NASA Contractor Report 168345

Balloon-Borne Pressure Sensor Performance Evaluation Utilizing Tracking Radars

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NASA

National Aeronautics and
Space Administration

Goddard Space Flight Center
Wallops Flight Facility
Wallops Island, Virginia 23337

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Prepared Under Contract No. NAS5-26930

National Aeronautics and
Space Administration

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PREFACE

This study was performed under Contract NAS5-26930 with the National Aeronautics and Space Administration. The Technical Monitor was Chester Parsons of NASA's Wallops Flight Facility. Al Holland and Arnold Torres, both of NASA, also provided valuable technical guidance.

We appreciate the cooperation and assistance provided by members of the Joule and Computer Science Corporation onsite support groups, as well as by other NASA personnel.

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CONTENTS

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INTRODUCTION

Pressure sensors on balloon-borne radiosondes are routinely utilized by NASA, the National Weather Service, and many other agencies to relate concurrent atmospheric measurements to the pressure-derived altitudes. Errors in the measured pressures contribute directly to errors in the calculated vertical distribution of atmospheric parameters including temperature, humidity, ozone, and wind velocity and direction.

The objective of this study was to evaluate the accuracy of the pressure sensors by comparing their derived altitudes with reference altitudes determined by C-Band radars. The balloon-borne sondes were launched at NASA's Wallops Flight Facility (WFF), and continuously tracked during their ascents by WFF C-Band radars.

PROCEDURES

The balloons were launched at the Meteorological Observation Center (MOC) on Wallops Island. The sonde measurements of pressure, temperature, and relative humidity were telemetered to TMQ-5 strip-chart recorders within the MOC during each balloon ascent. Launch, recording, and data encoding services were provided by Joule Corporation onsite-support personnel. The strip-chart records the elapsed time from launch. To enable the subsequent correlation with the radar measurements, the launch time was recorded to ±1 second.

The sonde measurements were processed through the ECC-PRD computer program by Computer Sciences Corporation onsite-support personnel. This program output provided the pressure-derived geopotential altitudes at a nominal rate of once per minute for subsequent comparisons with the radar measurements.

The radar tracking of each balloon ascent was performed by one of the three WFF C-Band radars; most of the flights were tracked by the FPS-16 radar on Wallops Island, very near the MOC. Each radar provided range, azimuth, and elevation measurements at one-second intervals from launch to burst. The radar measurements were made to an aluminized retroreflector suspended a few meters beneath the sondes. The C-Band radar measurement uncertainties, in such a balloon-tracking mode

(Selser, personal communication, 1983), are:

Range ±6m

Azimuth ±0.11°

Elevation ±0.11°

The radar measurements, on magnetic tape, were processed through the PASS-1, SMAD, and MESUP programs by Computer Science Corporation onsite-support personnel. The MESUP output provided the radar-derived geometric altitudes at a data interval of 1 second.

GeoScience Research Corporation converted the radar-derived geometric altitudes to geopotential altitudes for 38° latitude.

LAUNCH CONFIGURATION

Each launch incorporated two separate sondes to allow for intercomparisons of the sensors as well as correlating each with the radar. The sondes were of two types:

- sondes with standard baroswitches
- sondes with premium baroswitches and hypsometers.

All three paired-combinations were launched: standard/standard, standard/premium-hypsometer, premium-hypsometer/premium-hypsometer. All the radiosondes were produced by VIZ Manufacturing Company of Philadelphia, Pennsylvania.

The two sondes were attached to a narrow platform 15.3m beneath the balloon. The sondes were separated by 1.8m, mid-point to mid-point. The radar reflector was suspended an additional 4.6m below the sondes. The launch configuration is depicted in Figure 1.

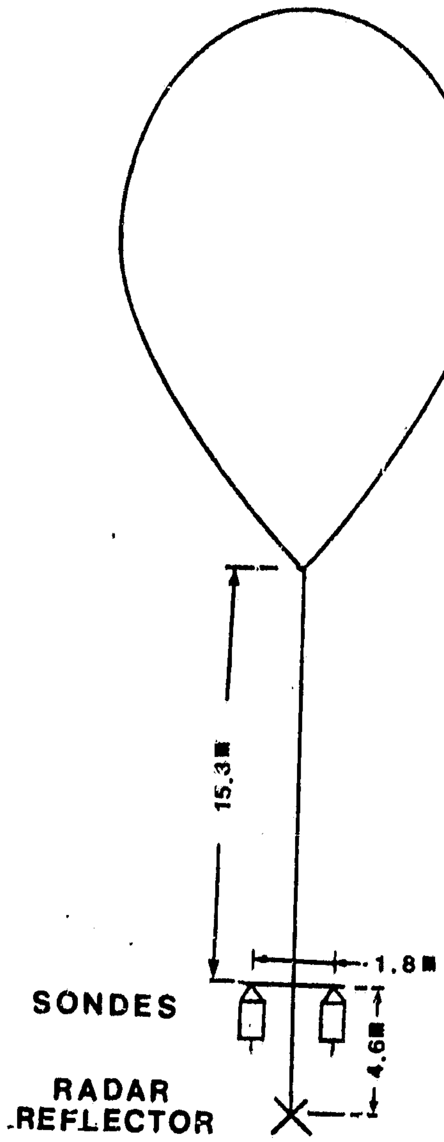

Figure 1 - Launch Configuration for All Sondes Tested.

RESULTS

STANDARD BAROSWITCHES

Launches of standard baroswitch sondes began on August 9, 1982, and the last standard baroswitch was flown on December 20, 1982. Table 1 is a compilation of test number, date, time of launch, sonde number, tracking radar, burst height and comments related to each flight.

Figure 1 through 10 in Appendix A illustrate the sonde minus radar differences for every five minutes from launch to burst for each flight. Test 344-1 failed as a result of ground equipment recorder malfunction immediately after launch. Test 344-11 failed forty minutes into flight with the loss of telemetry signal.

Four standard sondes demonstrated a continuous and divergent error throughout the flights when compared to radar; these were:

Test 344-4	Sondes 450 and 446
Test 344-5	Sonde 449
Test 344-9	Sonde 505.

It is noted that a baroswitch error of ±1 switch position would result in a curve of the same shape and magnitude as was experienced with the above four sondes. Review of the

TABLE 1

SONDES WITH STANDARD BAROSWITCHES

TEST NO.	DATE	TIME OF LAUNCH	SONDE	TRACKING RADAR	BURST HEIGHT	COMMENTS
344-1	08/09/82	14:39:50GMT	457 459	#3	28 km 16 mb	Ground Equipment Malfunction; No Data Recorded.
344-2	08/09/82	17:40:04	460 461	#5	35 km 5.6 mb	
344-3	08/11/82	13:54:08	462 463	#3	35 km 5.6 mb	
344-4	08/11/82	17:20:23	450 446	#3	35 km 5.6 mb	Divergent Sonde Errors.
344-5	08/12/82	13:59:47	449 451	#18	36 km 5.2 mb	Electrical Storm During Flight; Sonde 449 Diverges.
344-6	08/12/82	17:43:36	452 453	#18	31 km 12.6 mb	

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TABLE 1 (Continued)

TEST NO.	DATE	TIME OF LAUNCH	SONDE	TRACKING RADAR	BURST HEIGHT	COMMENTS
344-7	08/13/82	13:49:39	454 455	#5	28 km 15.5 mb	
344-8	08/16/82	17:25:47	456 448	#5	27 km 20 mb	
344-9	08/17/82	13:56:12	505 506	#5	37 km 4.1 mb	Sonde 505 Diverges.
344-10	08/17/82	17:29:18	507 508	#5	32 km 8.6 mb	
344-11	12/13/82	19:00:50	702	#3	10 km 201 mb	Lost Telemetry Signal 40 Minutes Into Flight.
344-13	12/20/82	05:59:30	707	#3	28 km 16 mb	

particular strip charts did not uncover any apparent operator errors.

The sonde-minus-radar differences for all 19 standard baroswitches are combined in Figure 2. In this Figure, the differences are plotted as a function of altitude. The standard baroswitches generally perform well up to 25 km; above that level, there is rapid divergence.

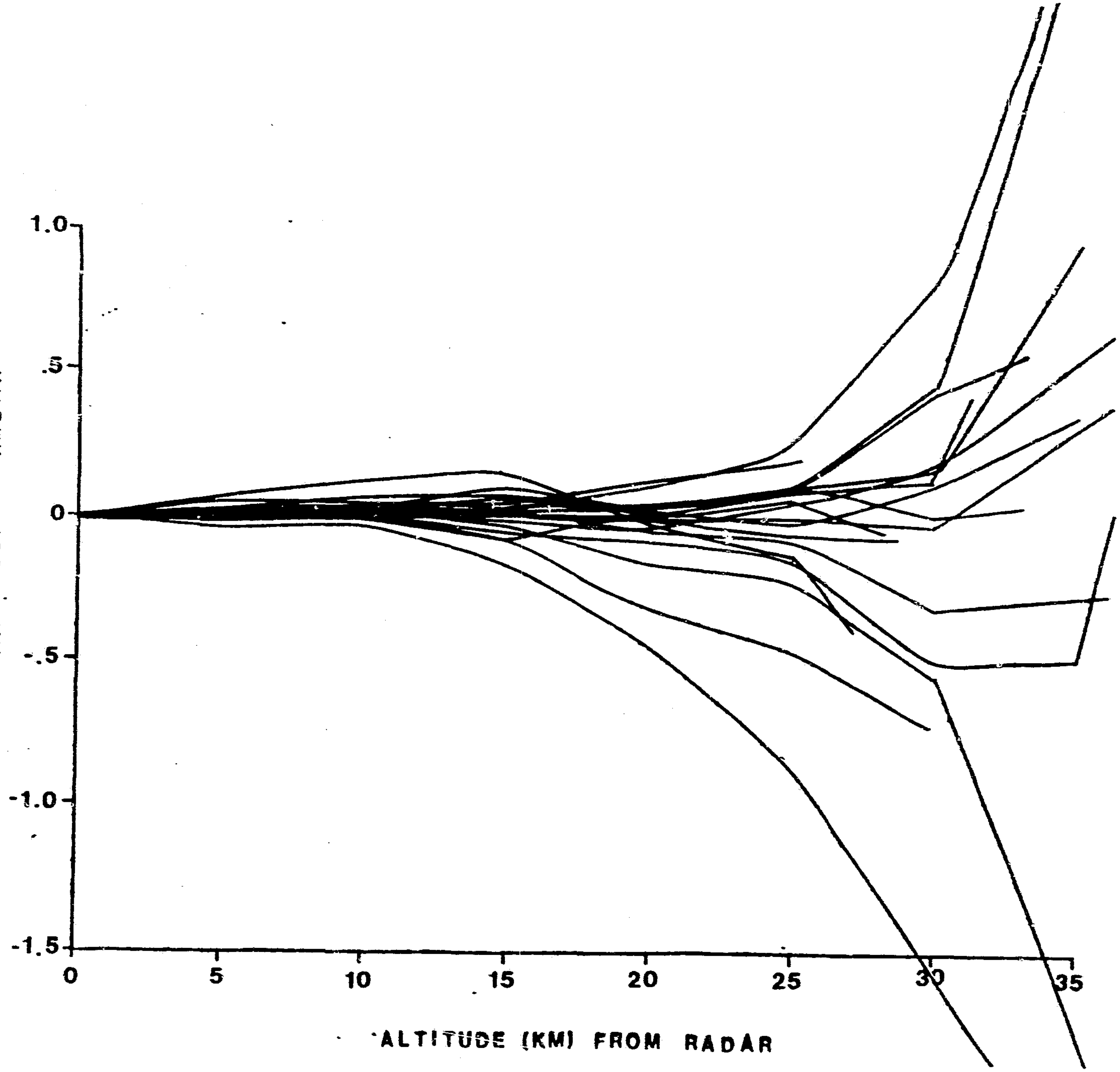

Figure 2 - Difference of Sonde-Derived Altitude Minus Radar Altitude for Each Standard Baroswitch Sonde.

PREMIUM BAROSWITCHES AND HYPSOMETERS

Premium baroswitches are those which exceed the requirements established for standard baroswitches and are selected by the manufacturer from baroswitches which are being processed through normal testing and quality control.

Launches of radiosondes with premium baroswitches and hypsometers began on December 13, 1982. Table 2 lists the test number, date, time of launch, sonde number, tracking radar, burst height and any comments related to a particular launch. A total of 26 sondes were flown with the last flight on January 25, 1983. Appendix B, Figures 1 through 25, illustrate the sonde-minus-radar altitude differences every five minutes from launch through burst.

Sonde number 997, launched January 25, 1983 at 18:02:14 with sonde number 996, experienced a complete loss of radio signal at approximately forty-five minutes into the flight and was not plotted. Sonde number 989, shown in Appendix B, Figure 2, and sonde number 981, Appendix B, Figure 14, are affected by apparent operator errors. The strip chart for sonde number 989 indicates that in setting the initial surface pressure into the baroswitch an error of one switch position was made, causing an altitude discrepancy throughout the flight. Analysis of the recorder data with the proper baroswitch calibration table for sonde number 981 indicates something other than the 981 calibration

TABLE 2

SONDES WITH PREMIUM BAROSWITCHES AND HYPSOMETERS

TEST NO.	DATE	TIME OF LAUNCH	SONDE	TRACKING RADAR	BURST HEIGHT	COMMENTS
344-11	12/13/82	19:00:50GMT	986	#3	35 km 5.7 mb	
344-12	12/14/82	15:01:30	987 989	#3	26 km 22.9 mb	Sonde 989: Operator Error.
344-13	12/20/82	05:59:30	7078	#3	28 km 16.3 mb	Anomalous Hypsometer.
344-14	01/10/83	14:43:49	992 993	#3	34 km 5.6 mb	
344-15	01/12/83	14:47:44	984 990	#3	35 km 5.6 mb	Loss of Radar Data for 13 Minutes Near End of Flight.
344-16	01/17/83	14:31:21	982 983	#3	33 km 7.7 mb	Loss of Radar Data for 10 Minutes Midflight.

TABLE 2 (Continued)

TEST NO.	DATE	TIME OF LAUNCH	SONDE	TRACKING RADAR	BURST HEIGHT	COMMENTS
344-17	01/17/83	18:02:51	980 985	#3	36 km 4.6 mb	Sonde 980 Hypsometer Stopped Early.
344-18	01/19/83	14:55:30	978 981	#3	35 km 6.1 mb	Sonde 978 Hypsometer Stopped Early. Sonde 981: Operator Error.
344-19	01/20/83	14:33:04	979 1009	#3	33 km 7.9 mb	No Hypsometer Measurements.
344-20	01/20/83	18:01:51	1007 1008	#5	33 km 7.1 mb	
344-21	01/24/83	14:42:19	1005 1006	#3	37 km 4.2 mb	
344-22	01/24/83	18:04:09	1003 1004	#3	36 km 5.2 mb	

TABLE 2 (Continued)

TEST NO.	DATE	TIME OF LAUNCH	SONDE	TRACKING RADAR	BURST HEIGHT	COMMENTS
344-23	01/25/83	14:32:42	995	#3	35 km	
			1002		6.5 mb	
344-24	01/25/83	18:02:14	996	#3	36 km	
			997		5.8 mb	Sonde 997 Lost Signal 45 Minutes Into Flight.

chart was used for the data on that flight.

The launch records on December 20, 1983 at 05:59:30 GMT did not list the premium sonde number used in this flight but referred to it by using the standard sonde number 707, the companion standard sonde launched with it, and adding a "B". The hypsometer within this sonde presented a peculiar pattern as shown in Figure 4 of Appendix B, but analysis of the recorded data and the calibration chart does not reveal any human error or equipment malfunction which might account for the pattern.

On January 20, 1983, at 14:33:04 GMT, launched sondes numbered 979 and 1009 lost the hypsometer telemetry signal but continued to receive the baroswitch pressure signal until burst.

The radar data gaps shown on Figures 7, 8, 9, and 10 of Appendix B were the result of local temporary power failures which caused gaps in the radar data recording. The radar maintained track on the sonde throughout the flight from launch to burst. All other sondes launched in this test series performed normally and the results appear in Figure 1 through 25 in Appendix B.

The hypsometer signals from sondes number 980 and 978 on January 17, 1983 and January 19, 1983 respectively, terminated earlier than burst. It is suspected that in both cases the hypsometer vials ran out of fluid.

The sonde-minus-radar differences for the twenty-five premium baroswitches are combined in Figure 3. As in Figure 2, the differences are plotted as a function of altitude. Except for the operator errors, as noted, the premium baroswitches versus radars tend to be more tightly bunched than the standard baroswitch differences. An additional difference is that the premium baroswitch differences from the radar are generally positive at the burst altitudes.

The combined difference plots for the twenty-two hypsometers are shown in Figure 4. The hypsometer-derived altitudes are generally within ±300 m of the radar standard at the burst altitudes.

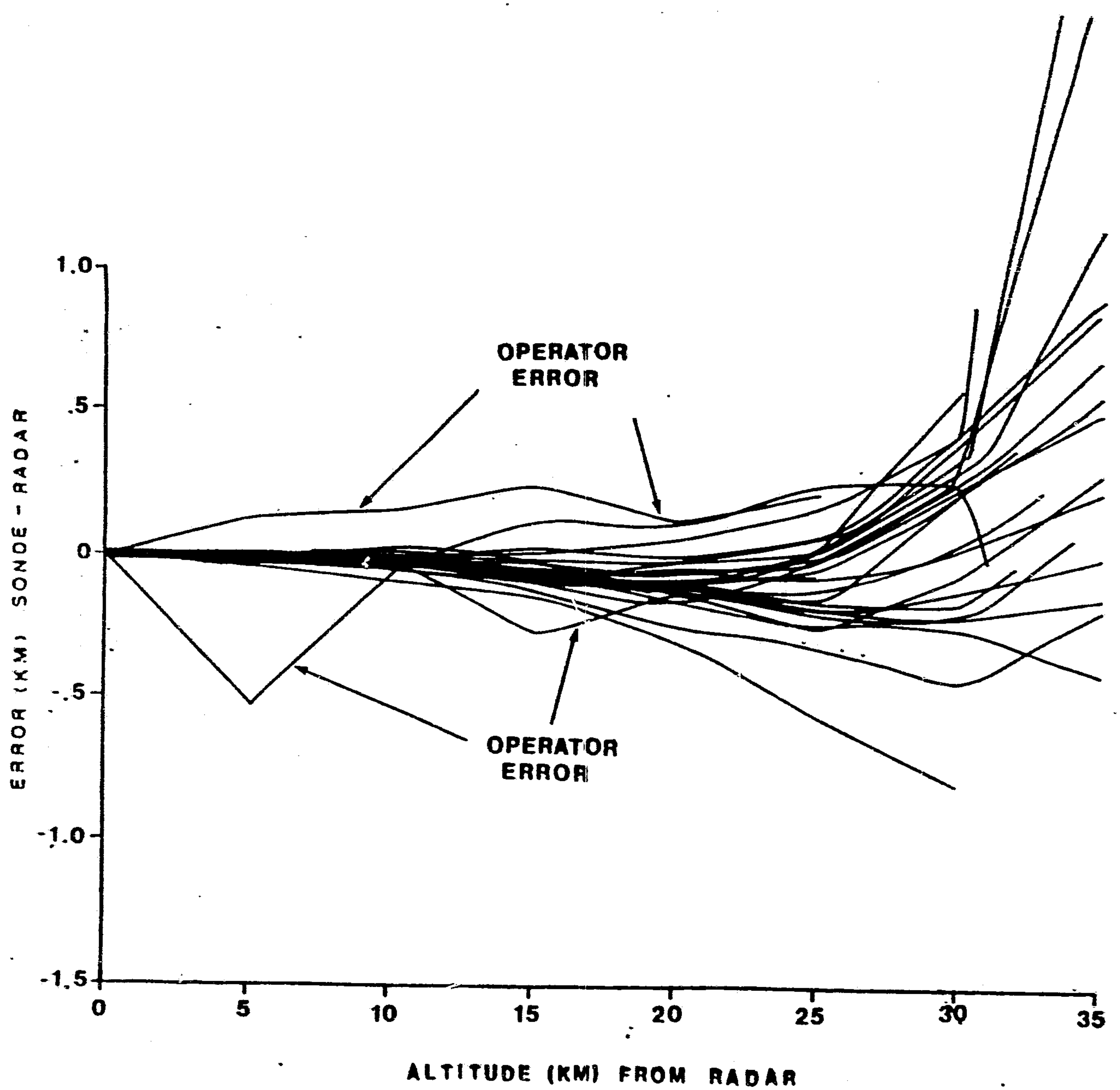

Figure 3 - Difference of Sonde-Derived Altitude Minus Radar Altitude for Each Premium Baroswitch Sonde.

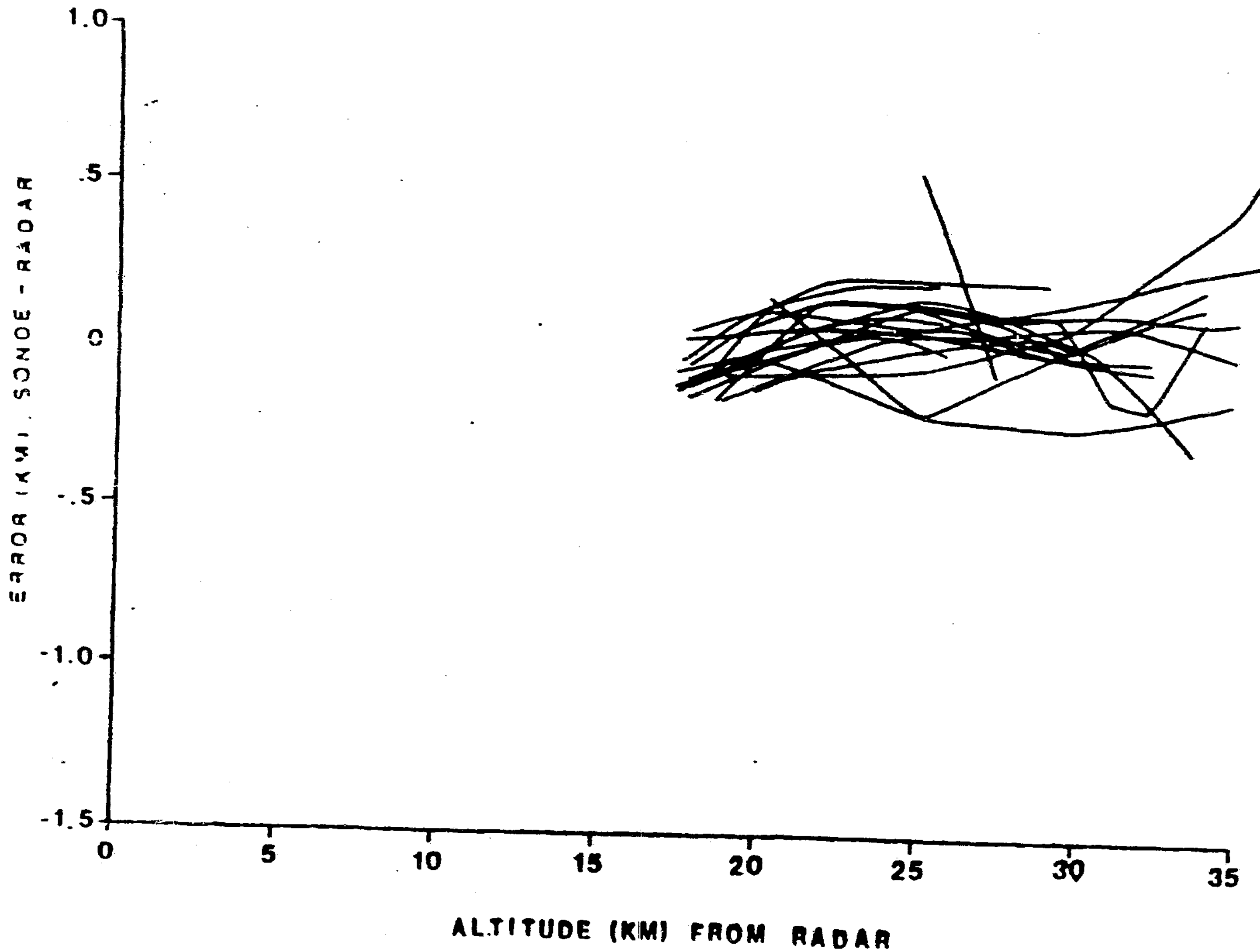

Figure 4 - Difference of Sonde-Derived Altitude Minus Radar Altitude for Each Hypsometer Sonde.

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RMS ALTITUDE DIFFERENCES

The rms differences between the pressure sensor-derived altitudes and radar-derived altitudes are listed at 5 km intervals in Table 3. These same rms values are graphically depicted in Figure 5. The sondes with indications of operator errors are not included in the rms computations.

TABLE 3.
SONDE-MINUS-RADAR RMS DIFFERENCES.

ALTITUDE	STANDARD BAROSWITCH		PREMIUM BAROSWITCH		HYPSOMETER	
(KM)	NO. OBS.	RMS(M)	NO.OBS.	RMS(M)	NO. OBS.	RMS(M)
35	4	1838	19	742	16	179
30	14	605	22	322	20	117
25	18	258	24	167	22	122
20	18	141	20	134	22	92
15	18	83	24	118		
10	18	49	24	56		
5	18	30	24	32		

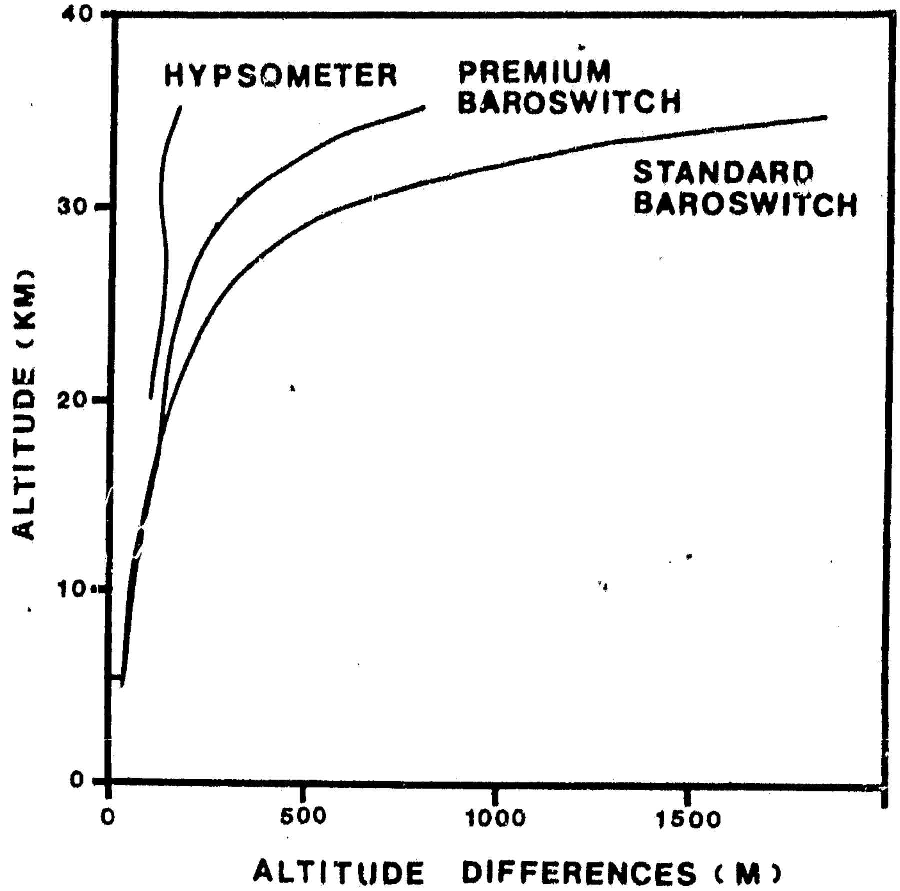

Figure 5 - Rms Differences Between Sonde-Derived Altitude and Radar Altitude for Each Type Sonde Tested.

SUMMARY

The pressure-measuring performance of standard baroswitches, premium baroswitches, and hypsometers in balloon-borne sondes have been correlated with tracking radars.

The standard and premium baroswitches generally perform well up to about 25 km altitude, above which they introduce rapidly divergent altitude errors. For measurements above 25 km, hypsometers provide significantly more reliable pressure measurements.

APPENDIX A

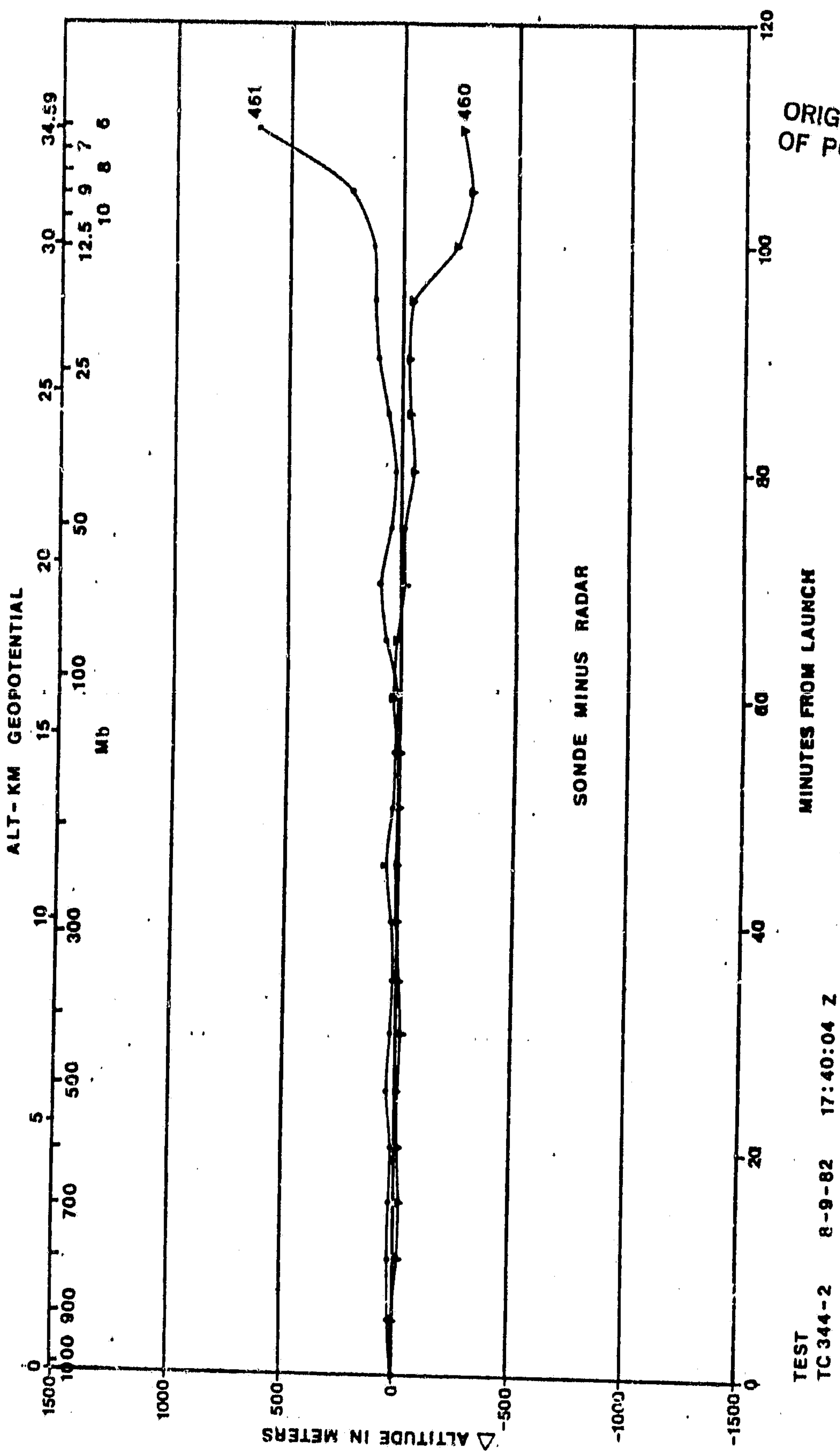
ALT-KM GEOPOTENTIAL
Mb
451
460
SONDE MINUS RADAR
MINUTES FROM LAUNCH
∆ ALTITUDE IN METERS
TEST
TC 344-2
8-9-82
17:40:04 Z

Figure 1

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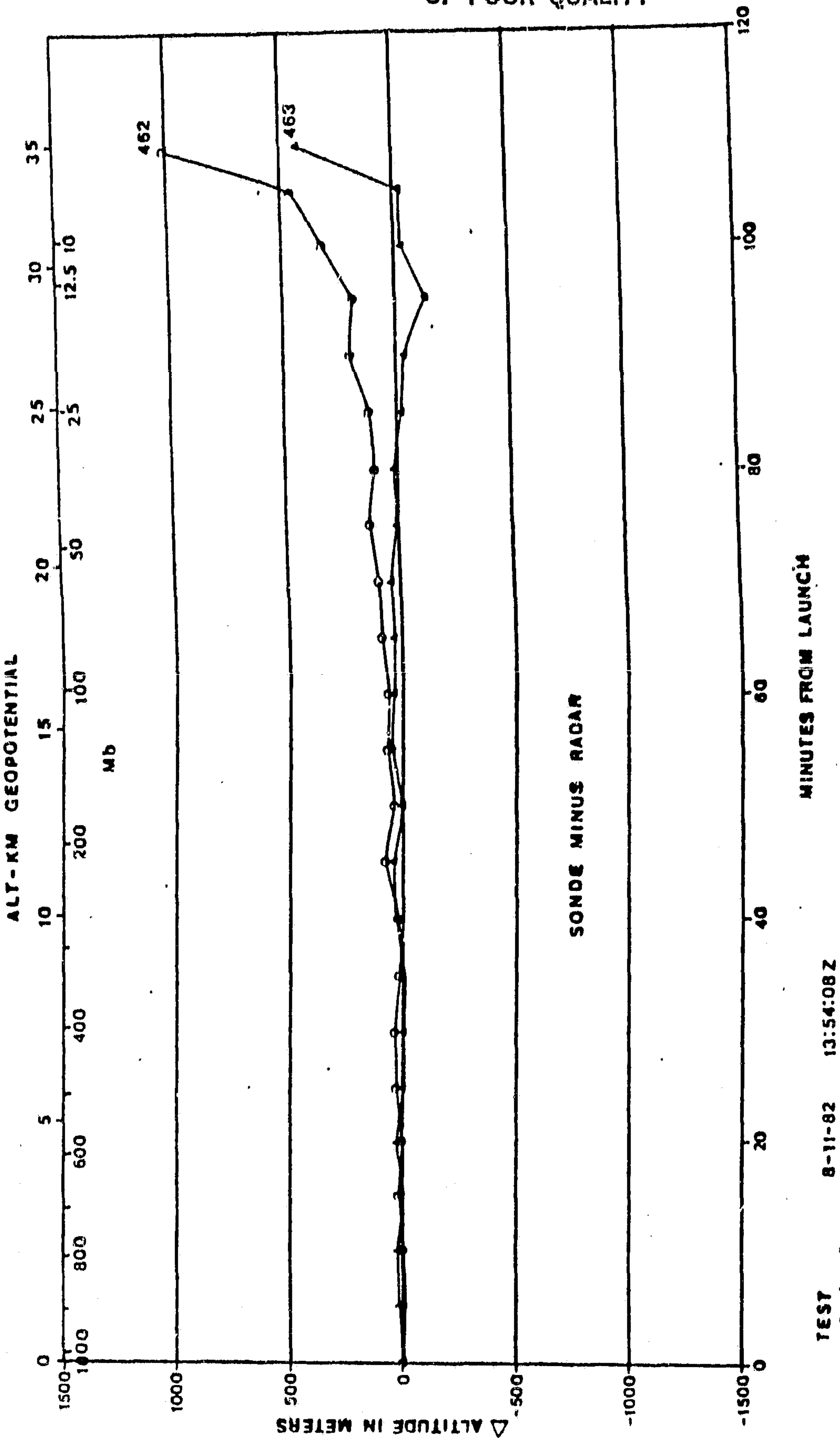

Figure 2

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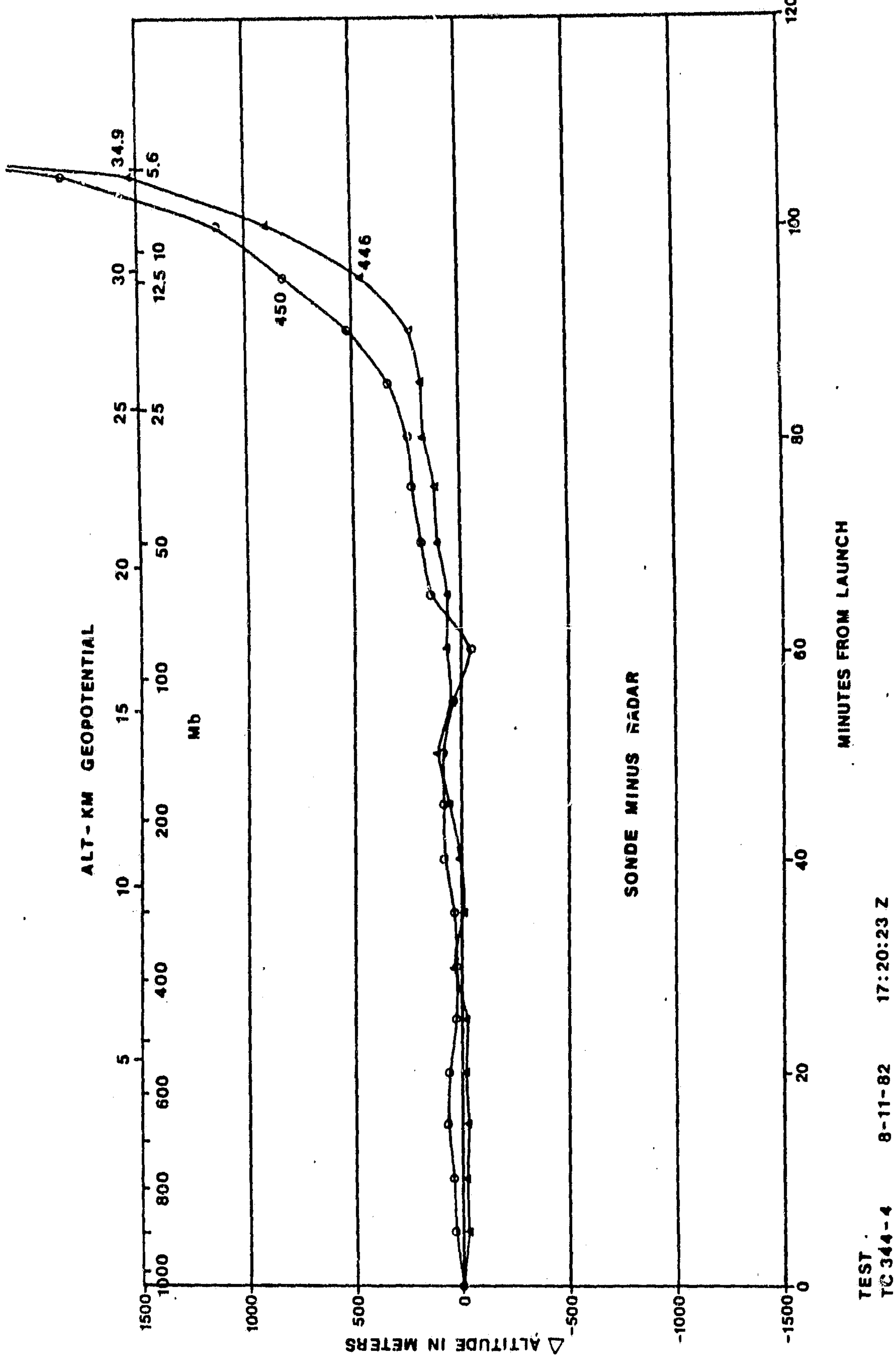

Figure 3.

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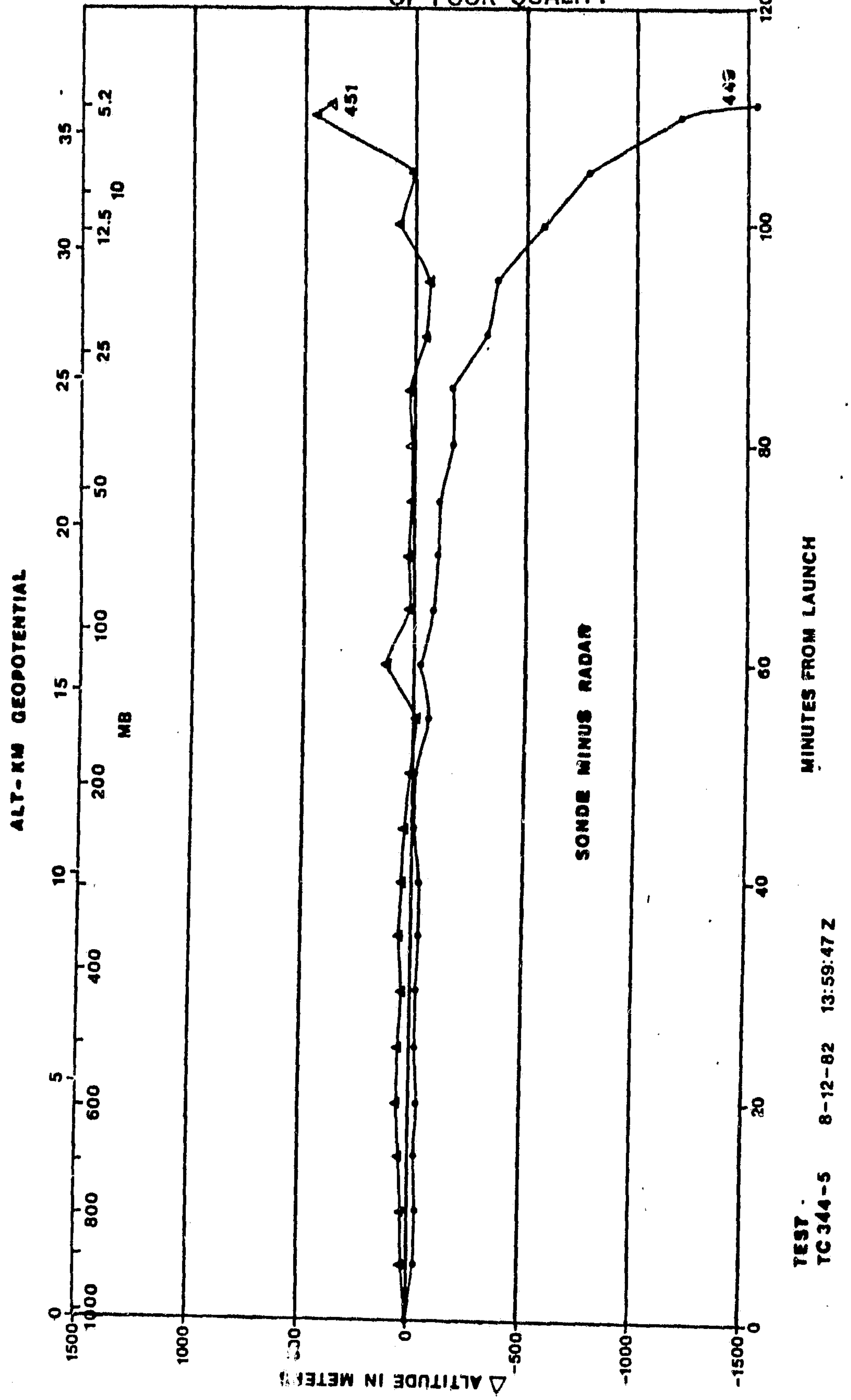

Figure 4.

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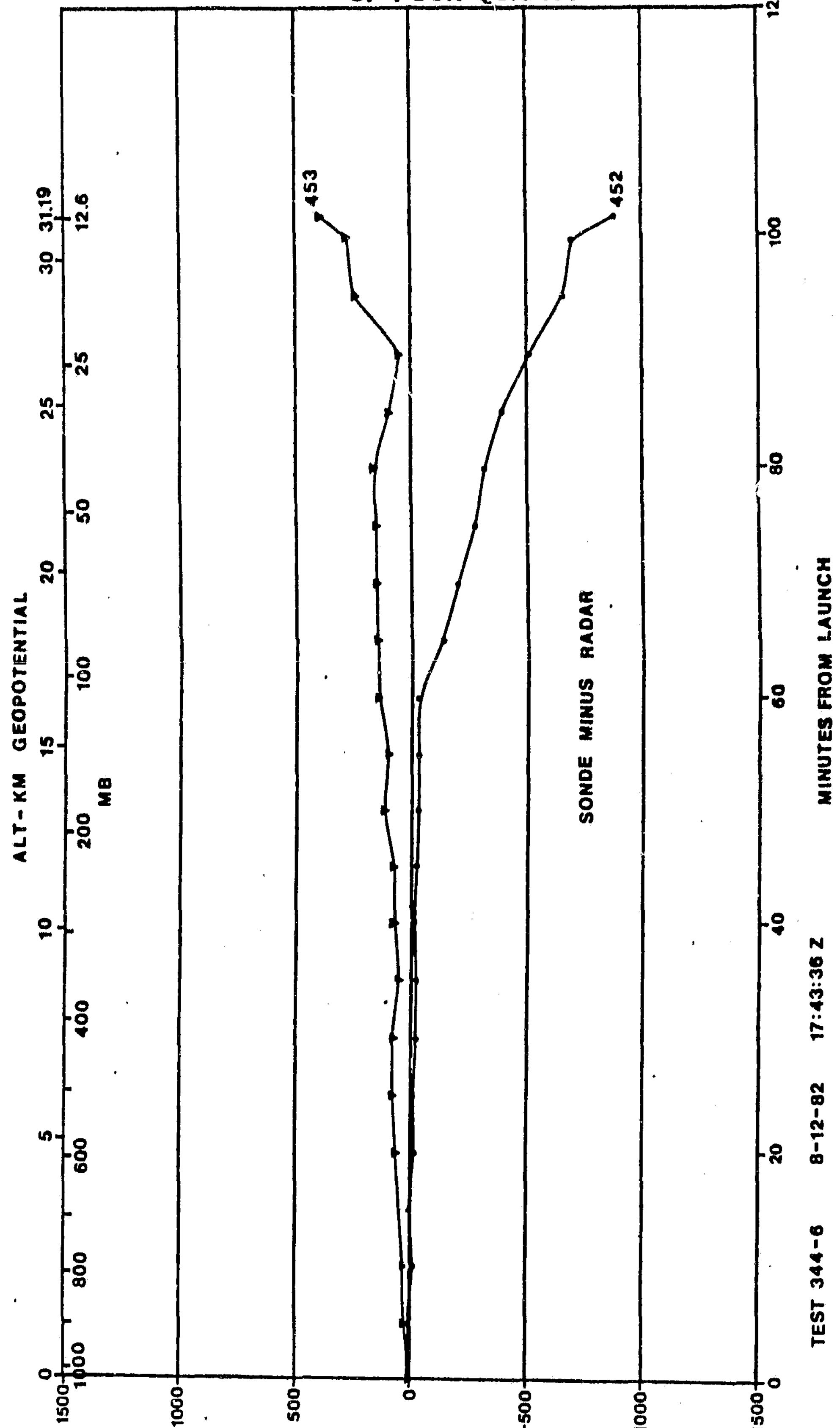

Figure 5.

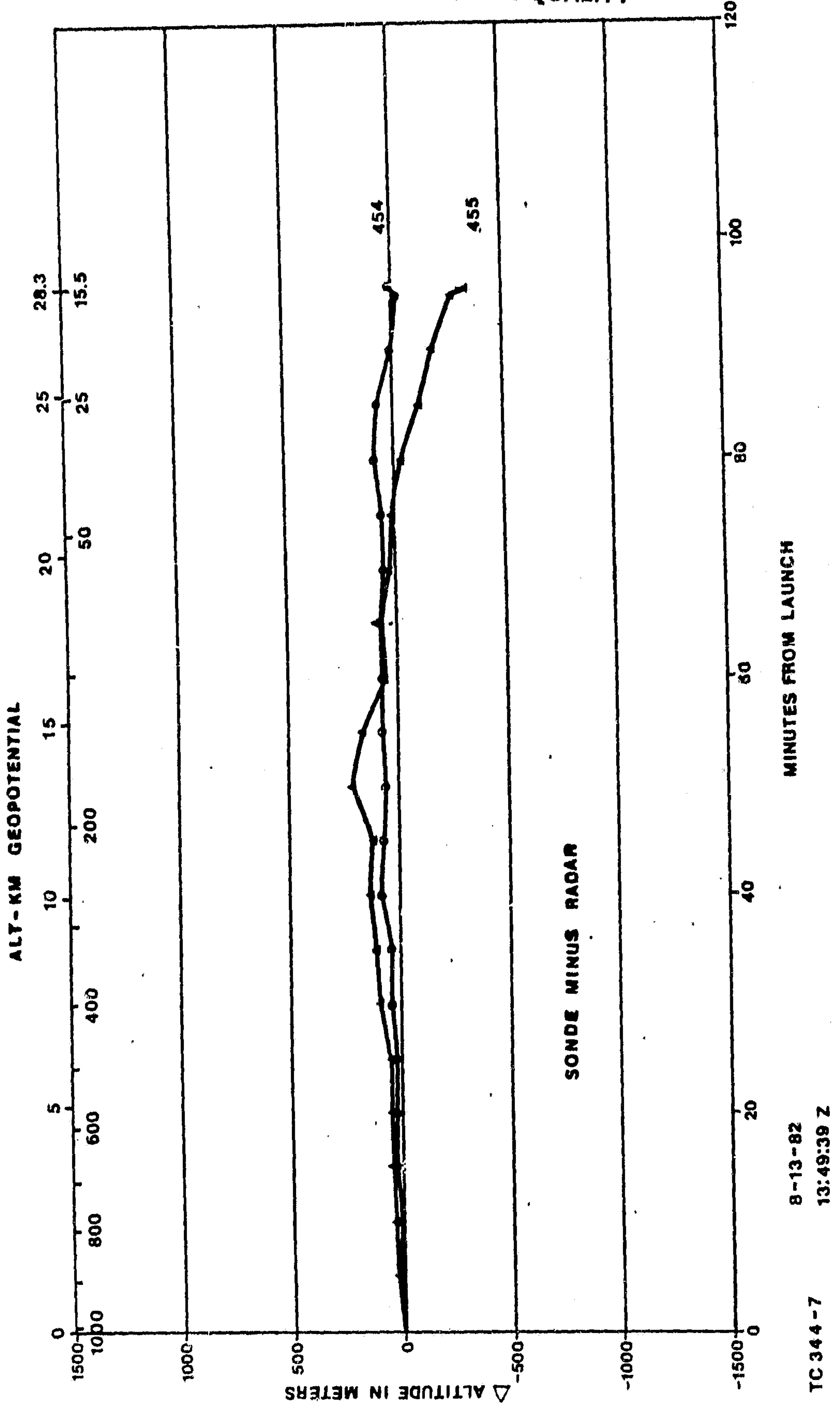
ALT-KM GEOPOTENTIAL
0
5
10
15
20
25
28.3
1000
800
600
400
200
50
25
15.5
454
455
SONDE MINUS RADAR
MINUTES FROM LAUNCH
0
20
40
60
80
100
120
∆ ALTITUDE IN METERS
1500
1000
500
0
-500
-1000
-1500
8-13-82
13:49:39 Z
TC 344-7

Figure 6.

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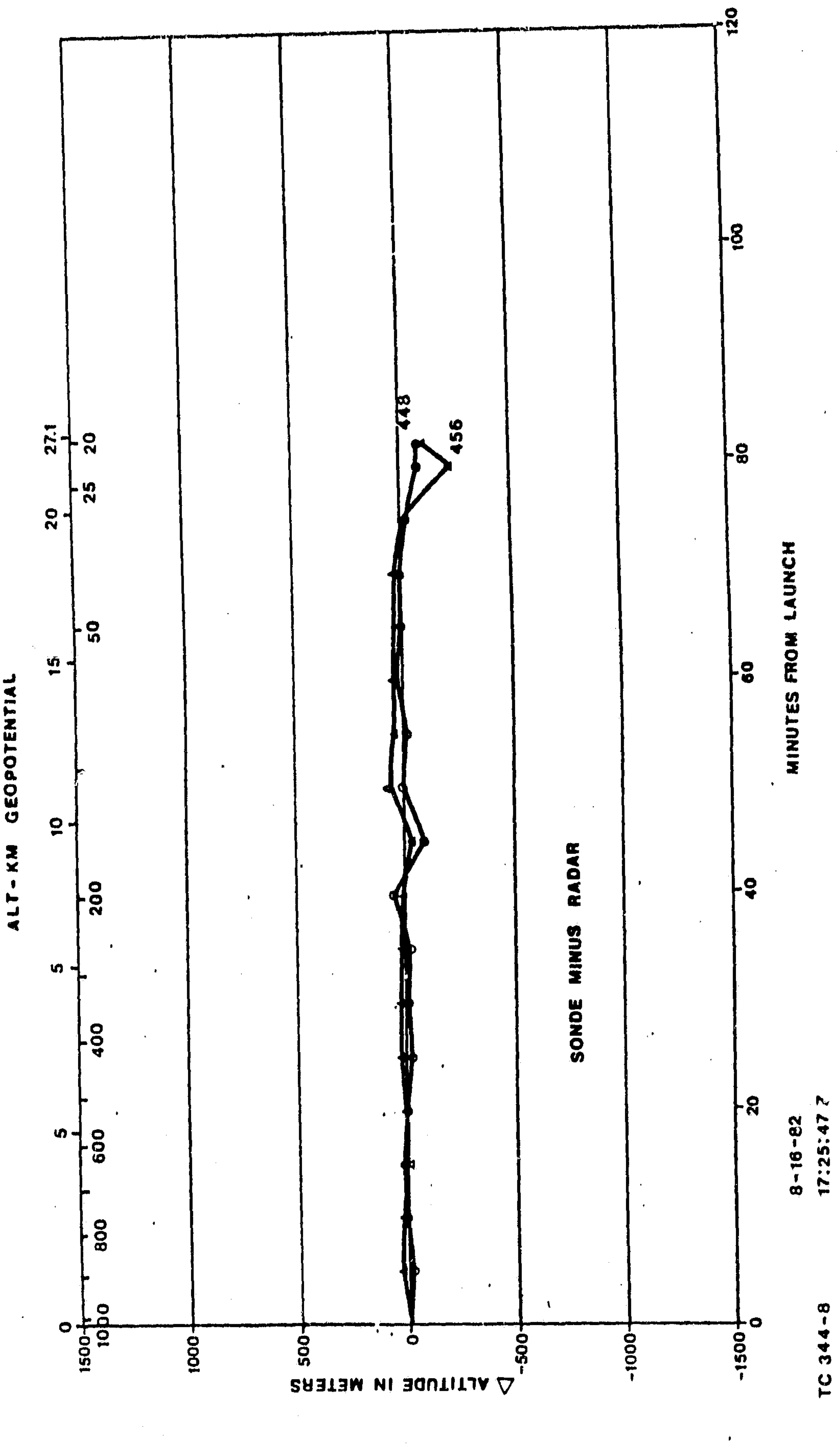

Figure 7.

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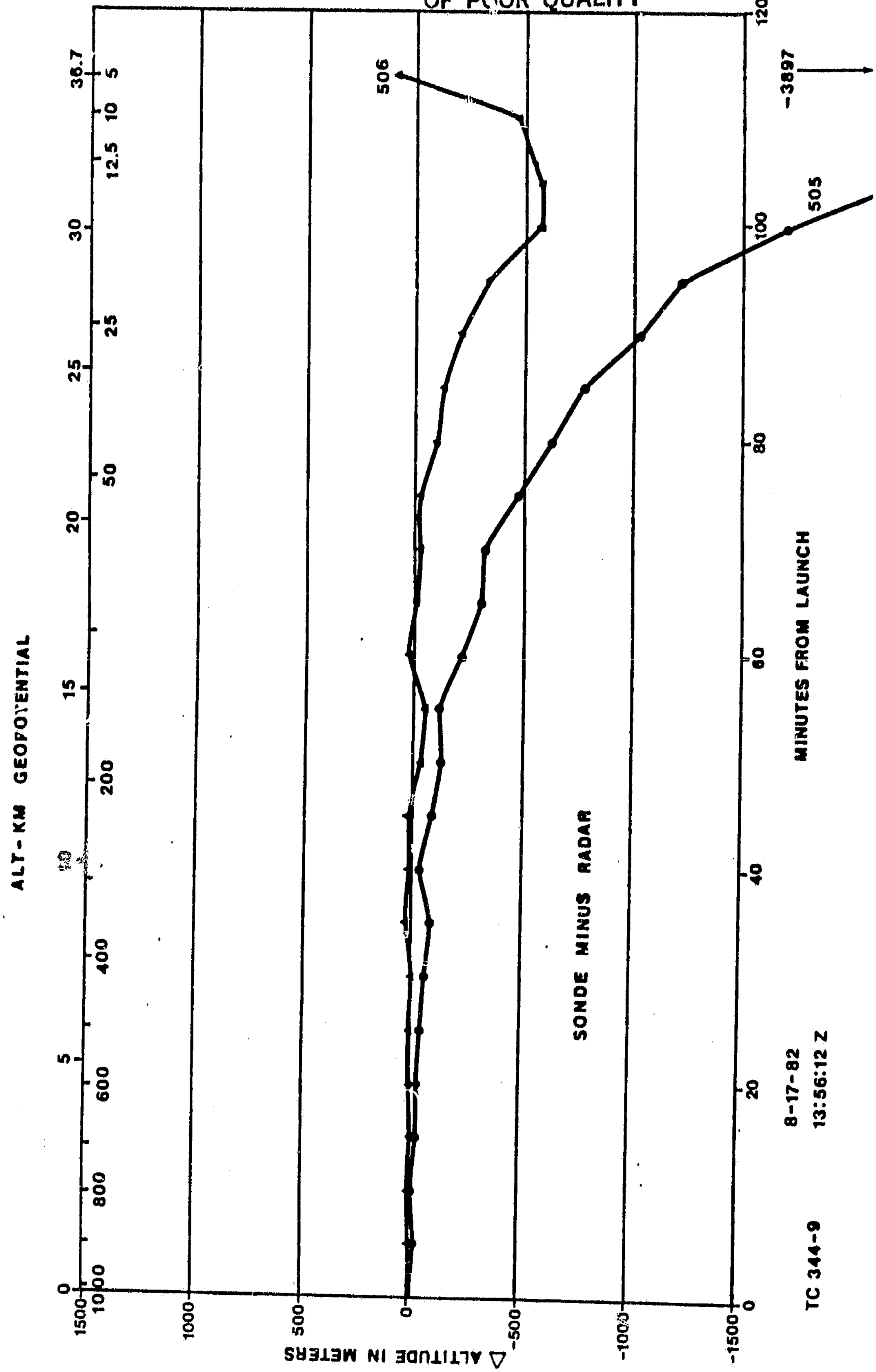

Figure 8.

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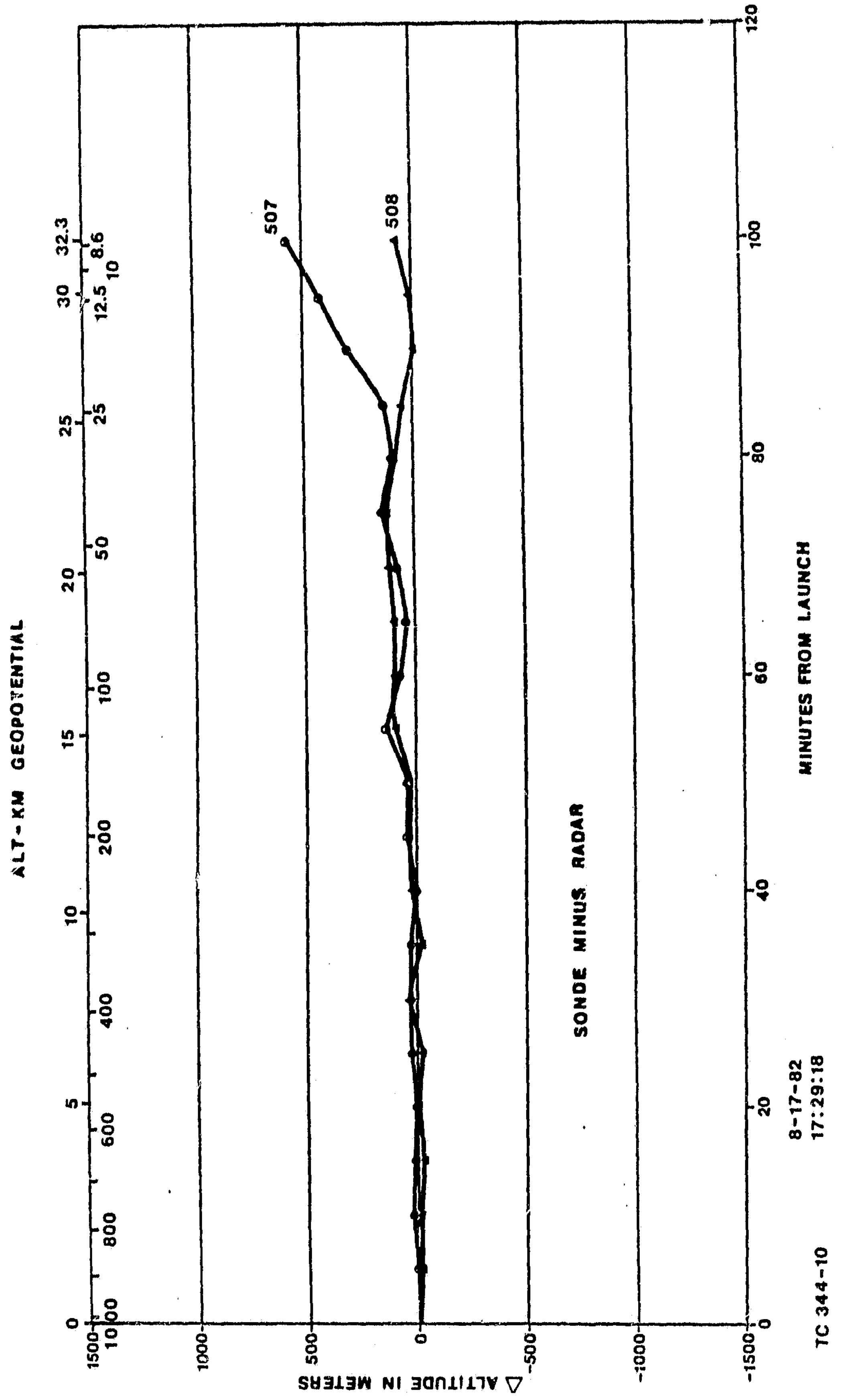

Figure 9.

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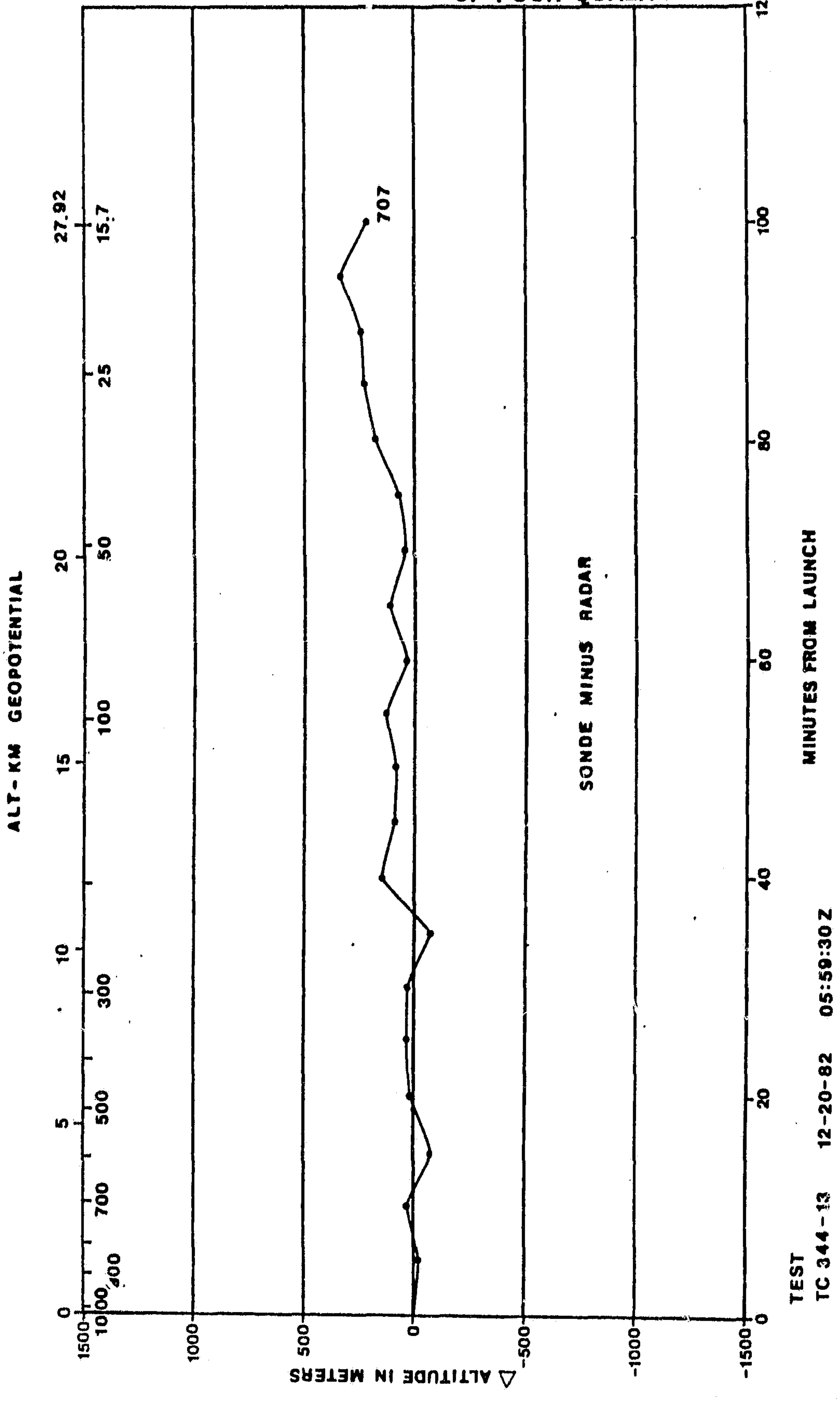


Figure 10.

APPENDIX B

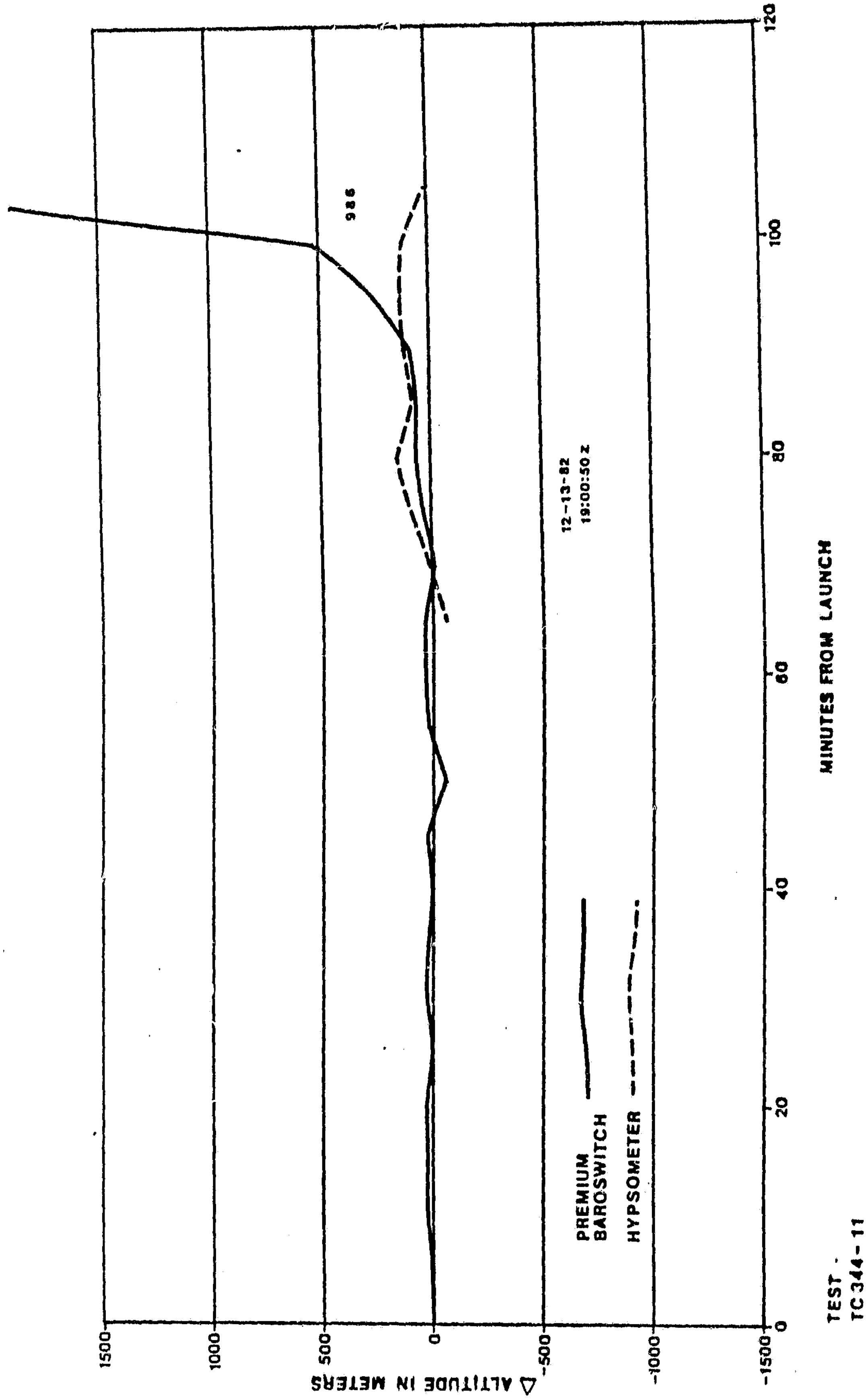

1500
1000
500
0
-500
-1000
-1500
∆ ALTITUDE IN METERS
0
20
40
60
80
100
120
MINUTES FROM LAUNCH
986
12-13-82
19:00:50 z
PREMIUM
BAROSWITCH
HYPSOMETER
TEST
TC344-11

Figure 1.

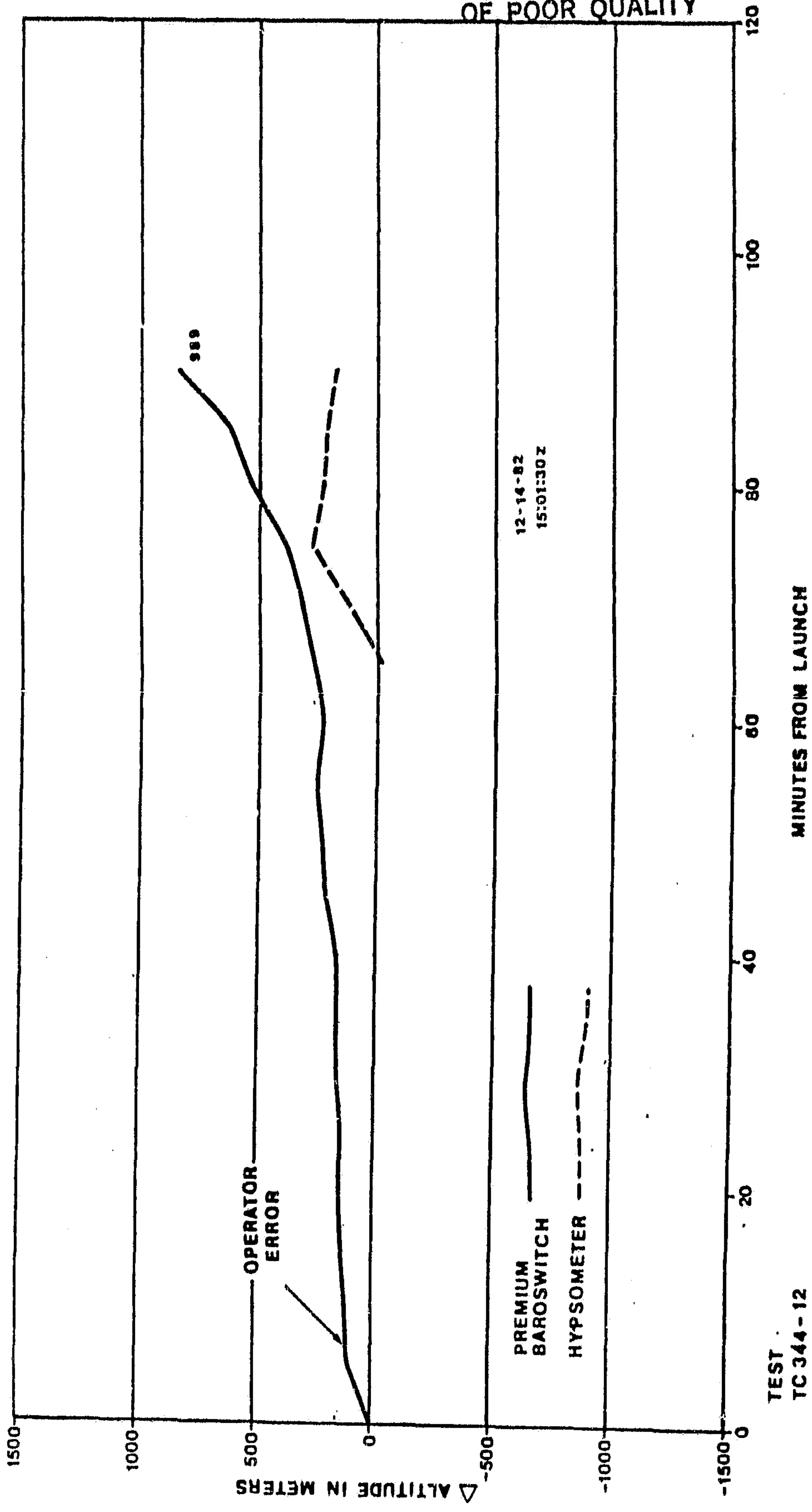
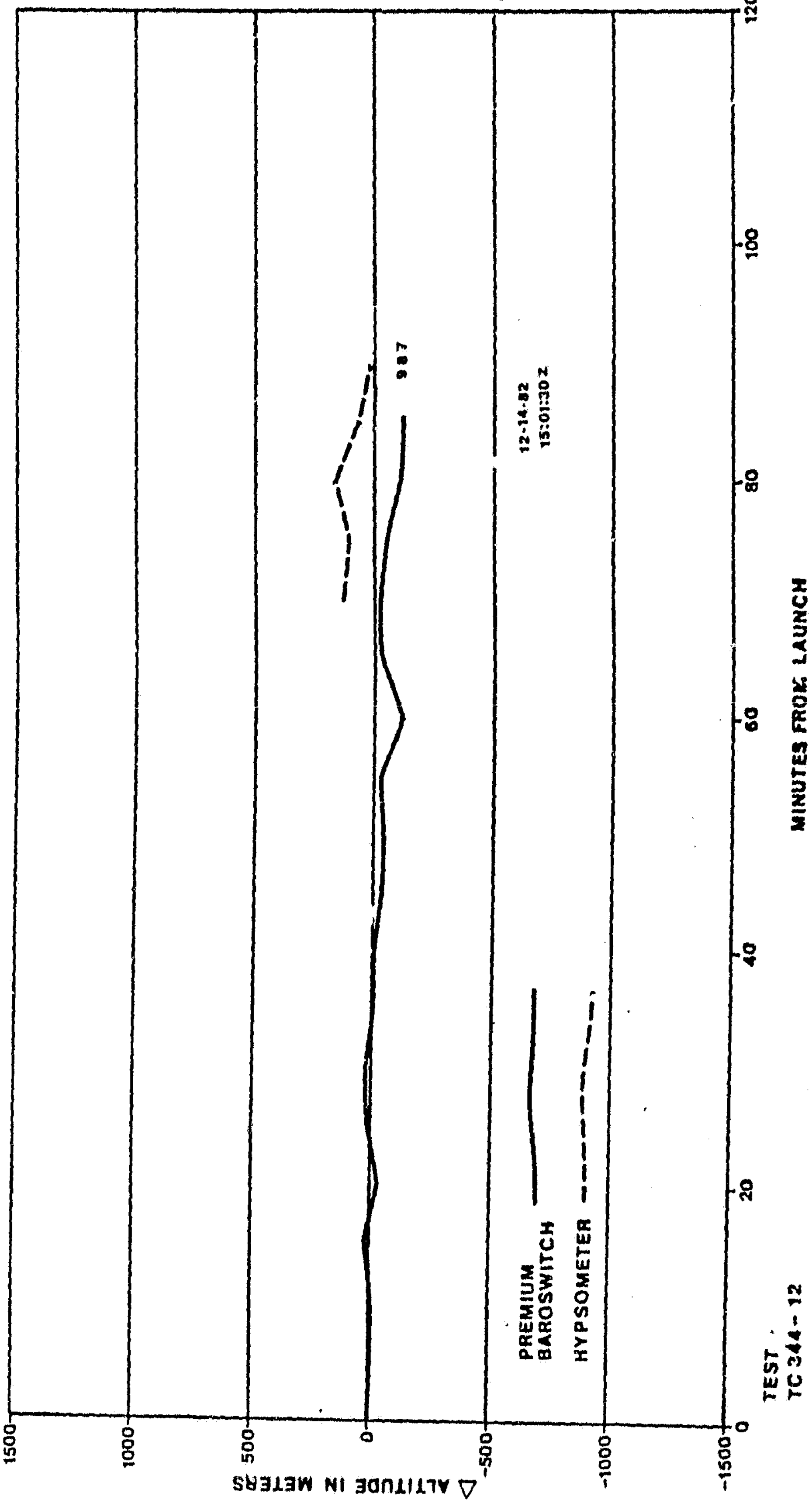

Δ ALTITUDE IN METERS
1500
1000
500
0
-500
-1000
-1500
MINUTES FROM LAUNCH
0
20
40
60
80
100
120
OPERATOR ERROR
PREMIUM BAROSWITCH
HYPSOMETER
TEST
TC 344-12
12-14-82
15:01:30 z

Figure 2.



1500
1000
500
0
-500
-1000
-1500
Δ ALTITUDE IN METERS
0
20
40
60
80
100
120
MINUTES FROM LAUNCH
987
12-14-82
15:01:30Z
PREMIUM
BAROSWITCH
HYPSOMETER
TEST
TC 344-12

Figure 3.

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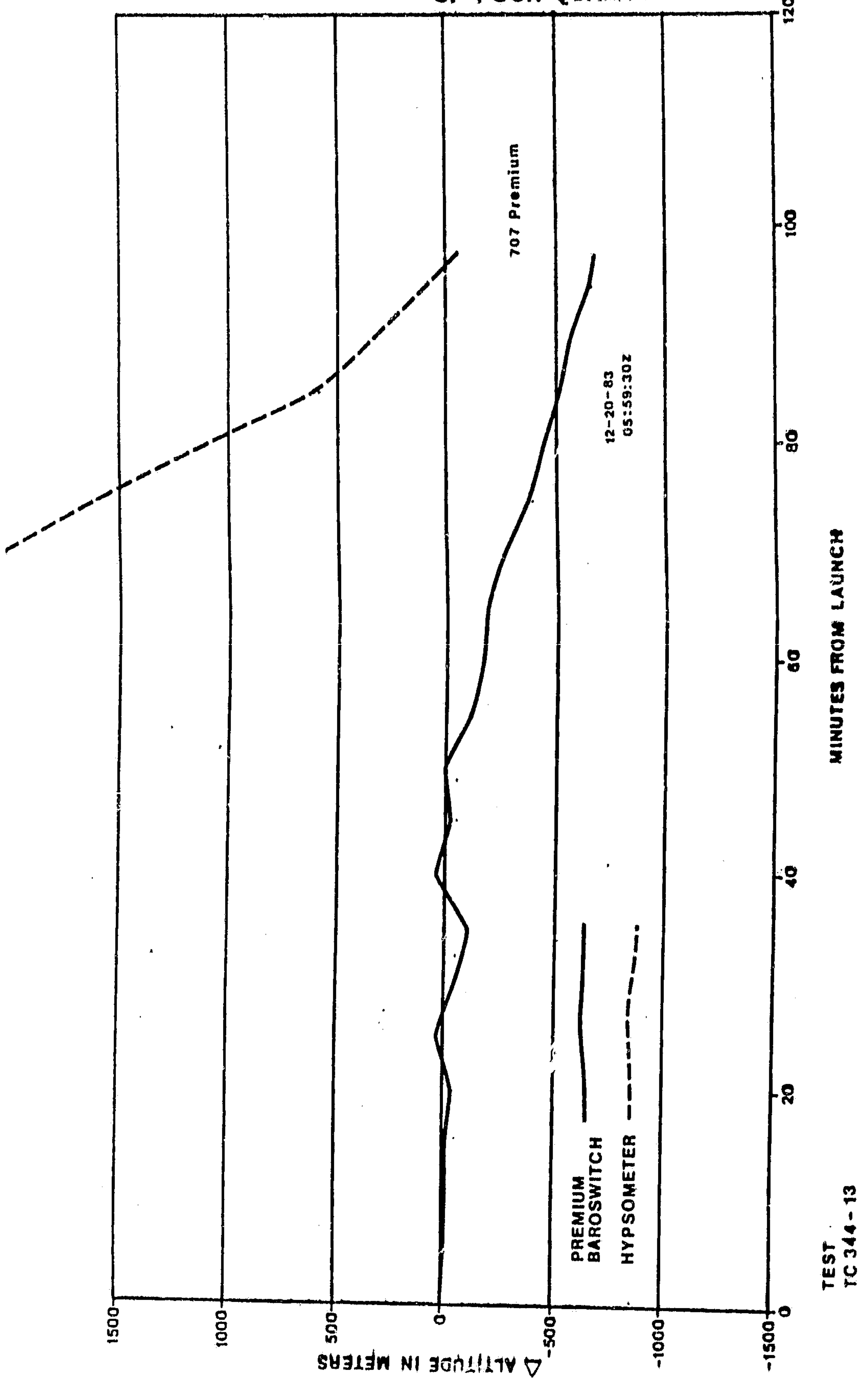


Figure 4.

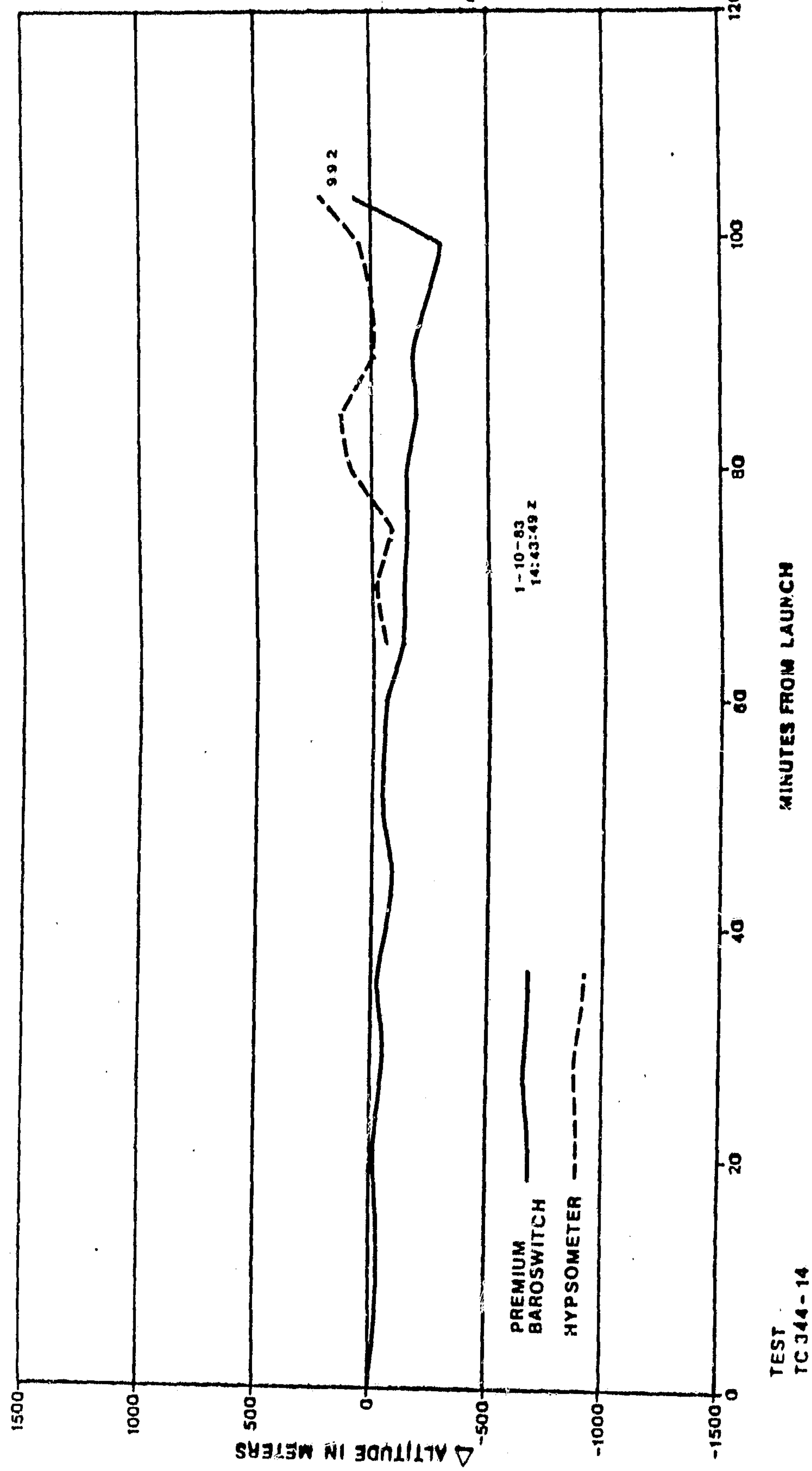
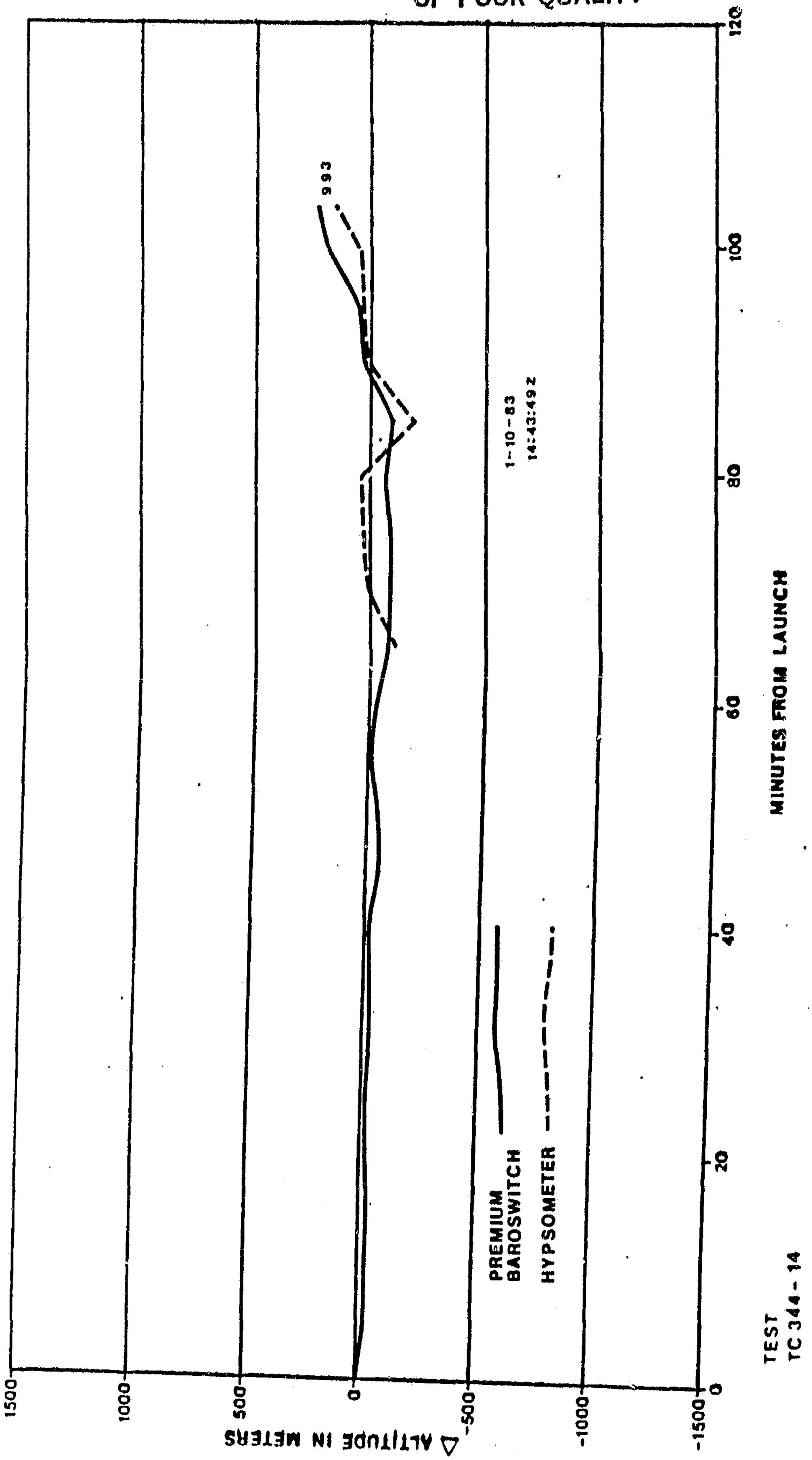

992
1-10-83
14:43:49 z
PREMIUM
BAROSWITCH
HYPSOMETER
TEST
TC 344-14
MINUTES FROM LAUNCH
0
20
40
60
80
100
120
Δ ALTITUDE IN METERS
1500
1000
500
0
-500
-1000
-1500

Figure 5.



1500
1000
500
0
-500
-1000
-1500
△ ALTITUDE IN METERS
0
20
40
60
80
100
120
MINUTES FROM LAUNCH
993
1-10-83
14:43:49 Z
PREMIUM
BAROSWITCH
HYPSOMETER
TEST
TC 344-14

Figure 6.

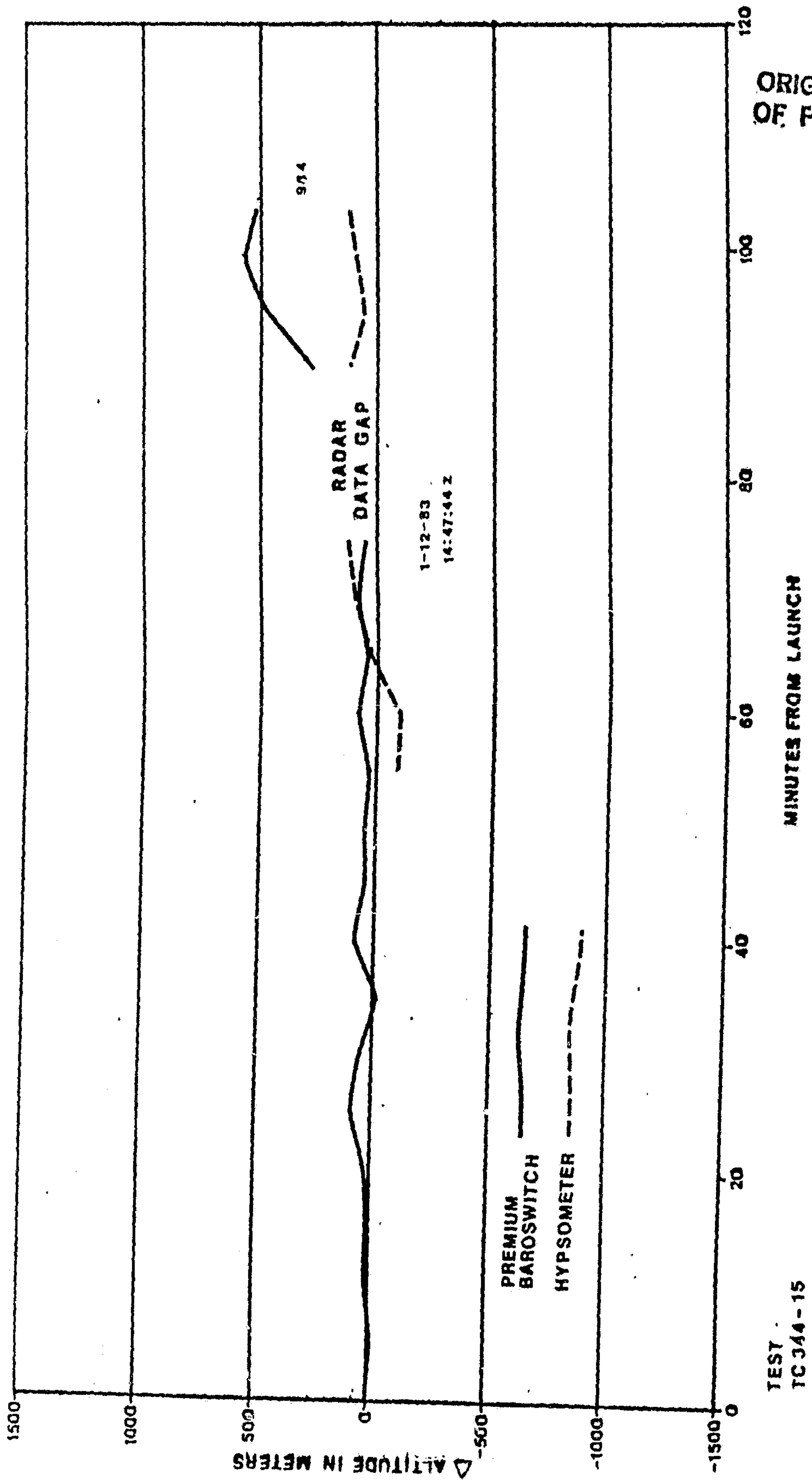

Δ ALTITUDE IN METERS
1500
1000
500
0
-500
-1000
-1500
MINUTES FROM LAUNCH
0
20
40
60
80
100
120
RADAR
DATA GAP
1-12-83
14:47:44 z
PREMIUM
BAROSWITCH
HYPSOMETER
TEST
TC 344-15

Figure 7.

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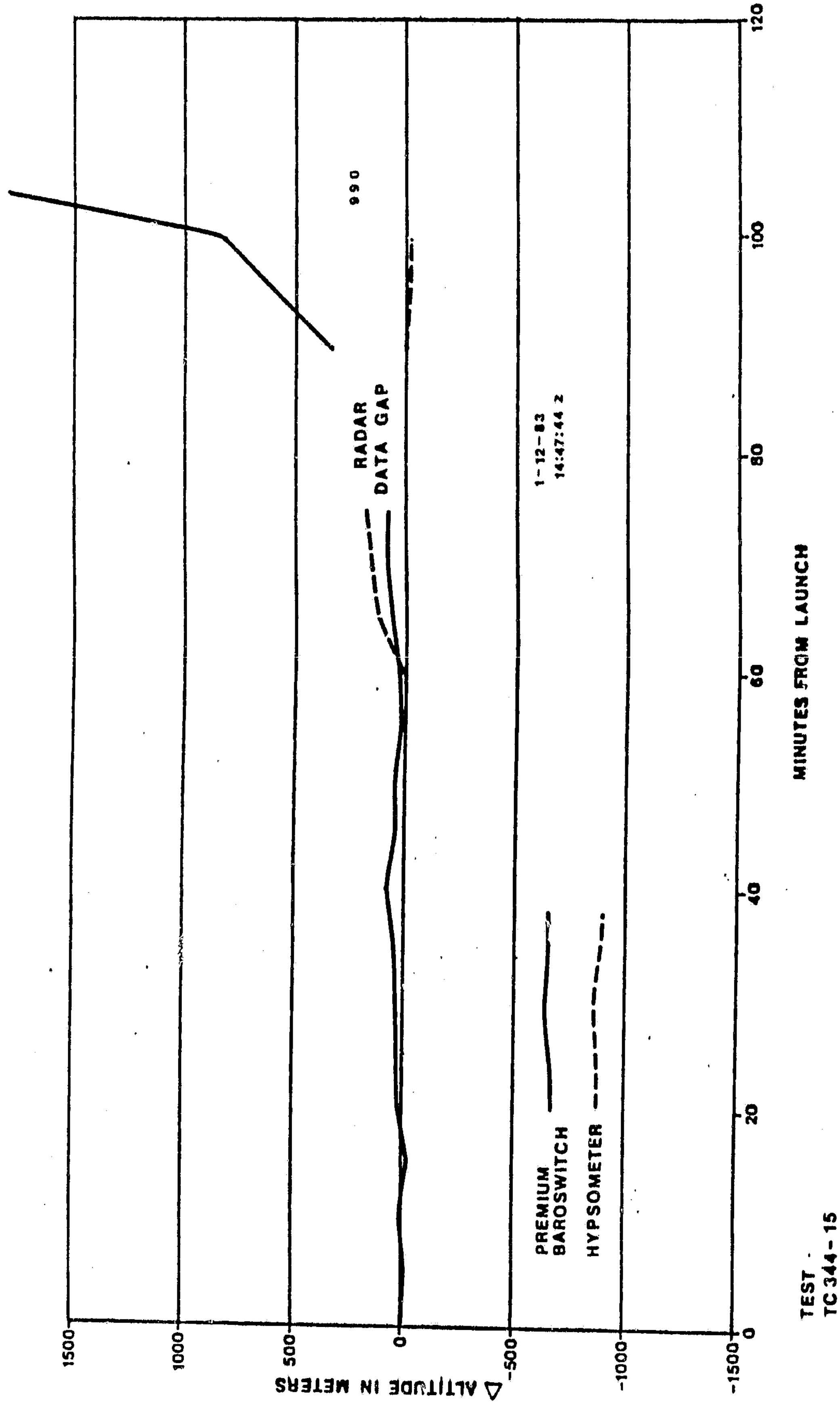

Figure 8.

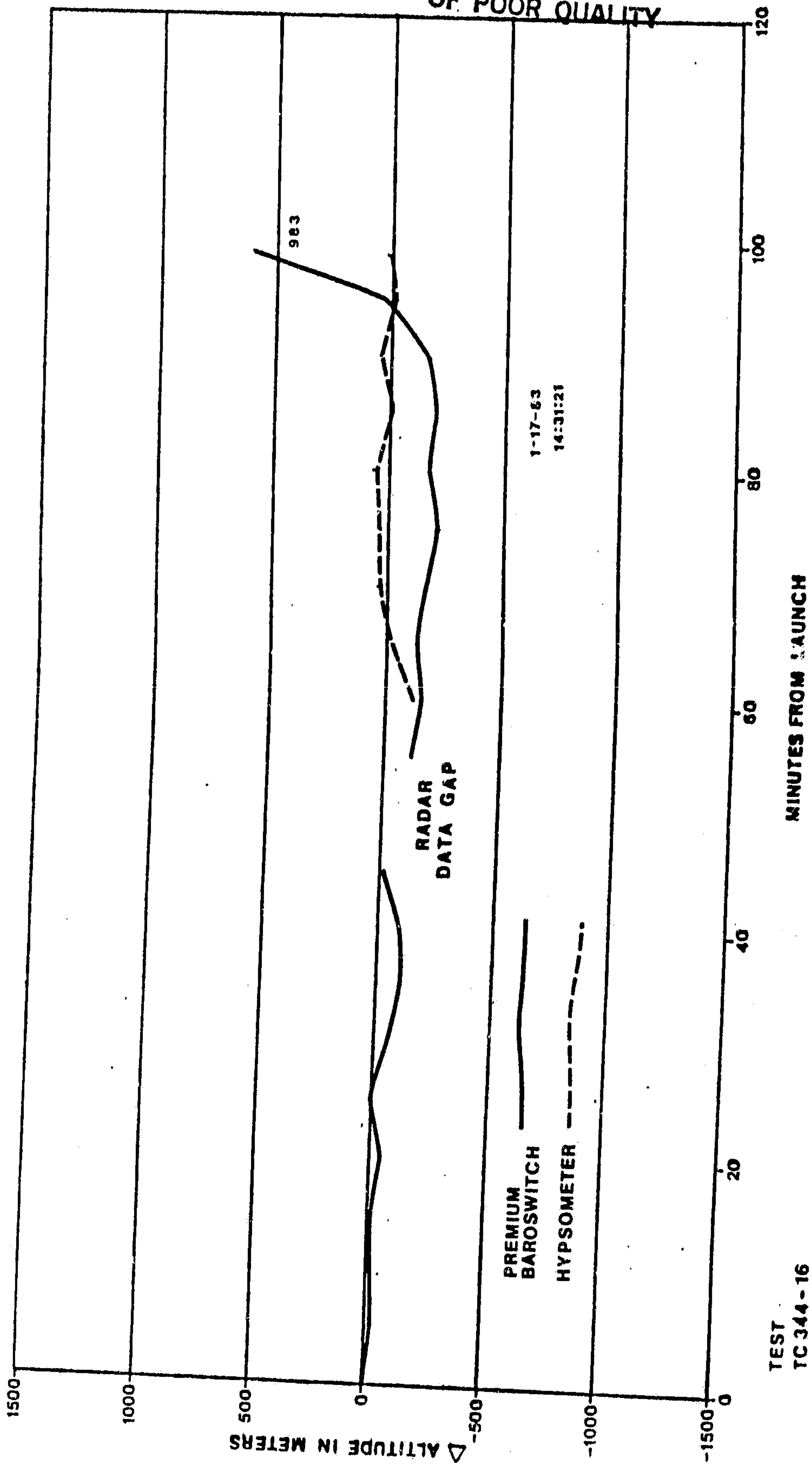
983
1-17-63
14:31:21
RADAR
DATA GAP
PREMIUM
BAROSWITCH
HYPSOMETER
TEST
TC 344-16
MINUTES FROM LAUNCH
0
20
40
60
80
100
120
Δ ALTITUDE IN METERS
1500
1000
500
0
-500
-1000
-1500

Figure 9.

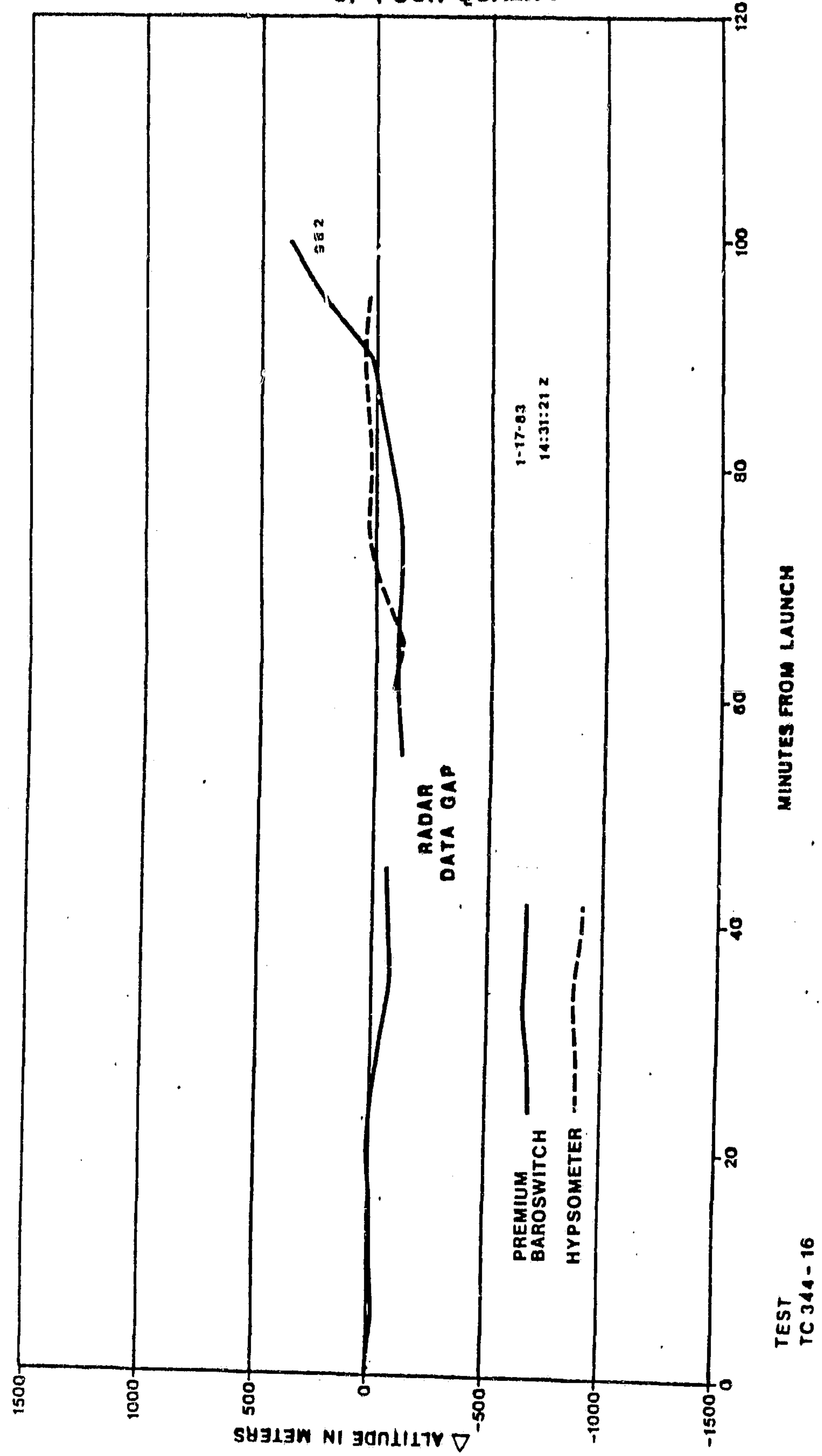
SB2
1-17-83
14:31:21 Z
RADAR
DATA GAP
PREMIUM
BAROSWITCH
HYPSOMETER
TEST
TC 344-16
MINUTES FROM LAUNCH
0
20
40
60
80
100
120
Δ ALTITUDE IN METERS
1500
1000
500
0
-500
-1000
-1500

Figure 10.

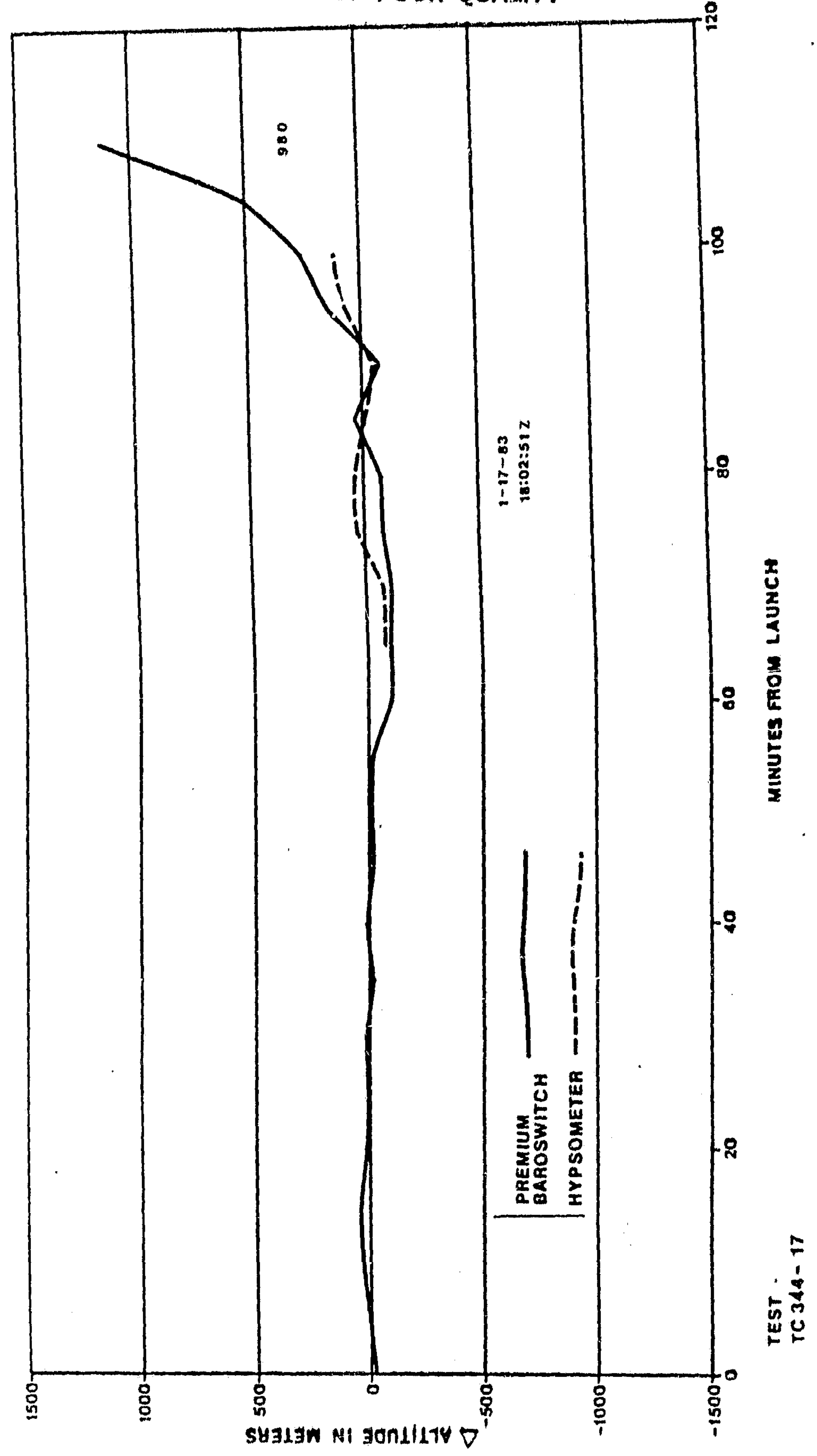
Δ ALTITUDE IN METERS
1500
1000
500
0
-500
-1000
-1500
0
20
40
60
80
100
120
MINUTES FROM LAUNCH
980
1-17-83
18:02:51 Z
PREMIUM BAROSWITCH
HYPSOMETER
TEST -
TC 344-17

Figure 11.

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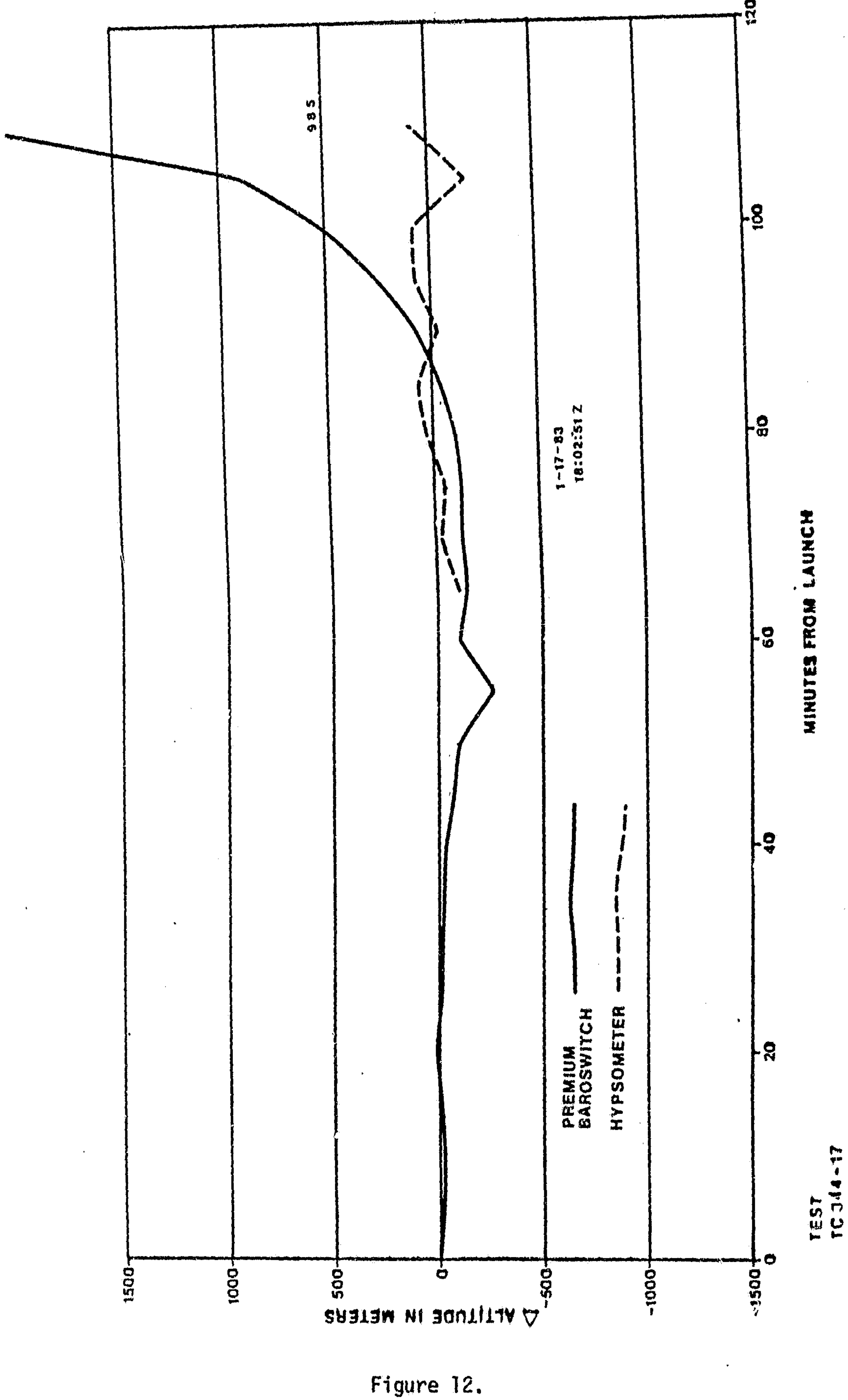

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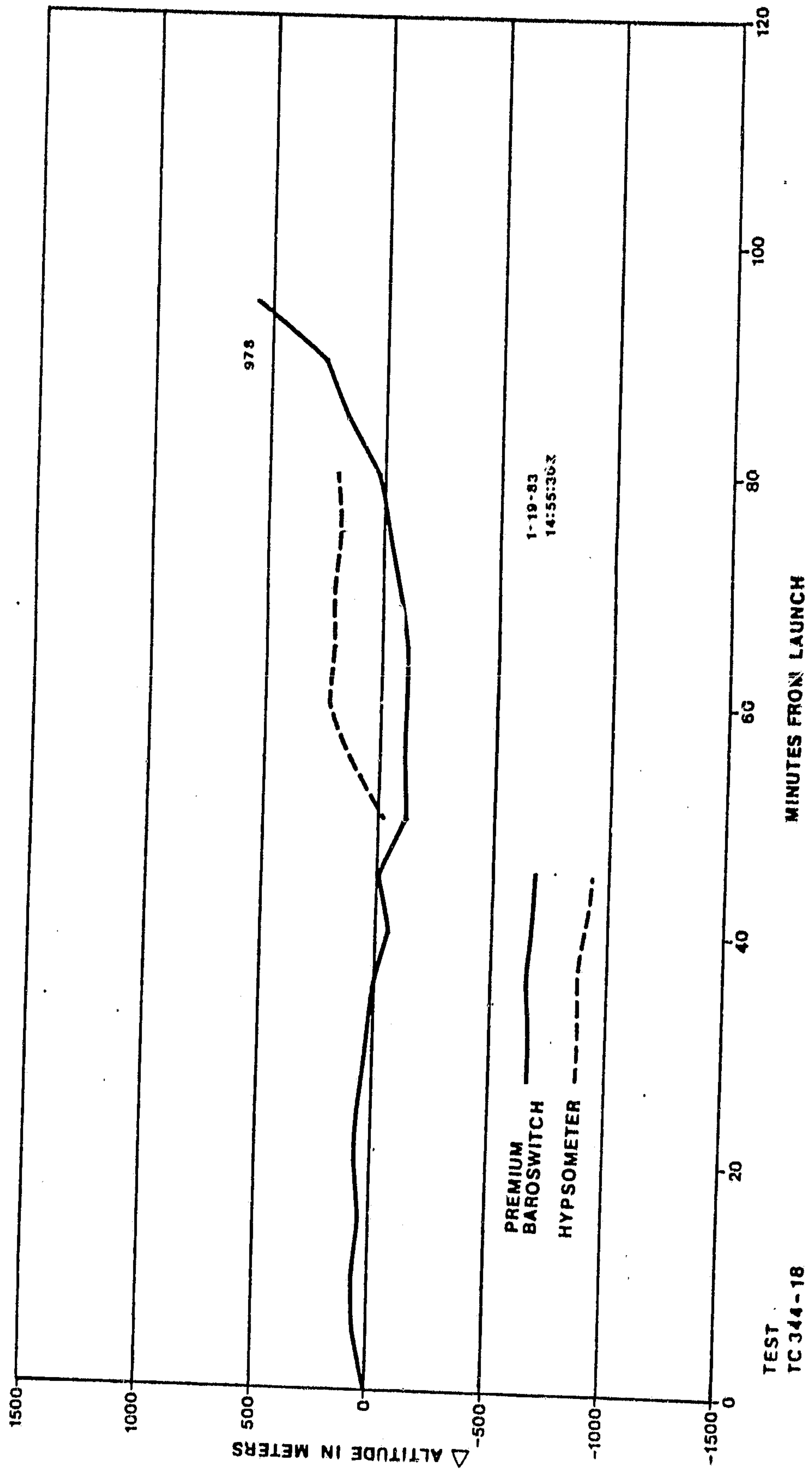

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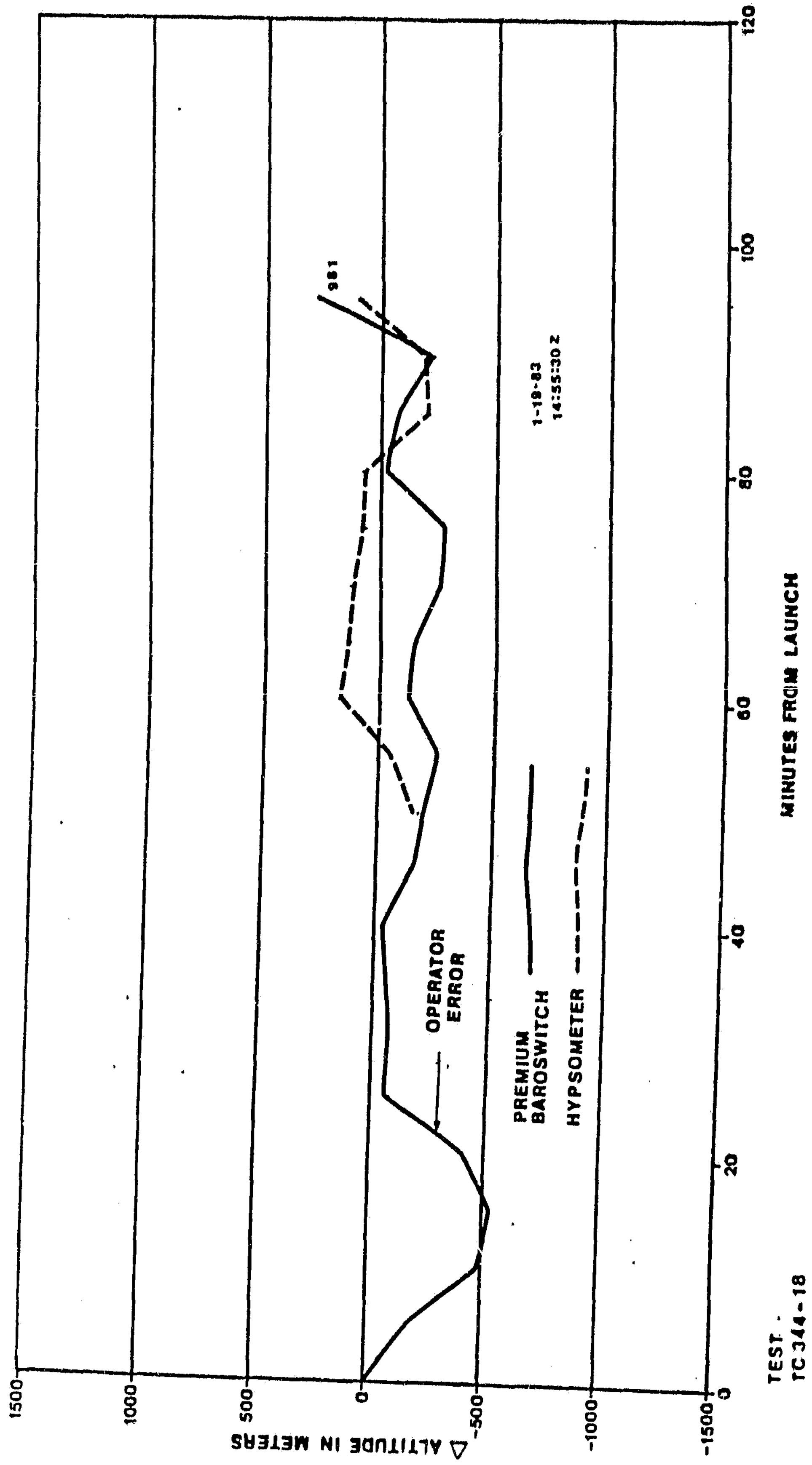
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Δ ALTITUDE IN METERS
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20
40
60
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100
120
MINUTES FROM LAUNCH
OPERATOR ERROR
981
1-19-83
14:55:30 Z
PREMIUM BAROSWITCH
HYPSOMETER
TEST - TC 344-18

Figure 14.

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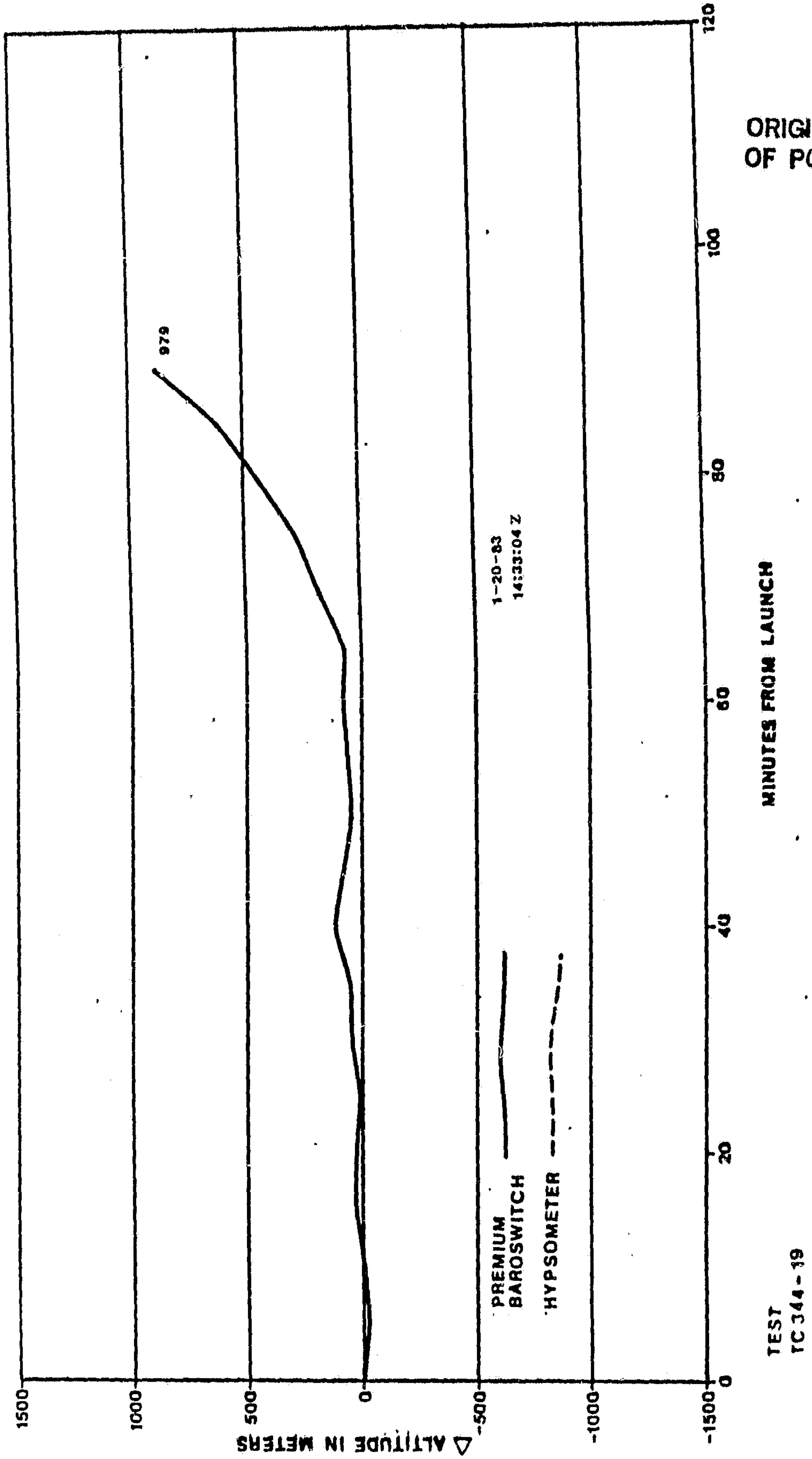

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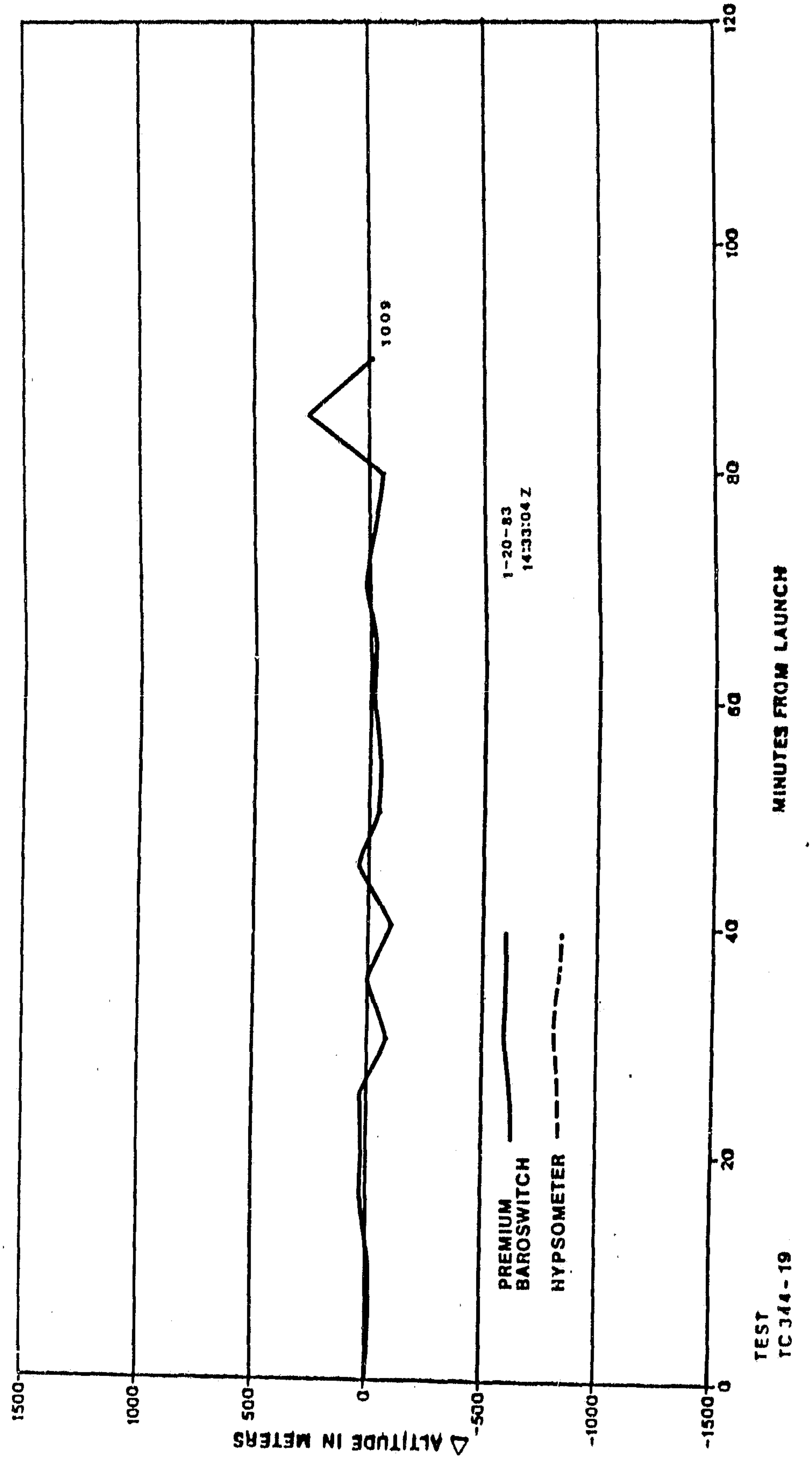

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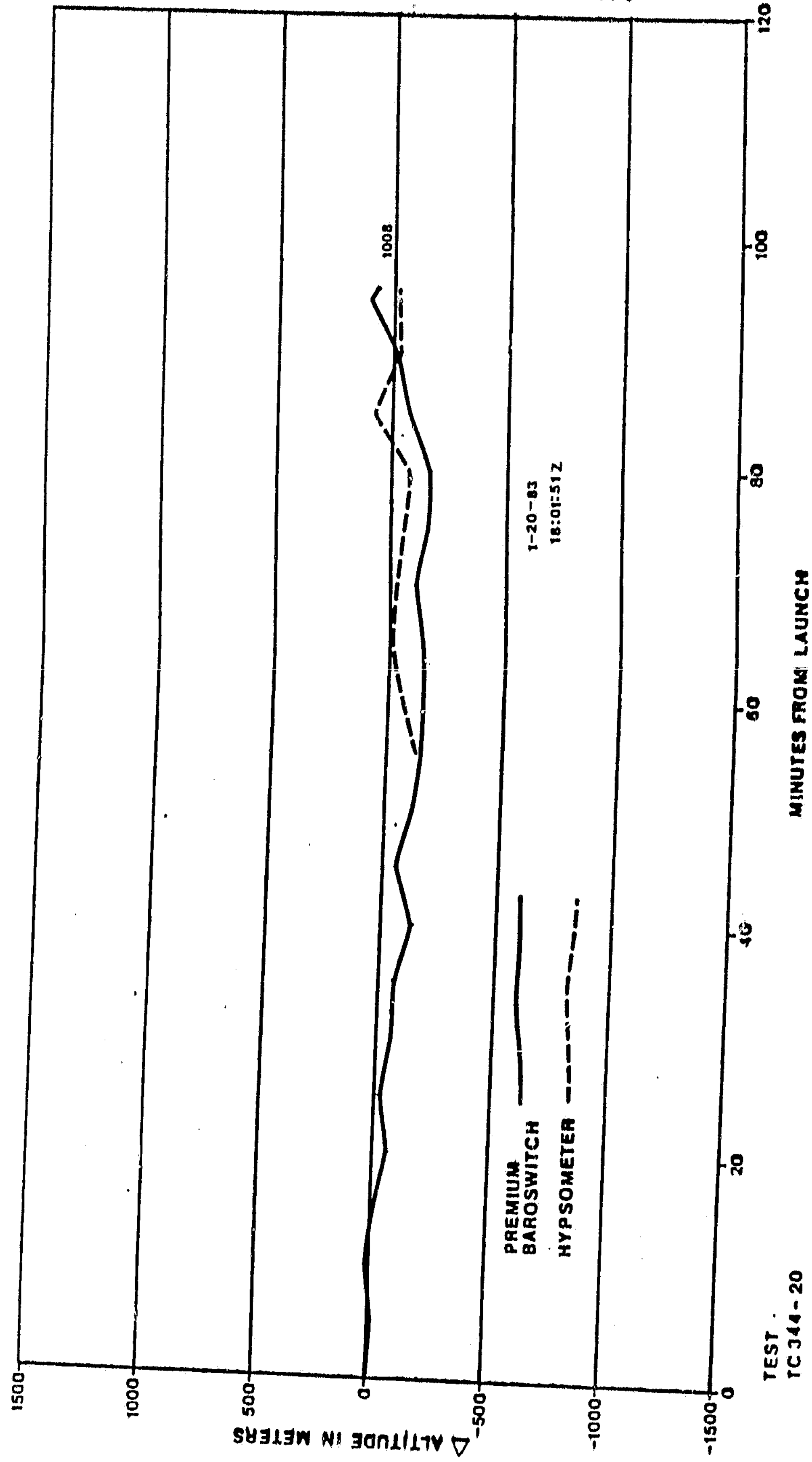

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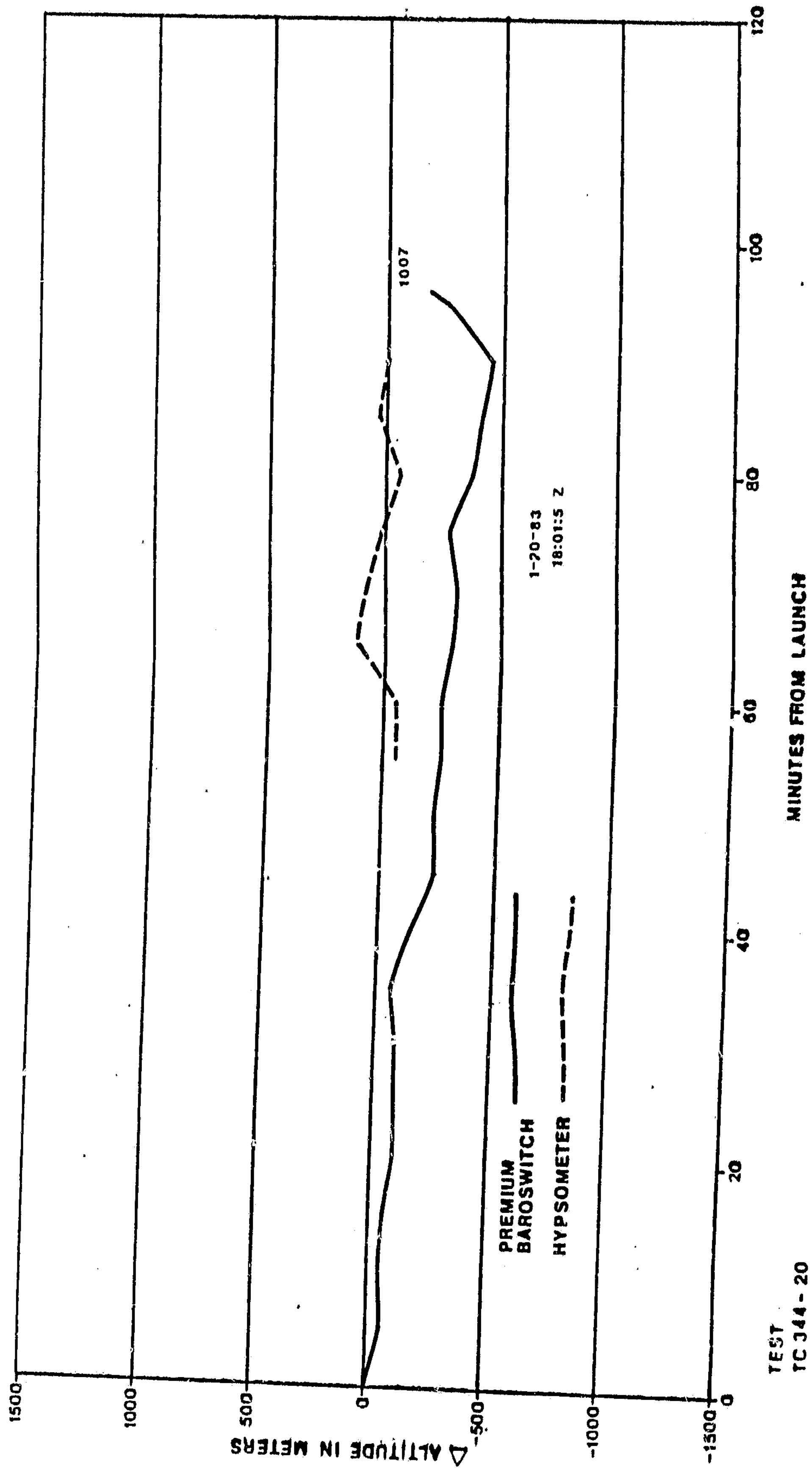
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120
1007
1-20-83
18:01:5 Z
PREMIUM BAROSWITCH
HYPSOMETER
TEST
TC 344-20

Figure 18.

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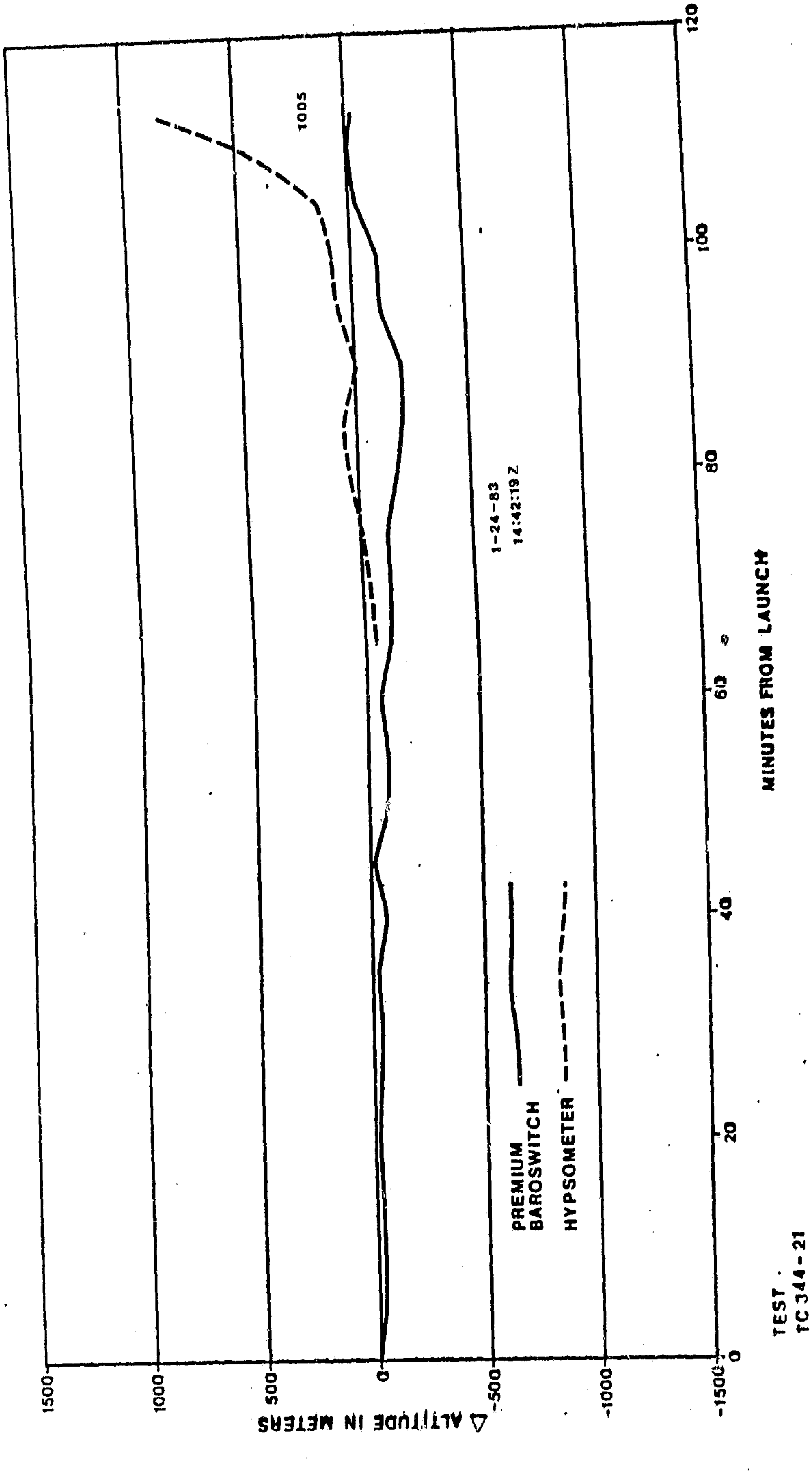

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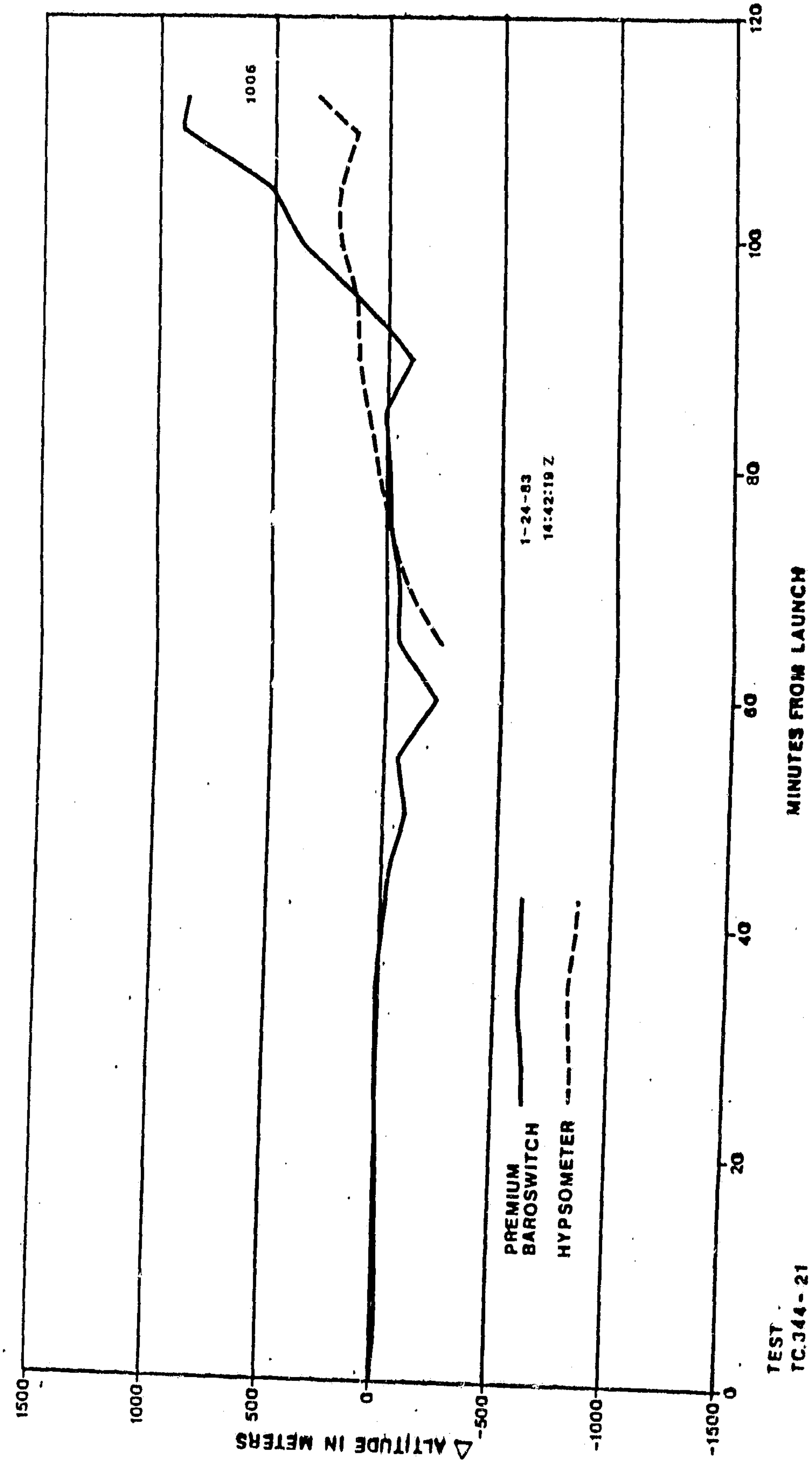

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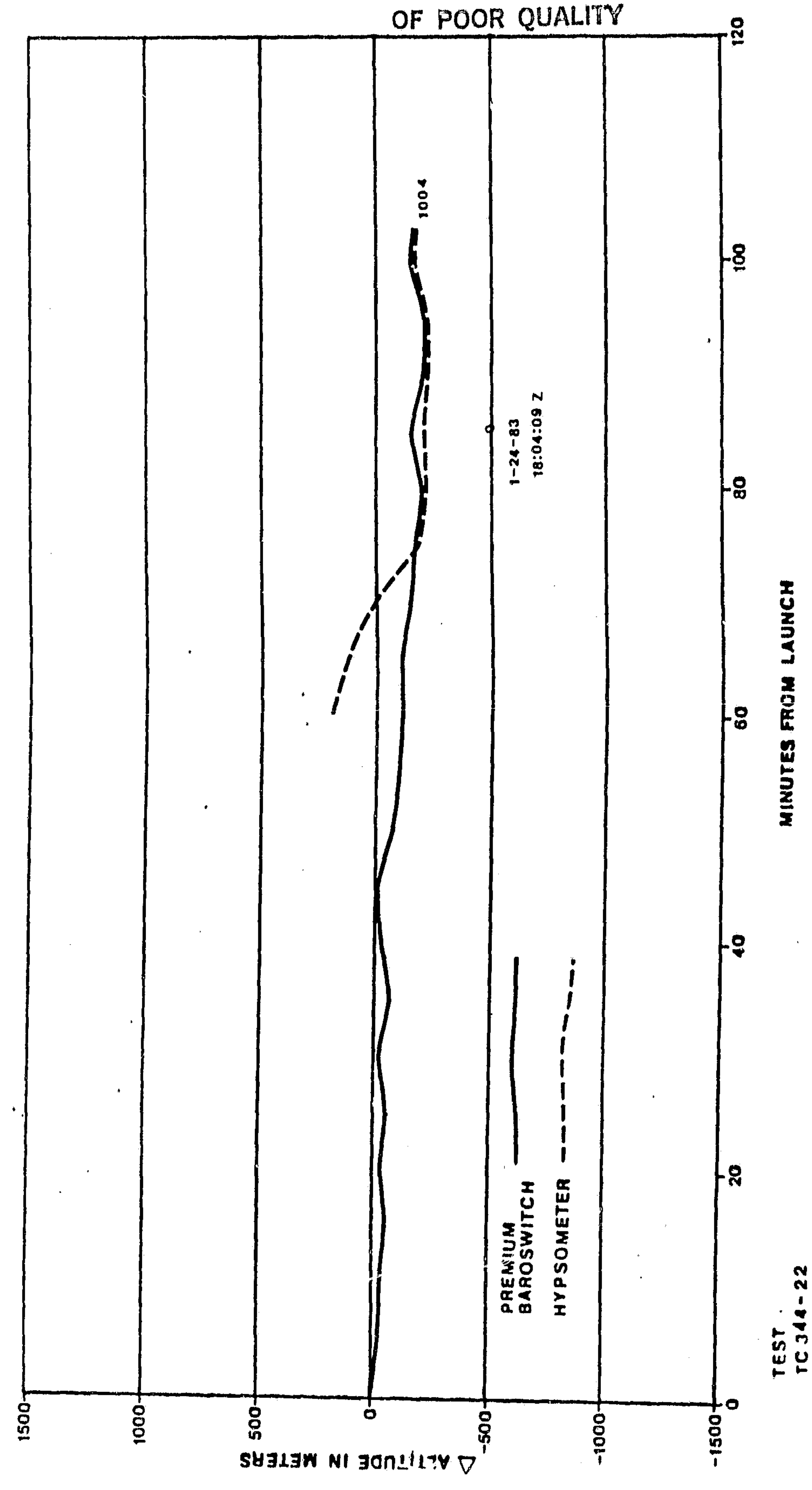

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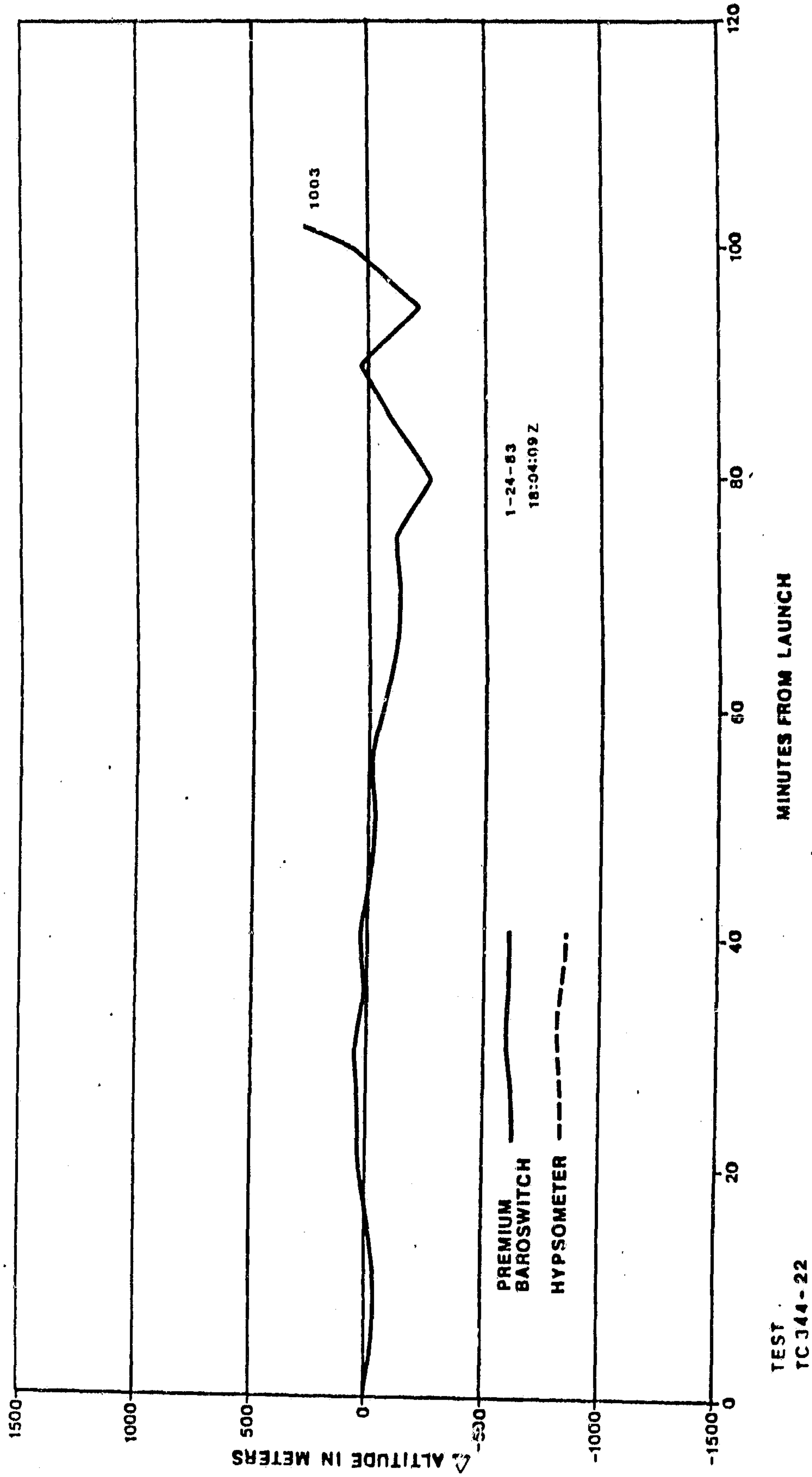

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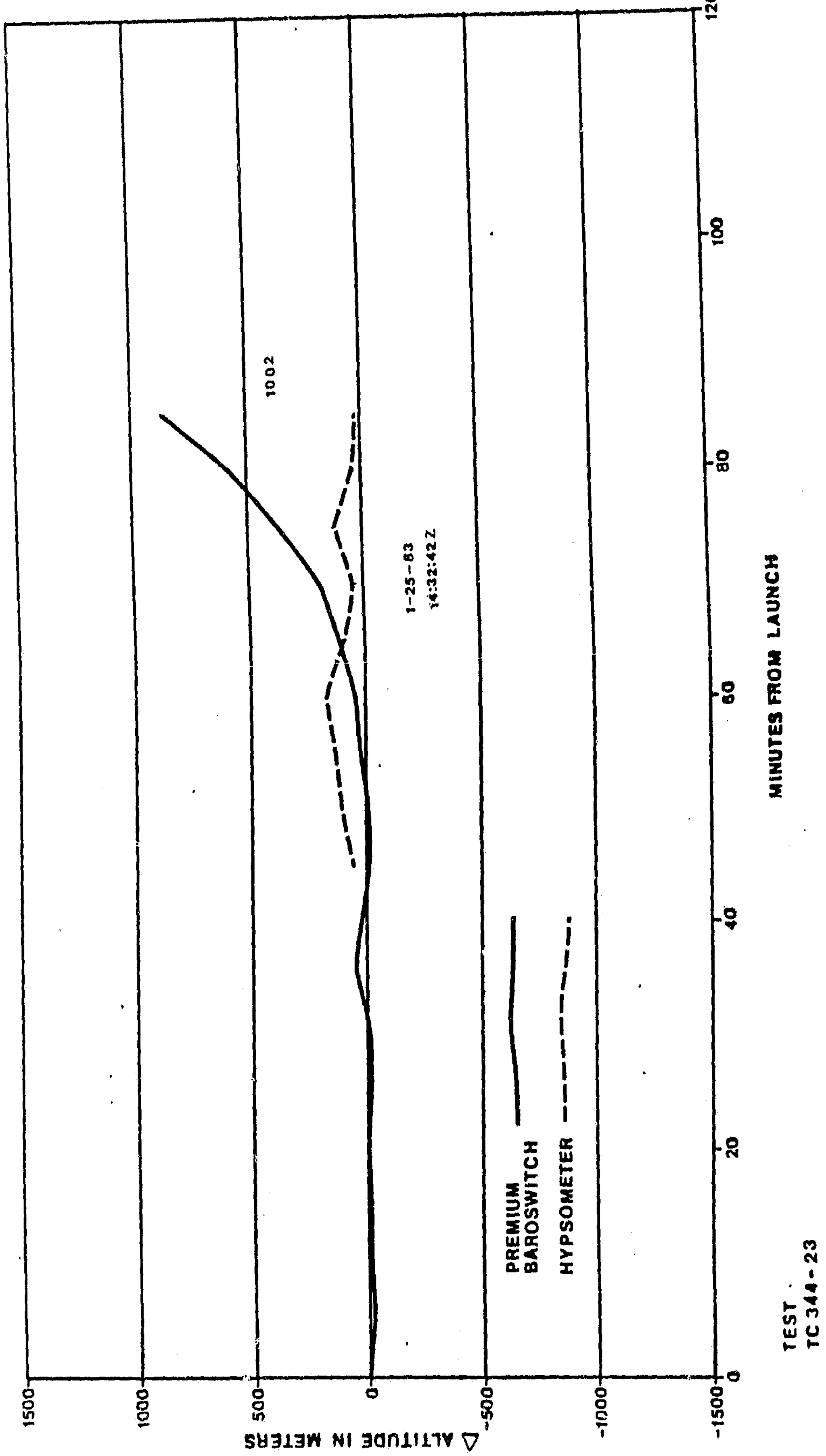

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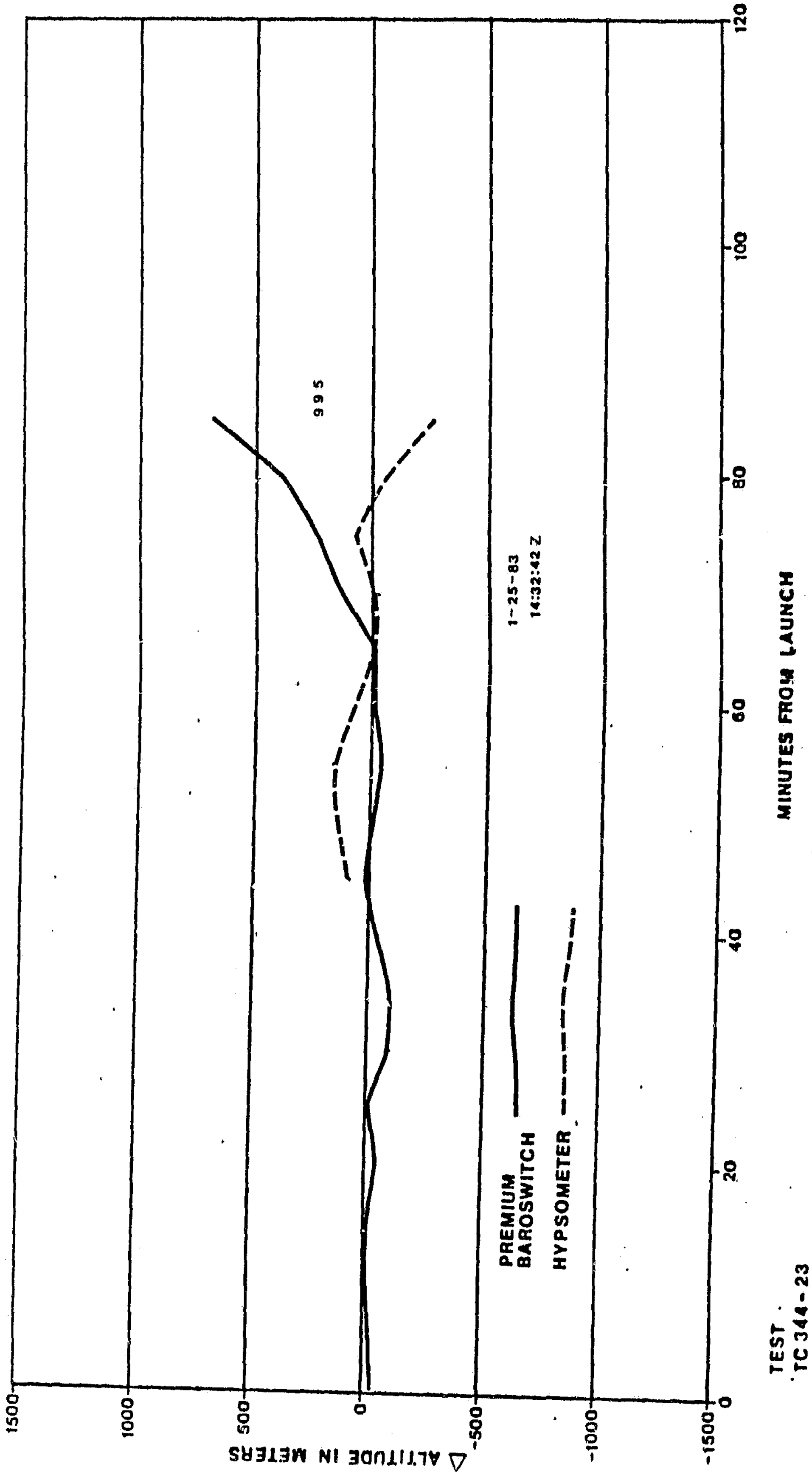

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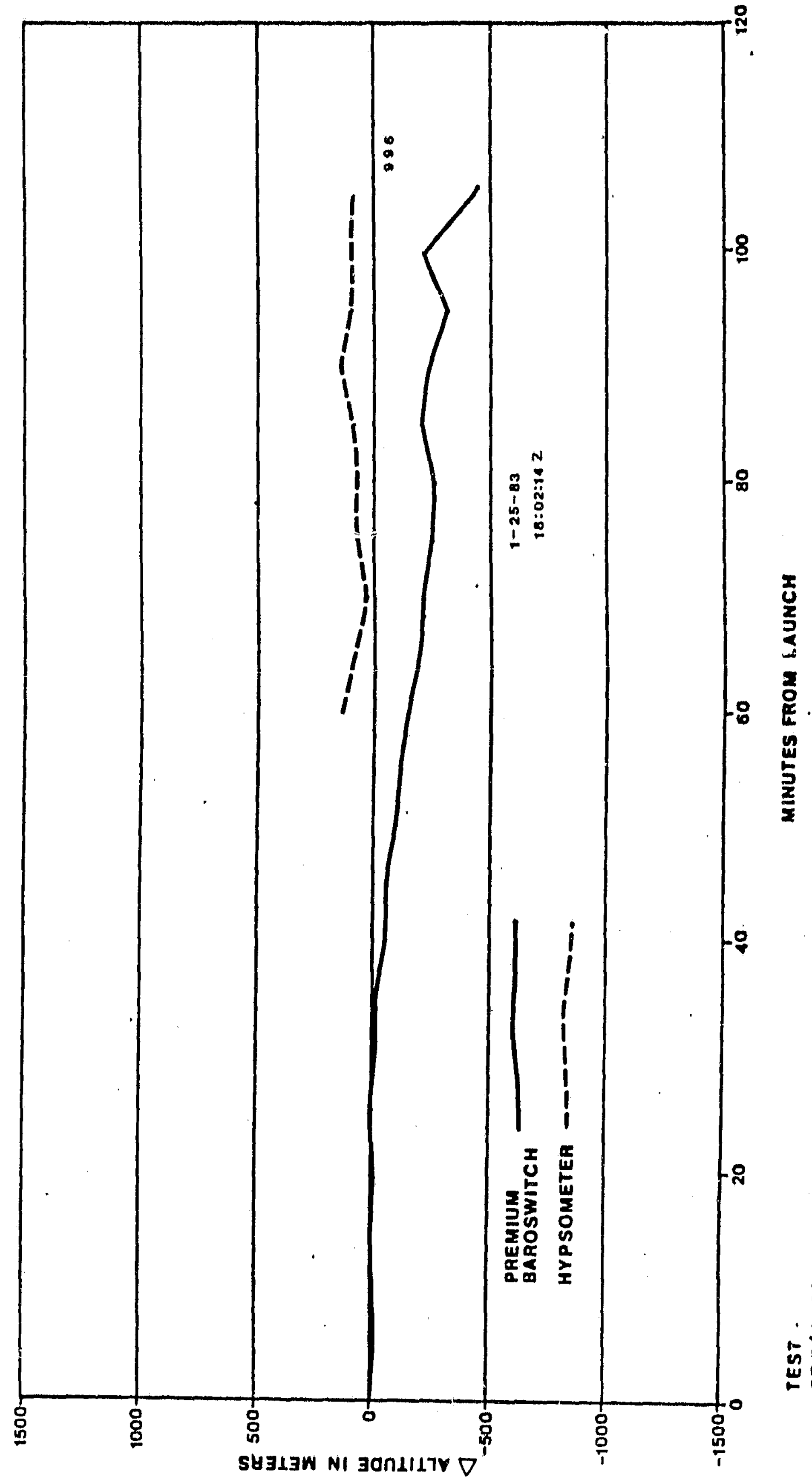

Figure 25.