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SATURN EARLY LAUNCH PHASE TRACKING BY CW DOPPLER

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ABSTRACT

19700

During the launch of SA-5 an experiment was conducted to determine the feasibility of using CW tracking systems for measuring vehicle position, velocity, and acceleration during the early launch phase. An analytical comparison has been made between one CW system and conventional optical data. Little difference was found between results given by the two systems. Least squares fits show the CW system having somewhat smaller variations. Possible utilization of a close-in CW system are discussed.

AUTHOR

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
OPERATION	1
INTERIM-OFFSET UDOP OPERATION	3
CLOSE-IN SYSTEM DEVELOPMENT	3
SCHEDULED IMPROVEMENTS	3
DATA HANDLING	6
DATA REDUCTION	6
RESULTS	7
PRESENT CAPABILITIES	7
FUTURE POTENTIAL	7
REFERENCES	45
APPROVAL	46
DISTRIBUTION	47

LIST OF ILLUSTRATIONS

Figure		Page
1.	UDOP Tracking System Functional Block Diagram	2
2.	UDOP Close-in Tracking System Antenna Locations	4
3.	UDOP and Camera Sites	5
4.	UDOP GDOP Stations 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5 (Sigma X)	9
5.	UDOP GDOP Stations 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5 (Sigma Y)	10
6.	UDOP GDOP Stations 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5 (Sigma Z)	11
7.	UDOP GDOP Stations 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5, 1.15.6 (Sigma X)	12
8.	UDOP GDOP Stations 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5, 1.15.6 (Sigma Y)	13
9.	UDOP GDOP Stations 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5, 1.15.6 (Sigma Z)	14
10.	UDOP GDOP Stations 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5, 1.4.1, 1.9.1 (Sigma X)	15
11.	UDOP GDOP Stations 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5, 1.4.1, 1.9.1 (Sigma Y)	16
12.	UDOP GDOP Stations 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5, 1.4.1, 1.9.1 (Sigma Z)	17
13.	SA5 CZR, UDOP 5 Station Solution (X)	18
14.	SA5 CZR, UDOP 5 Station Solution (Y)	19
15.	SA5 CZR, UDOP 5 Station Solution (Z)	20
16.	SA5 CZR, UDOP 5 Station Solution ($\dot{X}$)	21
17.	SA5 CZR, UDOP 5 Station Solution ($\dot{Y}$)	22
18.	SA5 CZR, UDOP 5 Station Solution ($\dot{Z}$)	23
19.	SA5 CZR, UDOP 5 Station Solution ($\ddot{X}$)	24
20.	SA5 CZR, UDOP 5 Station Solution ($\ddot{Y}$)	25
21.	SA5 CZR, UDOP 5 Station Solution ($\ddot{Z}$)	26
22.	SA5 CZR, UDOP 7 Station Solution (X)	27
23.	SA5 CZR, UDOP 7 Station Solution (Y)	28
24.	SA5 CZR, UDOP 7 Station Solution (Z)	29
25.	SA5 CZR, UDOP 7 Station Solution ($\dot{X}$)	30
26.	SA5 CZR, UDOP 7 Station Solution ($\dot{Y}$)	31
27.	SA5 CZR, UDOP 7 Station Solution ($\dot{Z}$)	32
28.	SA5 CZR, UDOP 7 Station Solution ($\ddot{X}$)	33
29.	SA5 CZR, UDOP 7 Station Solution ($\ddot{Y}$)	34
30.	SA5 CZR, UDOP 7 Station Solution ($\ddot{Z}$)	35
31.	SA5 CZR, UDOP 7 Station Solution, Smoothed ($\ddot{X}$)	36
32.	SA5 CZR, UDOP 7 Station Solution, Smoothed ($\ddot{Y}$)	37
33.	SA5 CZR, UDOP 7 Station Solution, Smoothed ($\ddot{Z}$)	38

LIST OF ILLUSTRATIONS (Continued)

Figure		Page
34.	CZR Close-in Impact Prediction	39
35.	5 Station UDOP Close-in Impact Prediction	40
36.	7 Station UDOP Close-in Impact Prediction	41
37.	Distance From Tower to Vehicle (CZR)	42
38.	Distance From Tower to Vehicle (5 Station UDOP)	43
39.	Distance From Tower to Vehicle (7 Station UDOP)	44

INTRODUCTION

The development of large space boosters has resulted in large and costly fuel facilities, service structures, umbilical towers, and support buildings, all located within the launch complex. The possibility of a mission abort during the early phases of flight makes it desirable to provide some protection to these facilities if possible. For manned vehicles, there is the even more important requirement to avoid aborting the crew into the umbilical tower or the middle of a fuel facility. Before any judgment can be made to abort, the vehicle position and velocity must be known in real time. From these basic data, impact points and relative distances to obstructions can be calculated.

The feasibility of using a close-in continuous wave tracking system to obtain metric data for the early launch phase was investigated during the launch of SA-5. The results were compared with data derived from fixed metric cameras (CZR-1 and RC-5) described in Reference 1, which is presently the most accurate means of obtaining metric data for the first 500 meters of vehicle flight altitude at the Atlantic Missile Range.

There is nothing new in using a CW tracking system to obtain metric data. What is new, however, are short baselines of a few meters to a few hundred meters in contrast to the conventional UDOP system with baselines of several kilometers and longer. The system presently used at the John F. Kennedy Space Center, NASA, is UDOP (UHF Doppler).

UDOP, basically is a 2-way, coherent, continuous-wave, tracking system. It is a highly reliable data source providing very accurate velocity measurements. The system, a descendant of DOVAP, (Doppler Velocity and Position) was developed by NASA-KSC.

OPERATION

UDOP consists of three basic groups:

(1) The ground transmitters
(2) The airborne transponder
(3) The ground receiver

In practice, a central record station and data handling systems are also used.

Figure 1 is a simplified, functional block diagram of the close-in UDOP tracking system. The transmitters use a primary frequency standard to derive frequencies used. The standard is multiplied to 50 mc and broadcast as a reference signal to the receiver sites. The 50 mc is multiplied to 450 mc and transmitted to the transponder onboard the vehicle as an interrogation signal. The transponder receives the 450 mc signal, doubles and re-transmits at 900 mc.

The ground stations simultaneously receive the 50 mc reference signal and the 900 mc transponder signal. The 50 mc signal is multiplied by 18 and compared to the 900 mc signal. The difference will be zero for a vehicle on the pad and there will be a

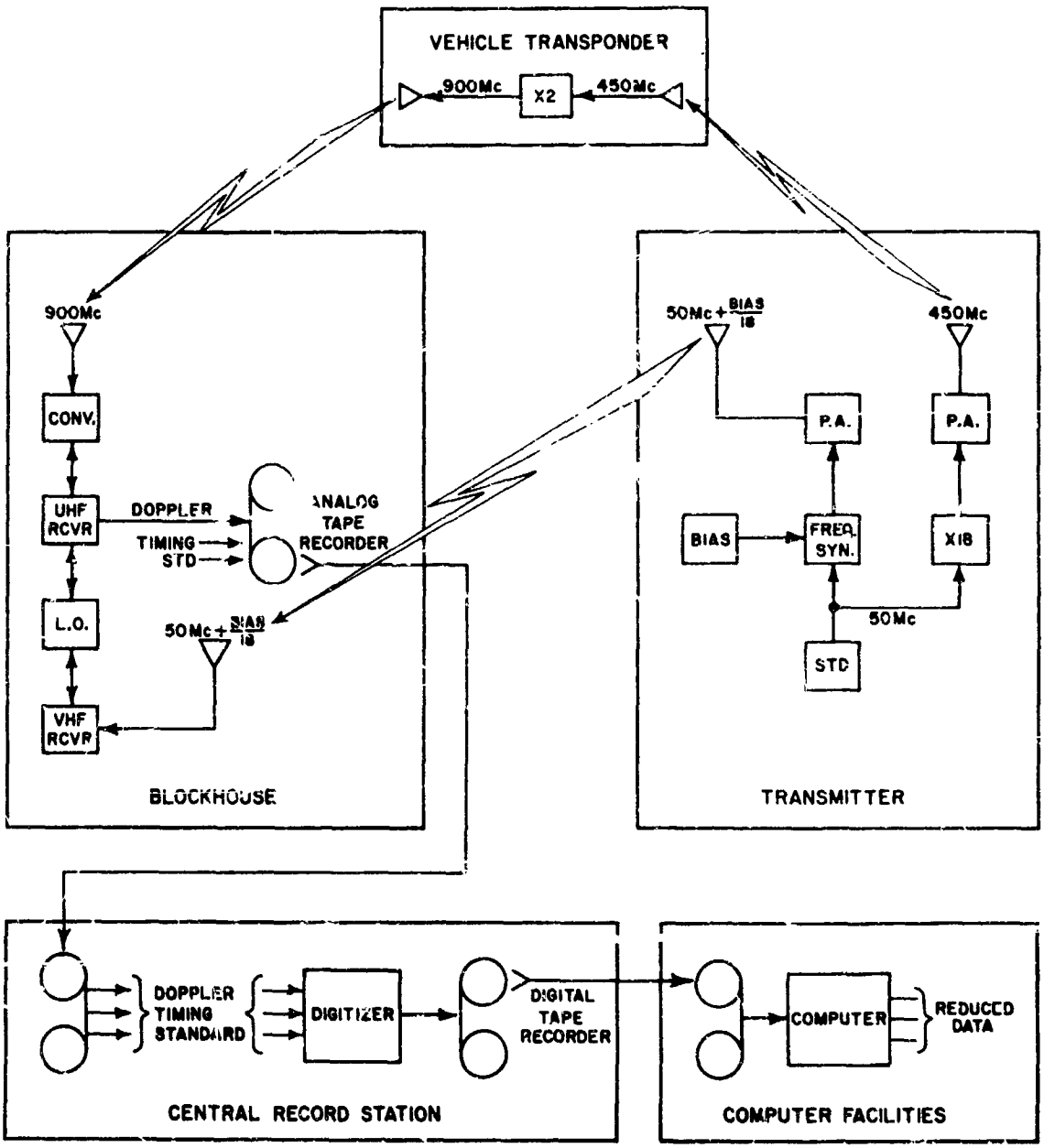

FIGURE 1. FUNCTIONAL BLOCK DIAGRAM CLOSE-IN TRACKING SYSTEM

doppler effect (measured in cycles per second) if the vehicle is in motion. This effect will be proportional to a loop velocity with amount depending on the location of the transmitter site, receiver sites, as well as vehicle position and velocity.

The UDOP ground receivers are double, super-heterodyne, dual-channel units with common local oscillators. All resulting frequencies after mixing are related to the frequency standard except those experiencing doppler shifts. Consequently, the doppler effects are measurable.

INTERIM-OFFSET UDOP OPERATION

The existing system operates in an offset mode where the reference frequency is raised to 5 kc higher than 900 mc causing a 5 kc beat frequency as long as the vehicle is on the pad. When the vehicle moves, the doppler effect adds to the 5 kc frequency. The primary advantage is simplification of data handling as the frequency varies from 5 kc rather than zero. This offset frequency is derived using phase-locked loop techniques further described in Reference 2.

CLOSE-IN SYSTEM DEVELOPMENT

Prior versions of the UDOP system did not provide particularly good data during the early launch phase because of system geometry. This was overcome by installing receiver systems within the launch complex.

The close-in UDOP tracking system used for SA-5 is shown in Figure 2 and Figure 3. The UDOP stations 1.15.1, 1, 2, 3, 4, 5, and 6 shown in Figure 2 and Stations 1.9, 1.4, and the transmitter site shown in Figure 3 were used to provide data. Camera stations shown in Figure 3 provided the data for comparison. The close-in system uses a front-end converter developed by NASA-KSC, and the standard UDOP receiver. Cable losses are decreased by having the first intermediate-frequency mixing and local oscillator multiplying by a converter in the field near the antenna.

SCHEDULED IMPROVEMENTS

Another tracking system similar to UDOP being developed by NASA-KSC is ODOP, (Offset Doppler). This system utilizes most of the existing UDOP equipment but also takes advantage of newer developments and techniques proven reliable since UDOP was developed. The ODOP system uses a transponder developed by JPL for the DSIF. Reference 2 described how the UDOP system was modified to track the JPL transponder (on a Ranger spacecraft) beyond the moon. The transponder is interrogated at 890 mc and responds on 960 mc. It is a sensitive, phase-locked loop device deriving an output coherently related to the input by 96/89. A functional block diagram is discussed in Reference 3.

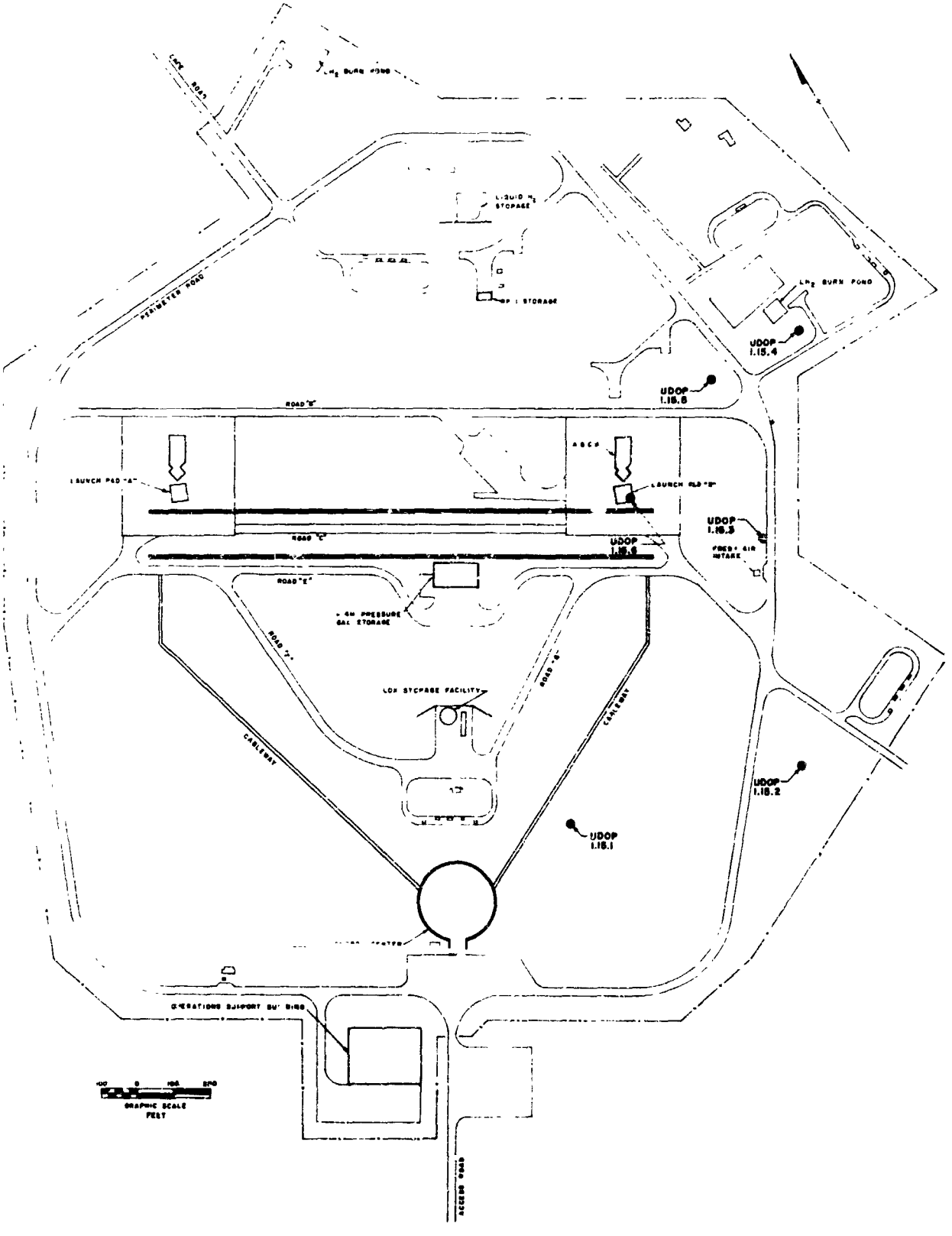

FIGURE 2. COMPLEX 37 CLOSE-IN TRACKING ANTENNA LOCATIONS

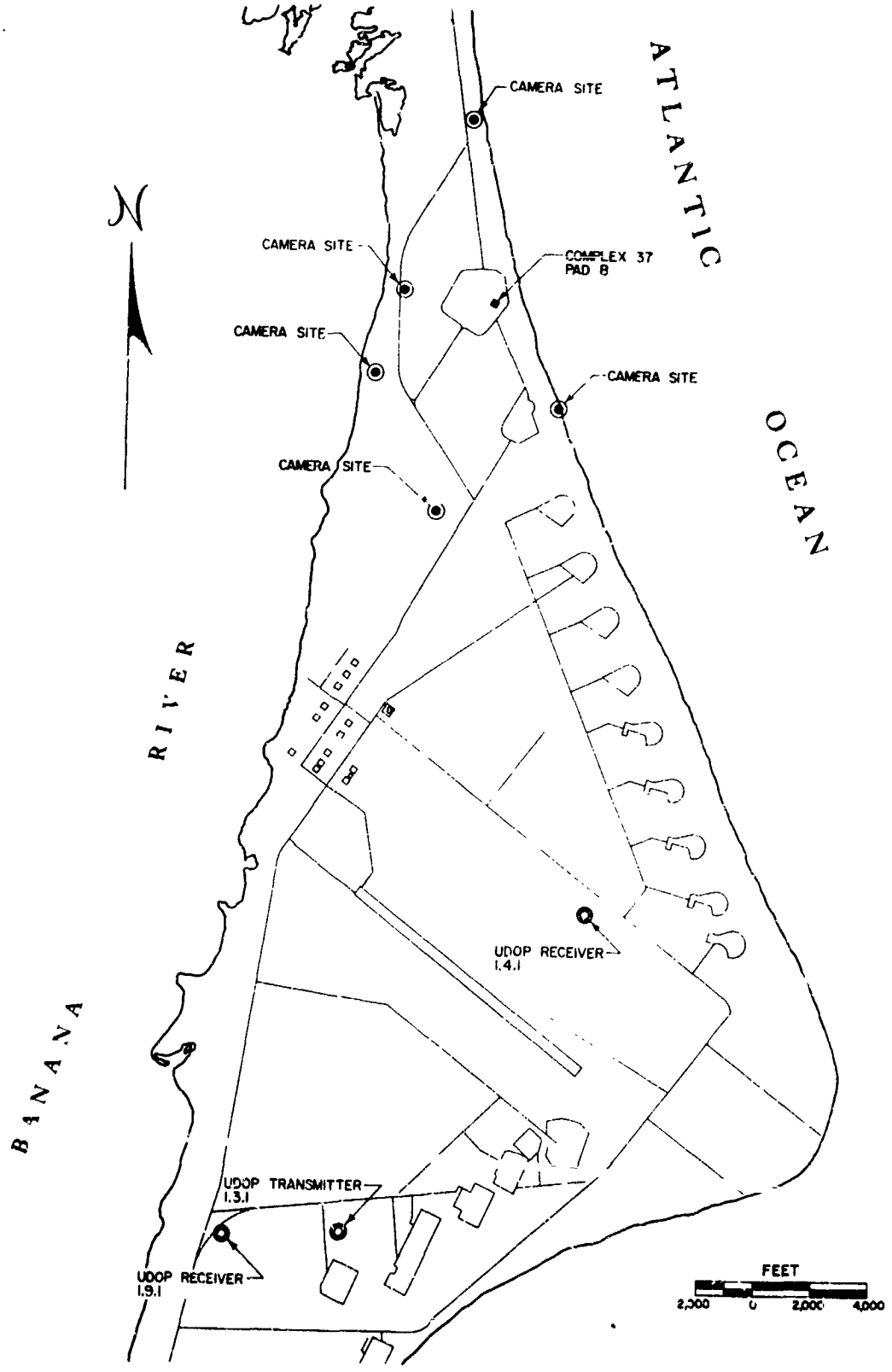

FIGURE 3. UDOP AND CAMERA SITES

The ODOP ground transmitter derives a reference frequency of 53.333 mc and an interrogator frequency of 890 mc minus 5 kc bias using phase-locked loop frequency synthesizers. A 960 mc test transmitter is used to calibrate the system.

The UDOP ground receivers front-end converters, and data handling equipment can be aligned to operate on ODOP frequencies.

During SA-6 launch the close-in tracking system will operate in the ODOP mode with the transmitter located at the UDOP transmitter site. During SA-7 launch, the close-in system will use an interrogator located within the complex to increase accuracy, mainly in the vertical position coordinate.

DATA HANDLING

During the SA-5 launch, the doppler frequencies, the 5 kc bias frequency, timing and standard frequency were recorded on two seven-channel analog tape recorders in Blockhouse 37. These data were later converted to digital form and reduced.

DATA REDUCTION

The UDOP digitized data recorded from each receiver station was fed to a computer which calculated positions X, Y, and Z. These positions were then fitted to a second degree polynomial using mid-point, moving arc smoothing over a one second interval. From this process, smoothed position, velocity, and acceleration were obtained.

The fixed metric camera data were reduced by the AFMTC, (RCA Data Reduction). However, to insure uniformity for comparison purposes, the unsmoothed fixed camera position data were fitted to a second degree polynomial using mid-point, moving arc smoothing over a one second interval to obtain smoothed position, velocity and acceleration.

The data presented were reduced to an earth fixed, right handed, rectangular cartesian coordinate system. The Y axis is normal to the Clark Spheroid of 1866 and positive upward. The X axis is positive in the direction of the flight azimuth. The origin for the UDOP system is at the vehicle transmitting antenna in vehicle launch position. The origin for the fixed camera system was the tip of the nose of the vehicle in launch position.

Two separate reductions were performed with the UDOP data. The first solution was obtained using only five of the six close-in stations. The pad receiver data was discarded due to excessive signal dropouts. The second solution used the five close-in stations plus the two outlying stations 1.4 and 1.9. The UDOP data was used as recorded and not edited.

RESULTS

To show the effects of geometry on accuracy, Geometrical Dilution of Precision (GDOP) solutions were calculated for three theoretical cases. Figures 4 to 6 present the GDOP position plots for the five close-in stations 1.15.1, 2, 3, 4, 5. Figures 7 to 9 are GDOP position plots for those stations plus a pad station. Figures 10 to 12 are GDOP postion plots for seven stations 1.15.1 to 5, 1.4 and 1.9. It is evident from these that the addition of the pad station 1.15.6 significantly improves the accuracy along the Y coordinate, whereas the addition of the two outlying stations improve X, Y and Z.

The following plots are based on actual data obtained during SA-5 launch. Figures 13 to 21 are plots of position, velocity, and acceleration versus time for the close-in UDOP (5 station solution) and the fixed camera data. The UDOP data are plotted as crosses and the fixed camera data are plotted as circles. Figures 22 to 30 are corresponding plots for the close-in stations supplemented by two outlying stations (7 stations solution). The fixed camera data are the same in each case. There is little apparent difference between the 5 and 7 station UDOP solutions for the position and velocity data. There is however, considerable improvement in the 7 station UDOP acceleration data. The most significant result is the excellent agreement with the fixed camera data exhibited by both the 5 and 7 station UDOP solutions. In addition, the noise, or scattering, of the UDOP data is less than the fixed camera data.

PRESENT CAPABILITIES

Vehicle performance evaluation:

In the past, trajectory data from liftoff could only be provided by optical instrumentation. As a result there have been many instances where loss of data have occurred because of poor visibility. Therefore, a close-in CW tracking system will insure data for evaluating early flight performance. As an example, the acceleration data in Figures 28 to 30 were fitted to a straight line to determine liftoff accelerations. The results are presented in Figures 31 to 33. The standard deviation of liftoff acceleration is $\pm$ 0.029 m/sec^2 for the fixed camera data and $\pm$ 0.023 m/sec^2 for the 7 station UDOP data.

FUTURE POTENTIAL

1. Real time trajectory information and impact prediction:

Efforts are underway at KSC to develop a prototype real time trajectory information and impact predictor system based on doppler data only. The accuracy potential of such a system is demonstrated in Figures 34 to 36. These plots, based on SA-5 data show the predicted impact points of the vehicle center of gravity in the XZ plane, assuming engine cutoff at a given flight time. The total flight time represented is 16 seconds. Both the 5 station and 7 station UDOP solution are in excellent agreement with the fixed camera data; the UDOP predictions being smoother.

2. Umbilical tower miss distance:

Under certain engine malfunction conditions it is possible for the Saturn vehicle to drift into the umbilical tower. Figures 37, 38, and 39 are plots of the distance between the SA-5 vehicle and the umbilical tower in the XZ plane from fixed camera, 5 stations and 7 station UDOP data (SA-5) respectively. The total flight time represented is 7.5 seconds, at which time the vehicle had cleared the umbilical tower. These plots show the feasibility of using a CW doppler system for detecting motion with respect to the umbilical tower.

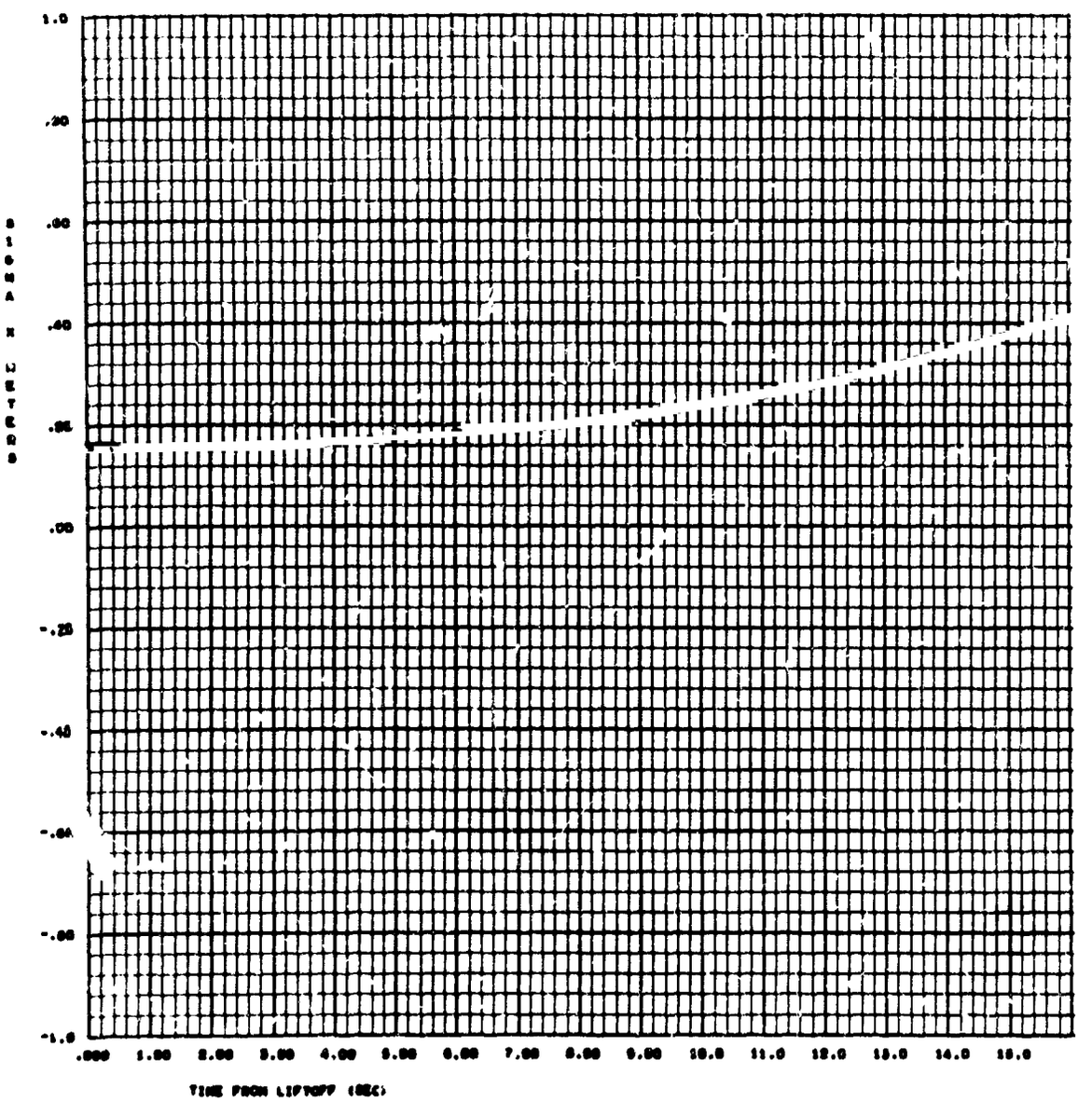

FIGURE 4. UDOP GOOP STATIONS 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5 (SIGMA X)

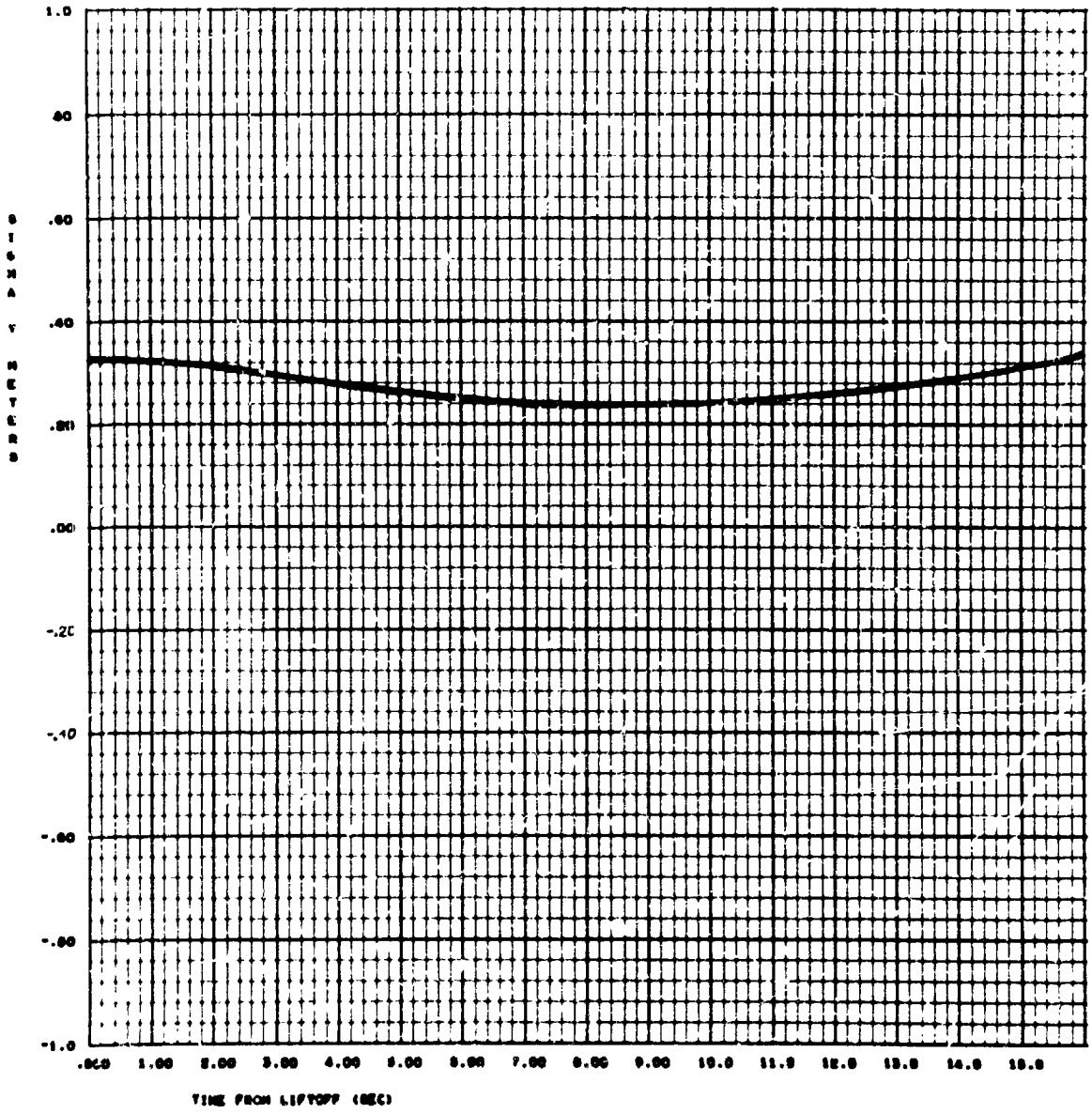

FIGURE 5. UDOP GDOP STATIONS 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5 (SIGMA Y)

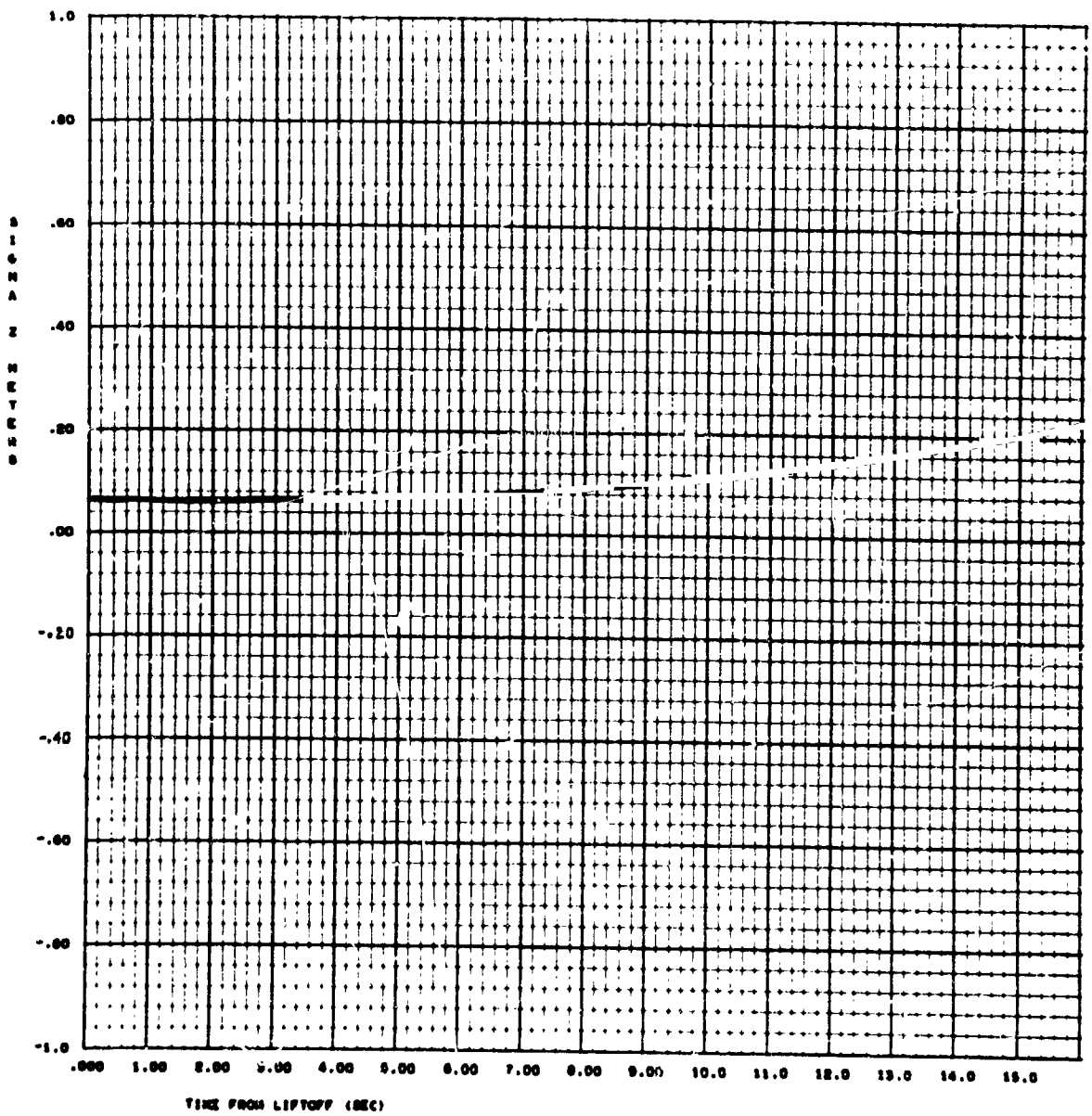

FIGURE 6. UDOP GDOP STATIONS 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5 (SIGMA Z)

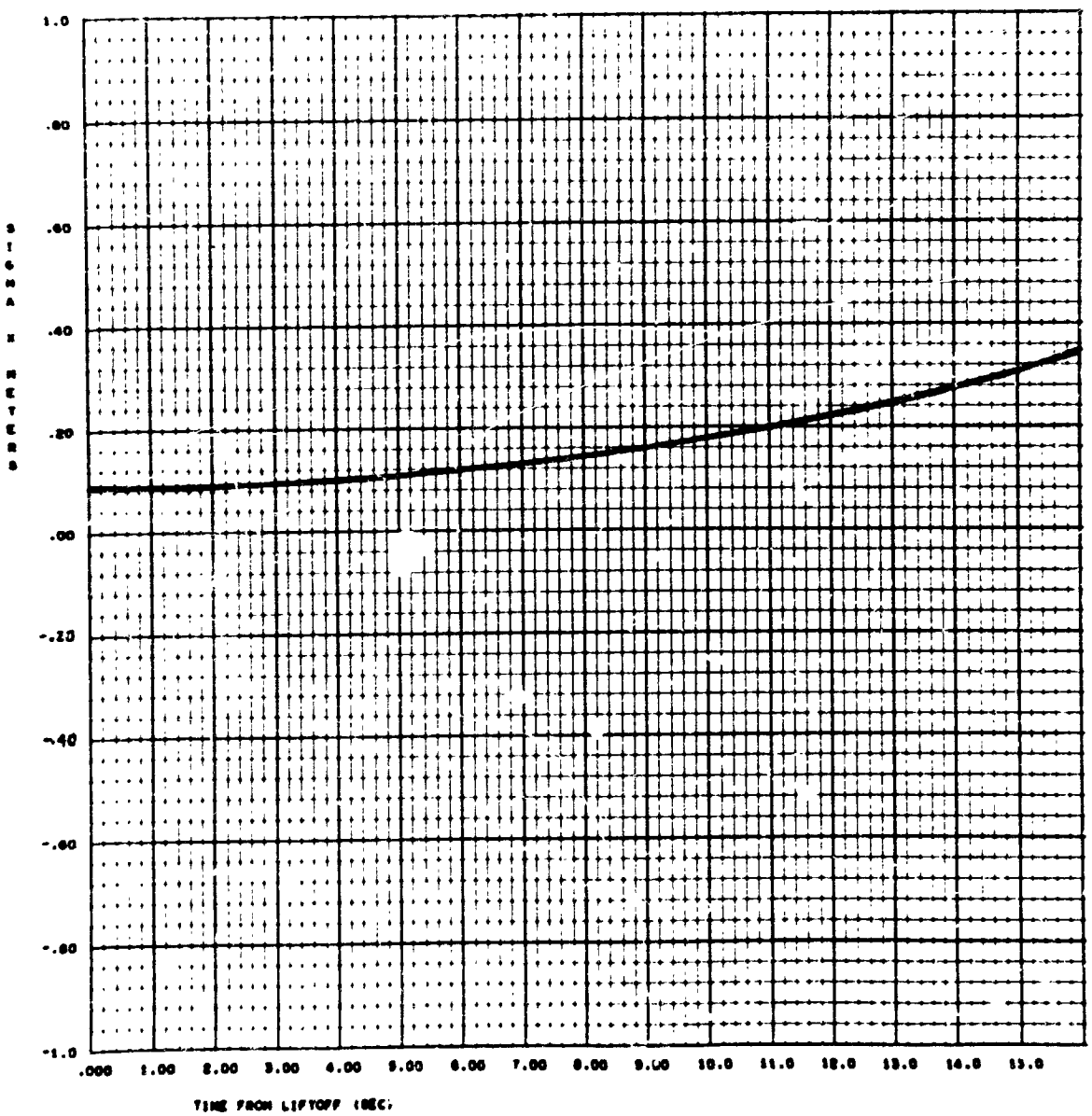

FIGURE 7. UDOP GDOP STATIONS 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5, 1.15.6 (SIGMA X)

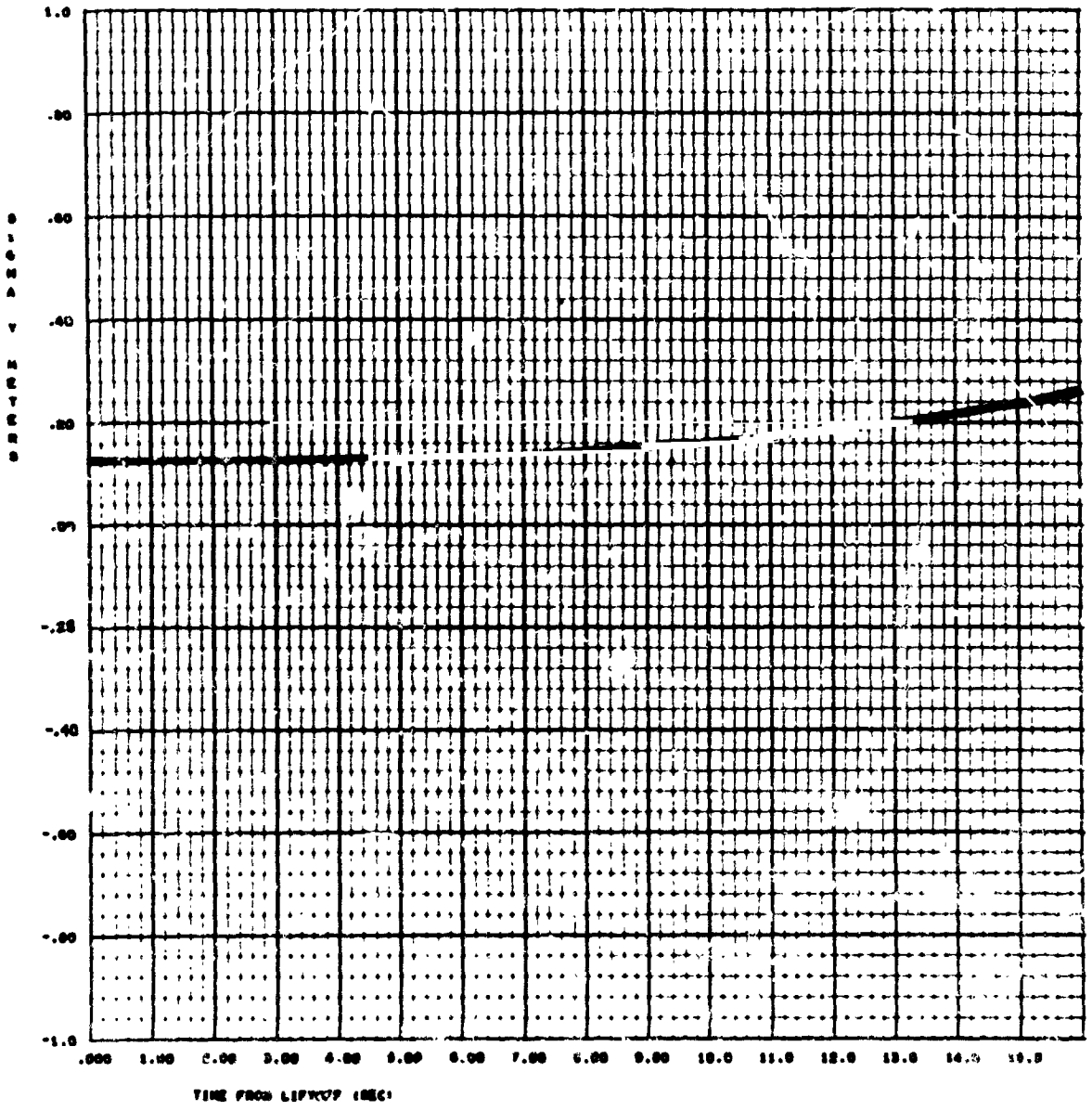

FIGURE 8. UDOP GDOP STATIONS 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5, 1.15.6 (SIGMA Y)

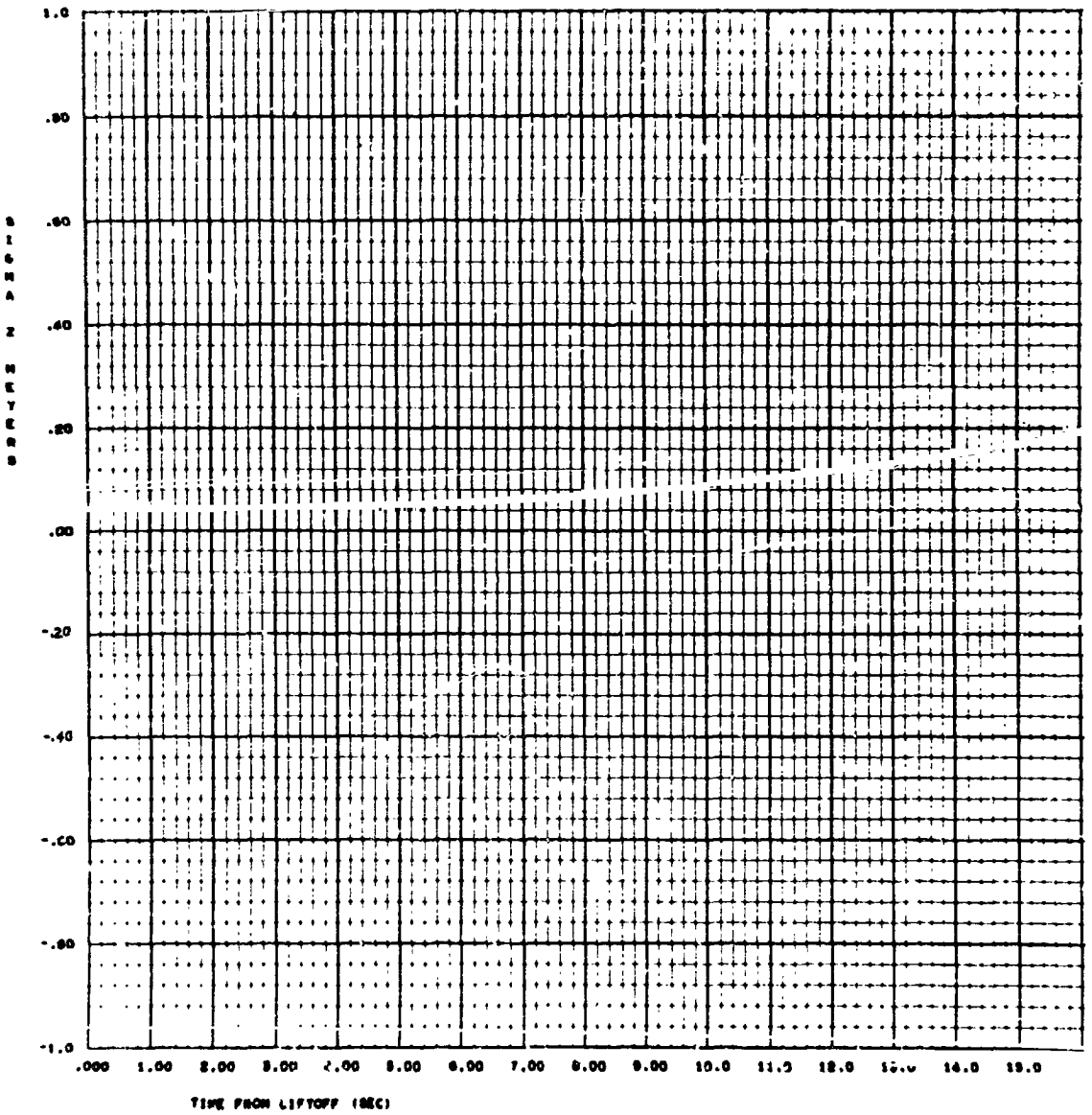

FIGURE 9. UDOP GDOP STATIONS 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5, 1.15.6 (SIGMA Z)

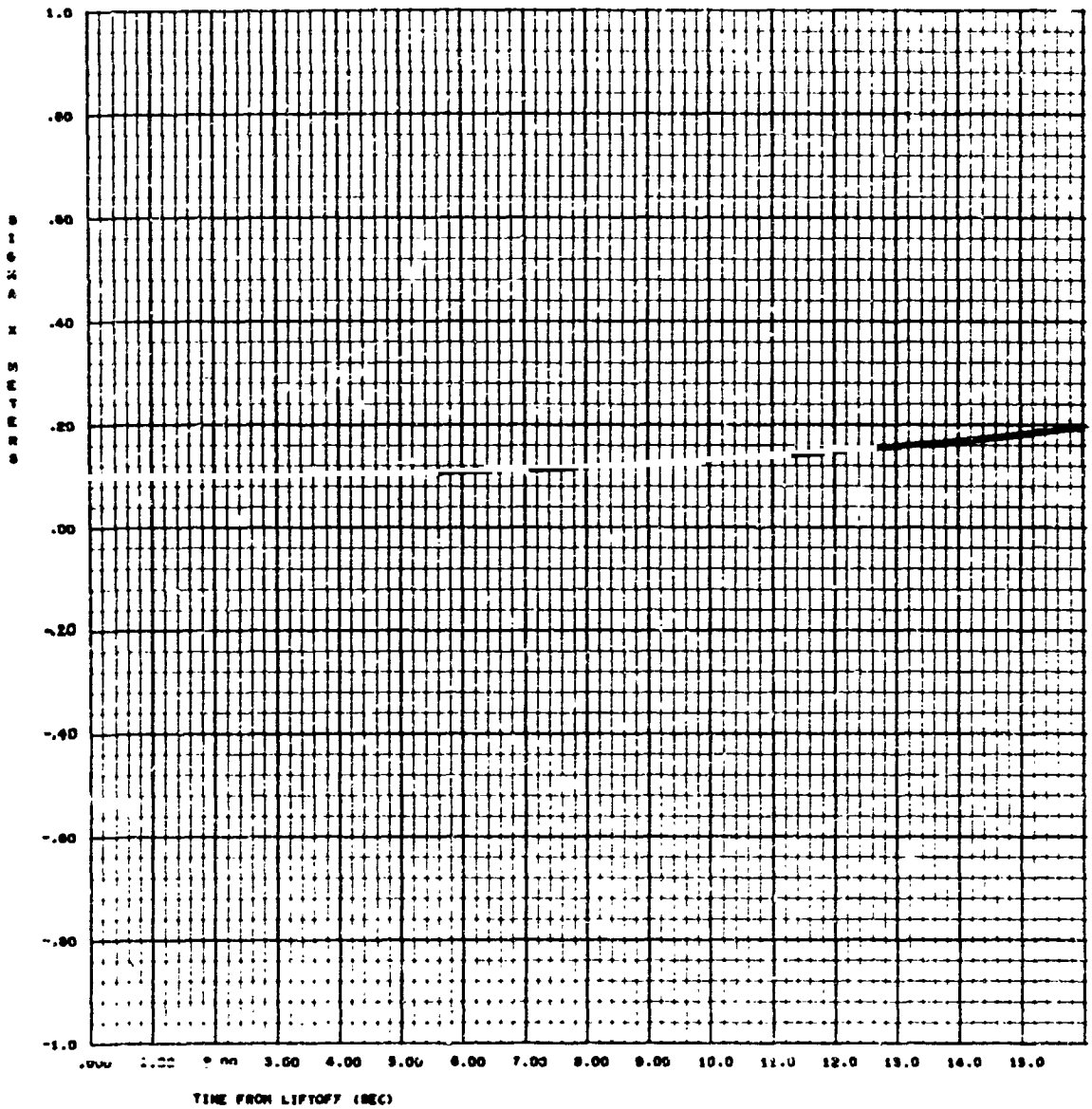

FIGURE 10. UDOP GDOP STATIONS 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5, 1.4.1, 1.9.1 (SIGMA X)

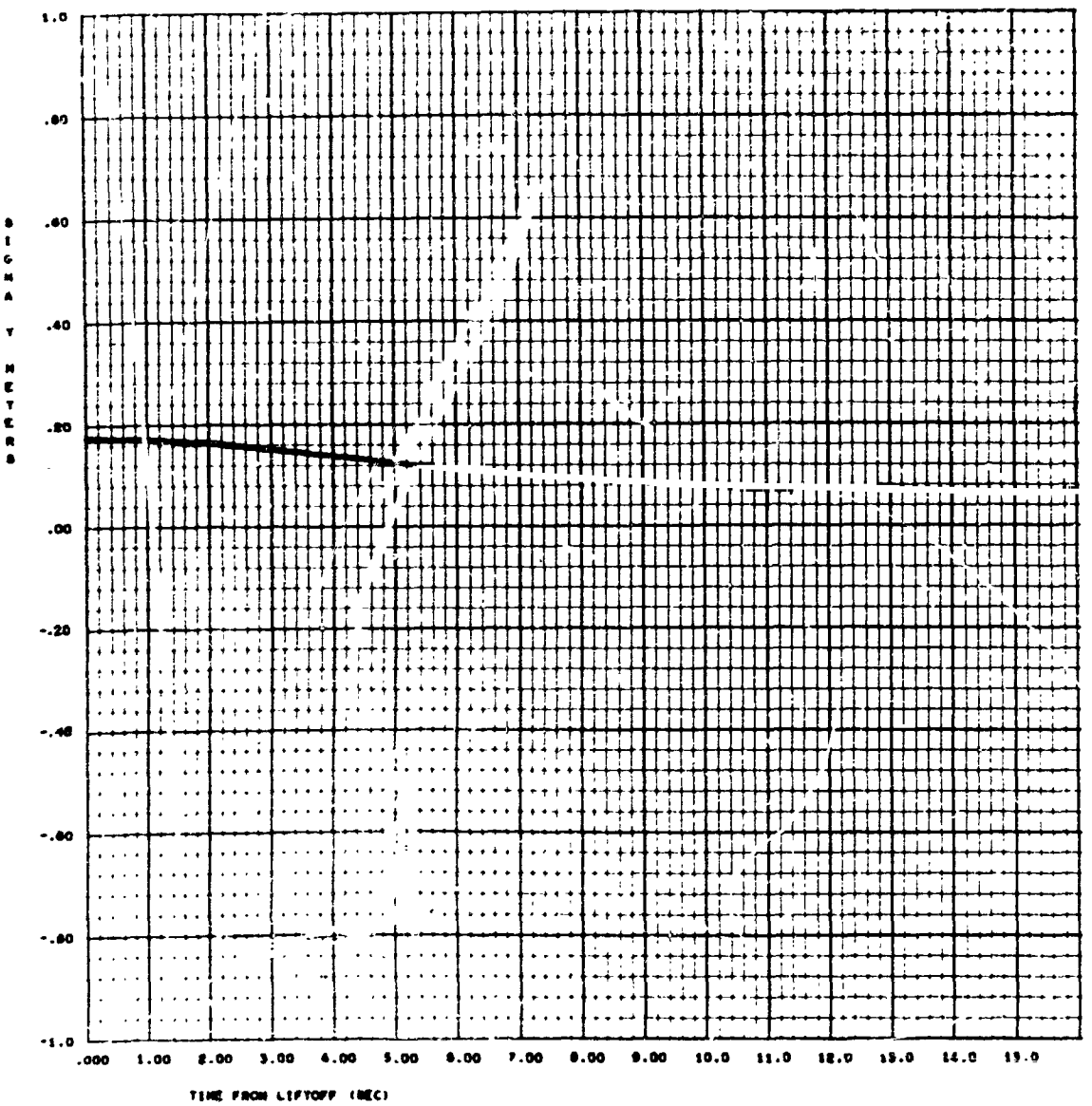

FIGURE 11. UDOP GDOP STATIONS 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5, 1.4.1, 1.9.1 (SIGMA Y)

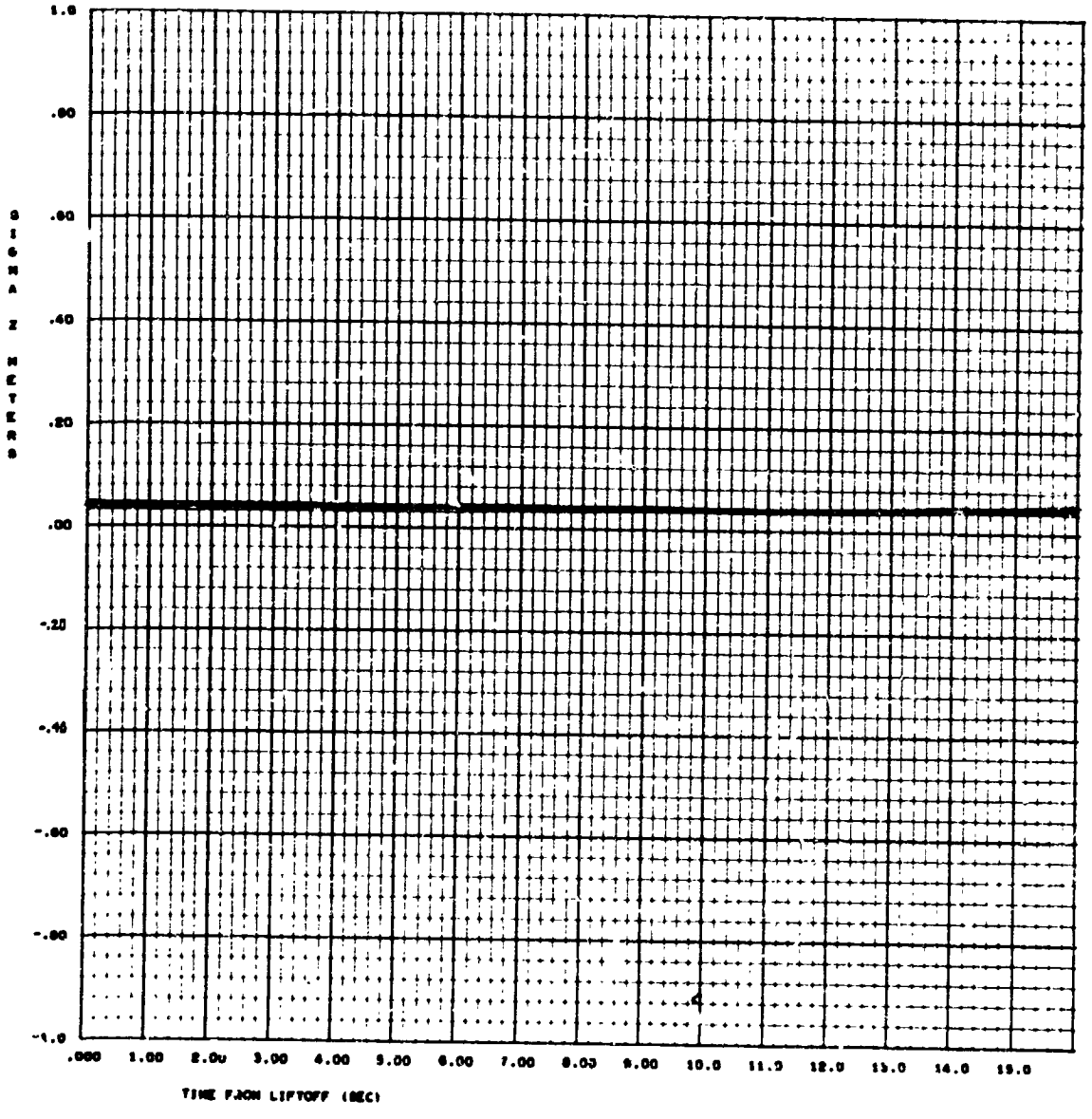

FIGURE 12. UDOP GDOP STATIONS 1.15.1, 1.15.2, 1.15.3, 1.15.4, 1.15.5, 1.4.1, 1.9.1 (SIGMA Z)

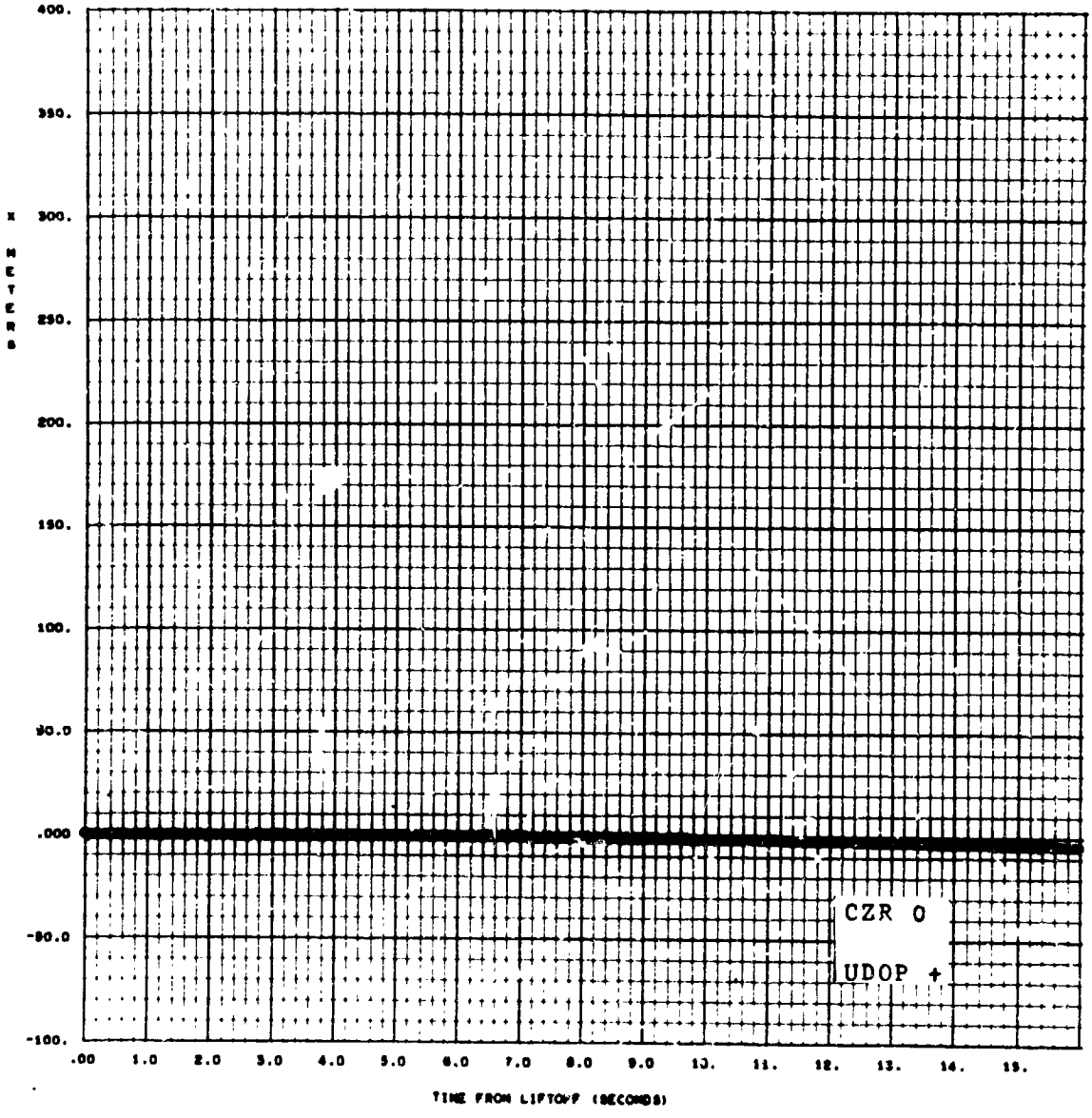

FIGURE 13. SA5 CZR, UDOP 5 STATION SOLUTION (X)

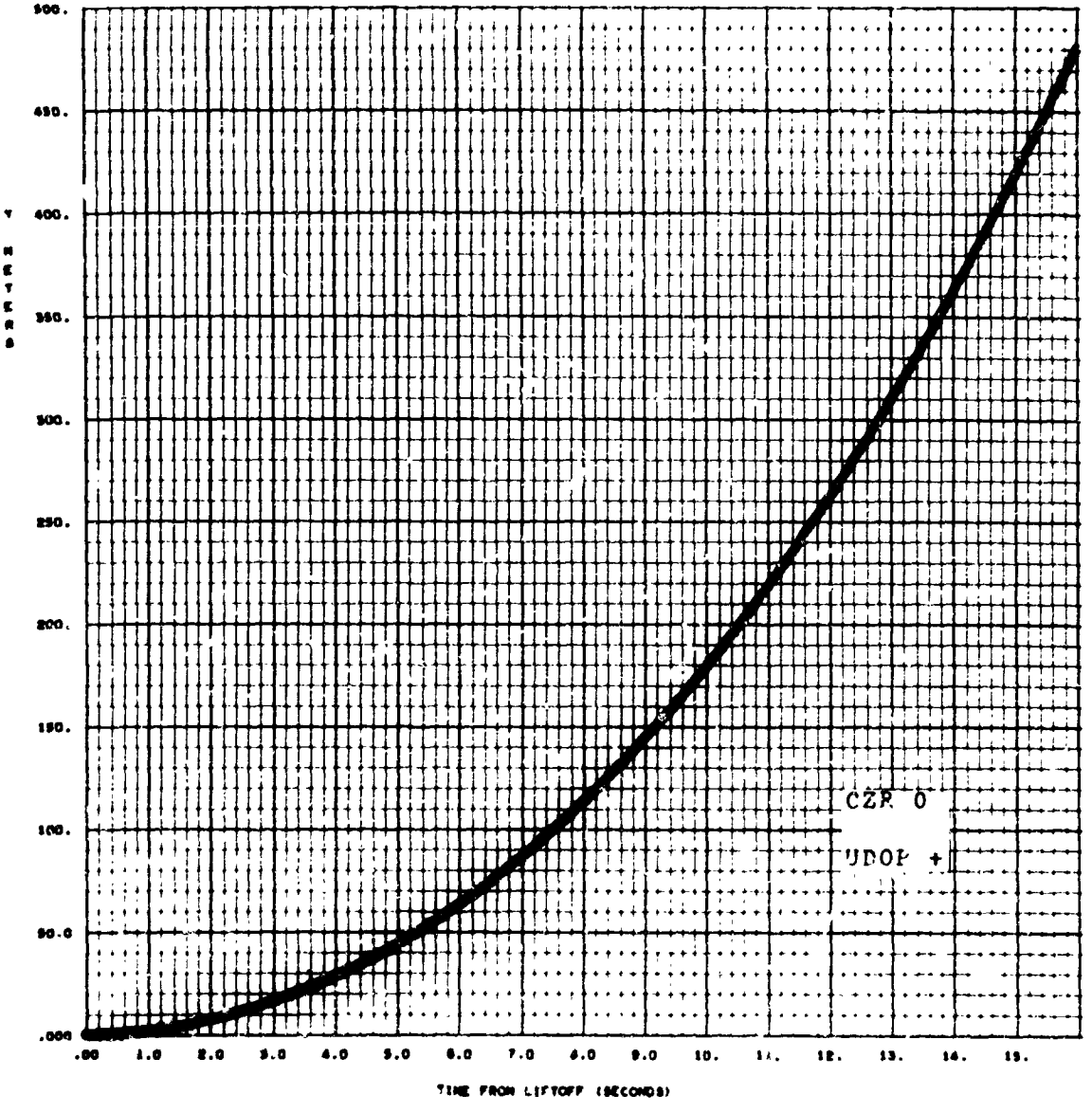

FIGURE 14. SA5 CZR, UDOP 5 STATION SOLUTION (Y)

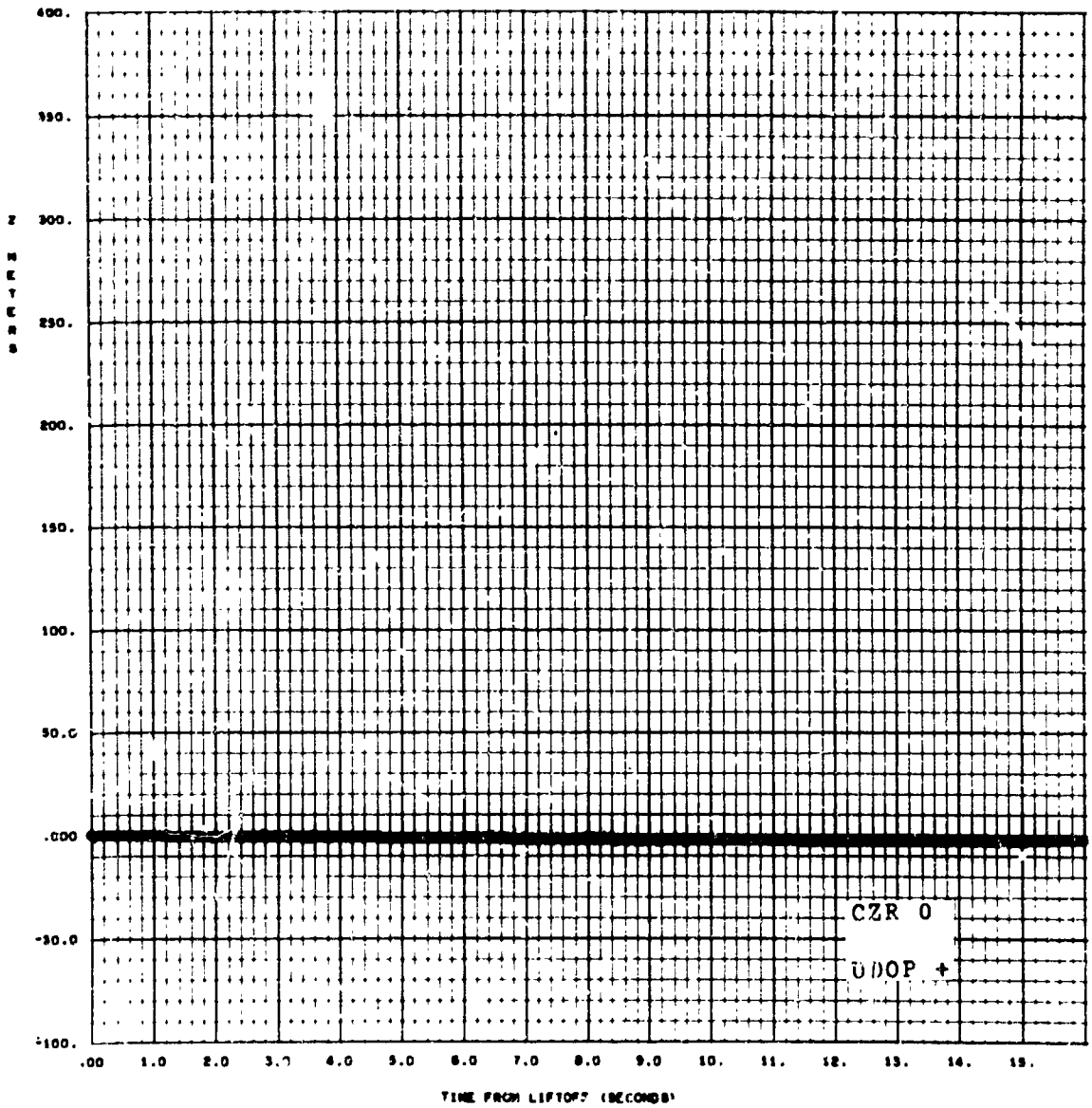

FIGURE 15. SA5 CZR, UDOP 5 STATION SOLUTION (Z)

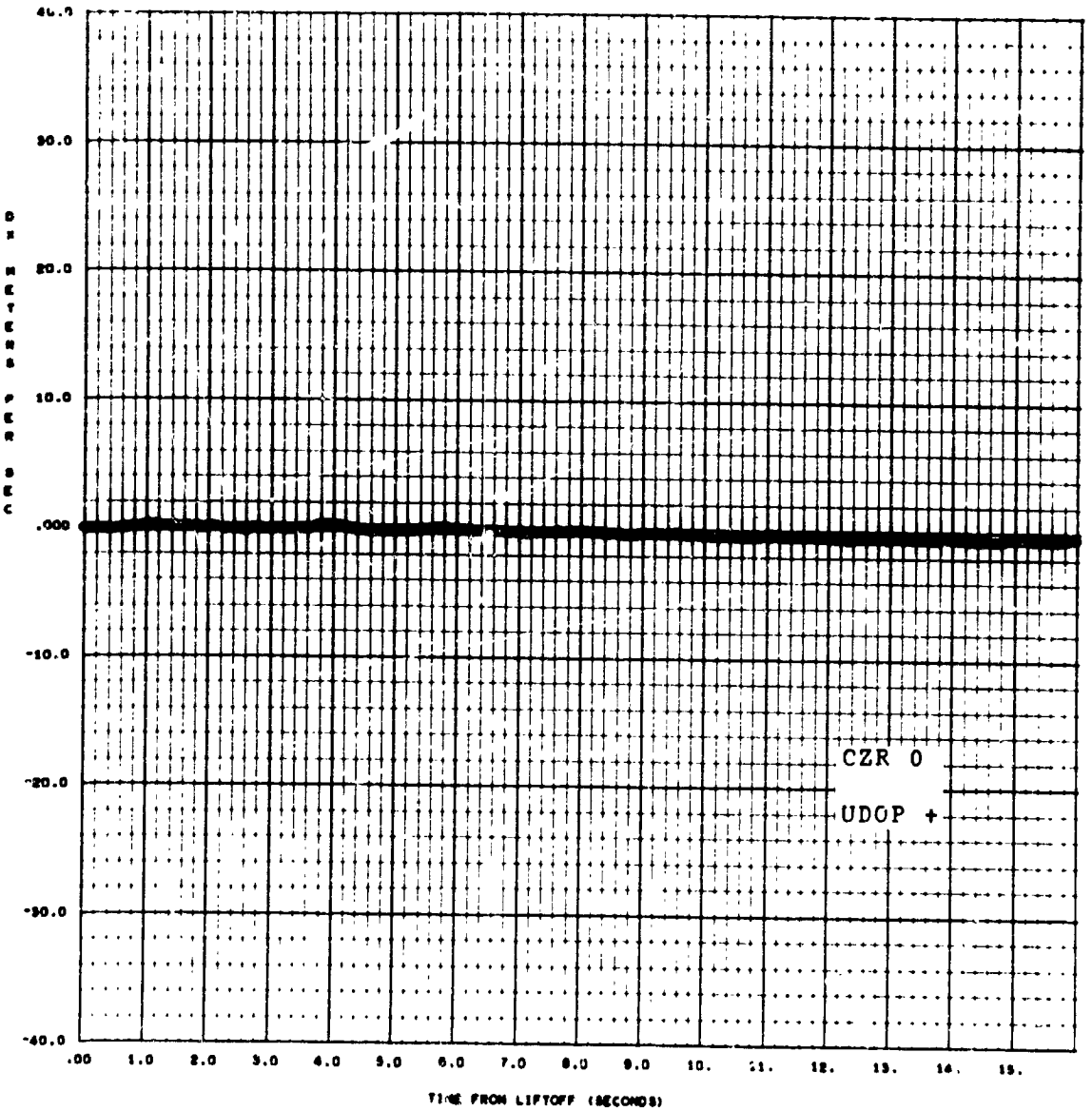

FIGURE 16. SA5 CZR, UDOP 5 STATION SOLUTION ($\dot{X}$)

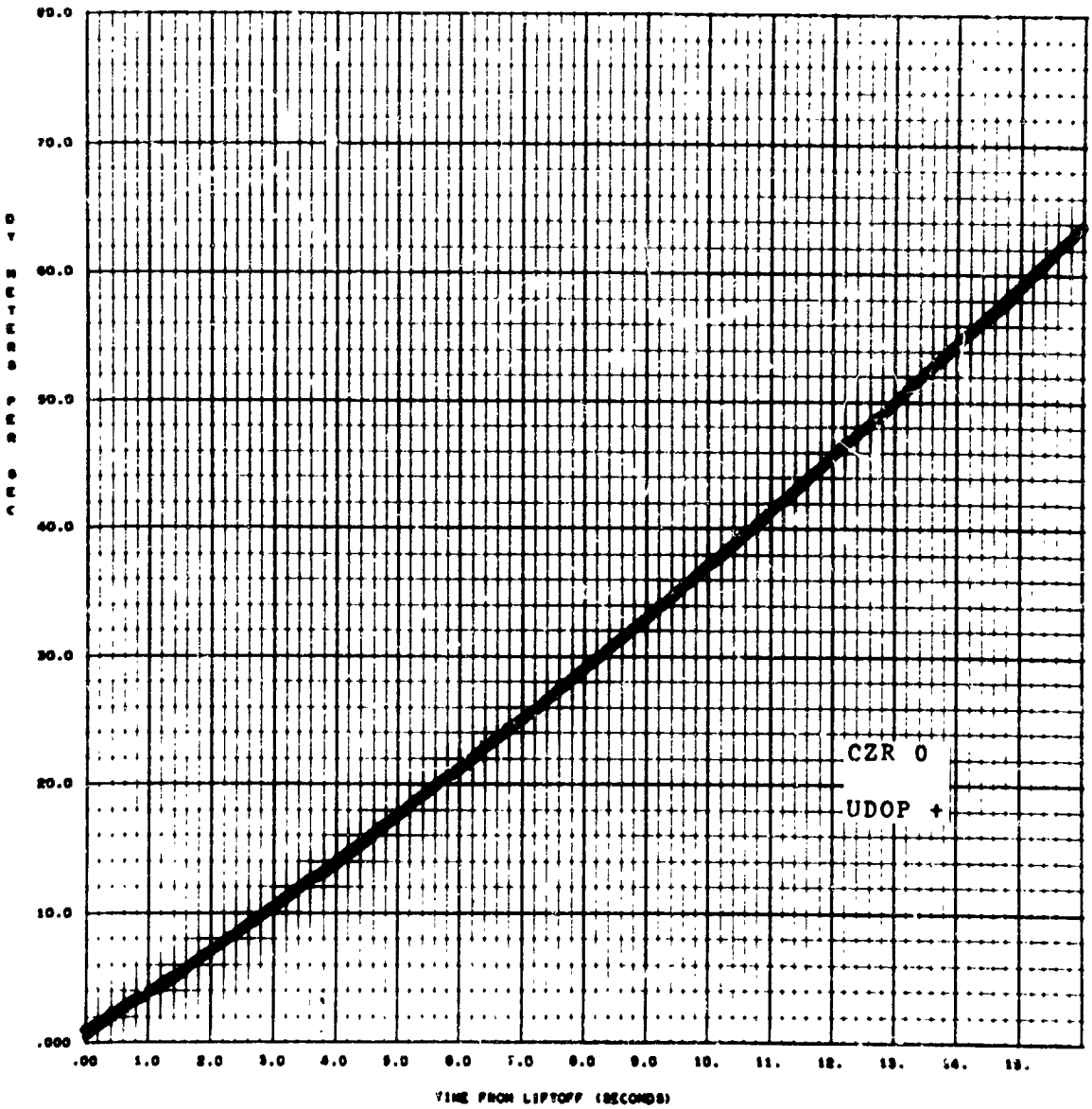

FIGURE 17. SA5 CZR, UDOP 5 STATION SOLUTION ($\dot{Y}$)

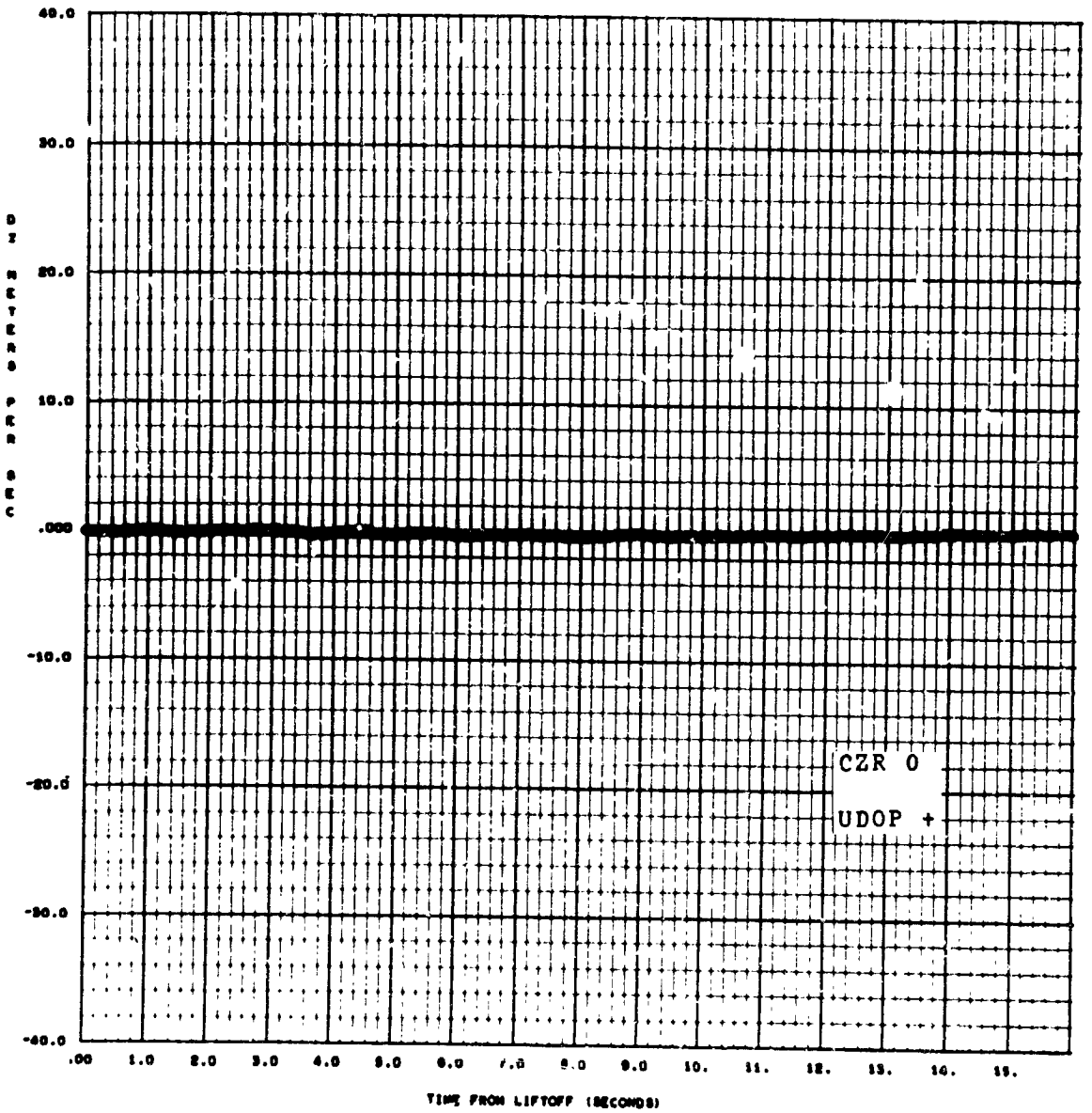

FIGURE 18. SA5 CZR, UDOP 5 STATION SOLUTION ($\dot{Z}$)

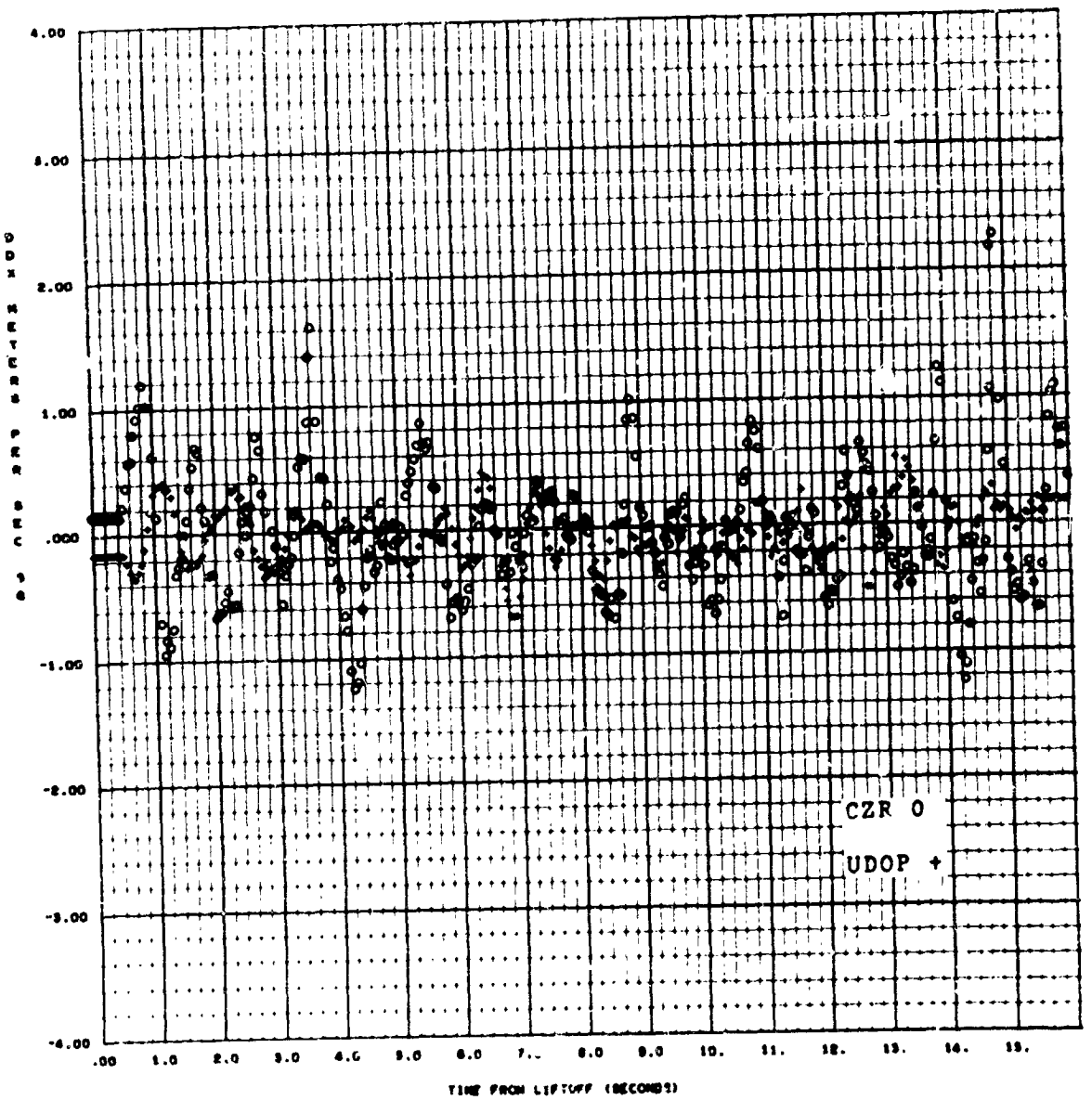

FIGURE 19. SA5 CZR, UDOP 5 STATION SOLUTION ($\ddot{X}$)

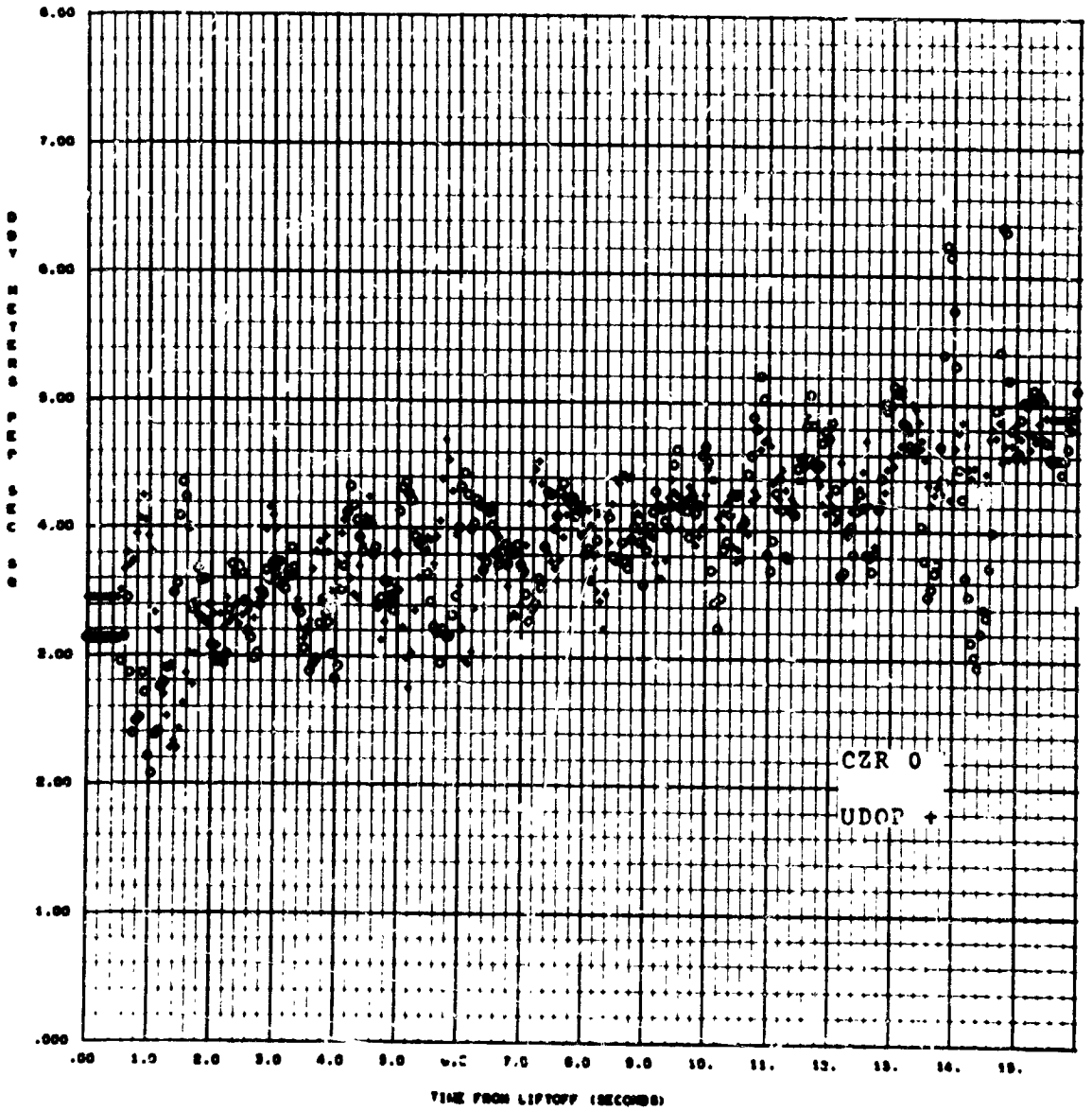

FIGURE 20. SA5 CZR, UDOP 5 STATION SOLUTION ($\ddot{Y}$)

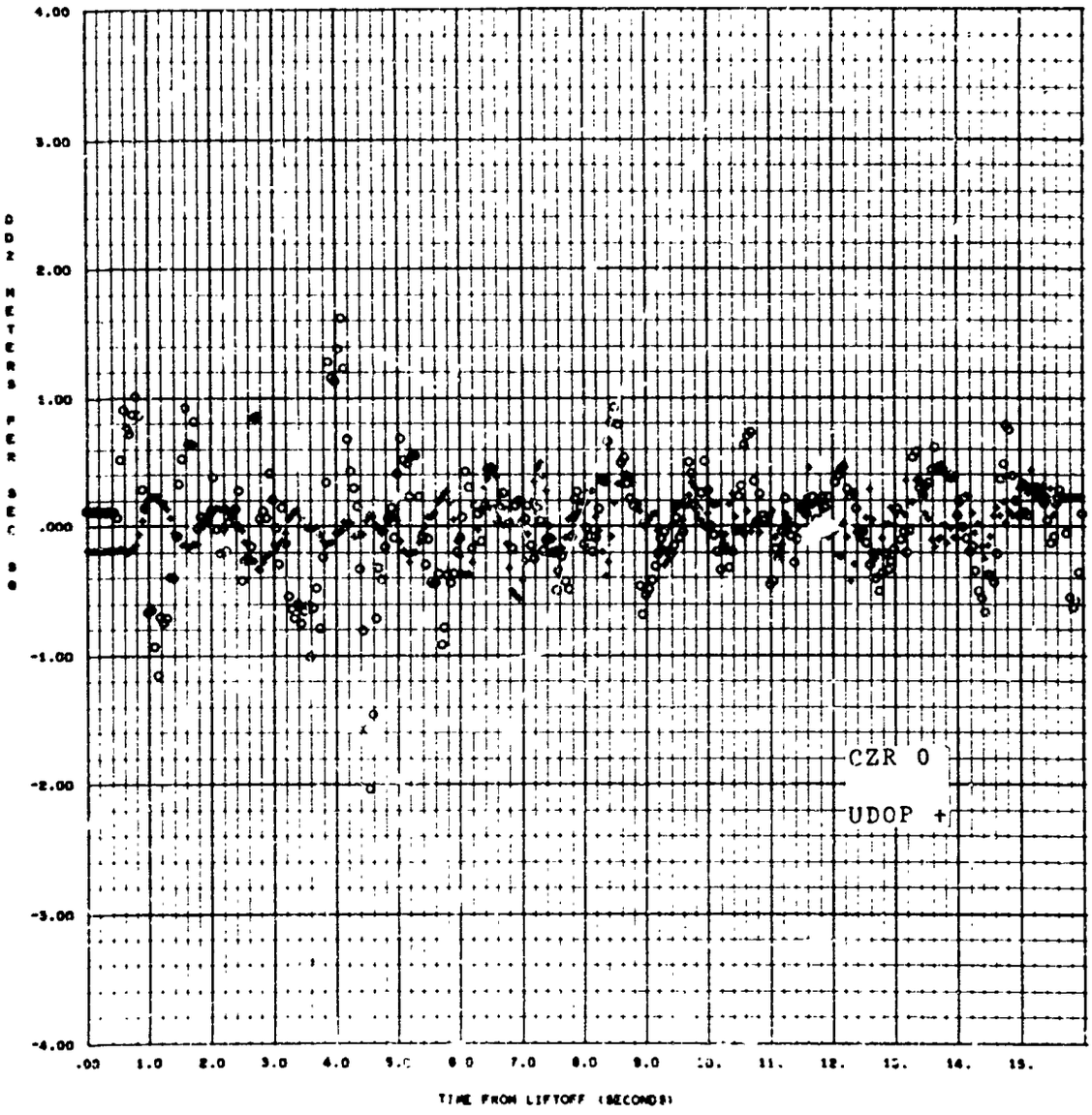

FIGURE 21 SA5 CZR, UDOP 5 STATION SOLUTION ($\ddot{Z}$)

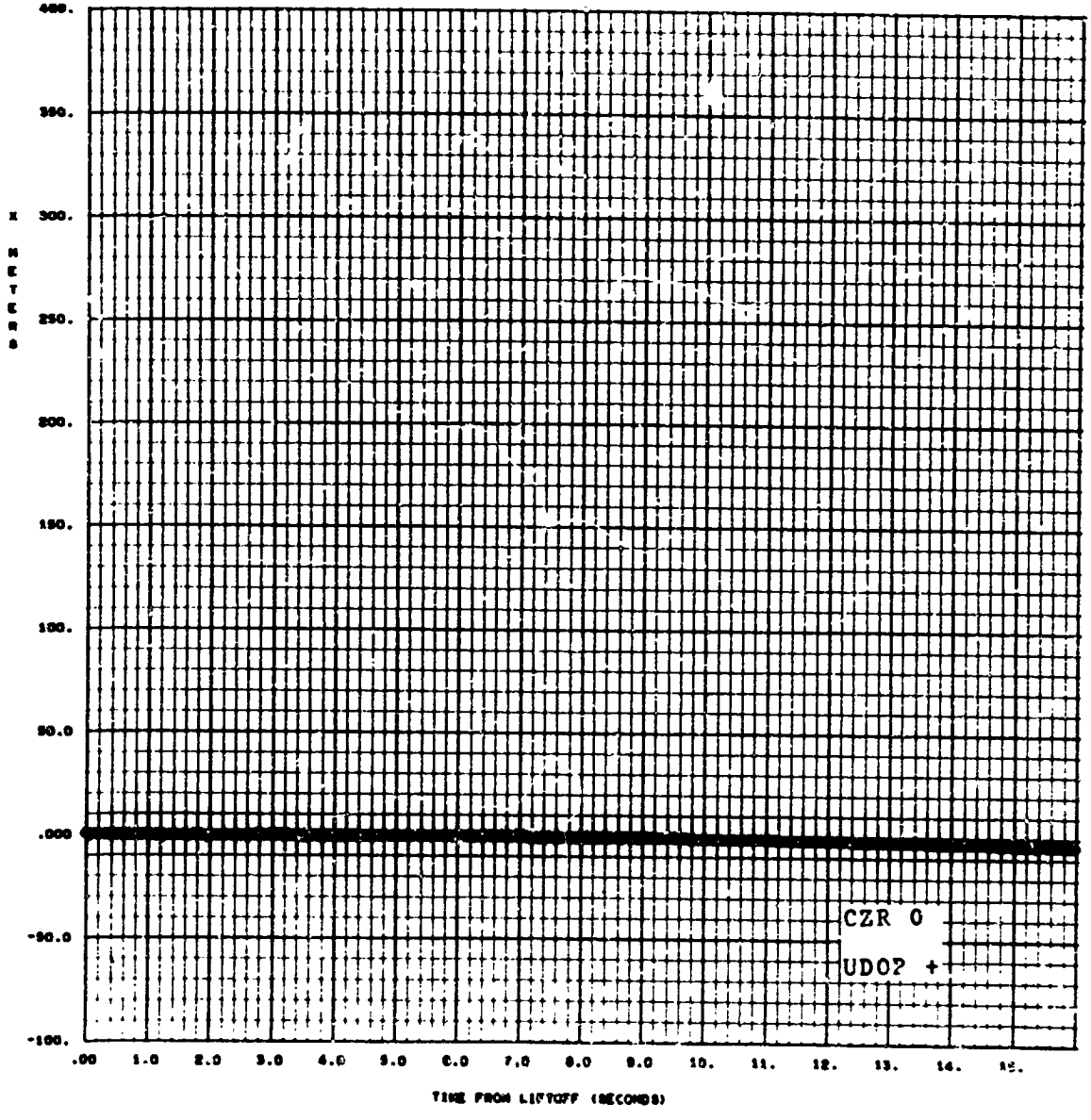

FIGURE 22. SA5 CZR, UDOP 7 STATION SOLUTION (X)

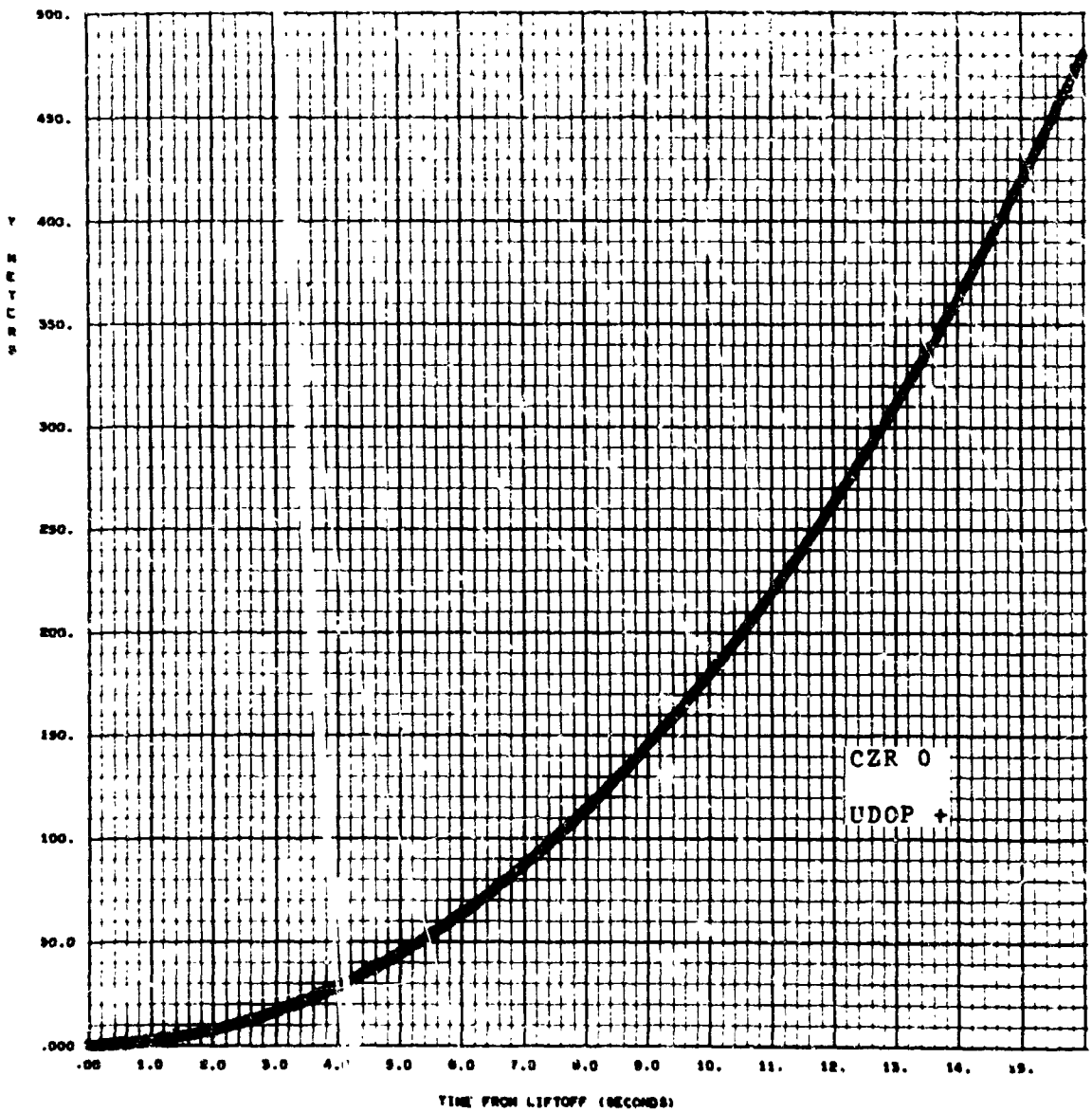

FIGURE 23. SA 5 CZR, UDOP 7 STATION SOLUTION (Y)

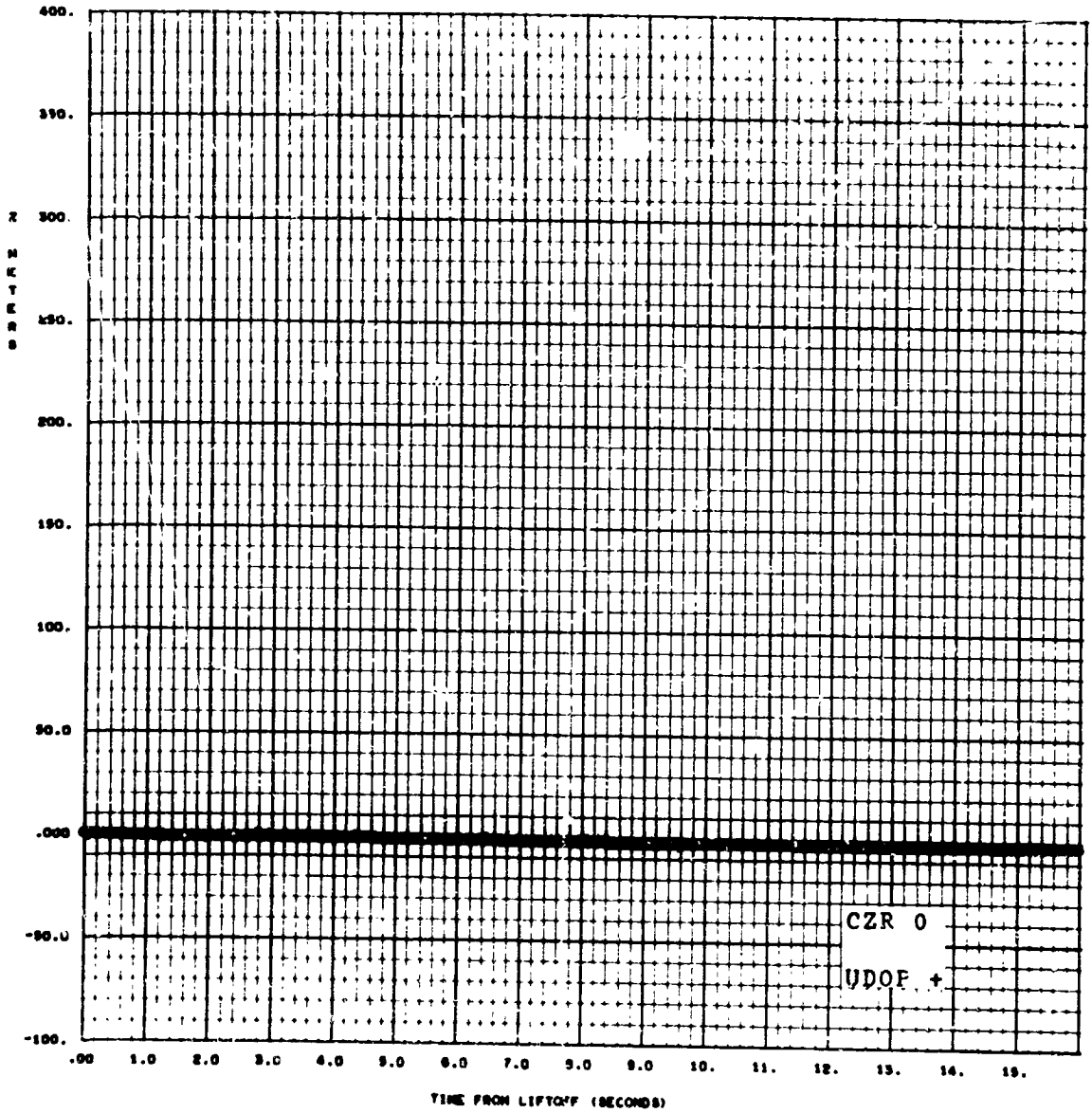

FIGURE 24. SA5 CZR, UDOP 7 STATION SOLUTION (Z)

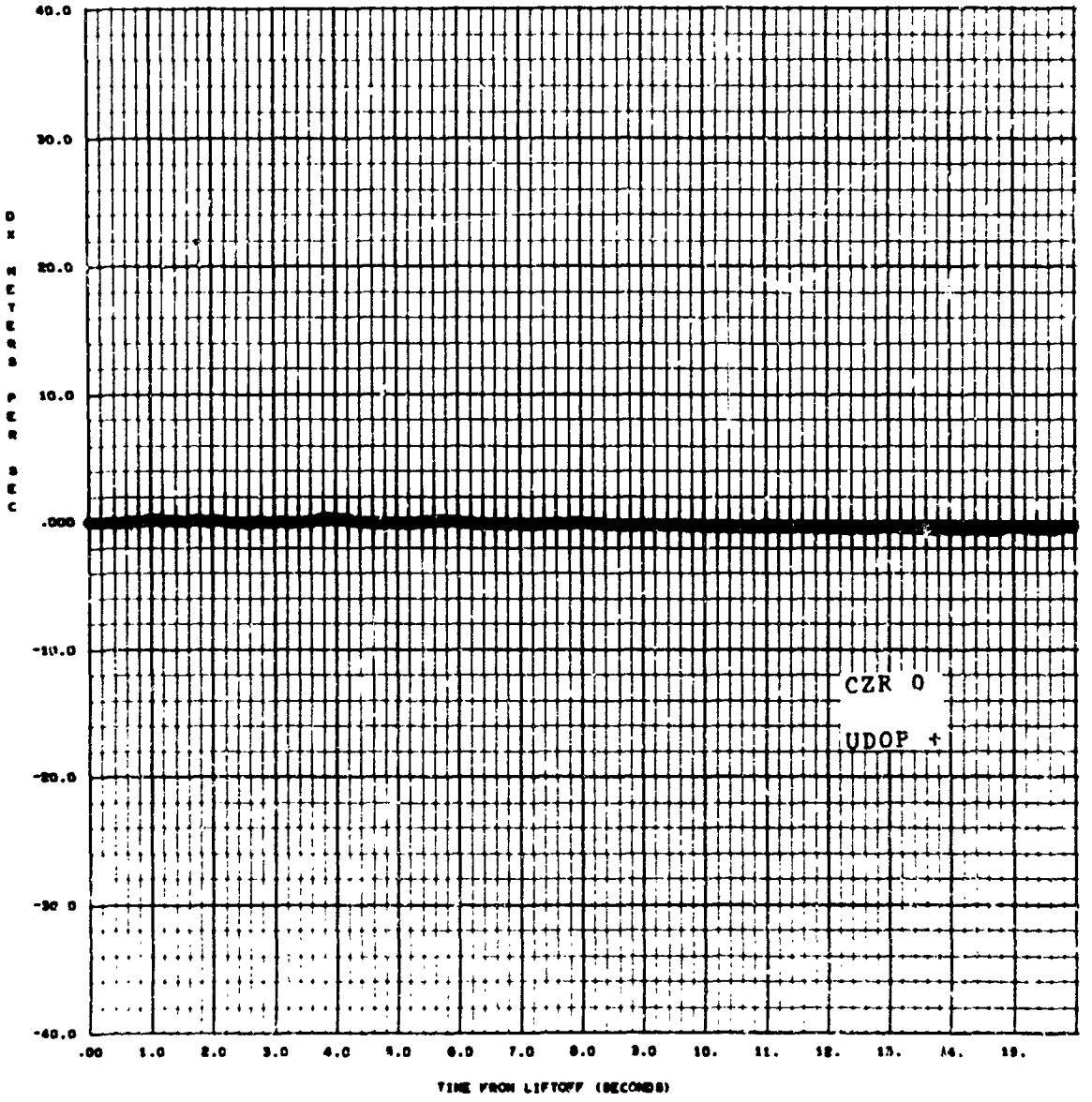

FIGURE 25. SA5 CZR, UDOP 7 STATION SOLUTION ($\dot{X}$)

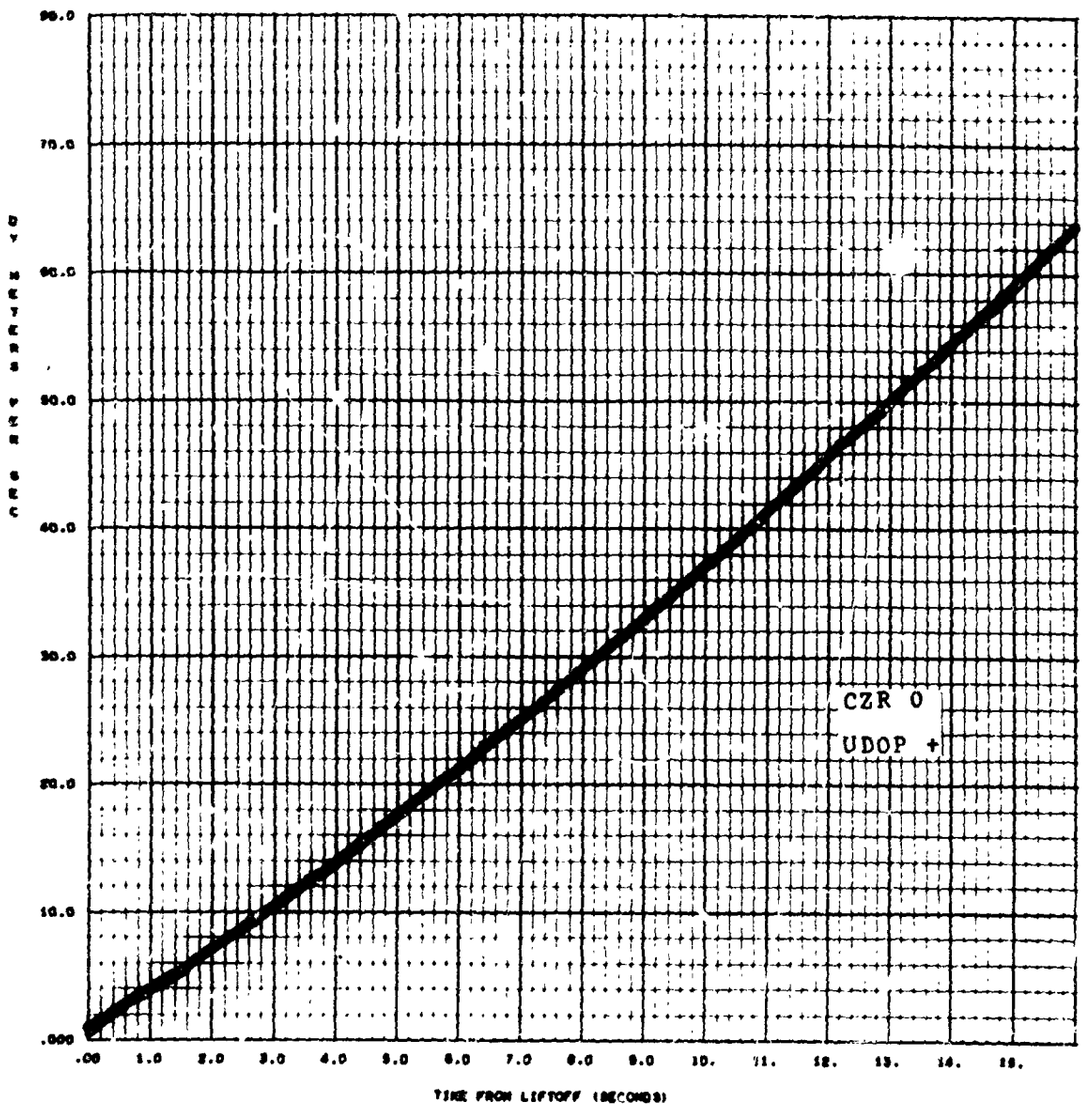

FIGURE 26. SA5 CZR, UDOP 7 STATION SOLUTION ($\dot{Y}$)

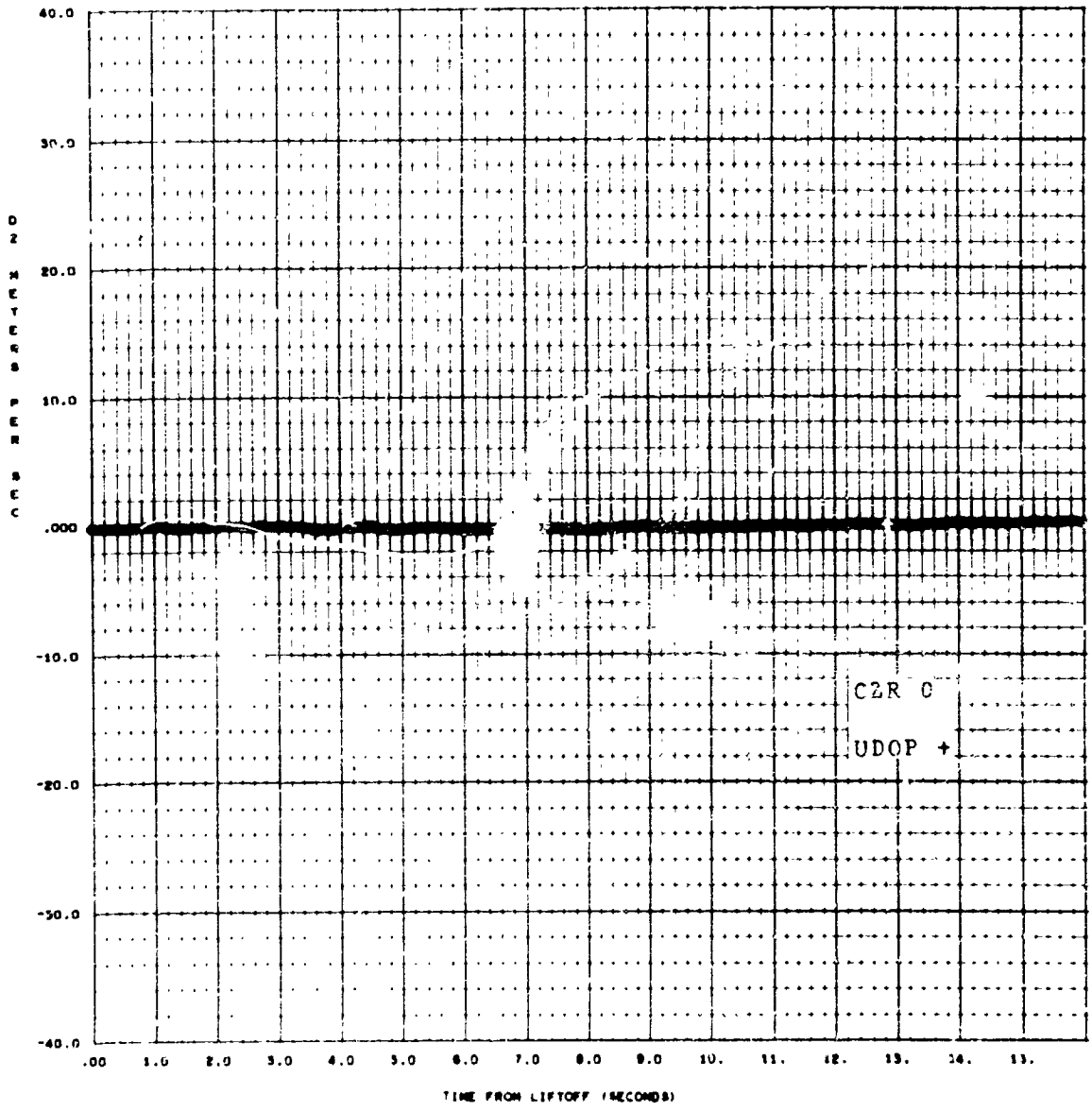

FIGURE 27. SA5 CZR, UDOP 7 STATION SOLUTION ($\dot{Z}$)

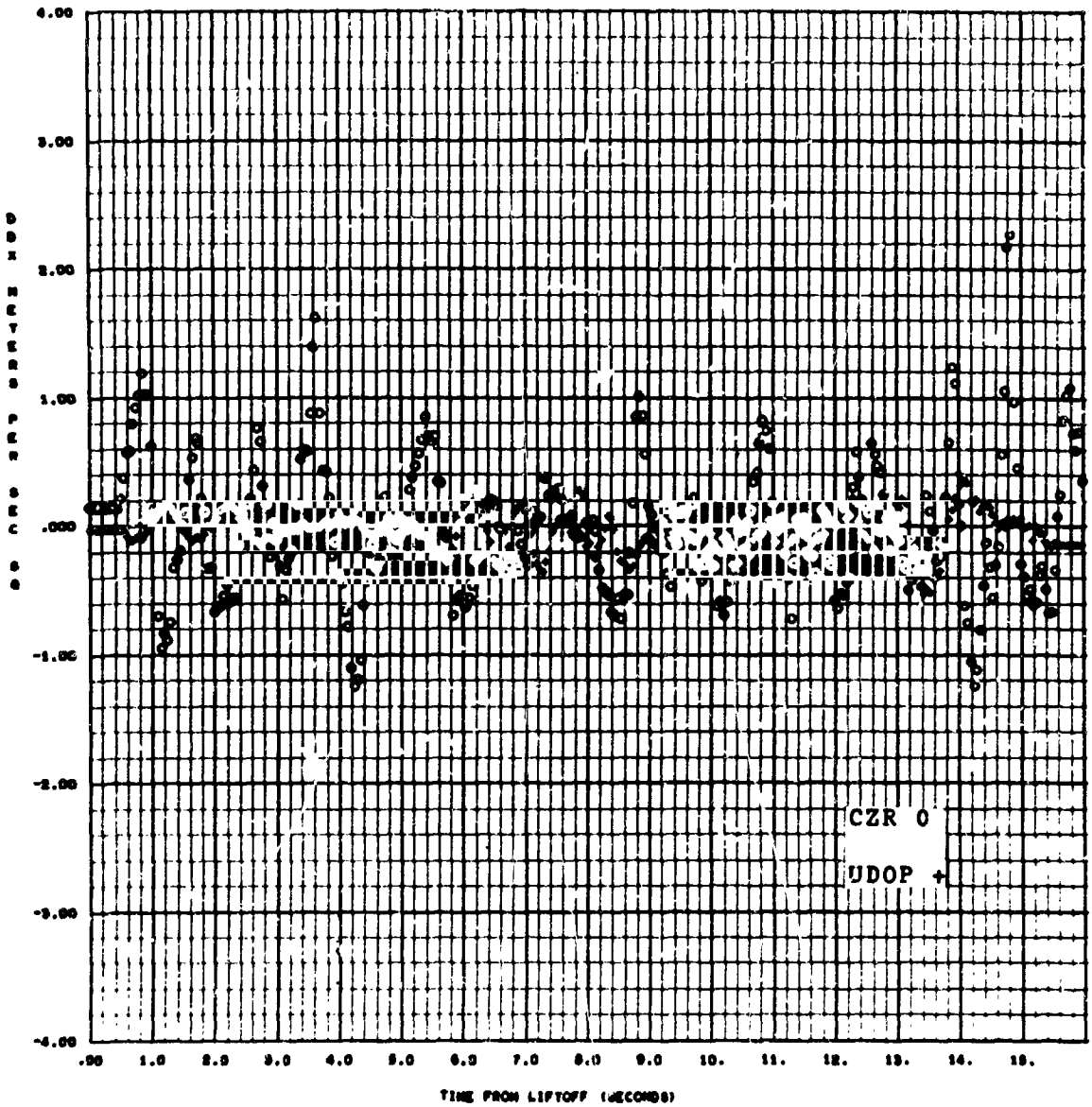

FIGURE 28. SA5 CZR, UDOP 7 STATION SOLUTION ($\ddot{X}$)

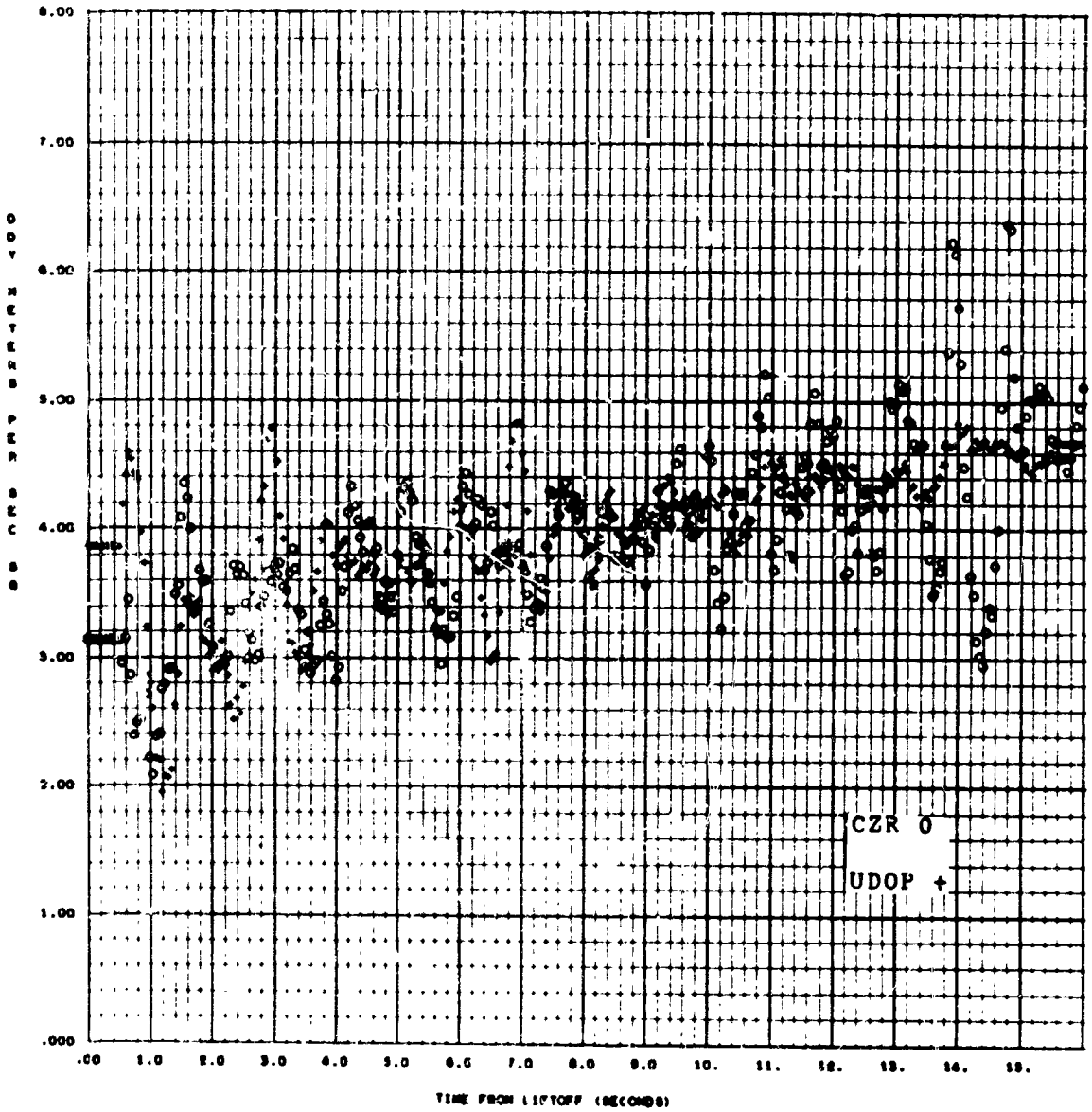

FIGURE 29. SA5 CZR, UDOP 7 STATION SOLUTION ($\ddot{Y}$)

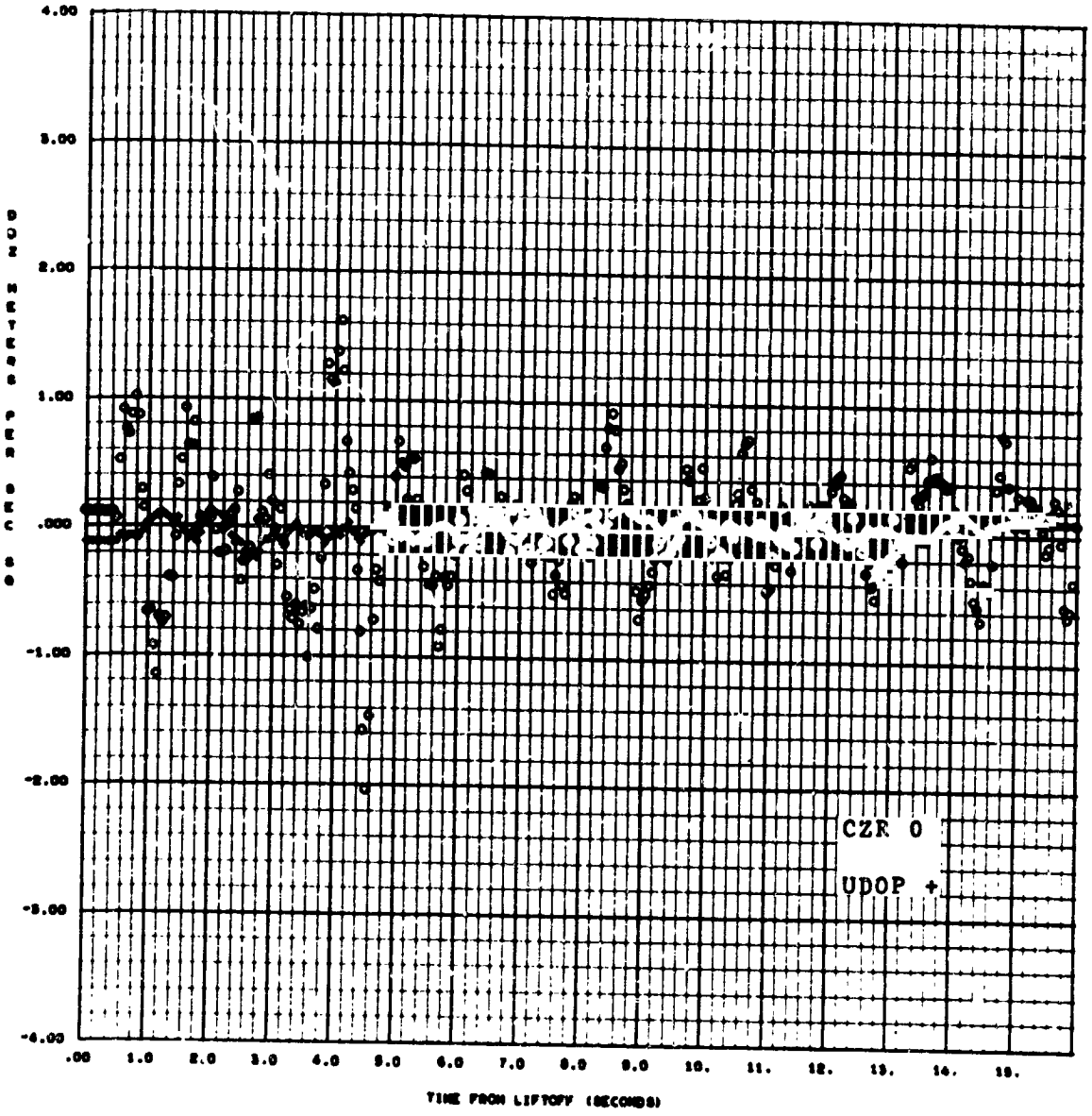

FIGURE 30. SA5 CZR, UDOP 7 STATION SOLUTION ($\ddot{Z}$)

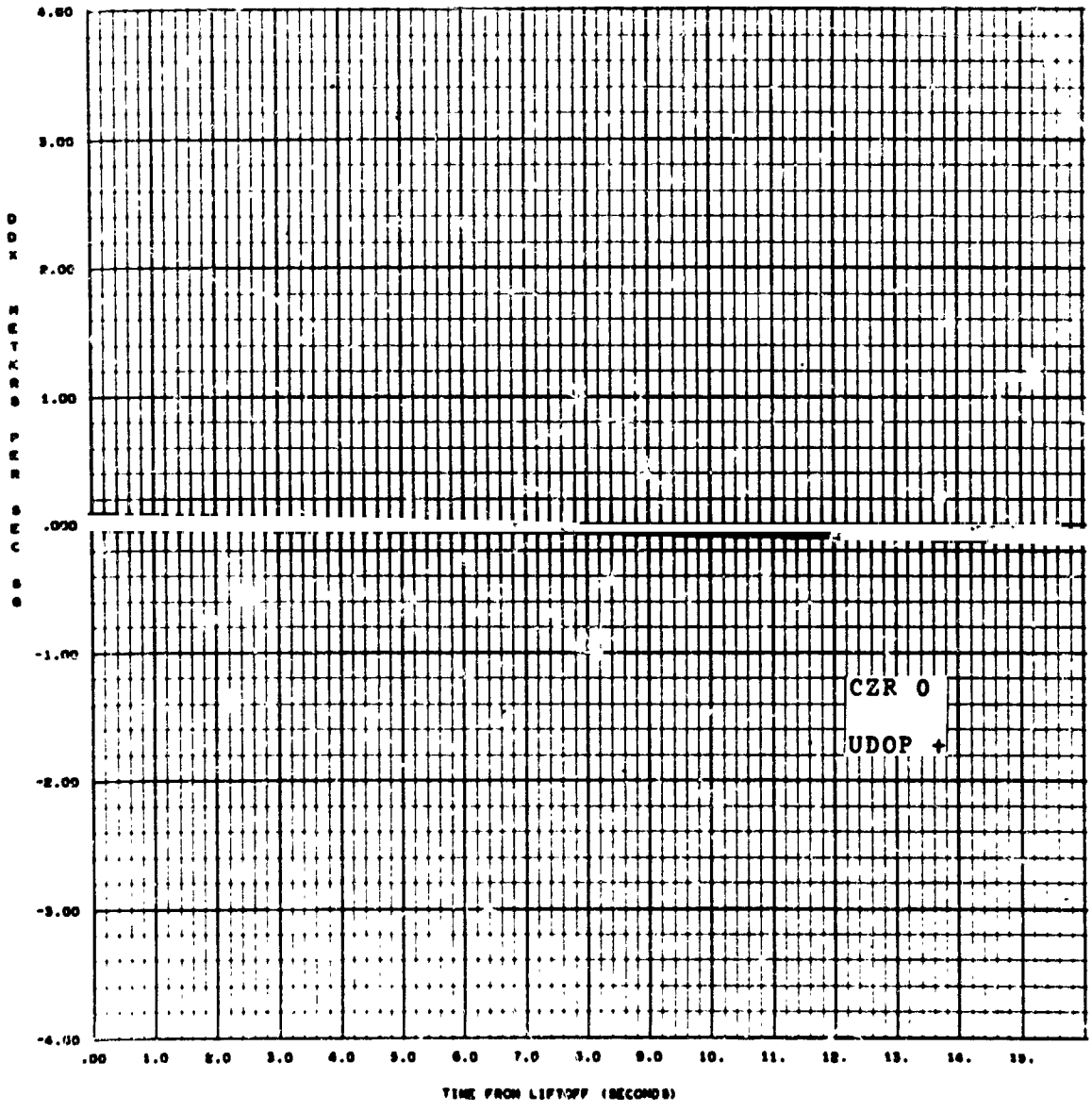

FIGURE 31. SA5 CZR, UDOP 7 STATION SOLUTION, SMOOTHED ($\ddot{X}$)

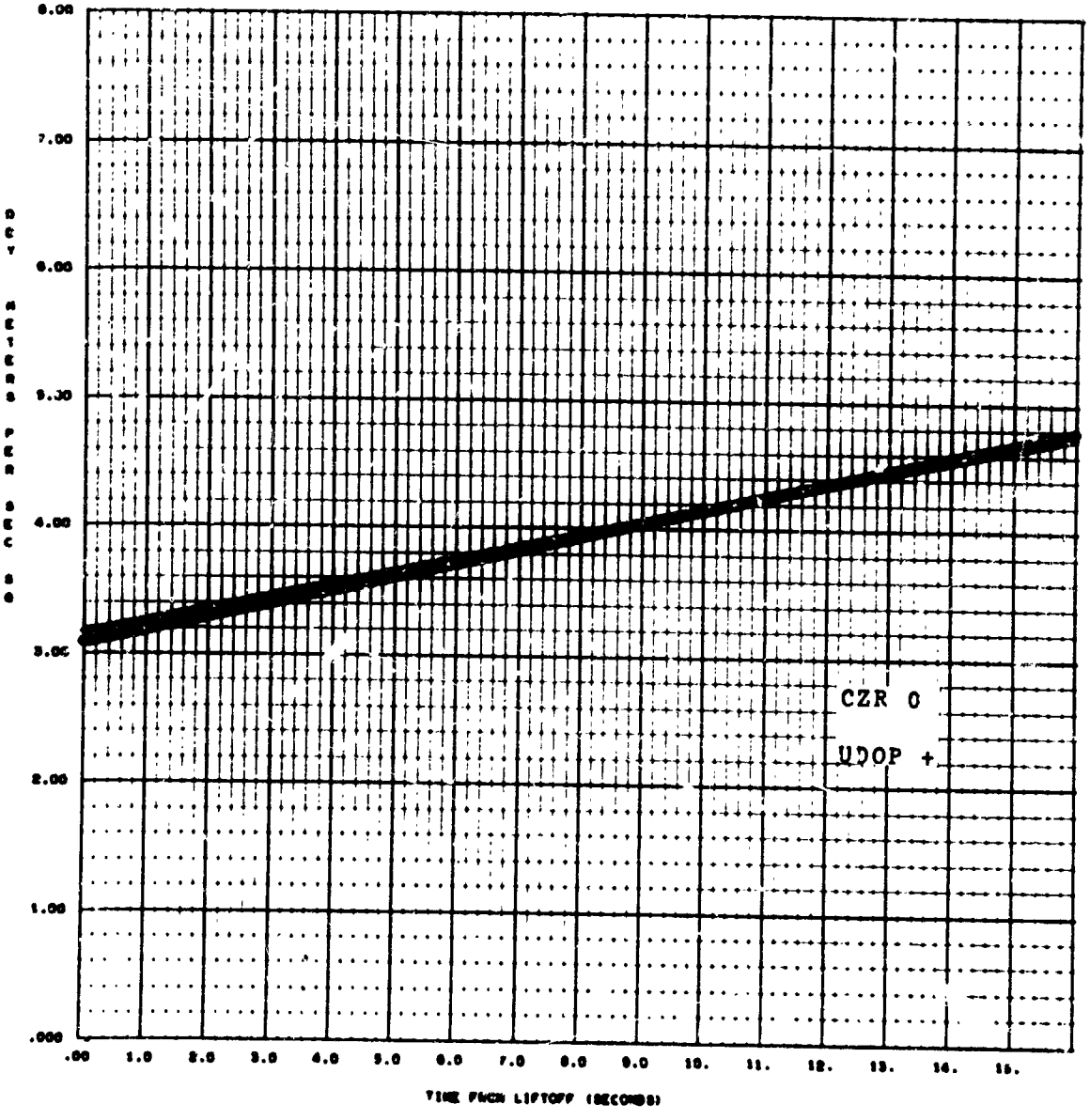

FIGURE 32. SA5 CZR, UDOP 7 STATION SOLUTION, SMOOTHED (Y)

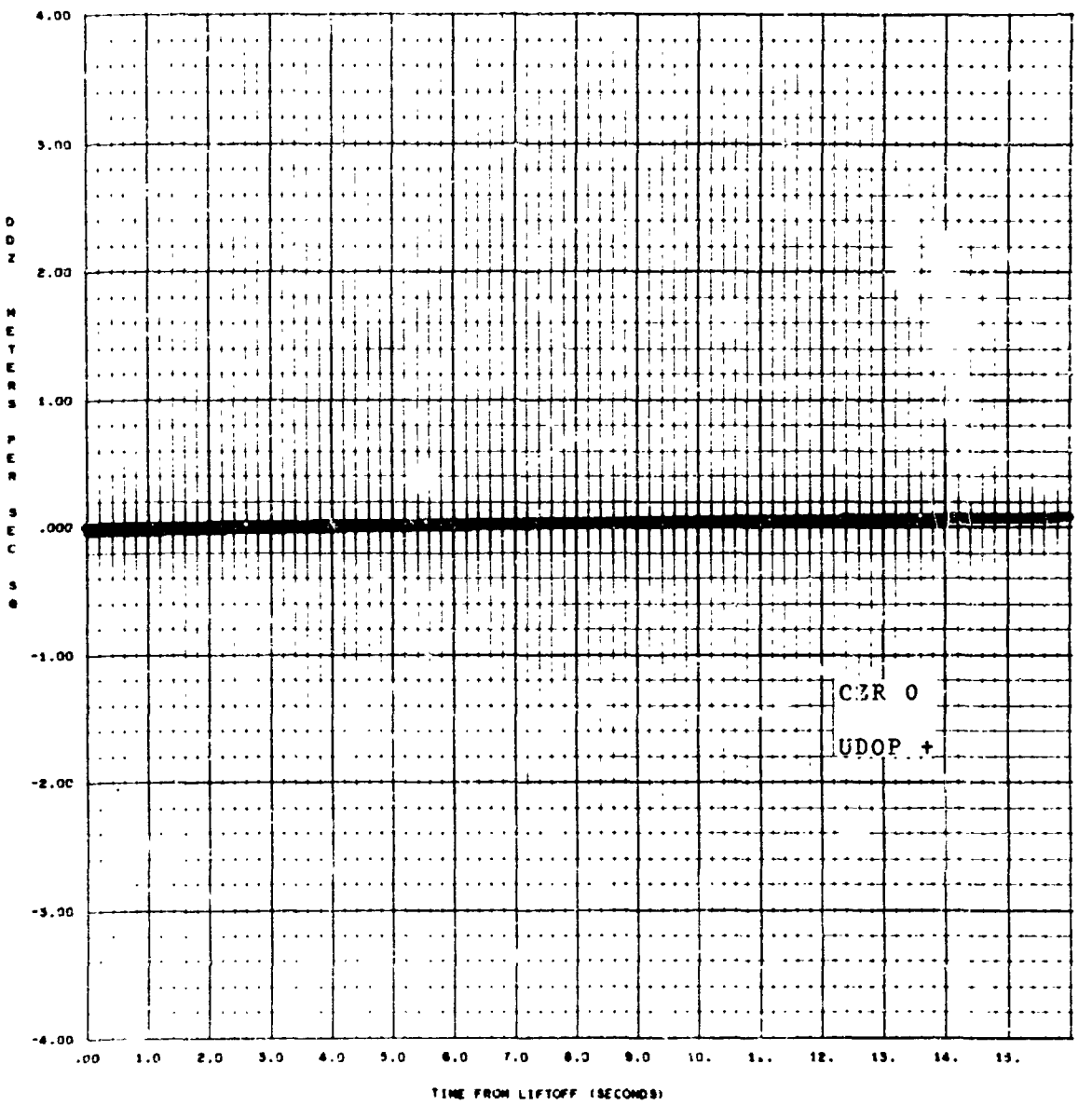

FIGURE 33. SA5 CZR, UDOP 7 STATION SOLUTION, SMOOTHED (Z)

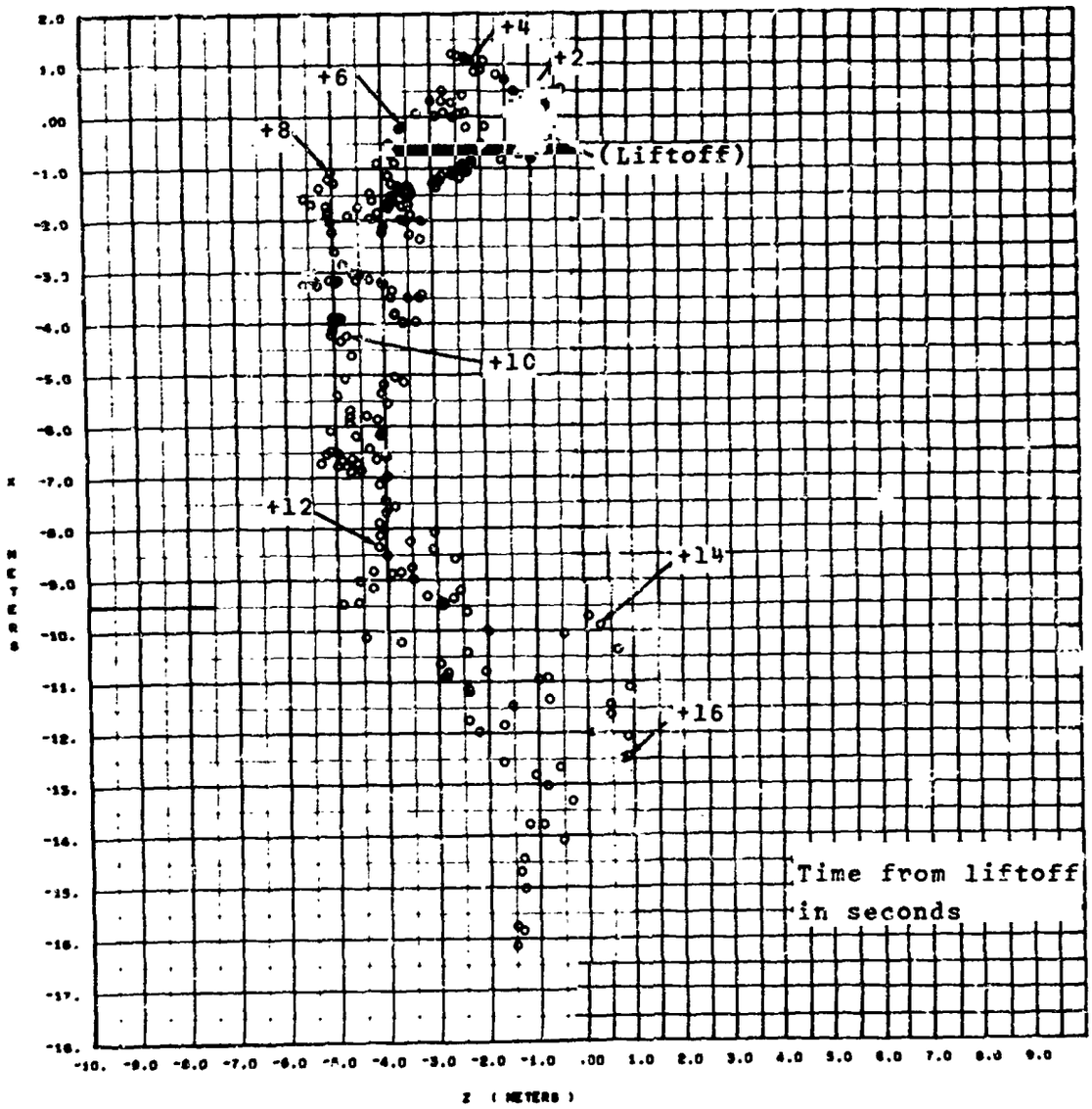

FIGURE 34. CZR CLOSE-IN IMPACT PREDICTION

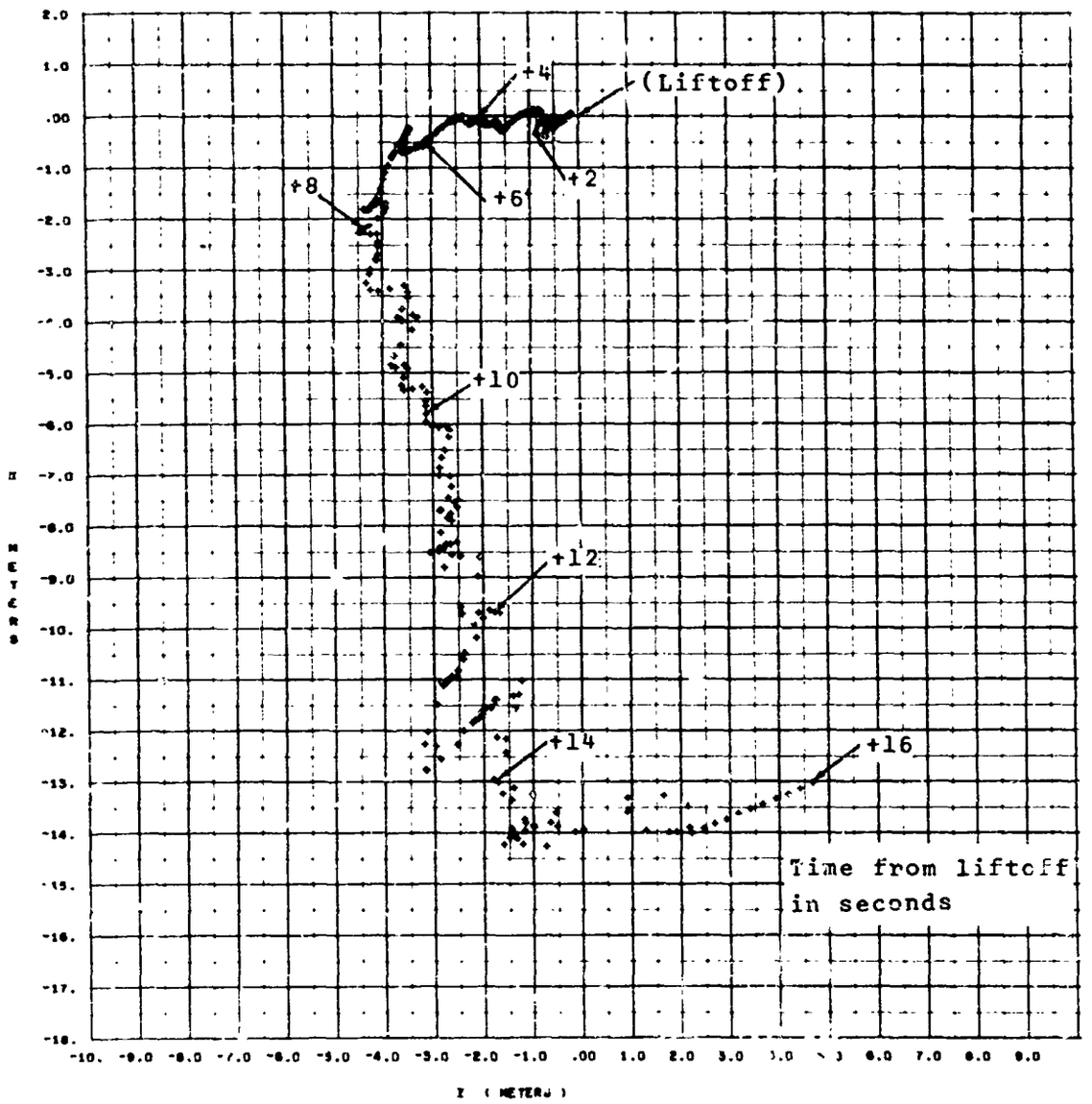

FIGURE 35. 5 STATION UDOP CLOSE-IN IMPACT PREDICTION

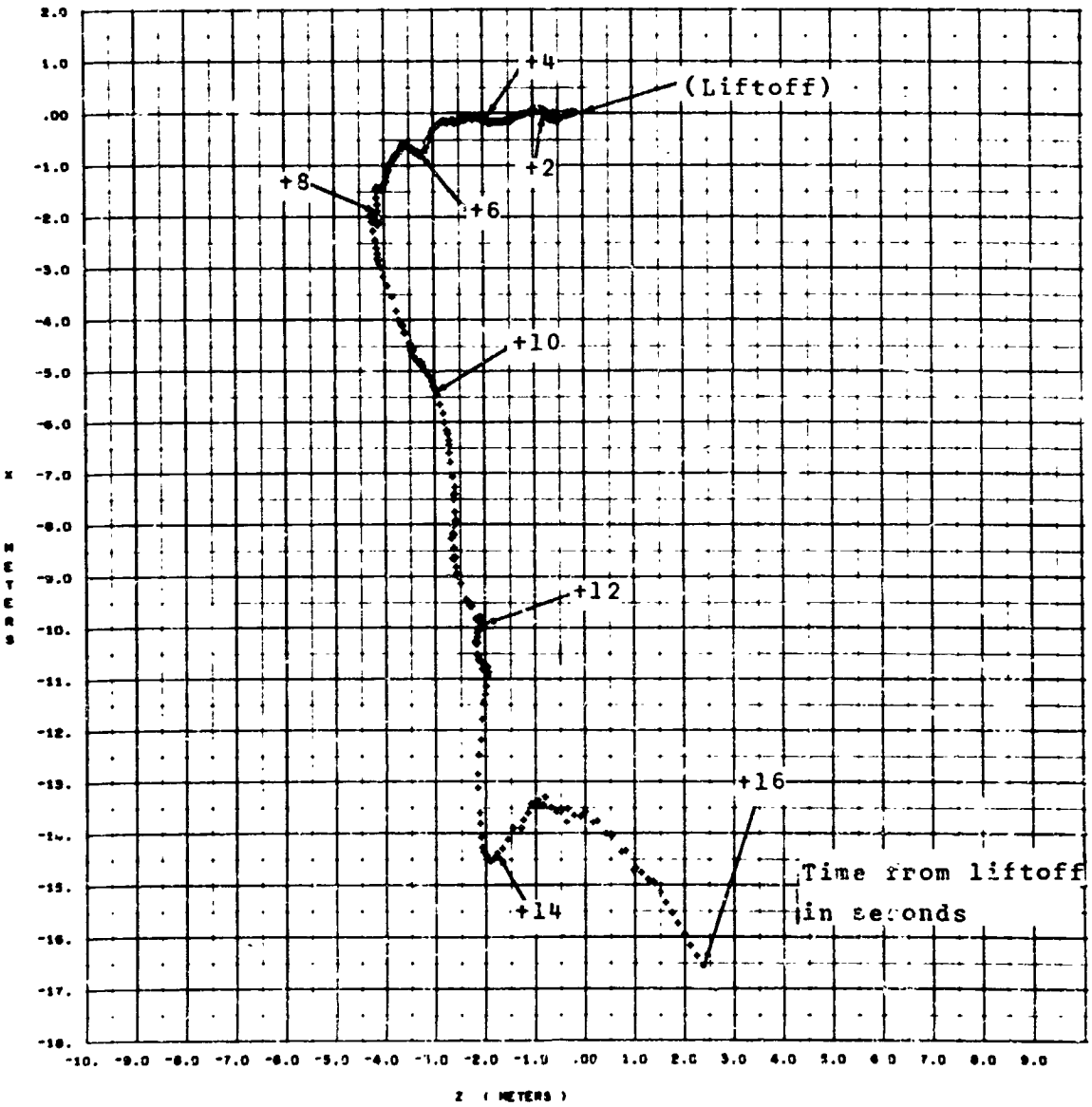

FIGURE 36. 7 STATION UDOP CLOSE-IN IMPACT PREDICTION

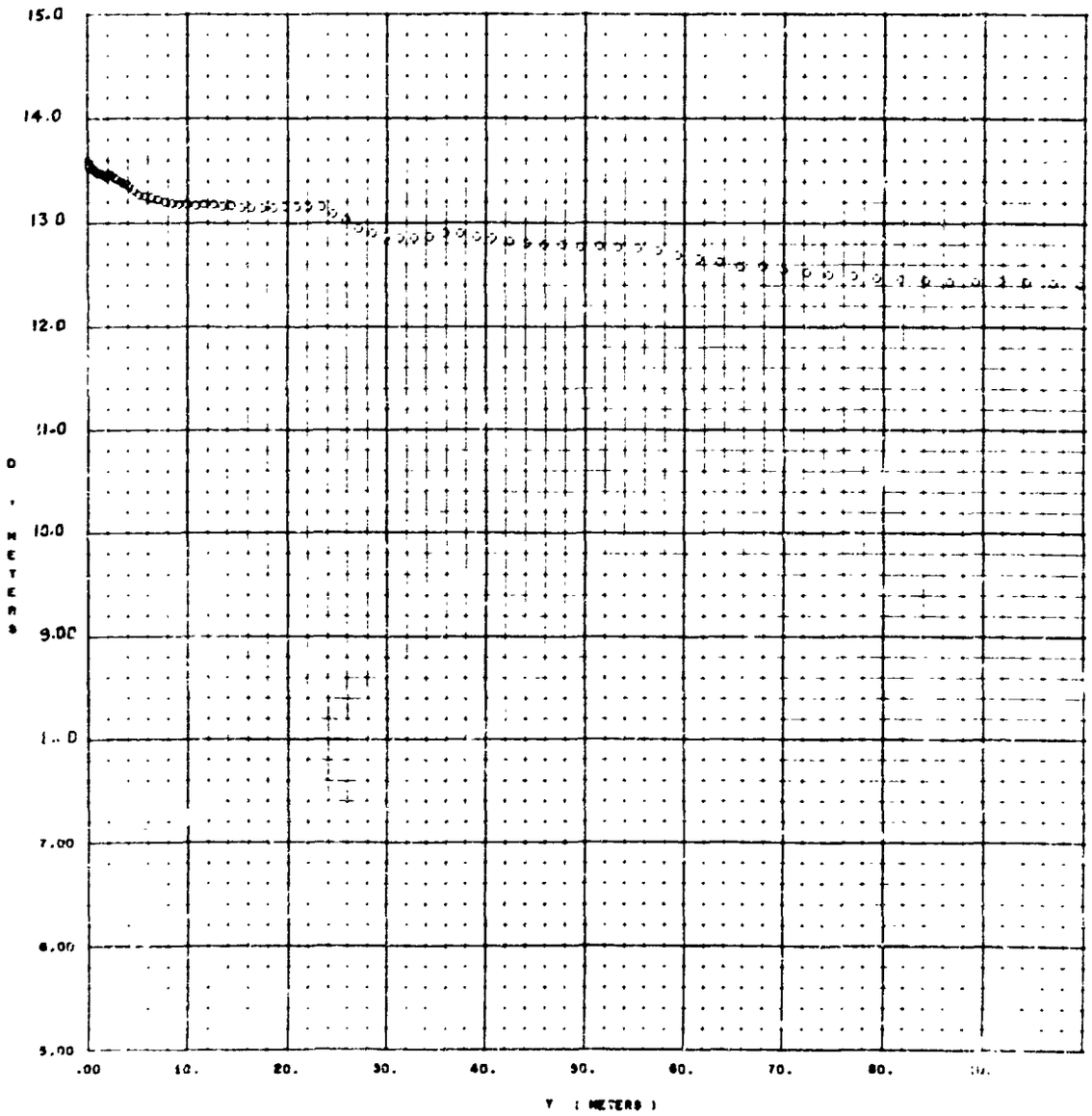

FIGURE 37. DISTANCE FROM TOWER TO VEHICLE (CZR)

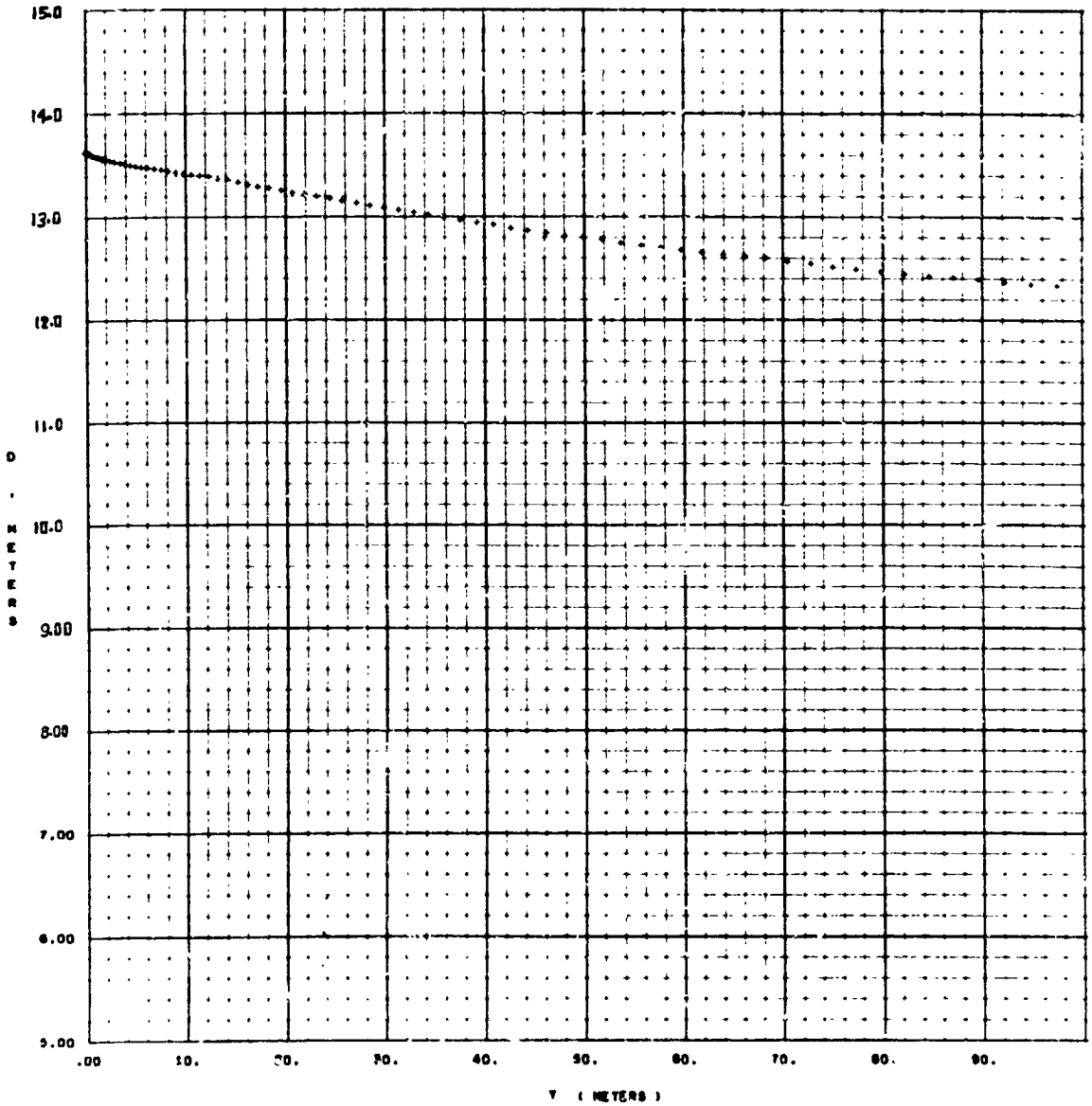

FIGURE 38. DISTANCE FROM TOWER TO VEHICLE (5 STATION UDOP)

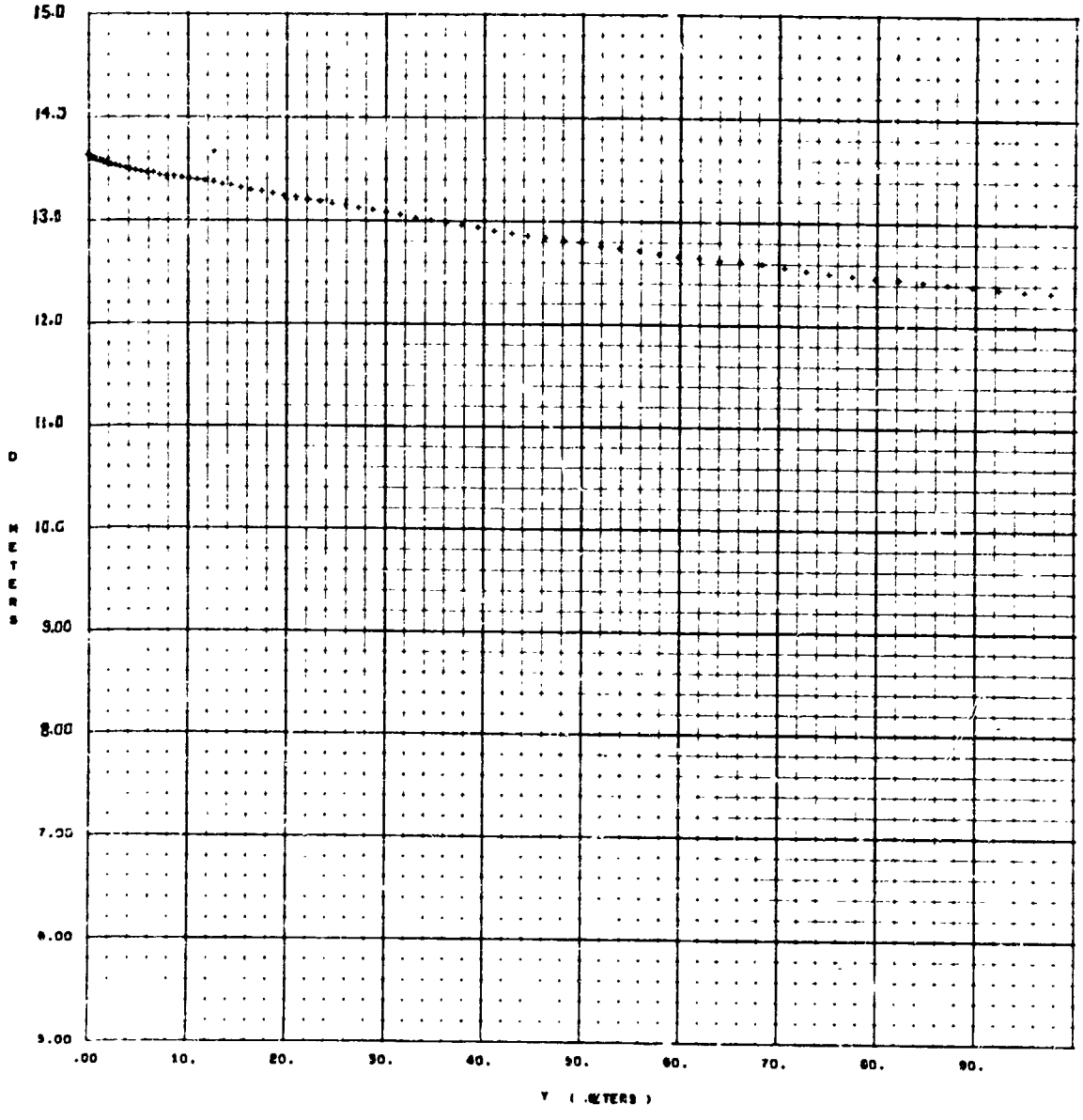

FIGURE 39. DISTANCE FROM TOWER TO VEHICLE (7 STATION UDOP)

REFERENCES

1. AMR Instrumentation Handbook, Volume I - Operational Systems, pages 2-49, 50, and 51

2. Interim-Offset UDOP System by F. Byrne and R. L. Baker, MTP-LOV-63-1, January 4, 1963

3. Experimental Operation of the UDOP System on Ranger 3, by W. W. Wood, MTP-LOD-62-8, May 4, 1962

APPROVAL

SP-79

SATURN EARLY LAUNCH PHASE
TRACKING BY CW DOPPLER

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