.4
6	10	200.8	-61.8	0.1	101.9	64.9	213.4
7	10	247.1	-216.2	0.4	250.2	-64.9	426.7
8	3	205.9	103.0	-1.5	287.2	-46.3	152.4
9	2	-308.9	154.4	0.5	250.2	-27.8	213.4
10	15	-216.2	-164.7	6.5	55.6	-176.1	6096.0
11	5	-247.1	92.7	0.0	-18.5	-148.3	6096.0
12	10	-61.8	30.9	5.1	-55.6	-129.7	9144.0
13	20	-92.7	-38.6	0.0	-166.8	-176.1	9144.0
14	5	-154.4	154.4	-15.2	-213.1	129.7	4572.0
15	5	92.7	61.8	-15.2	-185.3	-111.2	0.0

Atch 1

Table 5. IST Flight Profile

SEGMENT	DURATION (MIN)	VELOCITY (M/SEC)			POSITION (KM)		ALTITUDE (M)
		X	Y	Z	X	Y	
1	20	0.0	0.0	0.0	-185.3	-83.4	0.0
2	10	123.5	-46.3	5.1	-111.2	-111.2	3048.0
3	10	108.1	-108.1	0.0	-46.3	-176.1	3048.0
4	10	154.4	-15.4	0.0	46.3	-185.3	3048.0
5	10	15.4	139.0	0.0	55.6	-101.9	3048.0
6	10	61.8	15.4	-5.1	92.7	-92.7	0.0
7	10	139.0	-30.9	1.5	176.1	-111.2	914.4
8	5	123.5	61.8	0.0	213.1	-92.7	914.4
9	10	92.7	-46.3	-1.4	268.7	-120.5	91.4
10	30	-20.6	0.0	-0.1	231.6	-120.5	0.0
11	10	46.3	-61.8	0.2	259.4	-157.5	91.4
12	30	-159.6	30.9	3.3	-27.8	-101.9	6096.0
13	20	-15.4	139.0	0.0	-46.3	64.9	6096.0
14	10	139.0	30.9	-9.9	37.1	83.4	152.4
15	10	154.4	46.3	0.0	129.7	111.2	152.4
16	10	-30.9	-61.8	0.3	111.2	74.1	304.8
17	10	-169.9	61.8	-0.3	9.3	111.2	152.4
18	25	-135.9	-68.0	4.0	-194.6	9.3	6096.0
19	15	-41.2	144.1	0.0	-231.6	139.0	6096.0
20	10	15.4	61.8	-10.2	-222.4	176.1	0.0

CLOSE AIR SUPPORT MISSION

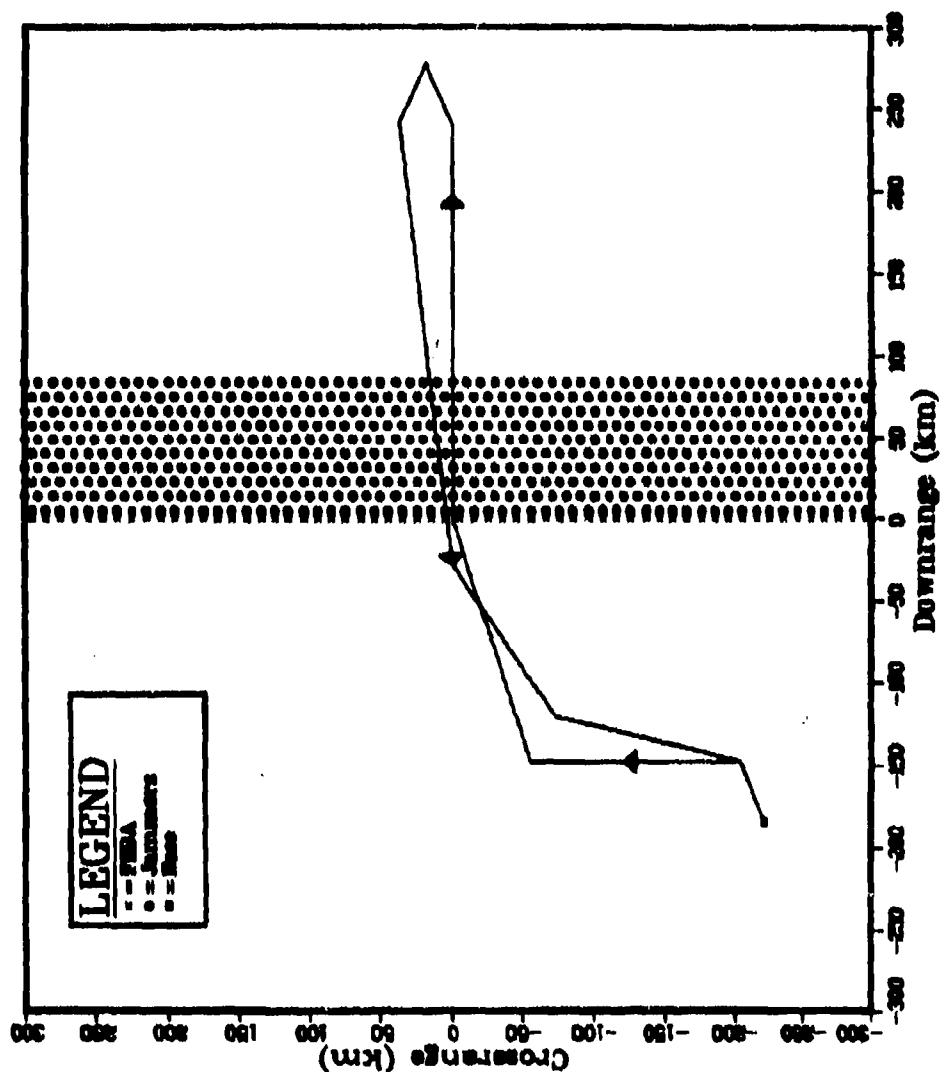


PL01 1 08.00.30 TWA 2 OCT, 1960 JOB-AM/25M . WPTB/RED DISPLA VER 7.3

Figure 1

Atch 1

ESCORT/INTERCEPT MISSION



PLOT 1 10.17.17 THUR 2 OCT, 1980 JCS-JM/ESS . MFWB/MSD 0100LA VER 4.3

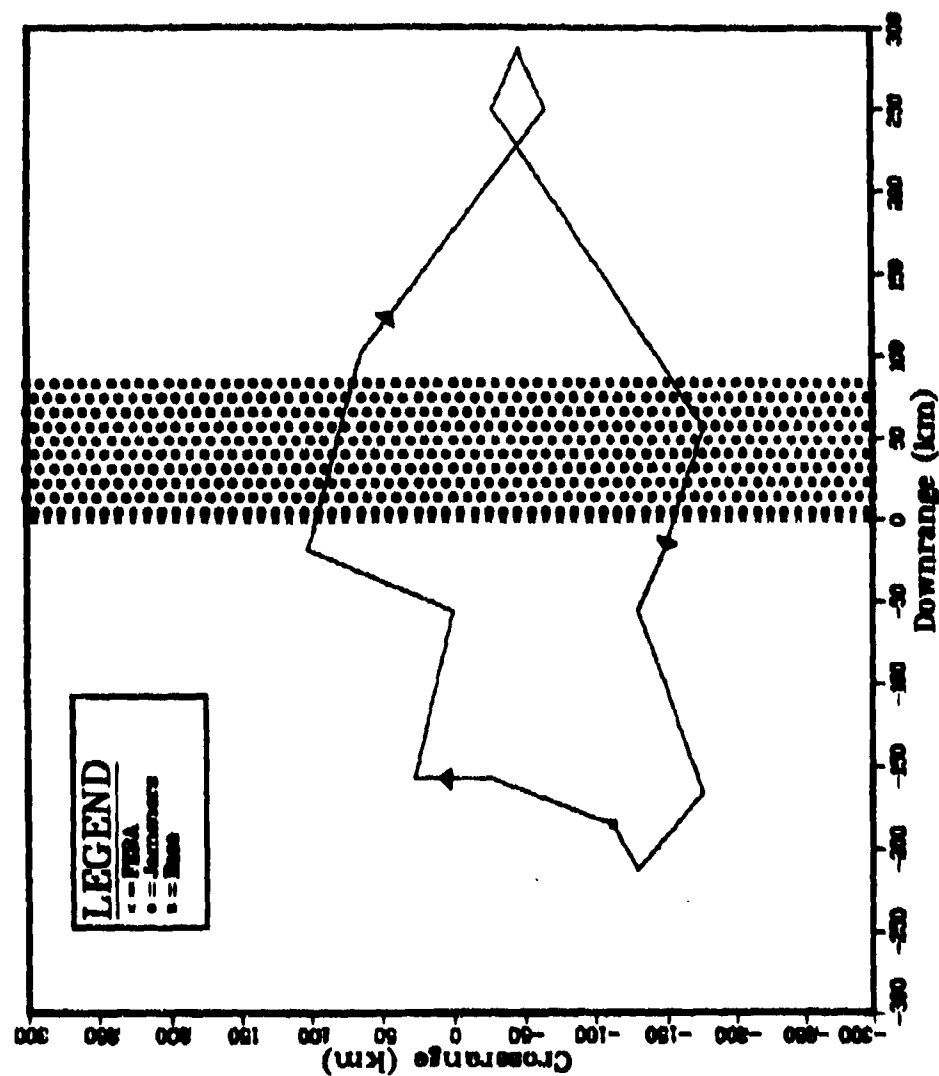
Figure 2

Atch 1

PL 01 1 10.31.19 8448 2 OCT, 1960 J00-141703 14-141703 01-000000 0001 100 2 1048 0115'01 1 1074

Atch 1

PREPLANNED DEEP STRIKE MISSION



PL 01 1 10.30.47 N4M 3 001, 1000 J00-J00/VE0 . MWV8/VE0 0100PL6 VE0 7.3

Figure 4

Atch 1

INTRATHEATER STOL TRANSPORT MISSION

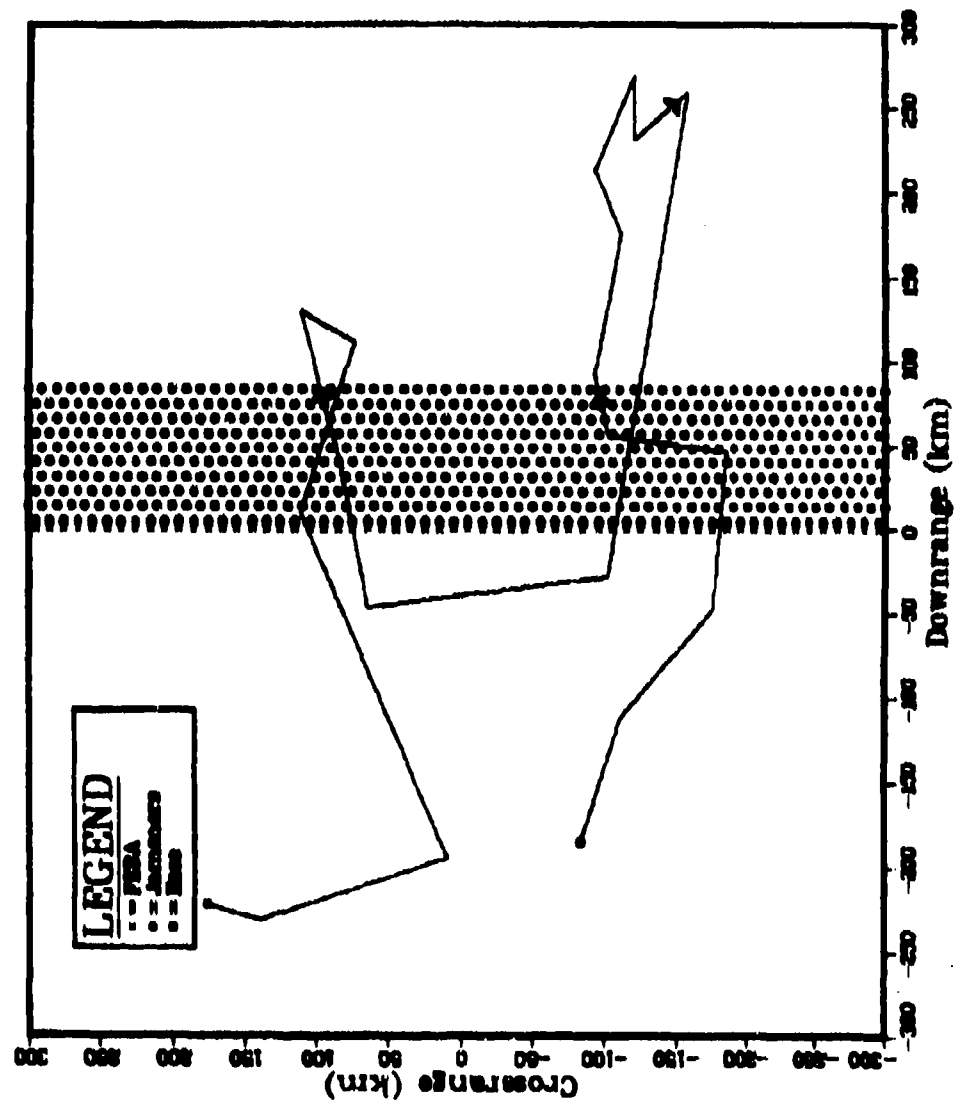


Figure 5

Atch 1

ATTACHMENT 2

AVERAGE SATELLITE VISIBILITY

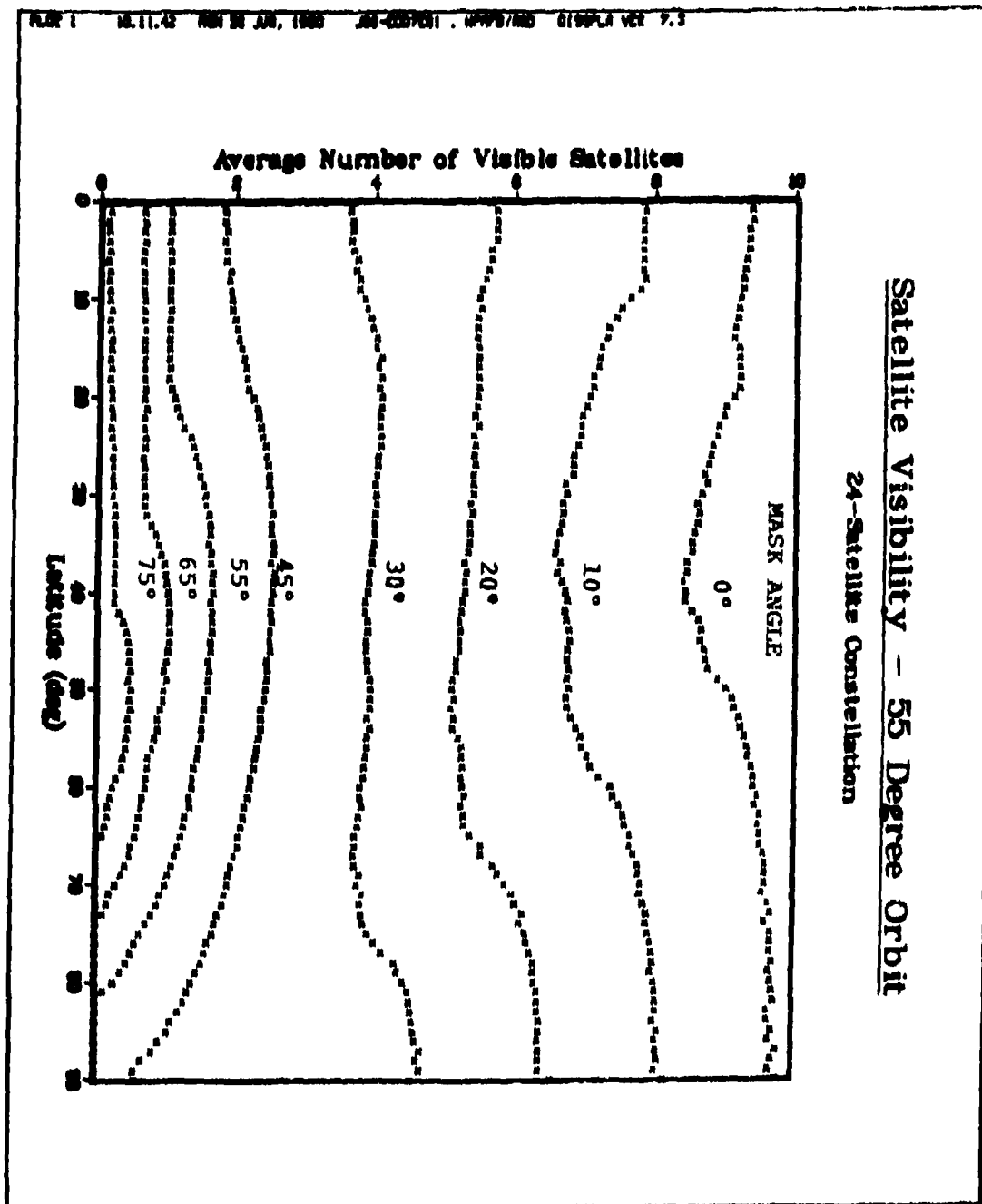


Figure 1

Atch 2

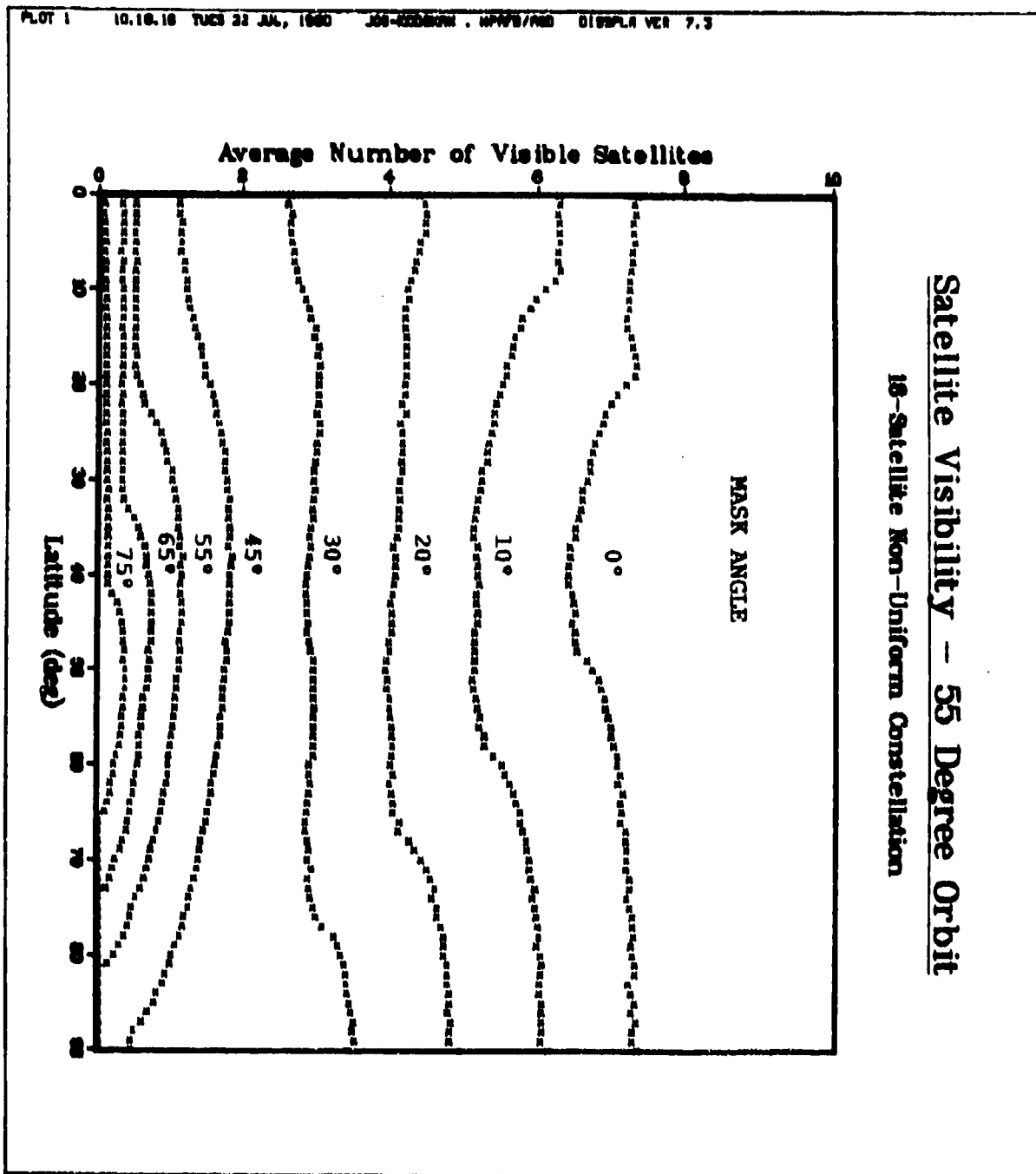


Figure 2

Atch 2

ATTACHMENT 3

DETAILED VISIBILITY TABLES

SATELLITE COVERAGE SIMULATION

24-SATELLITE CONSTELLATION
LATITUDE 0.00 DEGREES NORTH

MASK ANGLE	MINIMUM NUMBER OF SATELLITES IN VIEW DURING ONE DAY	AVERAGE NUMBER OF SATELLITES IN VIEW DURING ONE DAY
75.00	0	.11
65.00	0	.64
55.00	0	1.02
45.00	1	1.84
30.00	3	3.64
20.00	4	5.61
10.00	6	7.82
0.00	8	9.37

PERCENT OF TIME THAT AT LEAST
"N" SATELLITES ARE IN VIEW
AT LATITUDE 0.00 DEGREES NORTH

MASK ANGLE	9	8	7	6	5	4	3	2	1
75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.0
65.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	64.0
55.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.6	91.7
45.0	0.0	0.0	0.0	0.0	0.0	1.7	11.7	70.6	100.0
30.0	0.0	0.0	0.0	0.0	1.3	62.7	100.0	100.0	100.0
20.0	0.0	0.0	23.3	58.5	78.8	100.0	100.0	100.0	100.0
10.0	4.6	78.5	99.2	100.0	100.0	100.0	100.0	100.0	100.0
0.0	96.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

"N" (NUMBER OF SATELLITES)

Table 1

Atch 3

SATELLITE COVERAGE SIMULATION

24-SATELLITE CONSTELLATION
LATITUDE 45.00 DEGREES NORTH

MASK ANGLE	MINIMUM NUMBER OF SATELLITES IN VIEW DURING ONE DAY	AVERAGE NUMBER OF SATELLITES IN VIEW DURING ONE DAY
75.00	0	.45
65.00	0	1.06
55.00	1	1.69
45.00	1	2.53
30.00	3	3.92
20.00	4	5.24
10.00	5	6.74
0.00	6	8.68

PERCENT OF TIME THAT AT LEAST
"N" SATELLITES ARE IN VIEW
AT LATITUDE 45.00 DEGREES NORTH

MASK ANGLE	0	1	2	3	4	5	6	7	8	9
75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	45.0
65.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.7	82.9
55.0	0.0	0.0	0.0	0.0	0.0	0.0	16.5	52.1	100.0	100.0
45.0	0.0	0.0	0.0	0.0	0.0	4.4	50.4	93.5	100.0	100.0
30.0	0.0	0.0	0.0	0.0	11.3	80.8	100.0	100.0	100.0	100.0
20.0	0.0	0.0	6.4	33.1	83.5	100.0	100.0	100.0	100.0	100.0
10.0	8.8	30.2	45.6	94.0	100.0	100.0	100.0	100.0	100.0	100.0
0.0	62.7	72.3	96.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	9	8	7	6	5	4	3	2	1	

"N" (NUMBER OF SATELLITES)

Table 2

Atch 3

SATELLITE COVERAGE SIMULATION

24-SATELLITE CONSTELLATION
LATITUDE 70.00 DEGREES NORTH

MASK ANGLE	MINIMUM NUMBER OF SATELLITES IN VIEW DURING ONE DAY	AVERAGE NUMBER OF SATELLITES IN VIEW DURING ONE DAY
75.00	0	0.00
65.00	0	.28
55.00	0	1.03
45.00	1	1.94
30.00	3	3.86
20.00	4	5.93
10.00	6	7.85
0.00	8	9.62

PERCENT OF TIME THAT AT LEAST
"N" SATELLITES ARE IN VIEW
AT LATITUDE 70.00 DEGREES NORTH

MASK ANGLE									
75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
65.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.1
55.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	98.1
45.0	0.0	0.0	0.0	0.0	0.0	0.0	23.5	70.8	100.0
30.0	0.0	0.0	0.0	1.7	5.6	78.3	100.0	100.0	100.0
20.0	0.0	0.0	9.2	85.6	97.7	100.0	100.0	100.0	100.0
10.0	12.9	73.3	98.7	100.0	100.0	100.0	100.0	100.0	100.0
0.0	98.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	4	8	7	6	5	4	3	2	1
	"N" (NUMBER OF SATELLITES)								

Table 3

Atch 3

SATELLITE COVERAGE SIMULATION

18-SATELLITE NON-UNIFORM CONSTELLATION
LATITUDE 0.00 DEGREES NORTH

MASK ANGLE	MINIMUM NUMBER OF SATELLITES IN VIEW DURING ONE DAY	AVERAGE NUMBER OF SATELLITES IN VIEW DURING ONE DAY
-----	-----	-----
75.00	0	.06
65.00	0	.32
55.00	0	.51
45.00	0	1.14
30.00	1	2.63
20.00	3	4.36
10.00	5	6.29
0.00	6	7.35

PERCENT OF TIME THAT AT LEAST
"N" SATELLITES ARE IN VIEW
AT LATITUDE 0.00 DEGREES NORTH

MASK ANGLE									
75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6
65.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.1
55.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2	45.8
45.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	40.8	71.5
30.0	0.0	0.0	0.0	0.0	0.0	9.6	72.5	81.3	100.0
20.0	0.0	0.0	0.0	20.0	49.0	67.3	100.0	100.0	100.0
10.0	0.0	0.0	40.0	89.0	100.0	100.0	100.0	100.0	100.0
0.0	1.7	34.6	98.3	100.0	100.0	100.0	100.0	100.0	100.0
	9	8	7	6	5	4	3	2	1

	"N" (NUMBER OF SATELLITES)								

Table 4

Atch 3

SATELLITE COVERAGE SIMULATION

18-SATELLITE NON-UNIFORM CONSTELLATION
LATITUDE 45.00 DEGREES NORTH

MASK ANGLE	MINIMUM NUMBER OF SATELLITES IN VIEW DURING ONE DAY	AVERAGE NUMBER OF SATELLITES IN VIEW DURING ONE DAY
75.00	0	.33
65.00	0	.74
55.00	1	1.17
45.00	1	1.83
30.00	2	2.92
20.00	2	4.04
10.00	3	5.18
0.00	4	6.49

PERCENT OF TIME THAT AT LEAST
"N" SATELLITES ARE IN VIEW
AT LATITUDE 45.00 DEGREES NORTH

MASK ANGLE	9	8	7	6	5	4	3	2	1
75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.5
65.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	73.8
55.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	100.0
45.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	78.1	100.0
30.0	0.0	0.0	0.0	0.0	0.0	11.5	80.8	100.0	100.0
20.0	0.0	0.0	0.0	19.2	28.5	58.8	97.1	100.0	100.0
10.0	0.0	5.0	23.5	45.6	48.3	95.4	100.0	100.0	100.0
0.0	9.8	29.4	52.3	65.0	92.5	100.0	100.0	100.0	100.0
	9	8	7	6	5	4	3	2	1
	"N" (NUMBER OF SATELLITES)								

Table 5

Atch 3

SATELLITE COVERAGE SIMULATION

18-SATELLITE NON-UNIFORM CONSTELLATION
LATITUDE 70.00 DEGREES NORTH

MASK ANGLE	MINIMUM NUMBER OF SATELLITES IN VIEW DURING ONE DAY	AVERAGE NUMBER OF SATELLITES IN VIEW DURING ONE DAY
75.00	0	0.00
65.00	0	.24
55.00	0	.73
45.00	0	1.41
30.00	1	2.95
20.00	2	4.44
10.00	4	5.89
0.00	6	7.21

PERCENT OF TIME THAT AT LEAST
"N" SATELLITES ARE IN VIEW
AT LATITUDE 70.00 DEGREES NORTH

MASK ANGLE	0	1	2	3	4	5	6	7	8	9
75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
65.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.8
55.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.2	72.5	
45.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	36.5	97.9	
30.0	0.0	0.0	0.0	0.0	1.7	26.3	69.6	97.3	100.0	
20.0	0.0	0.0	0.0	7.7	46.7	91.7	97.7	100.0	100.0	
10.0	0.0	0.0	24.2	67.3	97.7	100.0	100.0	100.0	100.0	
0.0	2.3	35.6	83.5	100.0	100.0	100.0	100.0	100.0	100.0	
	9	8	7	6	5	4	3	2	1	

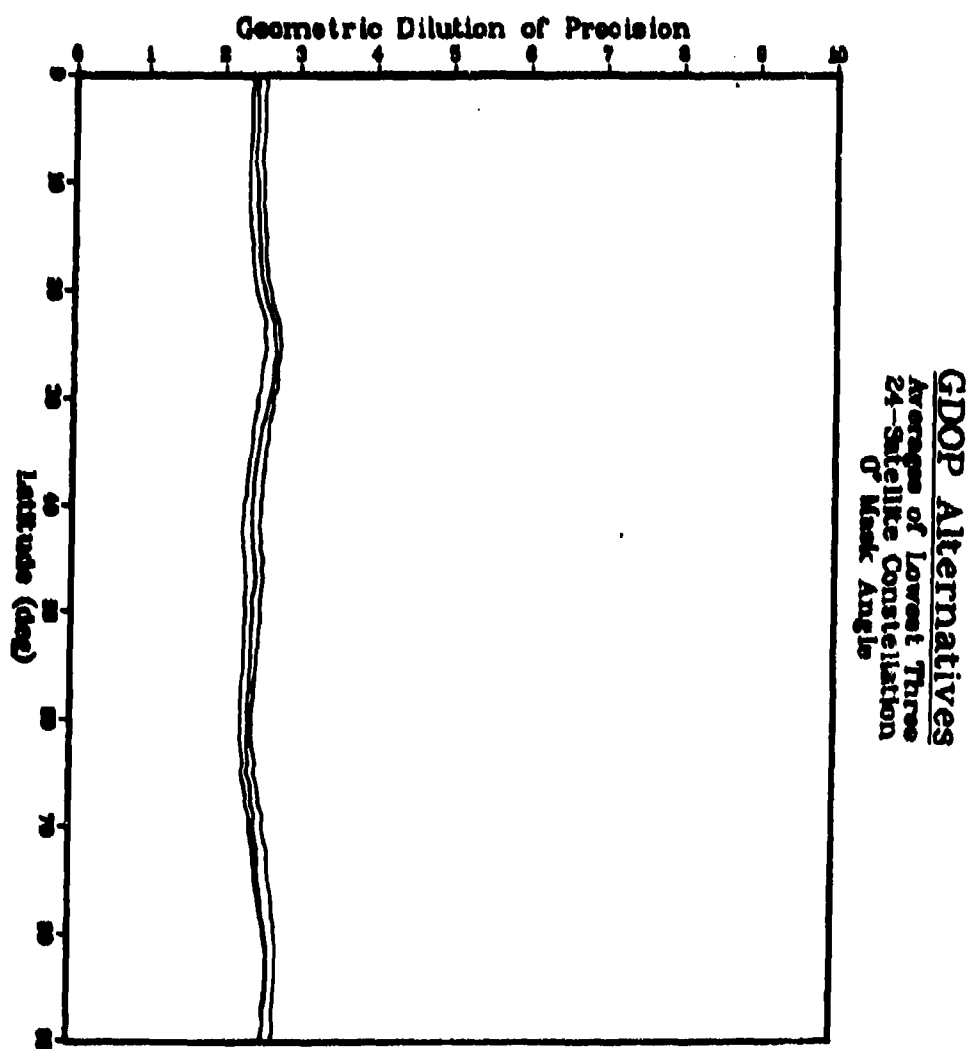
"N" (NUMBER OF SATELLITES)

Table 6

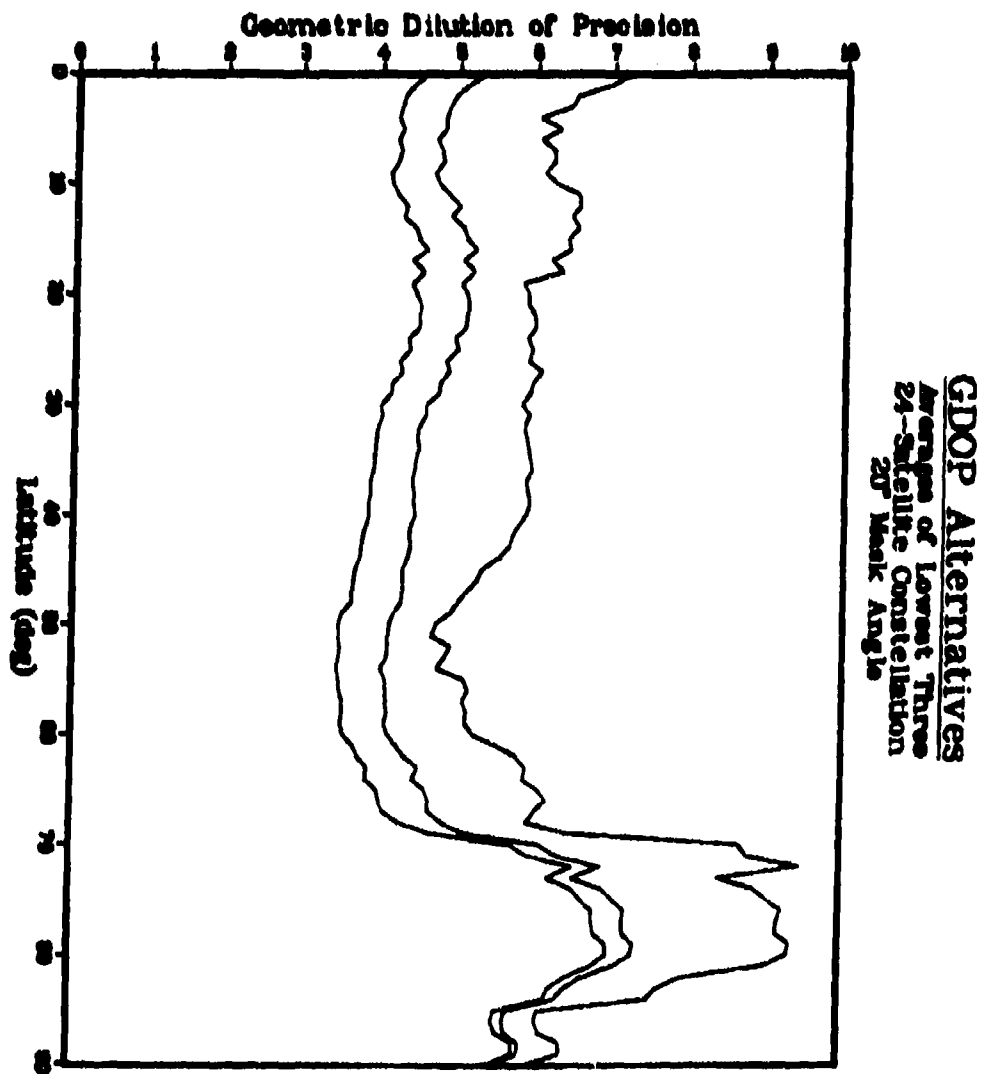
Atch 3

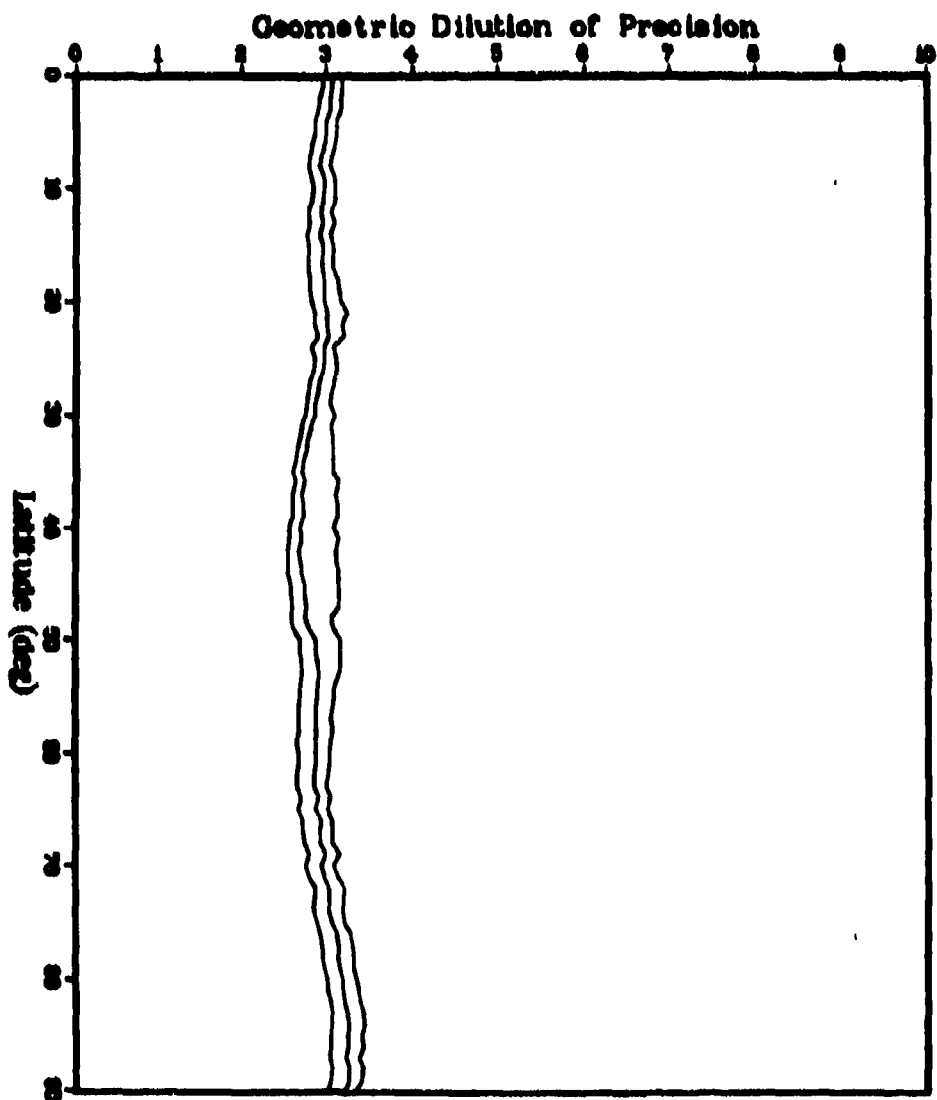
ATTACHMENT 4

AVERAGE GDOP

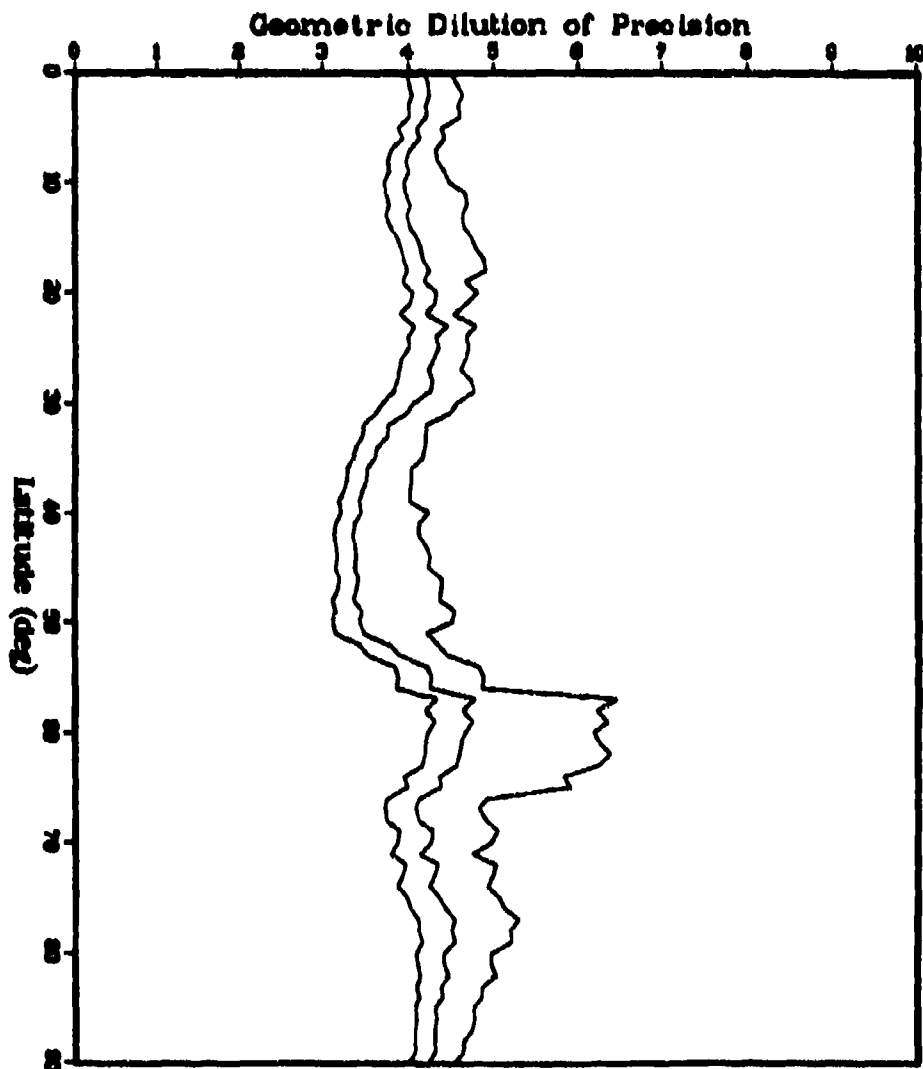


GDOP Alternatives Averages of Lowest Three 24-Satellite Constellation 10° Mask Angle

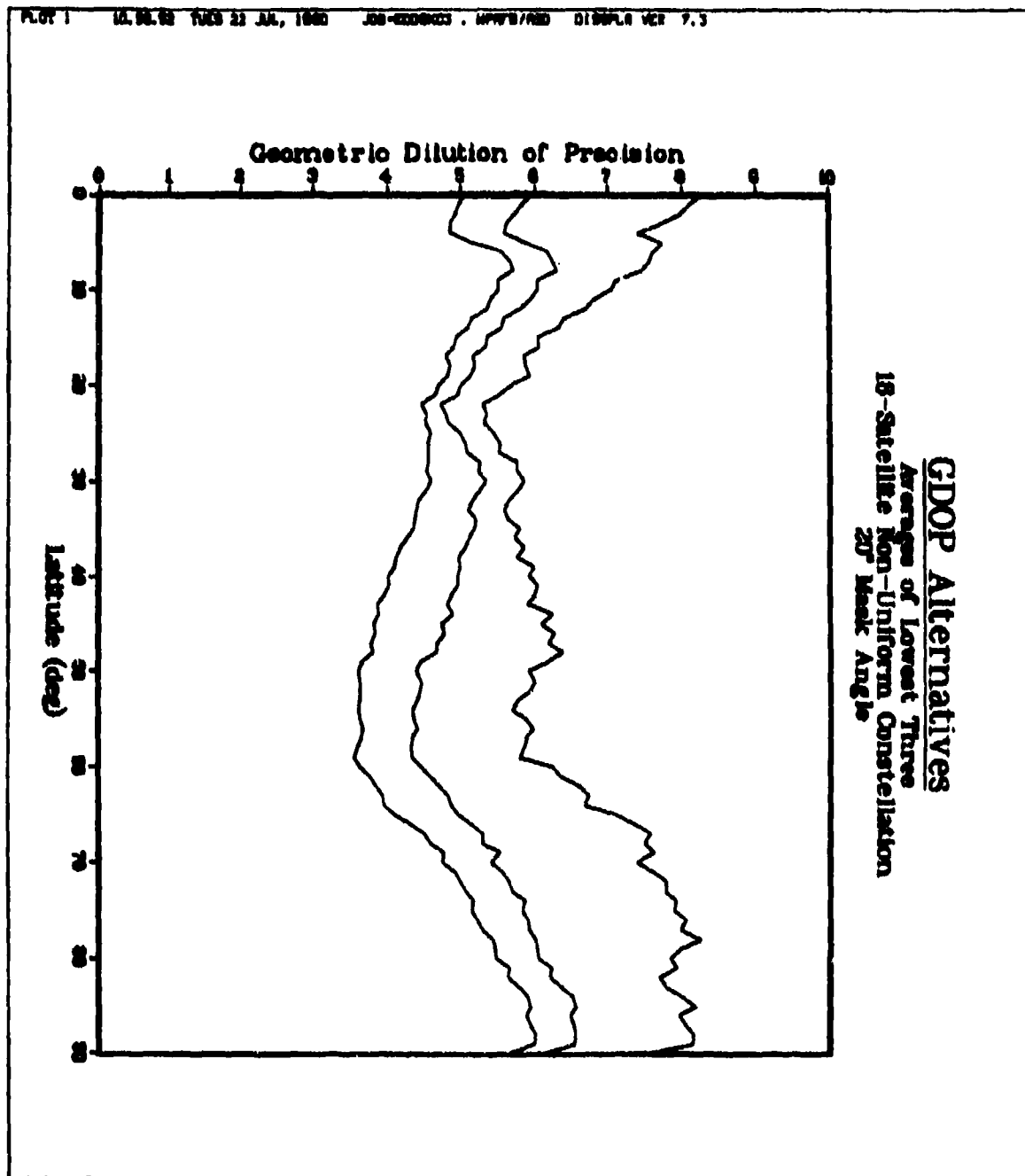




GDOP Alternatives
Averages of Lowest Three
 18-Satellite Non-Uniform Constellation
 of Mask Angle



GDOP Alternatives
Averages of Lowest Three
10-Satellite Non-Uniform Constellation
10° Mean Angle



ATTACHMENT 3

CAS SIMULATION

CAS MISSION

TIME = 0.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-185.32, -277.99, 0.00) HEADING = 90.00

SATELLITE	ORBIT	ID	J/S
1	1	1	21.77
5	3	2	21.59
6	3	3	16.97
7	1	4	22.88
7	3	5	22.57
8	1	6	20.12

SATELLITES	GDOP	SATELLITES	GDOP	SATELLITES	GDOP
1 2 3 4	4.30 *	1 2 3 5	3.90 *	1 2 3 6	15.20
1 2 4 5	9.44 *	1 2 4 6	5.44 *	1 2 5 6	6.91
1 3 4 5	2.92 *	1 3 4 6	4.10 *	1 3 5 6	5.83
1 4 5 6	4.11 *	2 3 4 5	3.93 *	2 3 4 6	16.88
2 3 5 6	308.91 *	2 4 5 6	7.00 *	3 4 5 6	5.82

SATELLITE	ORBIT	THETA	PHINRTH
1	1	58.01	-96.37
5	3	46.98	-23.62
6	3	11.53	131.67
7	1	63.96	43.09
7	3	65.93	144.92
8	1	28.30	-20.46

CAS MISSION

TIME = 300.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-185.32, -277.99, 0.00) HEADING = 90.00

SATELLITE	ORBIT	ID	J/S
1	1	1	21.44
5	3	2	21.75
6	3	3	17.20
7	1	4	23.03
7	3	5	22.14
8	1	6	20.09

SATELLITES				GDOP	SATELLITES				GDOP	SATELLITES				GDOP
1	2	3	4	4.34 *	1	2	3	5	3.88 *	1	2	3	6	18.62
1	2	4	5	11.21 *	1	2	4	6	5.00 *	1	2	5	6	6.40
1	3	4	5	2.98 *	1	3	4	6	4.20 *	1	3	5	6	5.87
1	4	5	6	4.06 *	2	3	4	5	3.90 *	2	3	4	6	13.06
2	3	5	6	25.37 *	2	4	5	6	5.92 *	3	4	5	6	6.83

SATELLITE	ORBIT	THETA	PHINRTH
1	1	55.64	-96.34
5	3	49.02	-25.32
6	3	9.23	128.82
7	1	65.74	44.09
7	3	63.98	149.15
8	1	27.82	-15.35

CAS MISSION

TIME = 600.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-185.32, -277.99, 0.00) HEADING = 90.00

SATELLITE	ORBIT	ID	J/S
1	1	1	21.10
5	3	2	21.91
6	3	3	17.42
7	1	4	23.19
7	3	5	21.71
8	1	6	20.07

SATELLITES	GDOP	SATELLITES	GDOP	SATELLITES	GDOP
1 2 3 4	4.40 *	1 2 3 5	3.87 *	1 2 3 6	22.46
1 2 4 5	13.92 *	1 2 4 6	4.70 *	1 2 5 6	5.96
1 3 4 5	3.06 *	1 3 4 6	4.32 *	1 3 5 6	5.95
1 4 5 6	4.02 *	2 3 4 5	3.88 *	2 3 4 6	10.85
2 3 5 6	12.61 *	2 4 5 6	5.18 *	3 4 5 6	8.37

SATELLITE	ORBIT	THETA	PHINRTH
1	1	53.24	-96.30
5	3	51.05	-26.96
6	3	6.92	124.83
7	1	67.55	44.97
7	3	62.00	148.44
8	1	27.61	-10.13

CAS MISSION

TIME = 900.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-185.32, -277.99, 0.00) HEADING = 90.00

SATELLITE	ORBIT	ID	J/S
1	1	1	20.77
5	3	2	22.07
6	3	3	17.63
7	1	4	23.35
7	3	5	21.28
8	1	6	20.07

SATELLITES	GDOP	SATELLITES	GDOP	SATELLITES	GDOP
1 2 3 4	4.49 *	1 2 3 5	3.87 *	1 2 3 6	29.18
1 2 4 5	18.48 *	1 2 4 6	4.49 *	1 2 5 6	5.60
1 3 4 5	3.16 *	1 3 4 6	4.49 *	1 3 5 6	6.07
1 4 5 6	3.99 *	2 3 4 5	3.88 *	2 3 4 6	7.44
2 3 5 6	8.73 *	2 4 5 6	4.66 *	3 4 5 6	10.98

SATELLITE	ORBIT	THETA	PHINRTH
1	1	50.83	-96.24
5	3	53.08	-28.53
6	3	4.63	117.98
7	1	69.39	45.73
7	3	60.01	147.77
8	1	27.68	-4.91

CAS MISSION

TIME = 1200.00 SECONDS

MASK ANGLE = 10.00 DEGREES

A/C (X,Y,Z) = (-148.26, -250.19, 9.14) HEADING = 53.13

SATELLITE	ORBIT	ID	J/S
1	1	1	52.40
5	3	2	67.40
6	3	3	52.40
7	1	4	73.44
7	3	5	60.40
8	1	6	52.40

SATELLITES				GDOP		SATELLITES				GDOP		SATELLITES				GDOP
1	2	3	4	4.59	*	1	2	3	5	3.89	*	1	2	3	6	43.26
1	2	4	5	27.72	*	1	2	4	6	4.34	*	1	2	5	6	5.30
1	3	4	5	3.28	*	1	3	4	6	4.71	*	1	3	5	6	6.24
1	4	5	6	3.97	*	2	3	4	5	3.87	*	2	3	4	6	8.48
2	3	5	6	6.92	*	2	4	5	6	4.27	*	3	4	5	6	16.20

SATELLITE	ORBIT	THETA	PHINRTH
1	1	48.73	-96.90
5	3	54.92	-30.80
6	3	2.26	112.54
7	1	70.80	46.07
7	3	58.15	147.20
8	1	27.60	-.80

CAS MISSION

TIME = 1500.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-135.90, -193.05, 9.14) HEADING = 12.20

SATELLITE	ORBIT	ID	J/S
1	1	1	52.79
5	3	2	68.21
6	3	3	52.79
7	1	4	73.74
7	3	5	60.33
8	1	6	52.79

SATELLITES				GDOP		SATELLITES				GDOP		SATELLITES				GDOP
1	2	3	4	4.73	*	1	2	3	5	3.93	*	1	2	3	6	88.79
1	2	4	5	56.18	*	1	2	4	6	4.24	*	1	2	5	6	5.05
1	3	4	5	3.43	*	1	3	4	6	5.02	*	1	3	5	6	6.48
1	4	5	6	3.95	*	2	3	4	5	3.88	*	2	3	4	6	7.82
2	3	5	6	5.91	*	2	4	5	6	3.97	*	3	4	5	6	31.57

SATELLITE	ORBIT	THETA	PHINRTH
1	1	46.91	-97.01
5	3	57.18	-32.83
6	3	.73	-28.00
7	1	72.19	46.33
7	3	55.89	147.07
8	1	28.01	2.76

CAS MISSION

TIME = 1800.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-123.55, -135.90, 9.14) HEADING = 12.20

SATELLITE	ORBIT	ID	J/S
1	1	1	53.04
5	3	2	68.98
6	3	3	53.04
7	1	4	73.95
7	3	5	59.93
8	1	6	53.04

SATELLITES				GDDP		SATELLITES				GDDP		SATELLITES				GDDP
1	2	3	4	4.91	*	1	2	3	5	3.98	*	1	2	3	6	1103.65
1	2	4	5	1786.29	*	1	2	4	6	4.17	*	1	2	5	6	4.84
1	3	4	5	3.61	*	1	3	4	6	5.45	*	1	3	5	6	6.81
1	4	5	6	3.94	*	2	3	4	5	3.89	*	2	3	4	6	7.36
2	3	5	6	5.28	*	2	4	5	6	3.74	*	3	4	5	6	779.97

SATELLITE	ORBIT	THETA	PHINRTH
1	1	45.09	-97.09
5	3	59.45	-34.75
6	3	3.54	-53.70
7	1	73.60	46.51
7	3	53.60	147.08
8	1	28.57	6.13

CAS MISSION

TIME = 2100.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-111.19, -78.76, 9.14) HEADING = 12.20

SATELLITE	ORBIT	ID	J/S
1	1	1	53.17
5	3	2	69.73
6	3	3	53.16
7	1	4	74.11
7	3	5	54.77
8	1	6	53.16

SATELLITES	GDOP	SATELLITES	GDOP	SATELLITES	GDOP
1 2 3 4	5.12 *	1 2 3 5	4.07 *	1 2 3 6	76.83
1 2 4 5	52.95 *	1 2 4 6	4.13 *	1 2 5 6	4.68
1 3 4 5	3.85 *	1 3 4 6	6.08 *	1 3 5 6	7.28
1 4 5 6	3.93 *	2 3 4 5	3.91 *	2 3 4 6	7.02
2 3 5 6	4.86 *	2 4 5 6	3.55 *	3 4 5 6	34.44

SATELLITE	ORBIT	THETA	PHINRTH
1	1	43.26	-97.15
5	3	61.75	-36.55
6	3	6.45	-57.38
7	1	75.02	46.61
7	3	51.28	147.25
8	1	29.28	9.27

CAS MISSION

TIME = 2400.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-98.84, -21.62, 9.14) HEADING = 12.20

SATELLITE	ORBIT	ID	J/S
1	1	1	53.25
5	3	2	70.49
6	3	3	53.25
7	1	4	74.26
7	3	5	53.25
8	1	6	53.25

SATELLITES				GDOP		SATELLITES				GDOP		SATELLITES				GDOP
1	2	3	4	5.37	*	1	2	3	5	4.19	*	1	2	3	6	40.51
1	2	4	5	26.98	*	1	2	4	6	4.12	*	1	2	5	6	4.54
1	3	4	5	4.15	*	1	3	4	6	7.09	*	1	3	5	6	7.92
1	4	5	6	3.94	*	2	3	4	5	3.95	*	2	3	4	6	6.79
2	3	5	6	4.58	*	2	4	5	6	3.41	*	3	4	5	6	16.99

SATELLITE	ORBIT	THETA	PHINRTH
1	1	41.43	-97.15
5	3	64.06	-38.25
6	3	9.39	-59.33
7	1	76.45	46.64
7	3	48.94	147.59
8	1	30.13	12.16

CAS MISSION

TIME = 2700.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-86.48, 35.52, 9.14) HEADING = 12.20

SATELLITE	ORBIT	ID	J/S
1	1	1	53.33
5	3	2	71.29
6	3	3	53.33
7	1	4	74.42
7	3	5	53.33
8	1	6	53.33

SATELLITES				GDOP		SATELLITES				GDOP		SATELLITES				GDOP
1	2	3	4	5.68	*	1	2	3	5	4.35	*	1	2	3	6	28.11
1	2	4	5	18.19	*	1	2	4	6	4.12	*	1	2	5	6	4.43
1	3	4	5	4.54	*	1	3	4	6	8.89	*	1	3	5	6	8.85
1	4	5	6	3.95	*	2	3	4	5	3.99	*	2	3	4	6	6.62
2	3	5	6	4.37	*	2	4	5	6	3.29	*	3	4	5	6	11.39

SATELLITE	ORBIT	THETA	PHINRTH
1	1	39.59	-97.10
5	3	66.39	-39.84
6	3	12.35	-60.75
7	1	77.89	46.60
7	3	46.59	148.13
8	1	31.10	14.77

CAS MISSION

TIME = 3000.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-74.13, 92.66, 9.14) HEADING = 12.20

SATELLITE	ORBIT	ID	J/S
1	1	1	53.39
5	3	2	72.09
6	3	3	53.39
7	1	4	74.59
7	3	5	53.39
8	1	6	53.39

SATELLITES	GDOP	SATELLITES	GDOP	SATELLITES	GDOP
1 2 3 4	6.06 *	1 2 3 5	4.58 *	1 2 3 6	22.02
1 2 4 5	13.79 *	1 2 4 6	4.14 *	1 2 5 6	4.35
1 3 4 5	5.08 *	1 3 4 6	12.75 *	1 3 5 6	10.22
1 4 5 6	3.96 *	2 3 4 5	4.03 *	2 3 4 6	6.52
2 3 5 6	4.23 *	2 4 5 6	3.20 *	3 4 5 6	8.66

SATELLITE	ORBIT	THETA	PHINRTH
1	1	37.76	-96.98
5	3	68.73	-41.34
6	3	15.33	-61.95
7	1	79.33	46.49
7	3	44.23	148.90
8	1	32.19	17.12

CAS MISSION

TIME = 3300.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-67.95, 92.66, 9.14) HEADING = 90.00

SATELLITE	ORBIT	ID	J/S
1	1	1	53.42
5	3	2	72.53
6	3	3	53.42
7	3	4	53.42
8	1	5	53.42

SATELLITES					GDOP		SATELLITES					GDOP		SATELLITES					GDOP
1	2	3	4		4.89	*	1	2	3	5	18.47	*	1	2	4	5	4.28		
1	3	4	5		12.36	*	2	3	4	5	4.12	*							

SATELLITE	ORBIT	THETA	PHINRTH
1	1	35.29	-96.72
5	3	70.74	-42.42
6	3	17.77	-61.77
7	3	42.14	149.27
8	1	33.65	20.22

CAS MISSION

TIME = 3600.00 SECONDS
A/C (X,Y,Z) = (-61.77,

MASK ANGLE = 10.00 DEGREES
92.66, 9.14) HEADING = 90.00

SATELLITE	ORBIT	ID	J/S
1	1	1	53.45
5	3	2	72.51
6	3	3	53.45
7	3	4	53.45
8	1	5	53.45

SATELLITES	GDOP	SATELLITES	GDOP	SATELLITES	GDOP
1 2 3 4	5.33 *	1 2 3 5	16.24 *	1 2 4 5	4.23
1 3 4 5	16.05 *	2 3 4 5	4.04 *		

SATELLITE	ORBIT	THETA	PHINRTH
1	1	32.83	-96.33
5	3	72.74	-43.47
6	3	20.21	-61.86
7	3	40.05	149.82
8	1	35.24	22.92

CAS MISSION

TIME = 3900.00 SECONDS
A/C (X,Y,Z) = (-55.60, 92.66, 9.14) MASK ANGLE = 10.00 DEGREES
HEADING = 90.00

SATELLITE	ORBIT	ID	J/S
1	1	1	53.47
2	1	2	69.81
5	3	3	72.62
6	3	4	53.47
7	3	5	53.47
8	1	6	53.47

SATELLITES	GDOP	SATELLITES	GDOP	SATELLITES	GDOP
1 2 3 4	18.73 *	1 2 3 5	3.58 *	1 2 3 6	4.05
1 2 4 5	12.01 *	1 2 4 6	23.20 *	1 2 5 6	3.93
1 3 4 5	5.99 *	1 3 4 6	14.76 *	1 3 5 6	4.21
1 4 5 6	23.62 *	2 3 4 5	3.99 *	2 3 4 6	4.19
2 3 5 6	51.32 *	2 4 5 6	4.27 *	3 4 5 6	3.99

SATELLITE	ORBIT	THETA	PHINRTH
1	1	30.36	-95.78
2	1	78.74	-122.70
5	3	74.73	-44.47
6	3	22.67	-62.12
7	3	37.97	150.60
8	1	36.93	25.27

CAS MISSION

TIME = 4200.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (9.27, 74.13, .03) HEADING = 90.00

SATELLITE	ORBIT	ID	J/S
1	1	1	61.42
2	1	2	80.24
5	3	3	82.76
6	3	4	61.42
7	3	5	61.42
8	1	6	61.42

SATELLITES				GDOP		SATELLITES				GDOP		SATELLITES				GDOP
1	2	3	4	36.97	*	1	2	3	5	3.67	*	1	2	3	6	4.02
1	2	4	5	12.34	*	1	2	4	6	12.43	*	1	2	5	6	3.91
1	3	4	5	7.01	*	1	3	4	6	13.72	*	1	3	5	6	4.20
1	4	5	6	46.69	*	2	3	4	5	3.99	*	2	3	4	6	3.98
2	3	5	6	104.27	*	2	4	5	6	4.22	*	3	4	5	6	3.96

SATELLITE	ORBIT	THETA	PHINRTH
1	1	27.77	-97.03
2	1	76.85	-124.26
5	3	76.19	-46.18
6	3	24.63	-64.26
7	3	36.59	151.22
8	1	38.23	27.34

CAS MISSION

TIME = 4500.00 SECONDS
A/C (X,Y,Z) = (46.33, 18.53, .03) MASK ANGLE = 10.00 DEGREES
HEADING = 146.31

SATELLITE	ORBIT	ID	J/S
1	1	1	64.92
2	1	2	78.27
3	3	3	84.02
6	3	4	64.92
7	3	5	64.92
8	1	6	65.35

SATELLITES				GDOP		SATELLITES				GDOP		SATELLITES				GDOP
1	2	3	4	5287.24	*	1	2	3	5	3.79	*	1	2	3	6	3.99
1	2	4	5	12.81	*	1	2	4	6	8.77	*	1	2	5	6	3.91
1	3	4	5	8.78	*	1	3	4	6	12.99	*	1	3	5	6	4.20
1	4	5	6	26878.42	*	2	3	4	5	3.99	*	2	3	4	6	3.81
2	3	5	6	2373.89	*	2	4	5	6	4.19	*	3	4	5	6	3.94

SATELLITE	ORBIT	THETA	PHINRTH
1	1	24.73	-97.42
2	1	74.53	-125.59
5	3	77.59	-47.35
6	3	26.37	-65.02
7	3	35.16	151.60
8	1	40.10	29.65

CAS MISSION

TIME = 4800.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (78.76, 50.96, .06) HEADING = 45.00

SATELLITE	ORBIT	ID	J/S
1	1	1	62.83
2	1	2	81.98
5	3	3	80.78
6	3	4	62.83
7	3	5	62.83
8	1	6	62.83

SATELLITES				GDOP		SATELLITES				GDOP		SATELLITES				GDOP
1	2	3	4	37.45	*	1	2	3	5	3.96	*	1	2	3	6	3.99
1	2	4	5	13.53	*	1	2	4	6	7.00	*	1	2	5	6	3.93
1	3	4	5	12.43	*	1	3	4	6	12.52	*	1	3	5	6	4.23
1	4	5	6	46.54	*	2	3	4	5	4.02	*	2	3	4	6	3.69
2	3	5	6	95.72	*	2	4	5	6	4.18	*	3	4	5	6	3.94

SATELLITE	ORBIT	THETA	PHINRTH
1	1	22.70	-97.21
2	1	72.86	-126.68
5	3	79.63	-48.68
6	3	29.05	-66.52
7	3	33.27	150.66
8	1	41.61	30.53

CAS MISSION

TIME = 5100.00 SECONDS
A/C (X,Y,Z) = (111.19, 83.40, .09) MASK ANGLE = 10.00 DEGREES
HEADING = 45.00

SATELLITE	ORBIT	ID	J/S
1	1	1	49.59
2	1	2	69.55
6	3	3	49.59
7	3	4	49.59
8	1	5	49.59

SATELLITES				GDOP	SATELLITES				GDOP	SATELLITES				GDOP
1	2	3	4	14.57 *	1	2	3	5	5.97 *	1	2	4	5	3.97
1	3	4	5	23.59 *	2	3	4	5	4.14 *					

SATELLITE	ORBIT	THETA	PHINRTH
1	1	20.69	-96.75
2	1	71.19	-127.80
6	3	31.74	-67.92
7	3	31.47	156.19
8	1	43.15	31.20

CAS MISSION

TIME = 5400.00 SECONDS

MASK ANGLE = 10.00 DEGREES

A/C (X,Y,Z) = (46.33,

37.06,

.31)

HEADING = -125.54

SATELLITE	ORBIT	ID	J/S
1	1	1	64.70
2	1	2	81.59
6	3	3	64.70
7	3	4	64.70
8	1	5	65.64
8	3	6	94.75

SATELLITES	GDOP		SATELLITES	GDOP		SATELLITES	GDOP
1 2 3 4	16.02	*	1 2 3 5	5.31	*	1 2 3 6	5.95
1 2 4 5	4.02	*	1 2 4 6	6.25	*	1 2 5 6	4.11
1 3 4 5	16.04	*	1 3 4 6	299.27	*	1 3 5 6	5.87
1 4 5 6	5.95	*	2 3 4 5	4.21	*	2 3 4 6	4.10
2 3 5 6	9.31	*	2 4 5 6	3.02	*	3 4 5 6	3.98

SATELLITE	ORBIT	THETA	PHINRTH
1	1	17.73	-91.60
2	1	68.31	-127.78
6	3	34.03	-66.05
7	3	29.09	157.90
8	1	46.07	32.87
8	3	79.34	138.17

GAS MISSION

TIME = 5700.00 SECONDS
A/C (X,Y,Z) = (-9.27,

MASK ANGLE = 10.00 DEGREES
55.60, 3.96) HEADING = -71.57

SATELLITE	ORBIT	ID	J/S
1	1	1	57.54
2	1	2	71.25
6	3	3	57.54
7	3	4	57.54
8	1	5	59.26
8	3	6	72.82

SATELLITES	GDOP	SATELLITES	GDOP	SATELLITES	GDOP
1 2 3 4	18.26 *	1 2 3 5	4.87 *	1 2 3 6	5.42
1 2 4 5	4.10 *	1 2 4 6	6.25 *	1 2 5 6	4.05
1 3 4 5	12.38 *	1 3 4 6	25.26 *	1 3 5 6	5.79
1 4 5 6	6.96 *	2 3 4 5	4.25 *	2 3 4 6	4.06
2 3 5 6	11.05 *	2 4 5 6	3.07 *	3 4 5 6	3.94

SATELLITE	ORBIT	THETA	PHINRTH
1	1	15.70	-85.17
2	1	65.97	-127.65
6	3	36.95	-65.13
7	3	26.58	161.39
8	1	48.52	33.64
8	3	76.89	138.48

CAS MISSION

TIME = 6000.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-64.86, 74.13, 7.62) HEADING = -71.57

SATELLITE	ORBIT	ID	J/S
1	1	1	54.29
2	1	2	67.32
6	3	3	54.29
7	3	4	54.29
8	1	5	57.63
8	3	6	68.79

SATELLITES	GDOP	SATELLITES	GDOP	SATELLITES	GDOP
1 2 3 4	21.84 *	1 2 3 5	4.57 *	1 2 3 6	5.97
1 2 4 5	4.21 *	1 2 4 6	6.29 *	1 2 5 6	3.99
1 3 4 5	10.26 *	1 3 4 6	12.60 *	1 3 5 6	5.06
1 4 5 6	8.50 *	2 3 4 5	4.32 *	2 3 4 6	4.02
2 3 5 6	13.68 *	2 4 5 6	3.13 *	3 4 5 6	3.91

SATELLITE	ORBIT	THETA	PHINRTH
1	1	13.94	-76.90
2	1	63.60	-127.51
6	3	39.86	-64.37
7	3	24.19	165.67
8	1	50.97	34.31
8	3	74.42	138.84

CAS MISSION

TIME = 6300.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-81.54, 9.27, 7.62) HEADING = -165.58

SATELLITE	ORBIT	ID	J/S
1	1	1	54.17
2	1	2	66.31
6	3	3	54.42
7	3	4	54.17
8	1	5	67.79
8	3	6	68.23

SATELLITES				GDOP		SATELLITES				GDOP		SATELLITES				GDOP
1	2	3	4	28.01	*	1	2	3	5	4.35	*	1	2	3	6	5.60
1	2	4	5	4.36	*	1	2	4	6	6.39	*	1	2	5	6	3.95
1	3	4	5	8.90	*	1	3	4	6	8.76	*	1	3	5	6	4.53
1	4	5	6	11.17	*	2	3	4	5	4.40	*	2	3	4	6	4.01
2	3	5	6	18.07	*	2	4	5	6	3.22	*	3	4	5	6	3.89

SATELLITE	ORBIT	THETA	PHINRTH
1	1	11.48	-67.06
2	1	60.78	-128.39
6	3	41.74	-64.10
7	3	22.59	168.33
8	1	53.58	35.38
8	3	72.75	138.66

CAS MISSION

TIME = 6600.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-98.22, -55.60, 7.62) HEADING = -165.58

SATELLITE	ORBIT	ID	J/S
1	1	1	54.03
2	1	2	65.12
6	3	3	54.83
7	3	4	54.03
8	1	5	68.95
8	3	6	67.67

SATELLITES				GDOP		SATELLITES				GDOP		SATELLITES				GDOP
1	2	3	4	40.69	*	1	2	3	5	4.19	*	1	2	3	6	5.29
1	2	4	5	4.57	*	1	2	4	6	6.54	*	1	2	5	6	3.91
1	3	4	5	7.99	*	1	3	4	6	6.96	*	1	3	5	6	4.14
1	4	5	6	16.61	*	2	3	4	5	4.50	*	2	3	4	6	4.01
2	3	5	6	26.87	*	2	4	5	6	3.34	*	3	4	5	6	3.88

SATELLITE	ORBIT	THETA	PHINRTH
1	1	9.58	-52.48
2	1	57.94	-124.37
6	3	43.61	-63.92
7	3	21.08	171.51
8	1	56.18	36.23
8	3	71.07	138.52

CAS MISSION

TIME = 6900.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-114.90, -120.46, 7.62) HEADING = -165.58

SATELLITE	ORBIT	ID	J/S
1	1	1	53.83
2	1	2	63.60
6	3	3	55.19
7	3	4	53.83
8	1	5	69.60
8	3	6	67.12

SATELLITES	GDOP	SATELLITES	GDOP	SATELLITES	GDOP
1 2 3 4	79.03 *	1 2 3 5	4.08 *	1 2 3 6	5.03
1 2 4 5	4.86 *	1 2 4 6	6.76 *	1 2 5 6	3.89
1 3 4 5	7.35 *	1 3 4 6	5.96 *	1 3 5 6	3.85
1 4 5 6	33.26 *	2 3 4 5	4.64 *	2 3 4 6	4.02
2 3 5 6	53.15 *	2 4 5 6	3.48 *	3 4 5 6	3.88

SATELLITE	ORBIT	THETA	PHINRTH
1	1	8.62	-32.80
2	1	55.09	-130.45
6	3	45.47	-63.81
7	3	19.69	175.28
8	1	58.78	36.90
8	3	69.40	138.42

CAS MISSION

TIME = 7200.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-131.58, -185.32, 7.62) HEADING = -165.58

SATELLITE	ORBIT	ID	J/S
1	1	1	53.59
2	1	2	61.56
6	3	3	55.39
7	3	4	53.59
8	1	5	70.41
8	3	6	66.12

SATELLITES				GDOP		SATELLITES				GDOP		SATELLITES				GDOP
1	2	3	4	3459.87	*	1	2	3	5	4.00	*	1	2	3	6	4.82
1	2	4	5	5.27	*	1	2	4	6	7.08	*	1	2	5	6	3.87
1	3	4	5	6.90	*	1	3	4	6	5.33	*	1	3	5	6	3.62
1	4	5	6	2229.75	*	2	3	4	5	4.80	*	2	3	4	6	4.36
2	3	5	6	4350.31	*	2	4	5	6	3.66	*	3	4	5	6	3.89

SATELLITE	ORBIT	THETA	PHINKTH
1	1	8.88	-11.56
2	1	52.22	-131.64
6	3	47.33	-63.77
7	3	18.44	179.72
8	1	61.36	37.40
8	3	67.73	138.36

CAS MISSION

TIME = 7500.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-148.26, -250.19, 7.62) HEADING = -165.58

SATELLITE	ORBIT	ID	J/S
1	1	1	53.06
2	1	2	53.06
6	3	3	54.49
7	3	4	53.06
8	1	5	71.07
8	3	6	64.71

SATELLITES				GDOP		SATELLITES				GDOP		SATELLITES				GDOP
1	2	3	4	82.43	*	1	2	3	5	3.95	*	1	2	3	6	4.65
1	2	4	5	5.90	*	1	2	4	6	7.53	*	1	2	5	6	3.87
1	3	4	5	6.58	*	1	3	4	6	4.90	*	1	3	5	6	3.44
1	4	5	6	32.36	*	2	3	4	5	5.00	*	2	3	4	6	4.13
2	3	5	6	54.33	*	2	4	5	6	3.89	*	3	4	5	6	3.90

SATELLITE	ORBIT	THETA	PHINRTH
1	1	10.25	5.94
2	1	49.35	-132.96
6	3	49.17	-63.77
7	3	17.37	-175.14
8	1	63.93	37.76
8	3	66.05	138.35

CAS MISSION

TIME = 7800.00 SECONDS

MASK ANGLE = 10.00 DEGREES

A/C (X,Y,Z) = (-166.79, -264.09, 3.81) HEADING = -126.87

SATELLITE ORBIT ID J/S

1	1	1	50.14
2	1	2	50.14
6	3	3	63.84
7	3	4	50.14
8	1	5	69.02
8	3	6	56.86

SATELLITES	GDOP		SATELLITES	GDOP		SATELLITES	GDOP
1 2 3 4	41.34	*	1 2 3 5	3.93	*	1 2 3 6	4.51
1 2 4 5	6.90	*	1 2 4 6	8.16	*	1 2 5 6	3.87
1 3 4 5	6.36	*	1 3 4 6	4.60	*	1 3 5 6	3.30
1 4 5 6	16.41	*	2 3 4 5	5.25	*	2 3 4 6	4.23
2 3 5 6	27.06	*	2 4 5 6	4.18	*	3 4 5 6	3.92

SATELLITE	ORBIT	THETA	PHINRTH
1	1	12.20	15.46
2	1	46.85	-133.96
6	3	51.49	-64.01
7	3	16.60	-167.25
8	1	66.17	37.73
8	3	64.02	138.66

CAS MISSION

TIME = 8100.00 SECONDS MASK ANGLE = 10.00 DEGREES
A/C (X,Y,Z) = (-185.32, -277.99, -.00) HEADING = -126.87

SATELLITE	ORBIT	ID	J/S
1	1	1	19.03
2	1	2	17.06
6	3	3	20.84
7	3	4	14.86
8	1	5	23.28
8	3	6	22.38

SATELLITES	GDOP	SATELLITES	GDOP	SATELLITES	GDOP
1 2 3 4	28.12 *	1 2 3 5	3.92 *	1 2 3 6	4.40
1 2 4 5	8.68 *	1 2 4 6	9.06 *	1 2 5 6	3.88
1 3 4 5	6.20 *	1 3 4 6	4.38 *	1 3 5 6	3.18
1 4 5 6	11.09 *	2 3 4 5	5.55 *	2 3 4 6	4.37
2 3 5 6	18.09 *	2 4 5 6	4.56 *	3 4 5 6	3.95

SATELLITE	ORBIT	THETA	PHINRTH
1	1	14.42	21.95
2	1	44.35	-135.03
6	3	53.80	-64.25
7	3	16.22	-158.72
8	1	68.40	37.62
8	3	61.99	139.07

ATTACHMENT 6

NAVIGATION PERFORMANCE IMPROVEMENT

24-SATELLITE CONSTELLATION

J/S Elimination Percentage

		MISSION				
		CAS	EI	HELO	IST	PPS
MASK	10°	69	69	81	59	56
	20°	45	27	60	34	37

Navigation Improvement Percentage

		MISSION				
		CAS	EI	HELO	IST	PPS
MASK	10°	34	44	9	19	31
	20°	8	7	2	4	6

Adjusted Navigation Improvement Percentage

		MISSION				
		CAS	EI	HELO	IST	PPS
MASK	10°	49	64	11	32	55
	20°	18	26	3	12	16

18-SATELLITE CONSTELLATION

J/S Elimination Percentage

MASK	MISSION				
	CAS	EI	HELO	IST	PPS
	10°	65	63	77	57
	20°	43	25	60	30

Navigation Improvement Percentage

MASK	MISSION				
	CAS	EI	HELO	IST	PPS
	10°	13	16	2	7
	20°	1	3	0	0

Adjusted Navigation Improvement Percentage

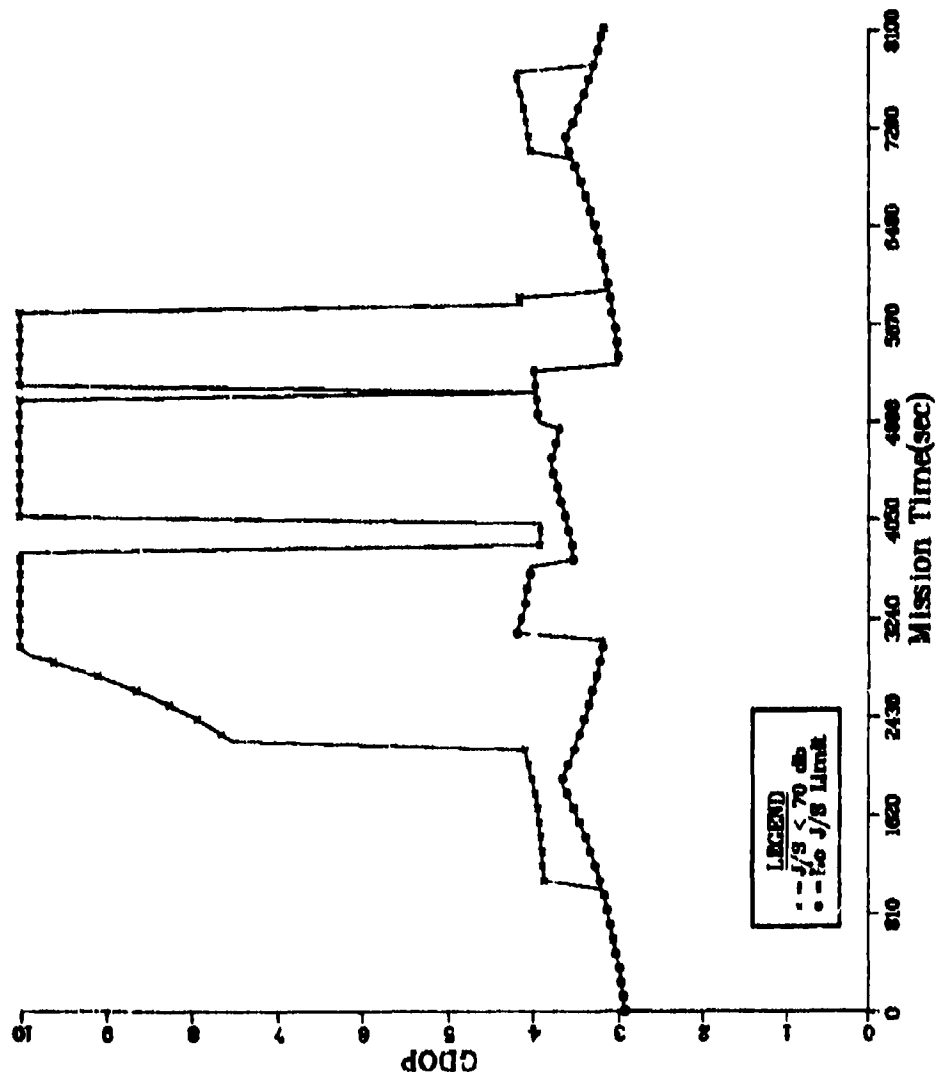
MASK	MISSION				
	CAS	EI	HELO	IST	PPS
	10°	20	25	3	12
	20°	2	12	0	0

Atch 6

ATTACHMENT 7

J/S IMPACT ON GDOP

GDOP Comparison for CAS Mission 24-Satellite Constellation 10° Mask Angle



Plot 1 15.43.28 THUR 23 OCT, 1980 JOP-7917204 - WPM/B/MSD 0159PLA VCR 1.3

Figure 1

Atch 7

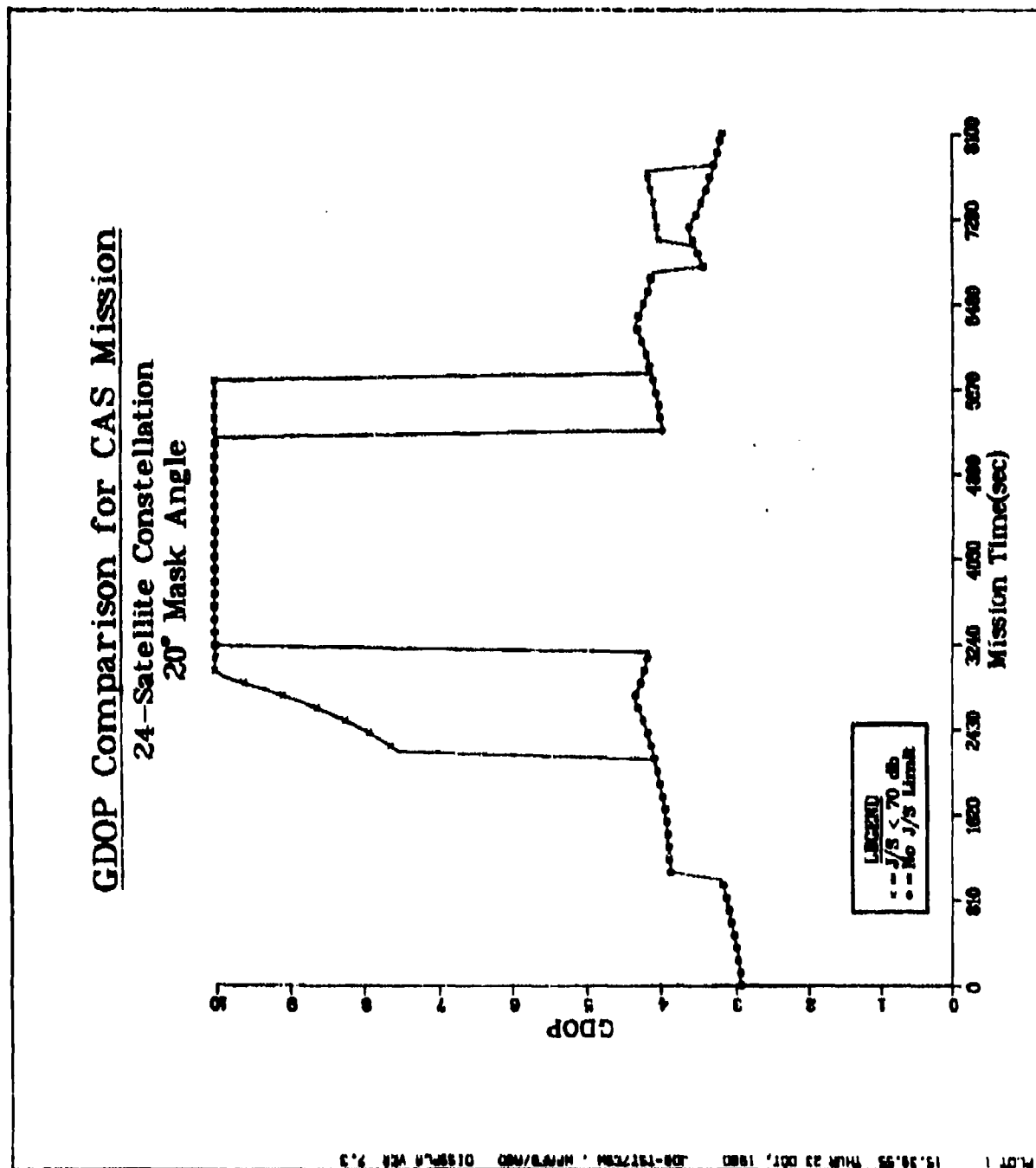


Figure 2

Atch 7

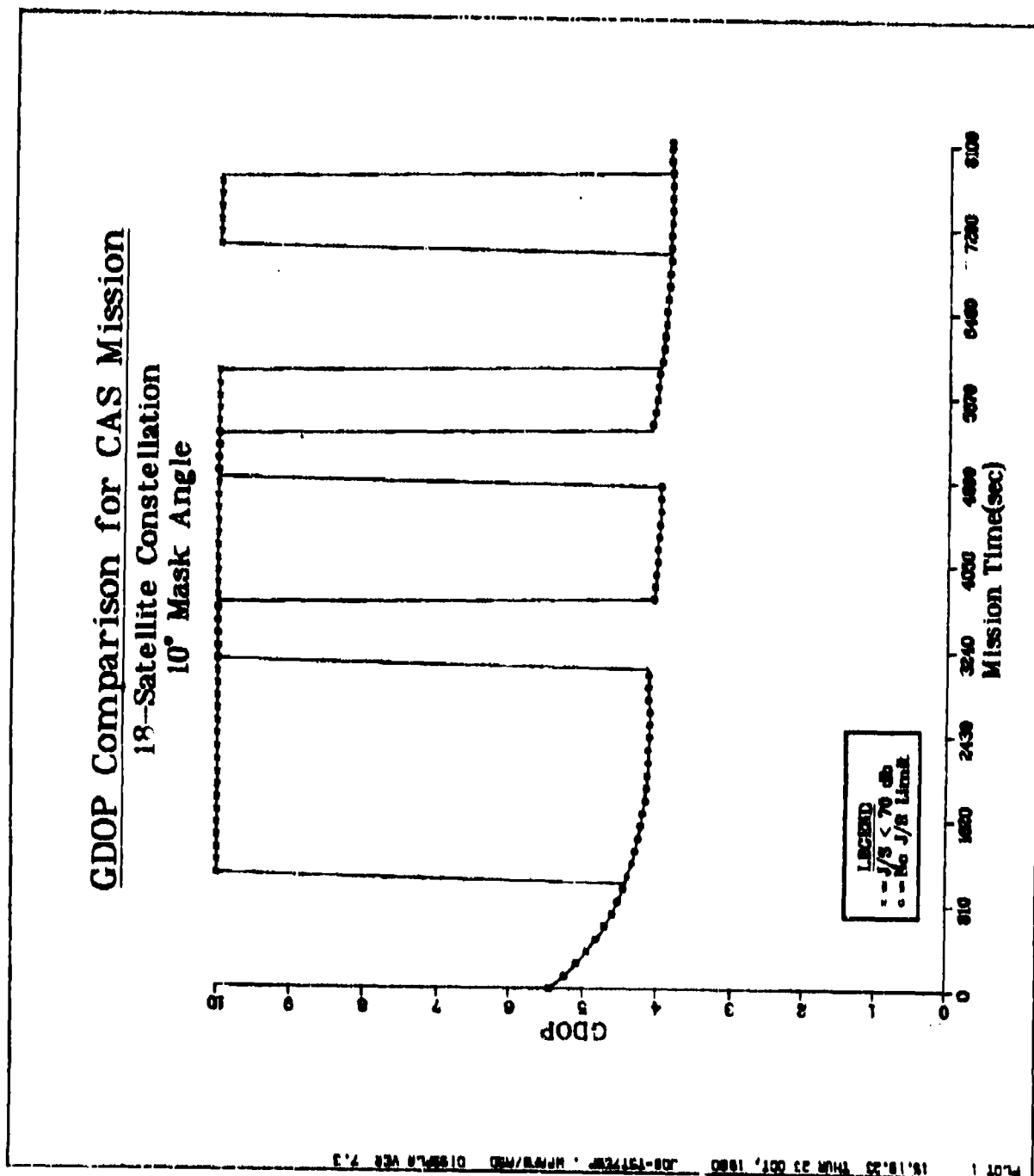


Figure 3

Atch 7

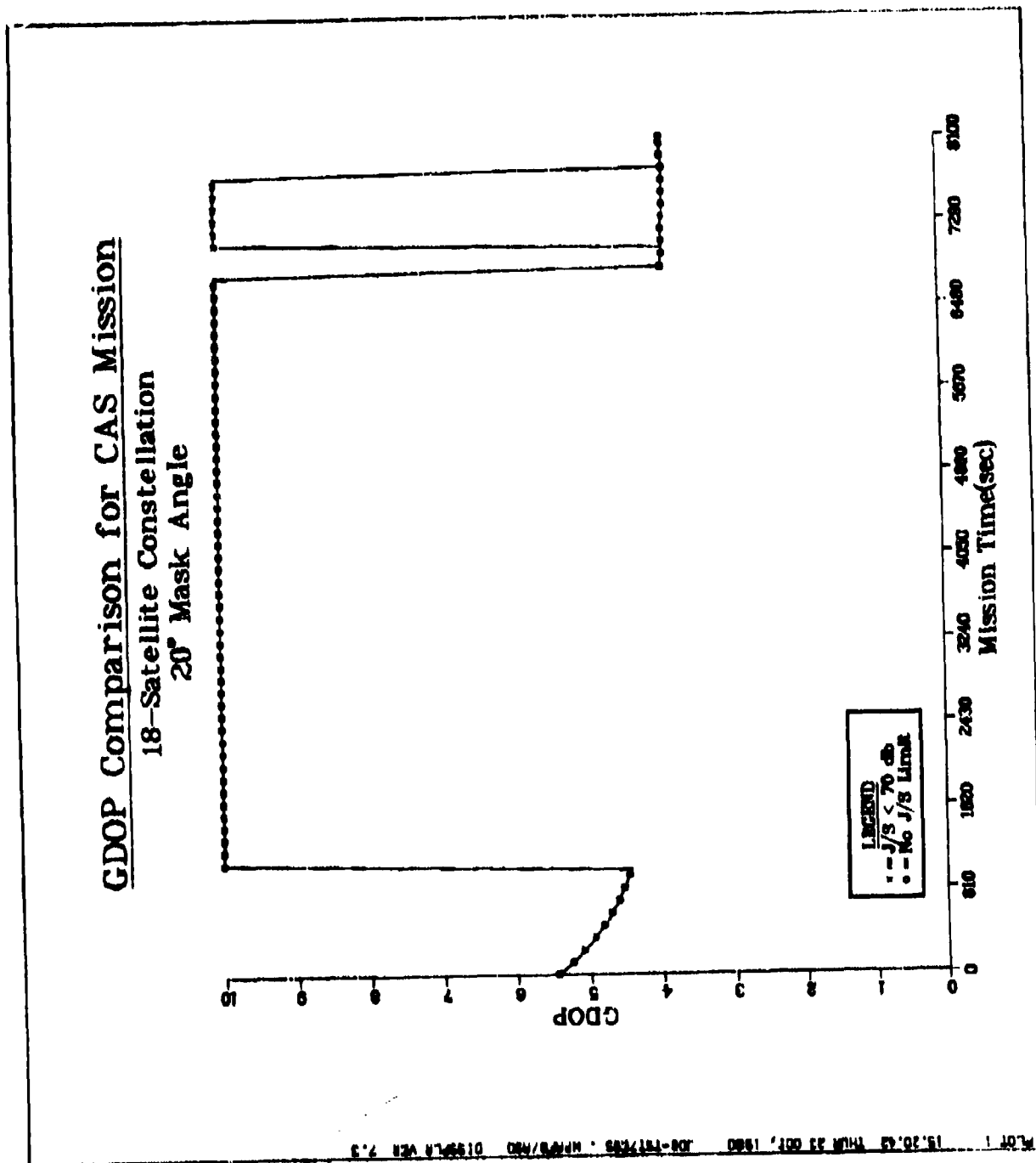


Figure 4

Atch 7

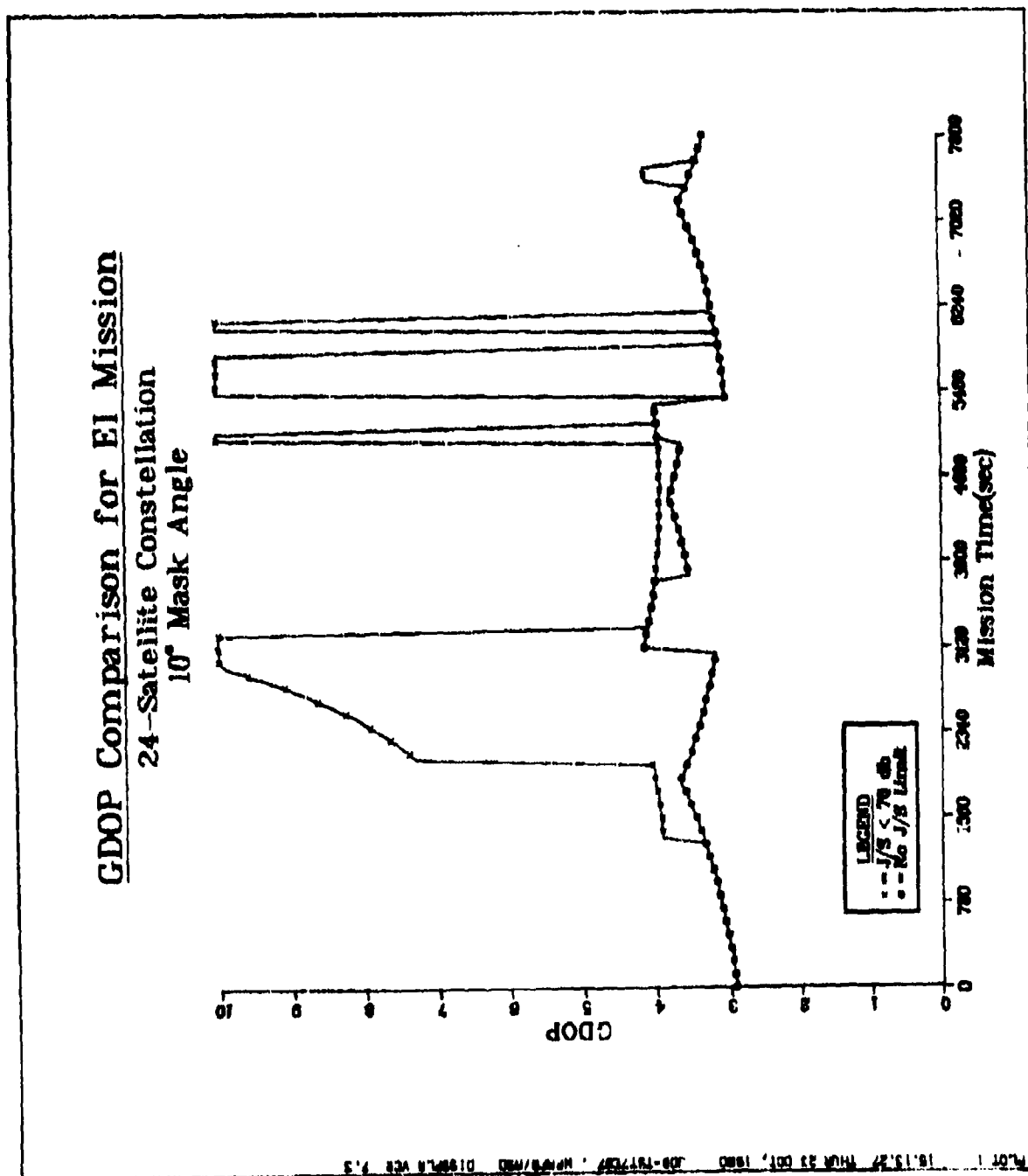


Figure 5

Atch 7

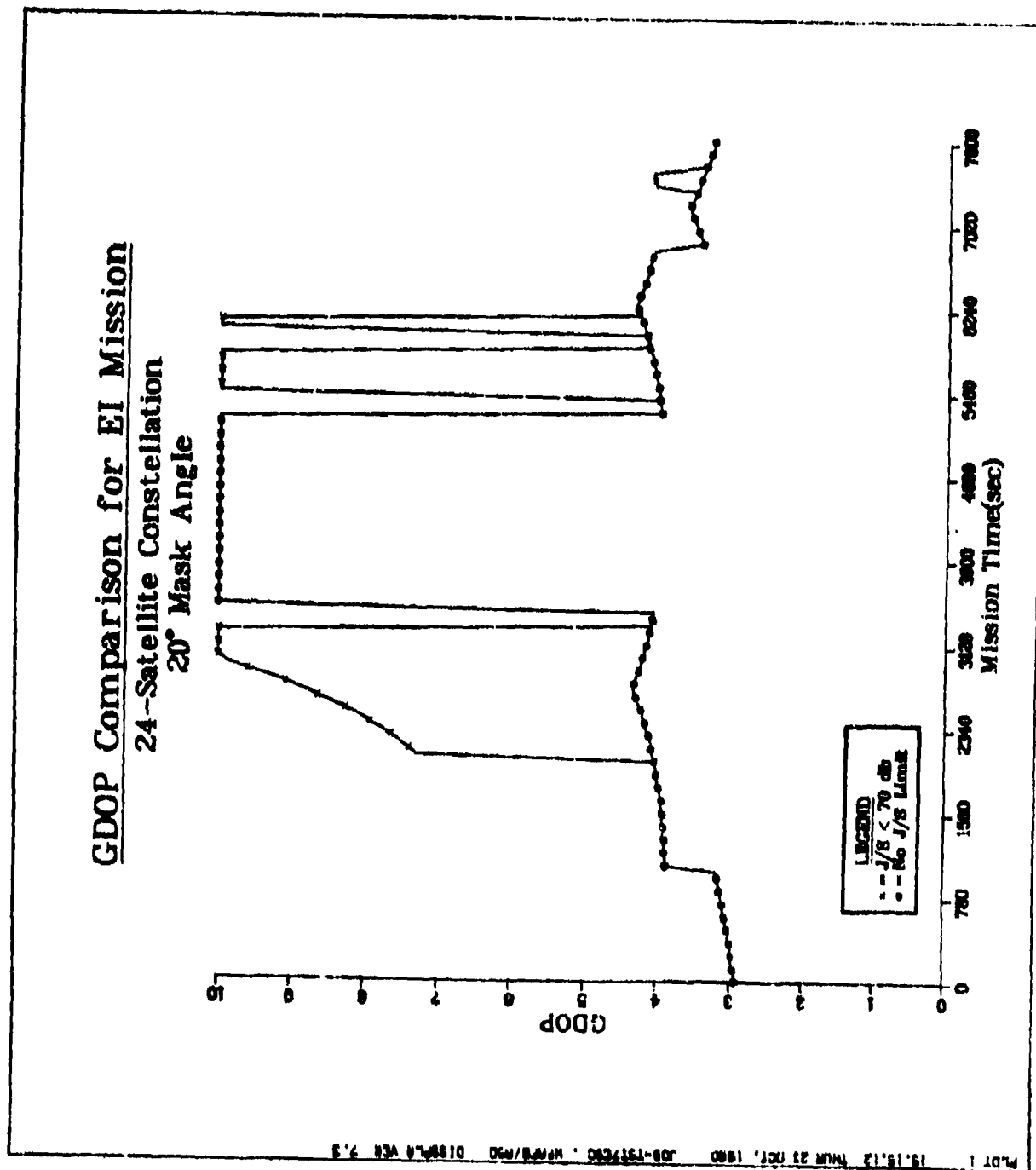


Figure 6

Atch 7

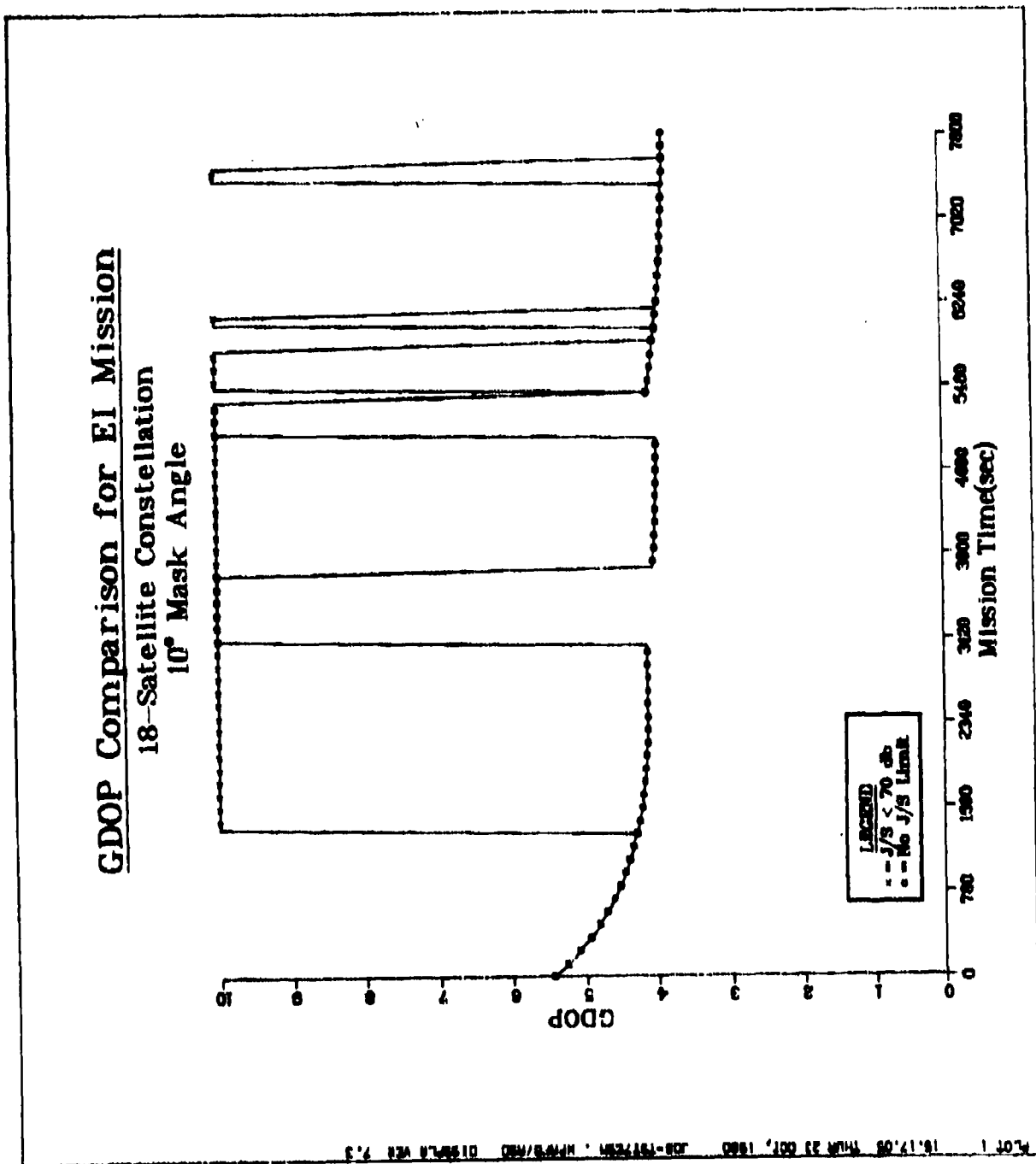


Figure 7

Atch 7

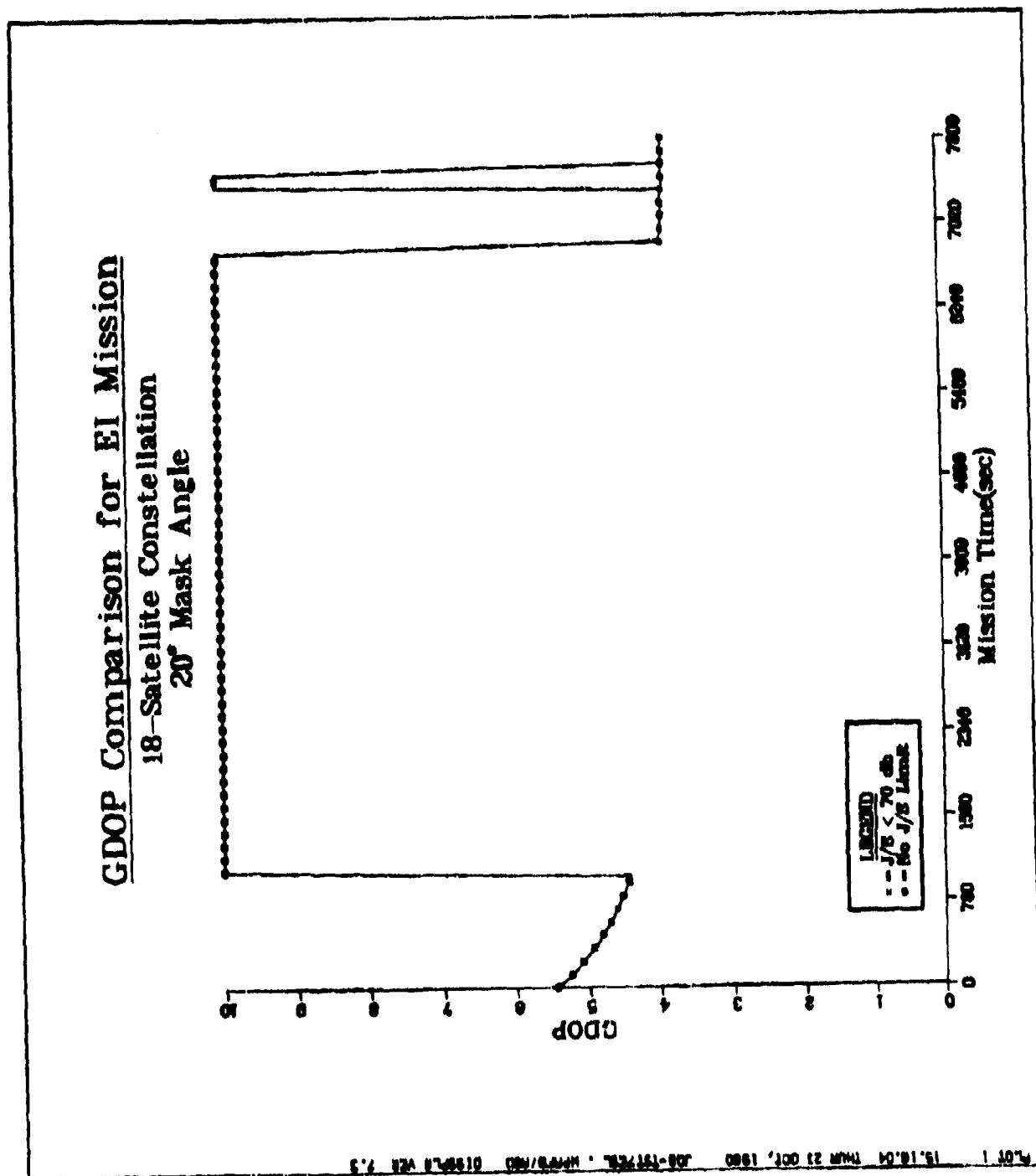


Figure 8

Atch 7

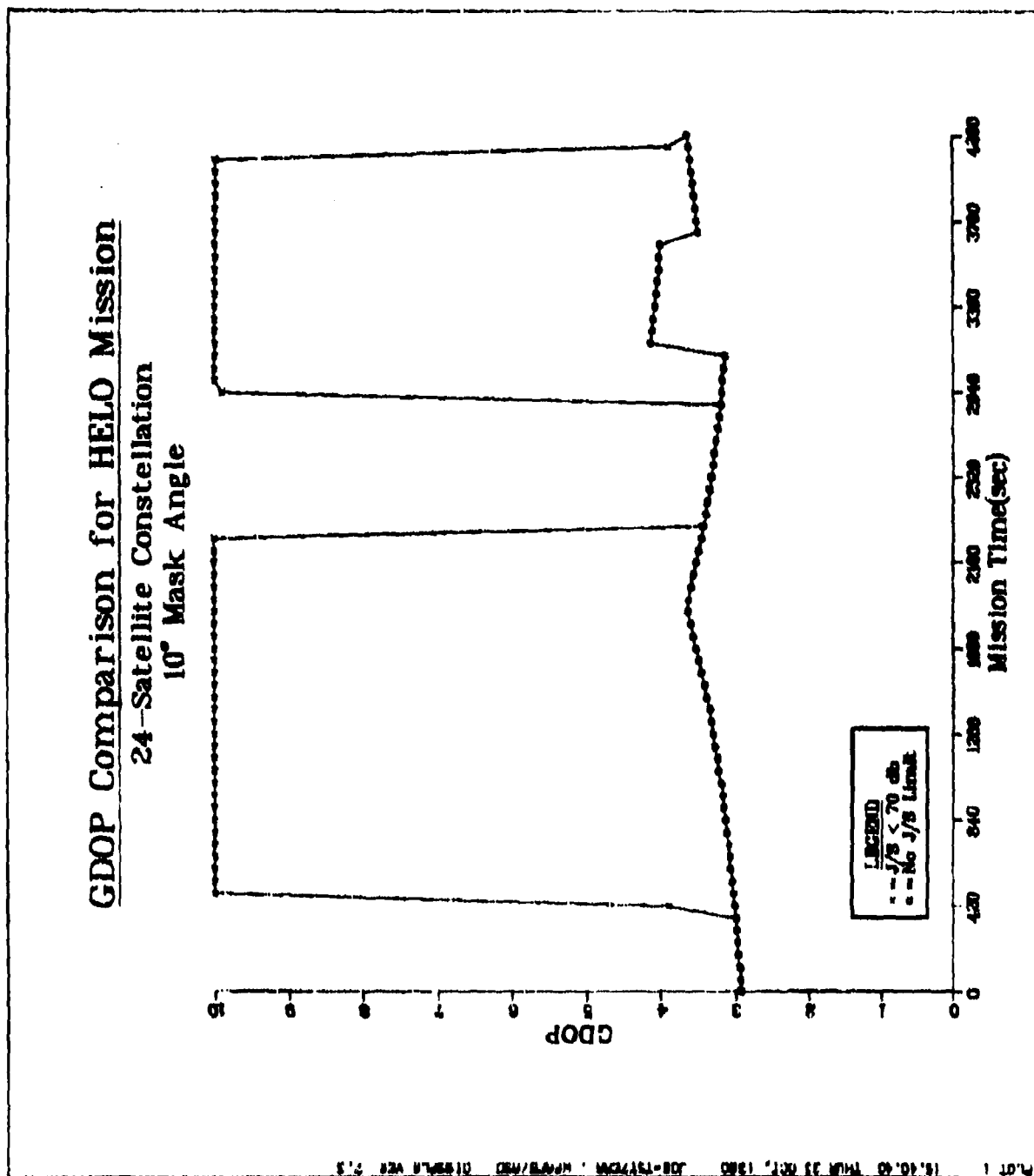


Figure 9

Atch 7

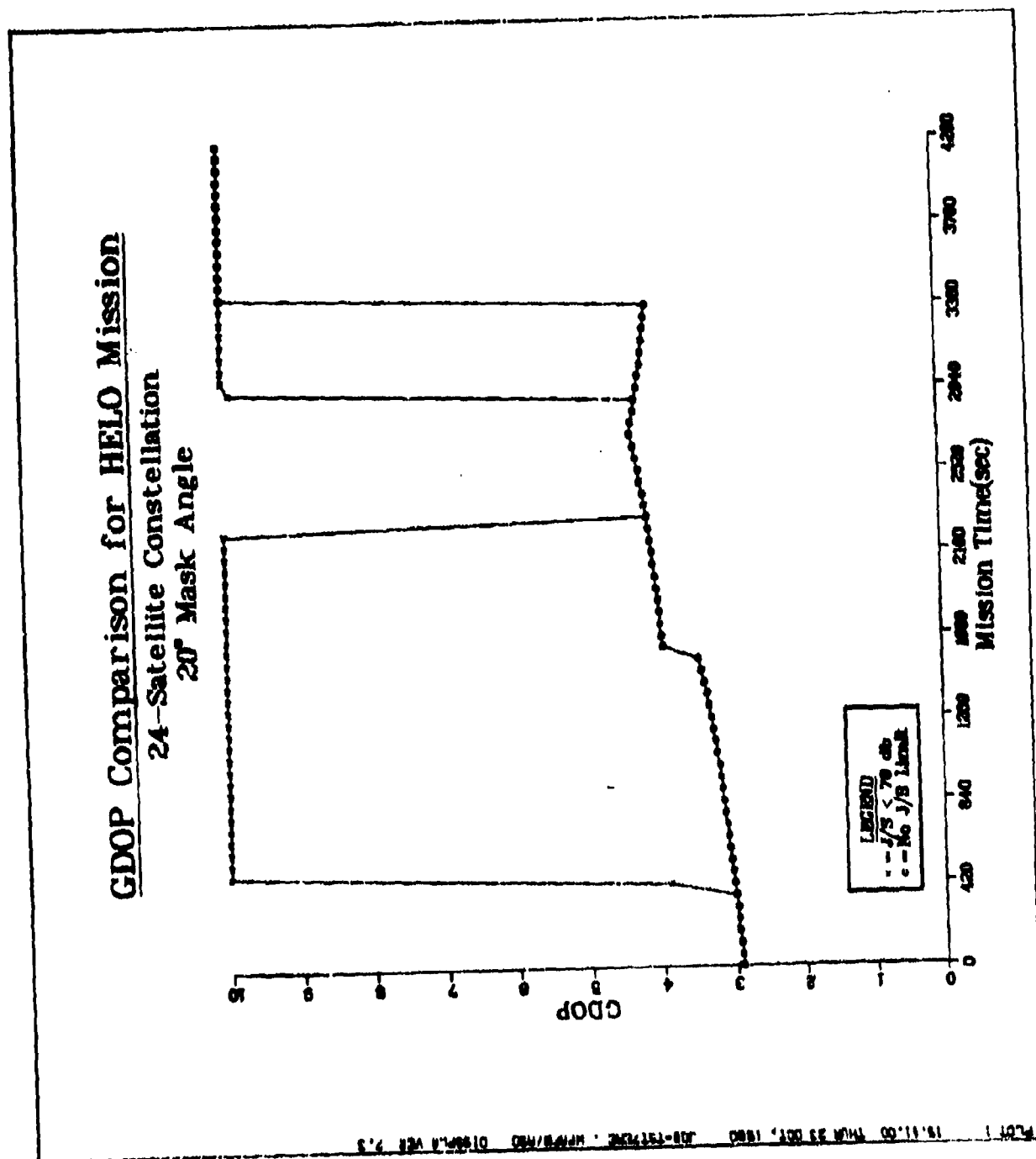


Figure 10

Atch 7

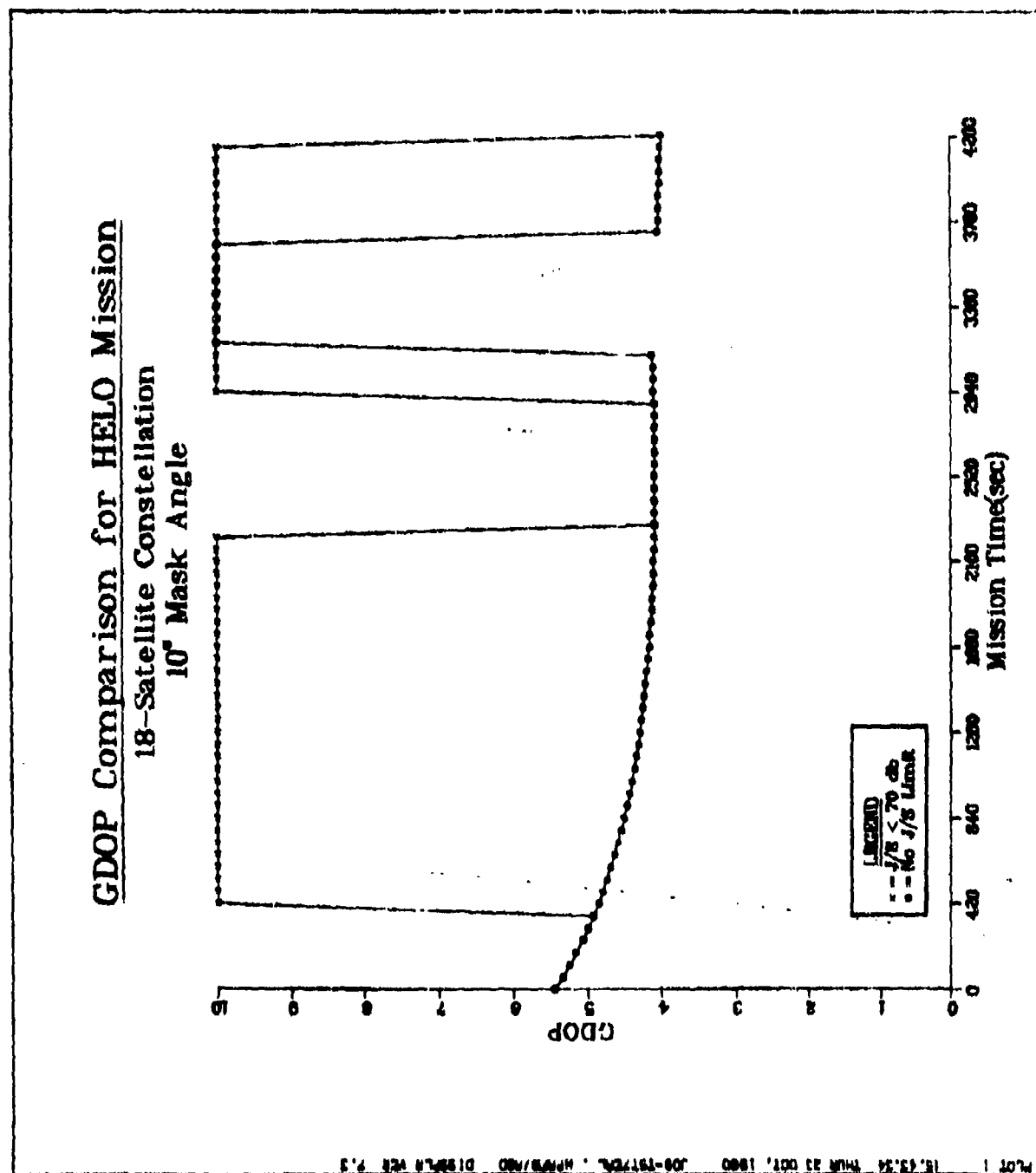


Figure 11

Atch 7

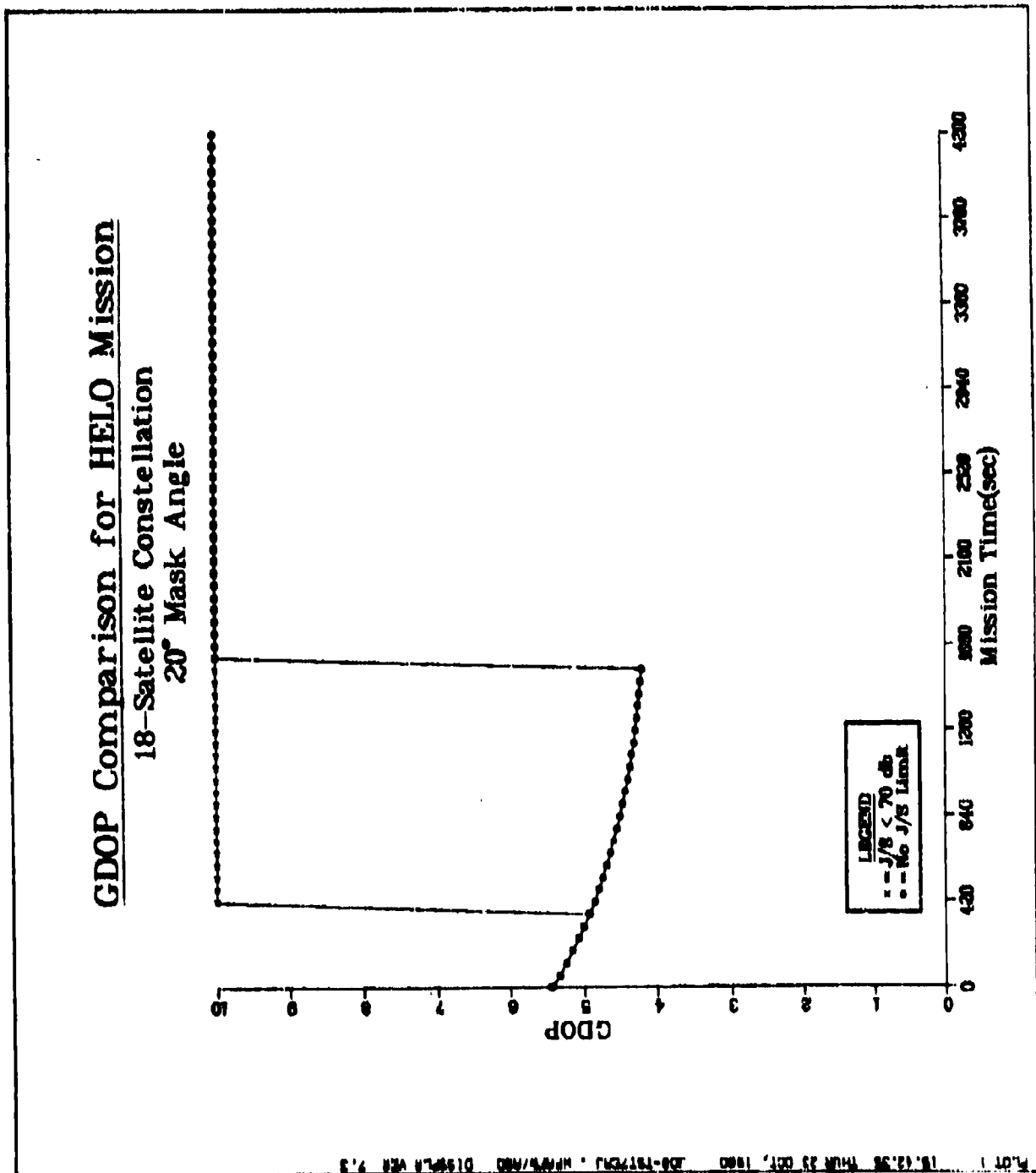


Figure 12

Atch 7

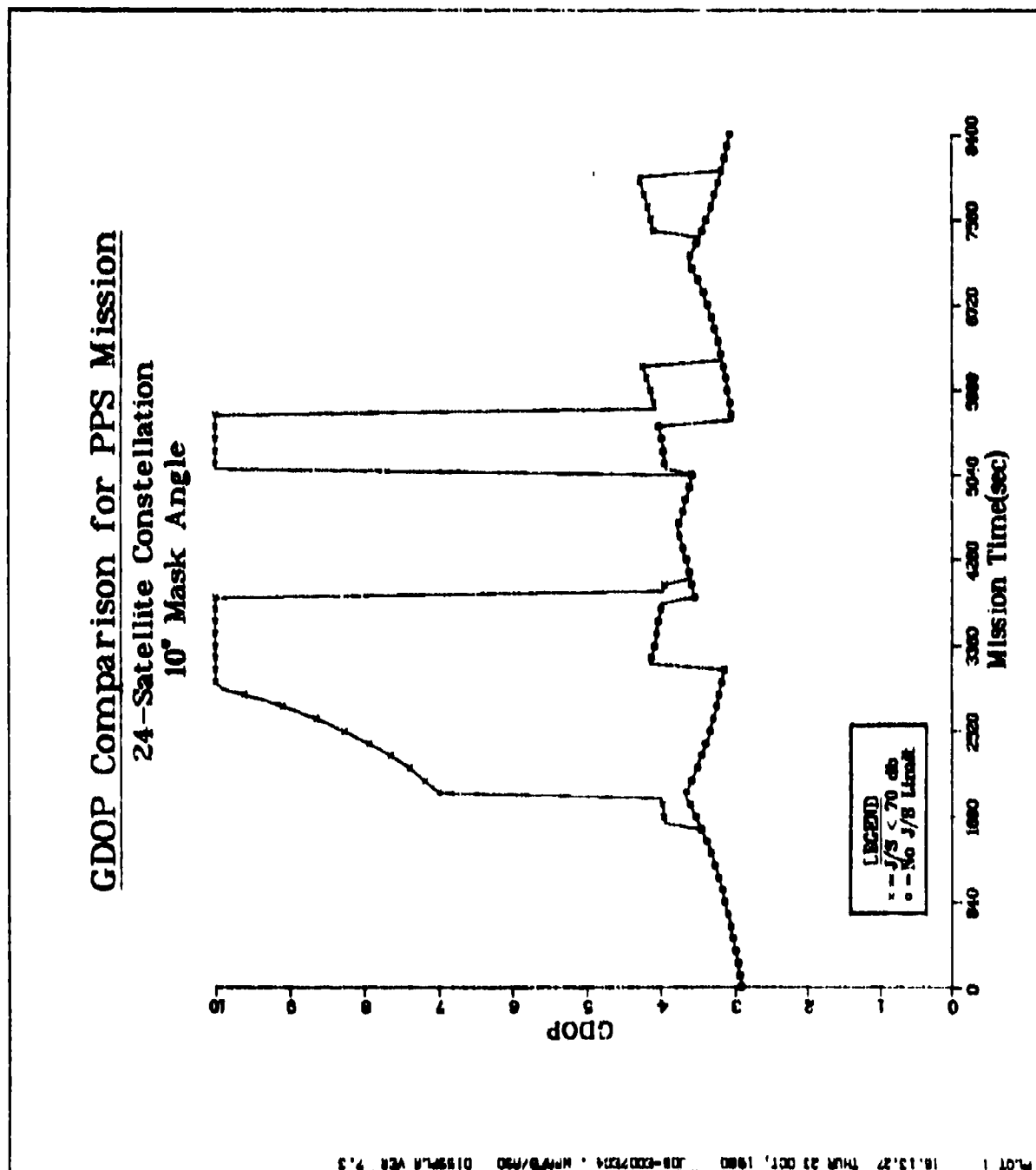


Figure 13

Atch 7

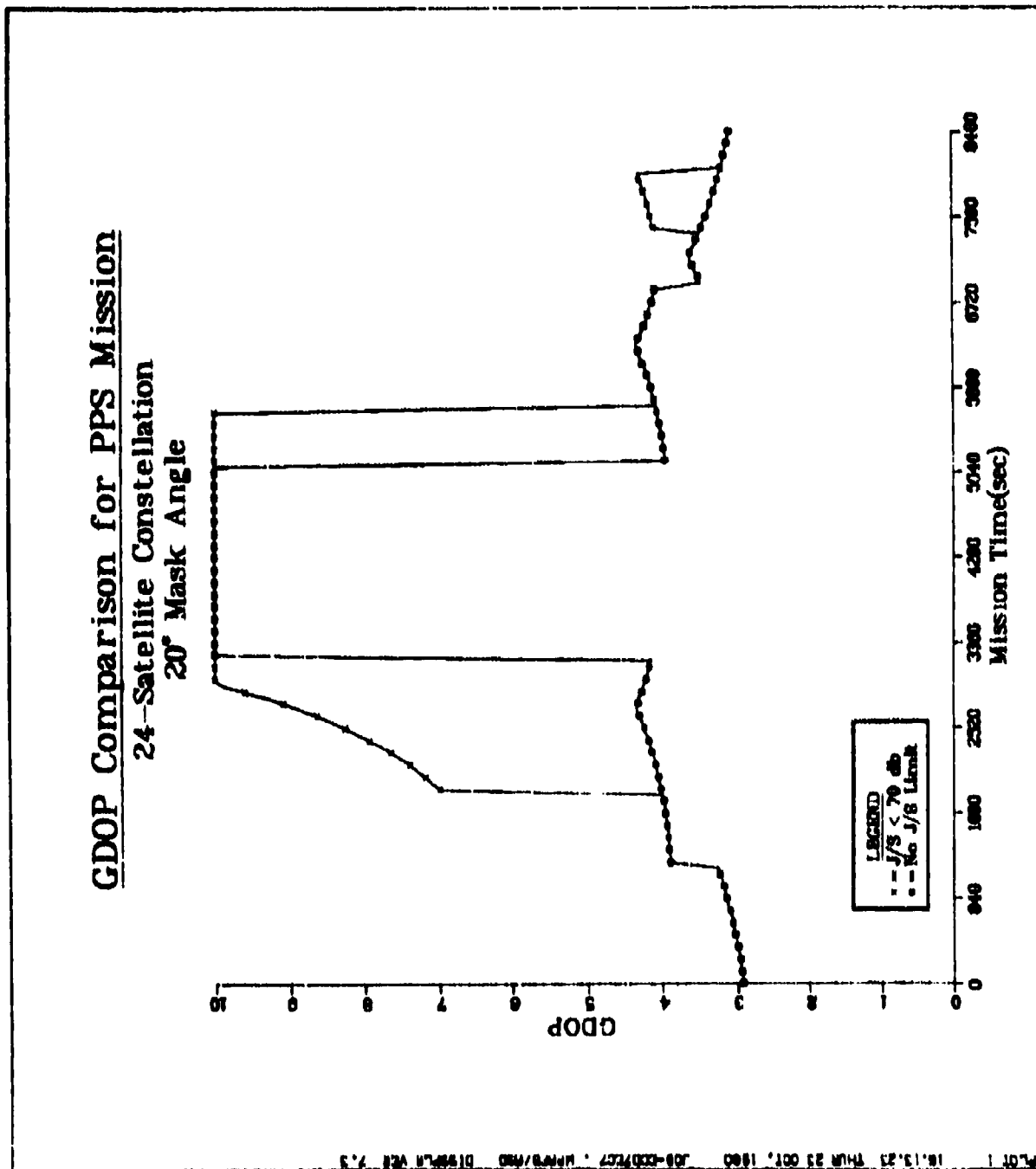


Figure 14

Atch 7

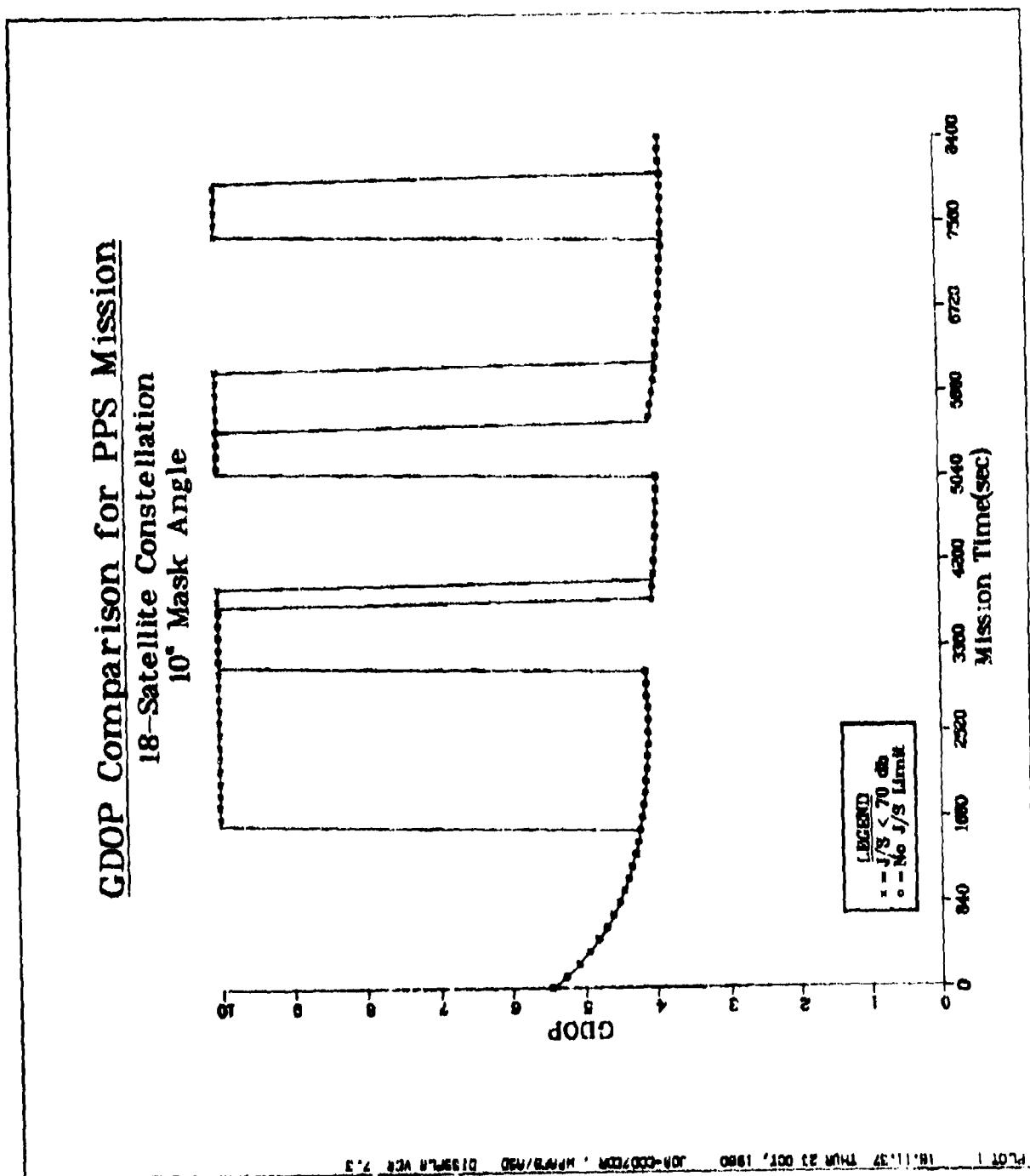


Figure 15

Atch 7

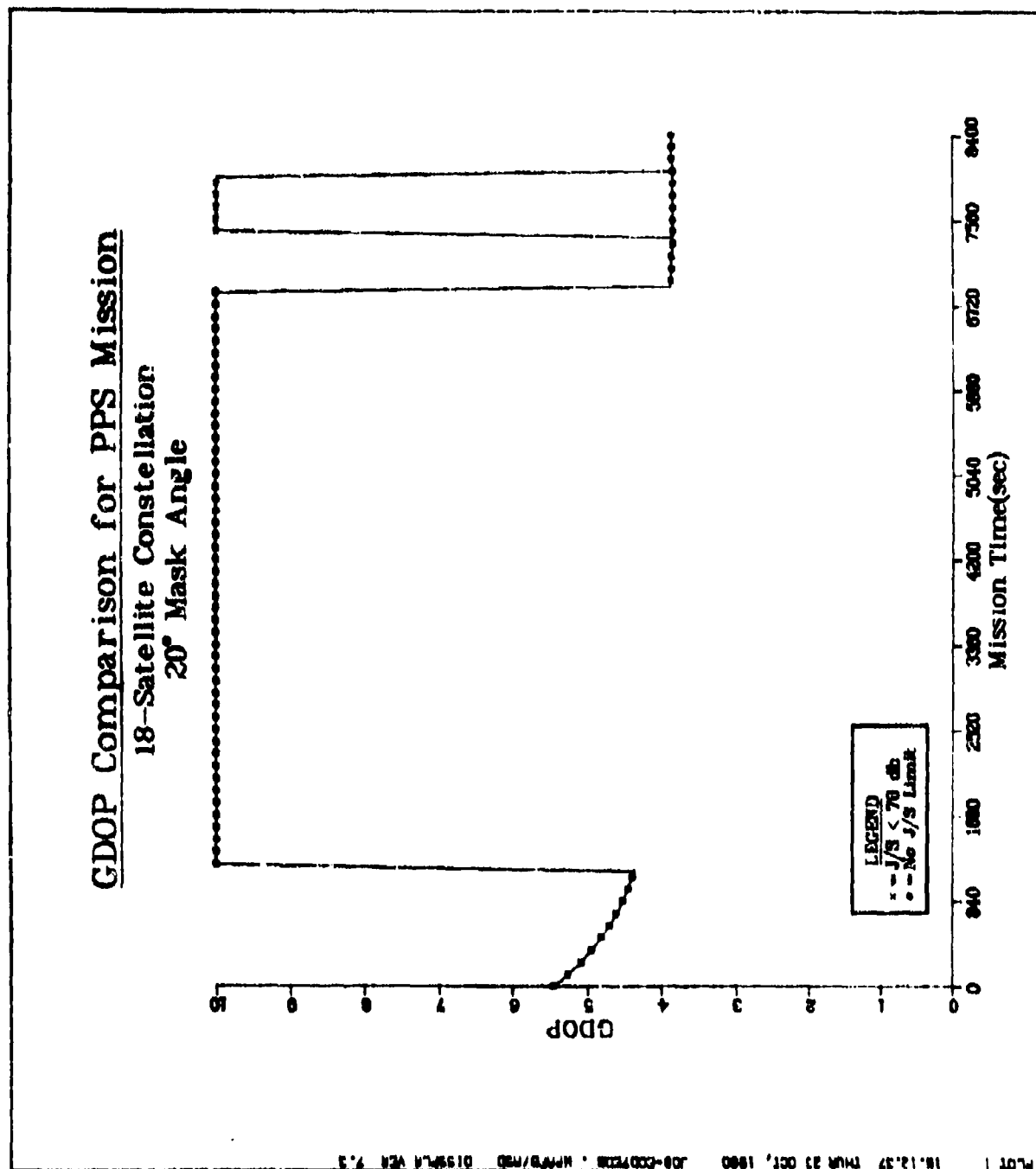


Figure 16

Atch 7

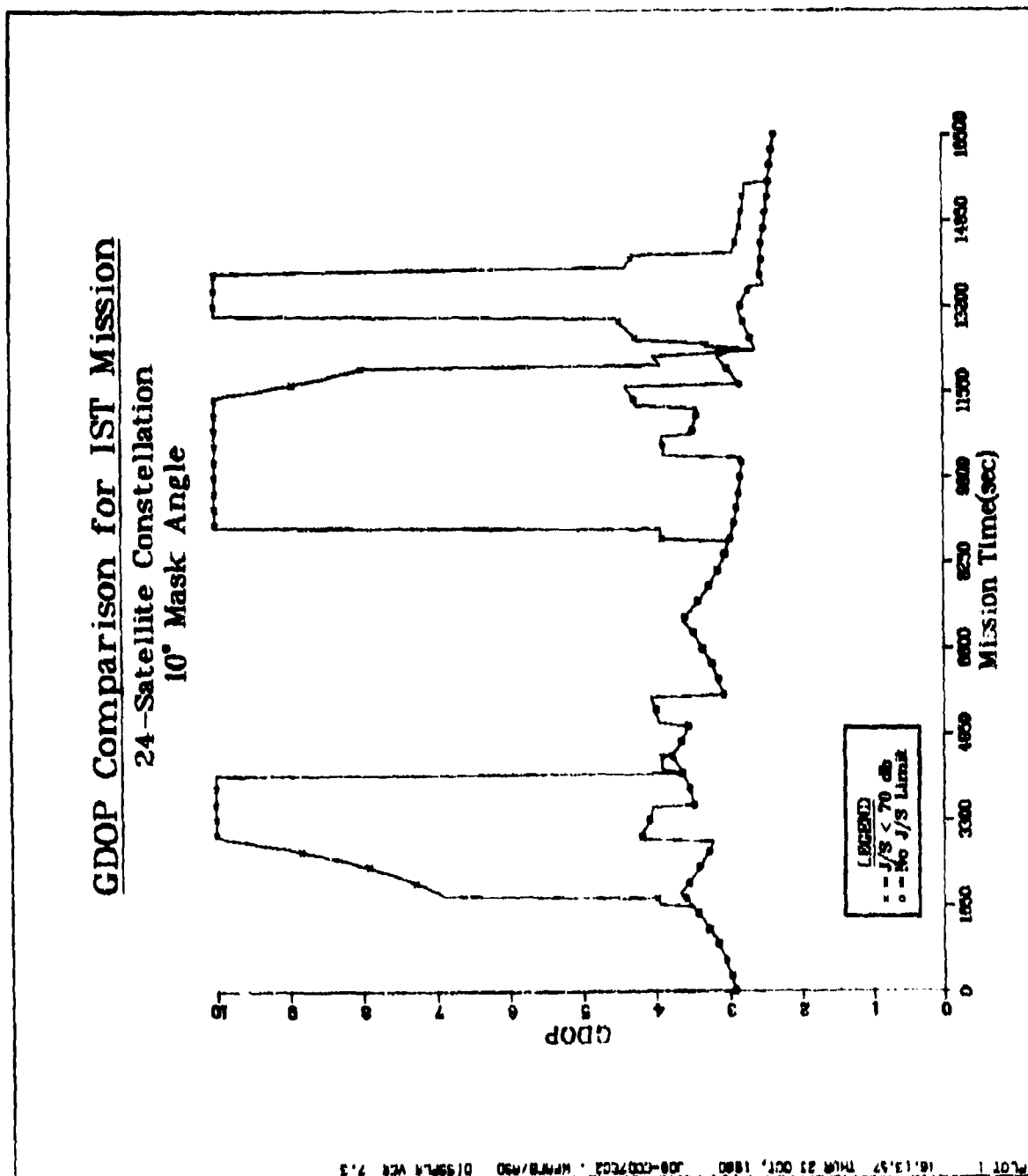


Figure 17

Atch 7

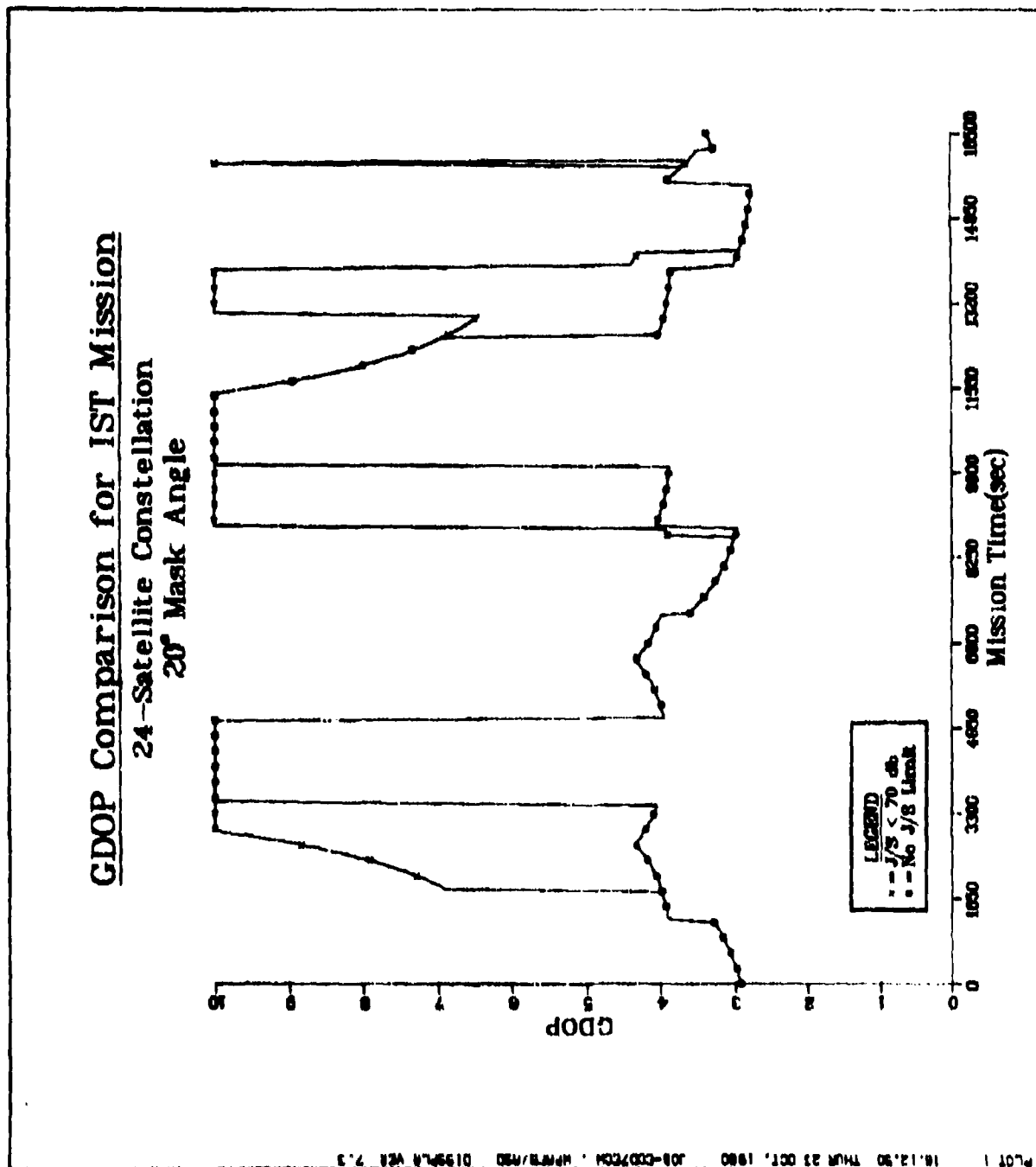


Figure 18

Atch 7

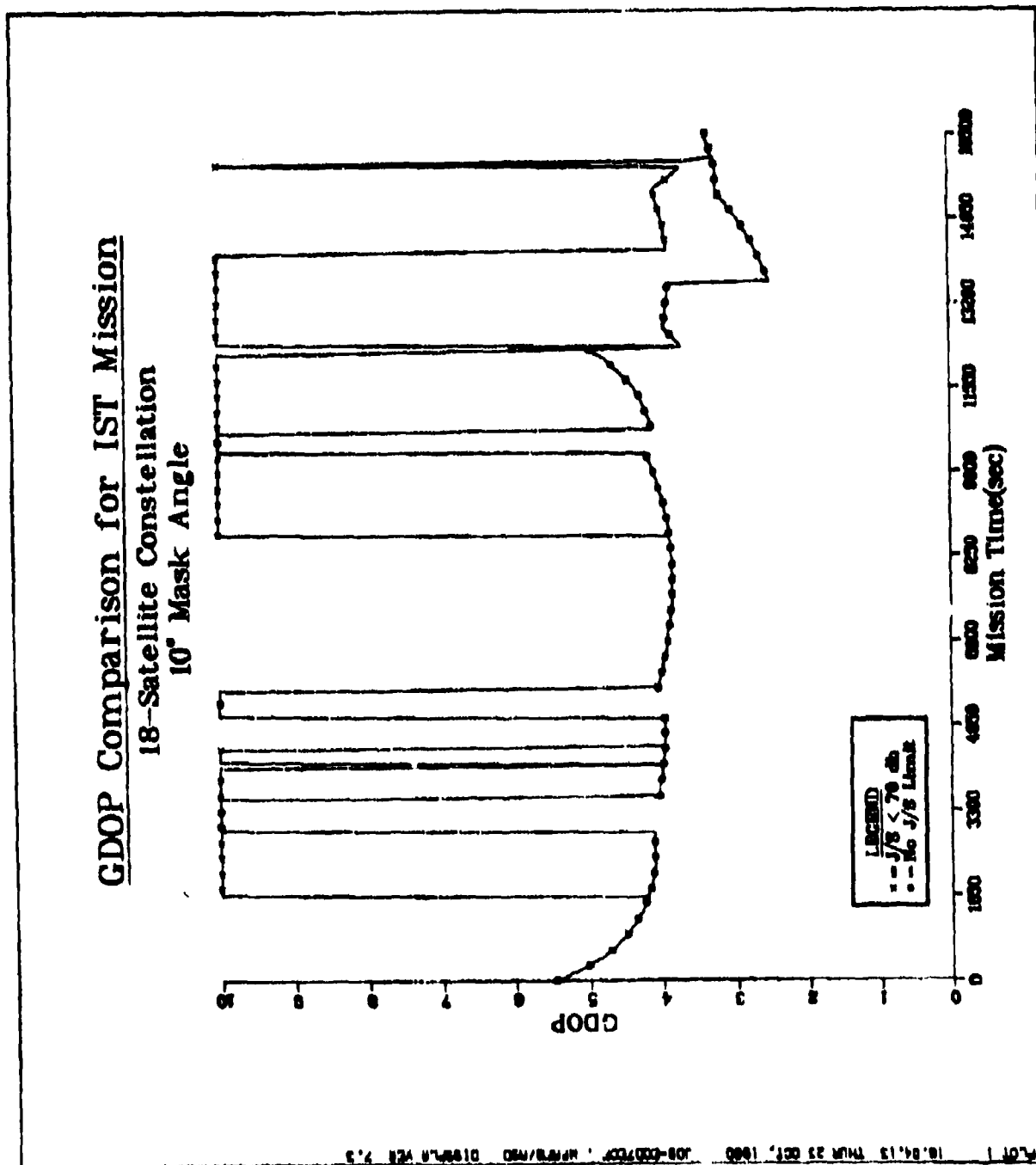


Figure 19

Atch 7

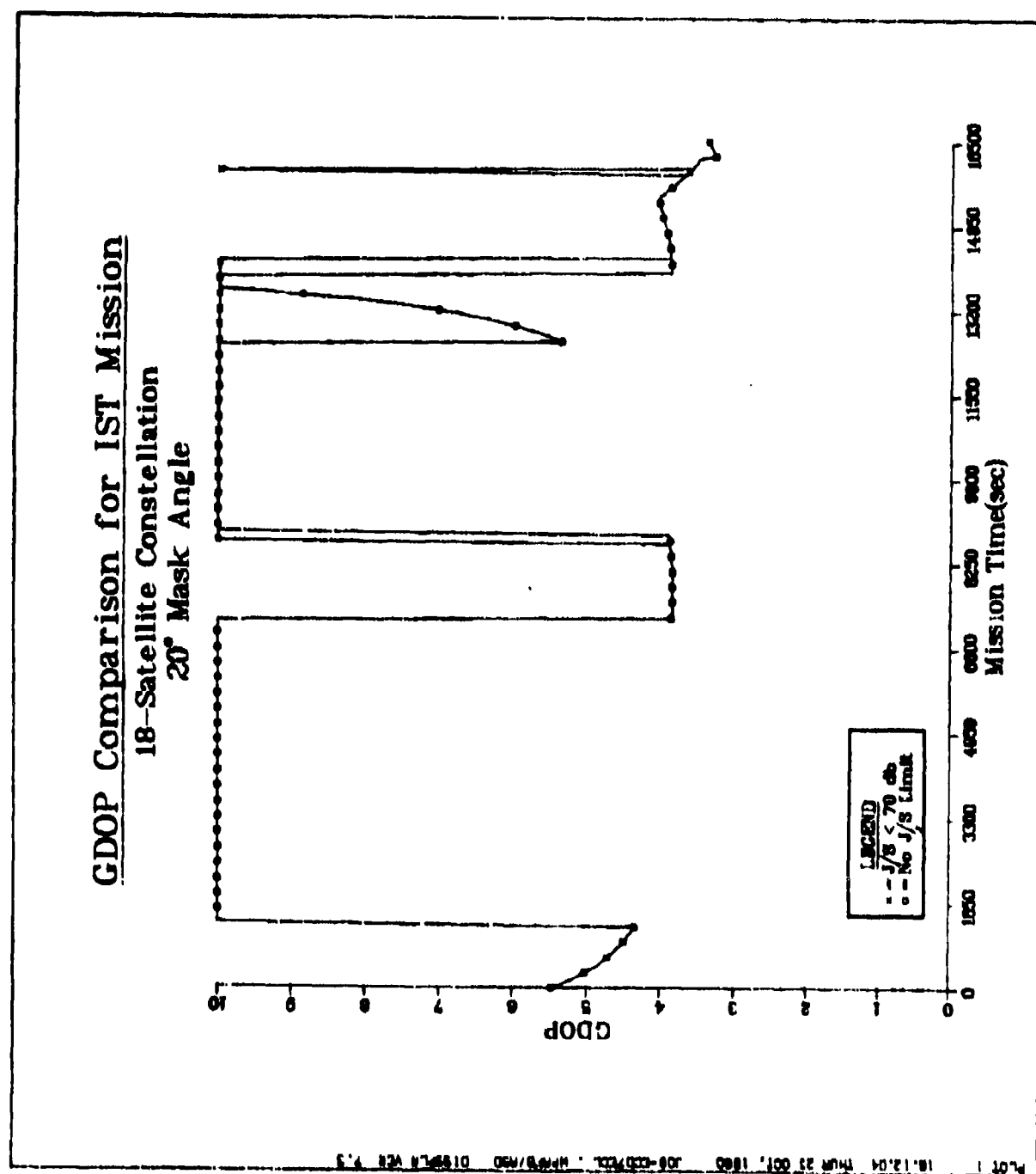


Figure 20

Atch 7

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1. R. M. Edwards and W. E. Shephard, Global Positioning System Jamming to Signal Ratio Analysis, Avionics Laboratory, Wright-Patterson Air Force Base, Ohio 45433, AFWAL-TR-80-1045, November 1980.
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3. P. S. Jorgensen, Nav Star/Global Positioning System 18-Satellite Constellations, The Aerospace Corporation, El Segundo, California 90245.

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