

77-36 III

Ref

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FIELD TESTING OF A PULSE TRILATERATION AUTOMATIC  
VEHICLE MONITORING SYSTEM IN PHILADELPHIA  
Volume III: Test Histograms

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AUGUST 1978

FINAL REPORT

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VIRGINIA 22161

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Washington DC 20590

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16. Abstract <p>This report describes the Pulse Trilateration Automatic Vehicle Monitoring (AVM) system developed by Hazeltine Corporation, and presents results of the Phase I test program in Philadelphia. The Hazeltine system determines the position of mobile units by measuring the arrival times of the leading edges of vehicle pulse transmissions at a limited number of fixed receiver sites. Differences in time-of-arrival (TOA) of the transmissions are used by a central processor to compute the coordinates of the mobile units. Fixed signpost transmitters are used to improve time of passage accuracy at slow vehicle speed locations.</p> <p>The Hazeltine system covers fixed route, random route, and special-case situations, in both low- and high-rise regions, and provides time-of-departure data for fixed route bus/transit applications. Data acquisition is automatic, with the basic data recorded on magnetic tape. Evaluation of the system's performance is provided by off-line simulation, which reflects the conditions and processing procedures proposed for the Phase II AVM tests in Los Angeles.</p> <p>The report is divided into four volumes. This volume contains time point and location accuracy histograms for the fixed route, random route, and special case tests discussed in Volume 2 (Section 4).</p> <p>Volume 1 is an Executive Summary of the Philadelphia test results. Volume 2, which presents the test results and data, describes the Hazeltine AVM system and the Philadelphia test configuration in detail, explains the data analysis and reduction techniques used, and proposes changes which would be made prior to Phase II. Volume 4 accounts for aborted and excluded tests, and reproduces vehicle log sheets for all the tests.</p>					
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## PREFACE

The work reported herein was performed for the Department of Transportation, Transportation Systems Center (DOT/TSC) in support of the Urban Mass Transportation Administration's (UMTA) research and development efforts in Automatic Vehicle Monitoring (AVM), aimed at the development and testing of advanced location technologies suitable for multi-user vehicle systems.

Government representatives responsible for the overall management of the program and for directing the contractual work include Mr. D. Symes of DOT/UMTA and Messrs. B.E. Blood and B.W. Kliem of DOT/TSC.

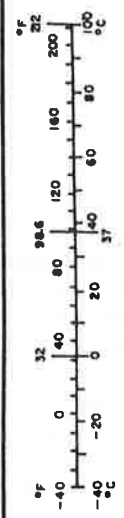
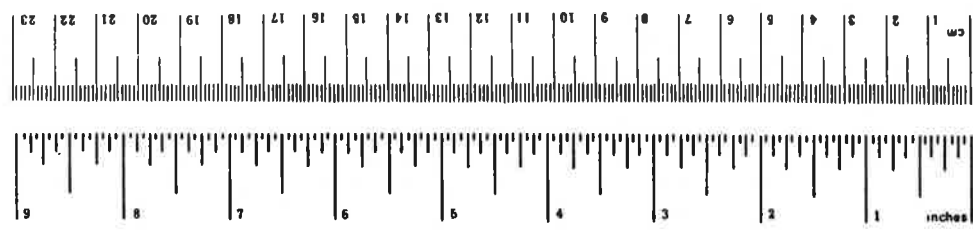
Hazeltine personnel contributing to the program included: Messrs. A.R. Abraham, J.B. Cohen, W.L. Corrigan, F.R. Dayton, G.N. Kerness, P. Nikolados, J.F. O'Connor, A.H. Riccio, W.C. Rogoza, L.E. Smith, and S.M. Weinstein.

## NOTE

During the winter of 1976-77, four different techniques for automatically locating land vehicles were tested in both the low- and high-rise regions in Philadelphia PA. The tests were carried out by four different companies under separate contracts to the U.S. Department of Transportation, Transportation Systems Center. The tests were designed to evaluate the techniques for their applicability as location subsystems for automatic vehicle monitoring systems. This document represents one of the contractors' final report. A summary report on all systems tested is available as report No. UMTA-MA-06-0041-77-2.

# METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures		Approximate Conversions from Metric Measures	
Symbol	When You Know	Multiply by	To Find
<b>LENGTH</b>			
in	inches	2.5	centimeters
ft	feet	30	centimeters
yd	yards	0.9	meters
mi	miles	1.6	kilometers
<b>AREA</b>			
in <sup>2</sup>	square inches	6.5	square centimeters
ft <sup>2</sup>	square feet	0.09	square meters
yd <sup>2</sup>	square yards	0.8	square meters
mi <sup>2</sup>	square miles	2.6	square kilometers
	acres	0.4	hectares
<b>MASS (weight)</b>			
oz	ounces	28	grams
lb	pounds	0.45	kilograms
	short tons (2000 lb)	0.9	tonnes
<b>VOLUME</b>			
tsp	teaspoons	5	milliliters
Tbsp	tablespoons	15	milliliters
fl oz	fluid ounces	30	milliliters
c	cups	0.24	liters
pt	pints	0.47	liters
qt	quarts	0.95	liters
gal	gallons	3.8	liters
ft <sup>3</sup>	cubic feet	0.03	cubic meters
yd <sup>3</sup>	cubic yards	0.76	cubic meters
<b>TEMPERATURE (exact)</b>			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature
<b>TEMPERATURE (exact)</b>			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature



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## INTRODUCTION

This volume contains time point and location accuracy histograms which reflect the results of the Philadelphia tests of the Hazeltine AVM System. The histograms, grouped together in one volume for convenience, are referred to in Volume 2, Section 4.

FIXED ROUTE, LARGE TRIANGLE (HAC) HISTOGRAMS



Fixed Route Time Point Accuracy Histogram, Large Triangle (HAC), System Level, Time Points Plotted, ID 216-TP

FIGURE 1.

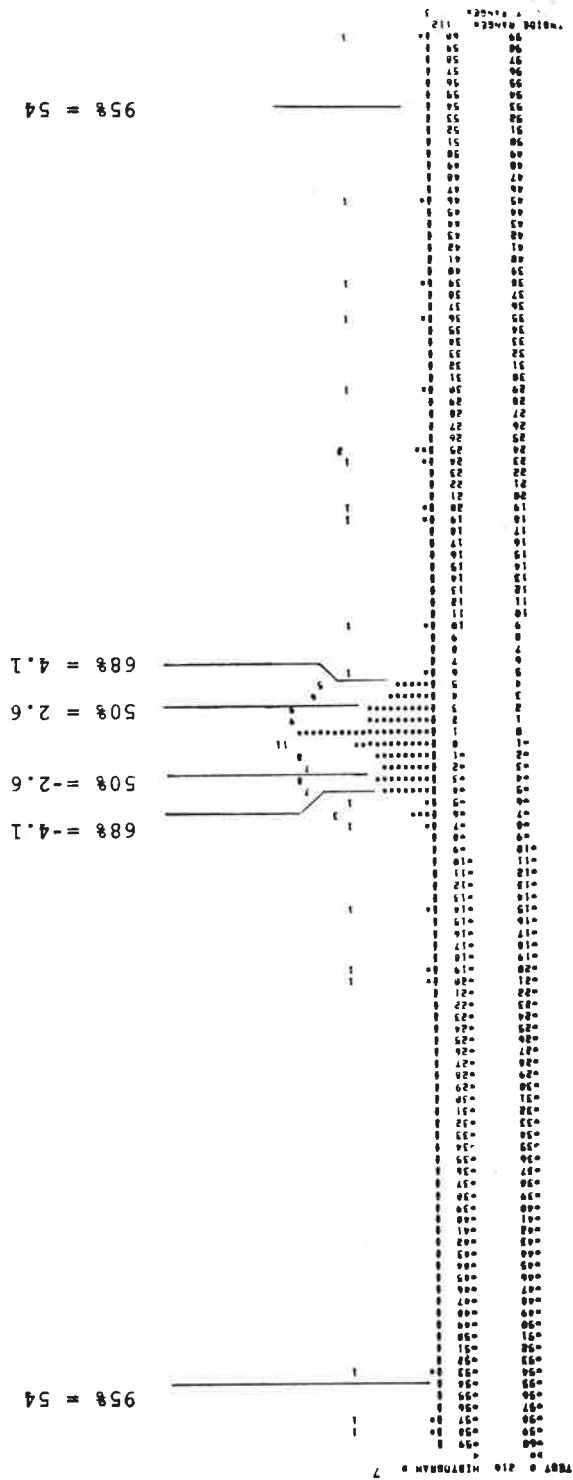
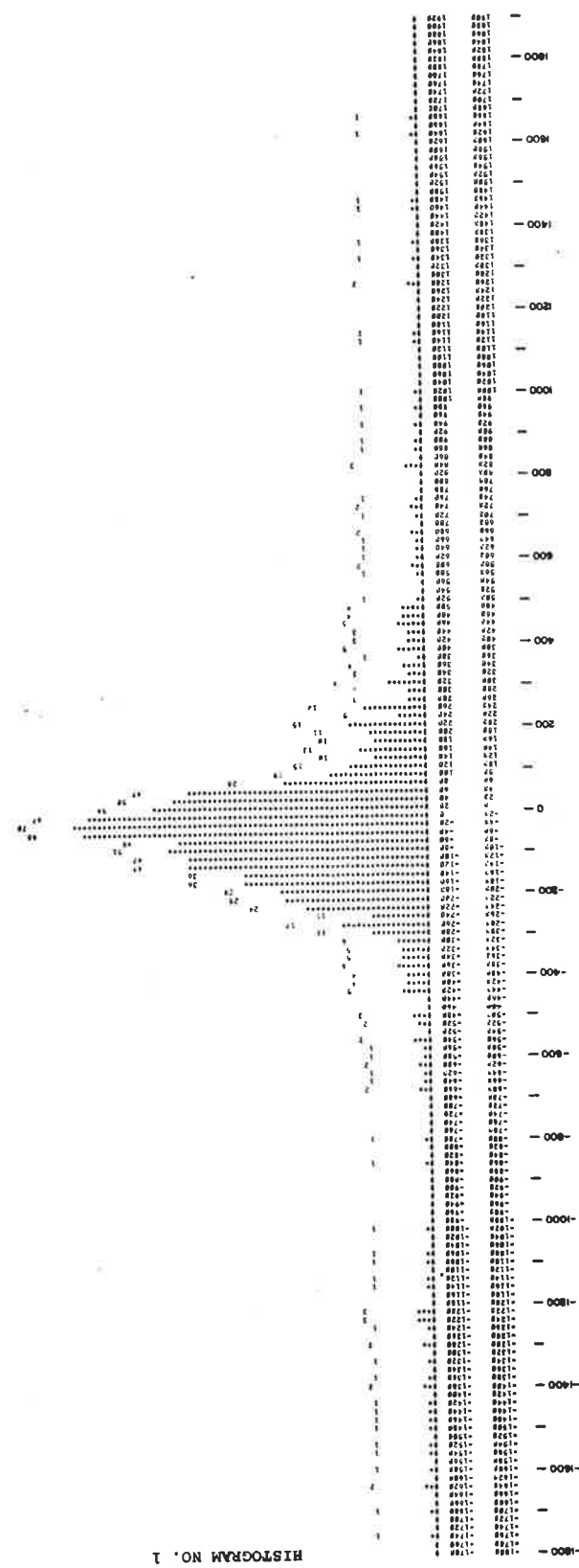
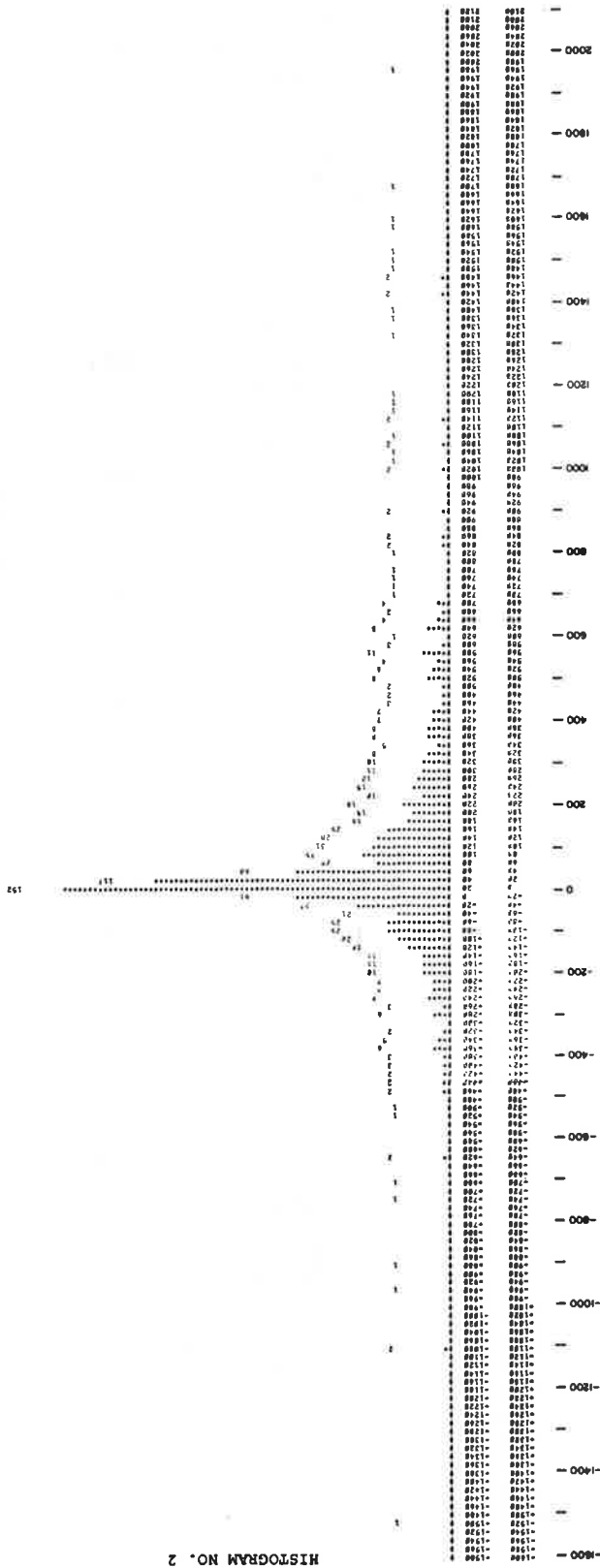


FIGURE 2.



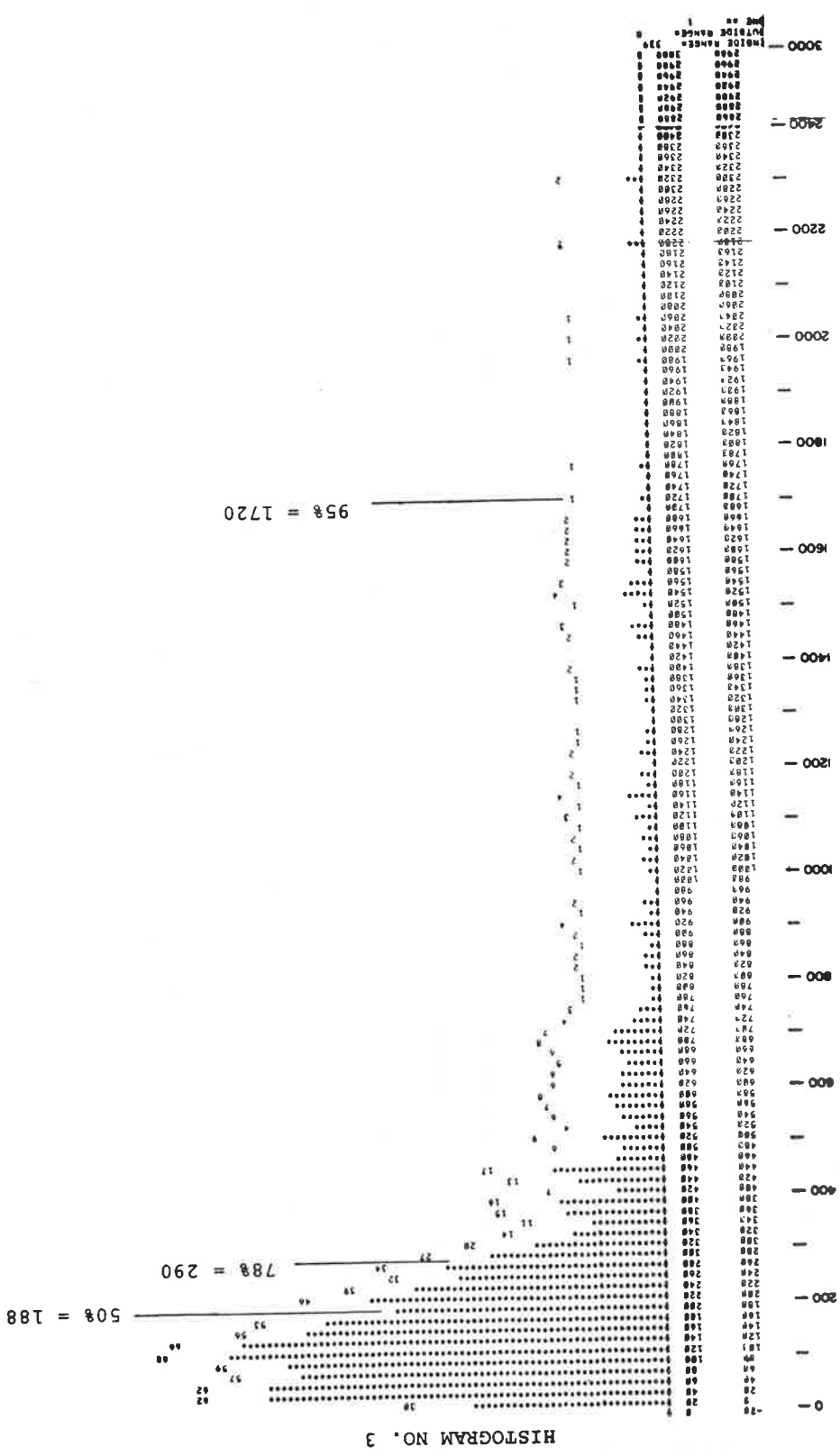
Fixed Route Location Accuracy Histogram, Large Triangle (HAC), System Level, Check Points Plotted, ID 216

FIGURE 3.



Fixed Route Location Accuracy Histogram, Large Triangle (RAC), System Level, Check Points Plotted, ID 216

FIGURE 3. (cont.)

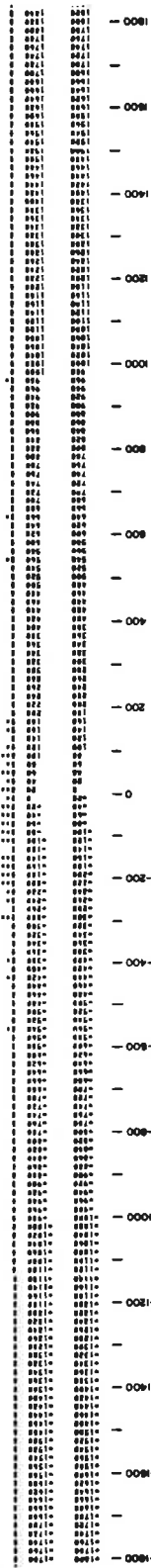


Fixed Route Location Accuracy Histogram, Large Triangle (HAC), System Level, Check Points Plotted, ID 216

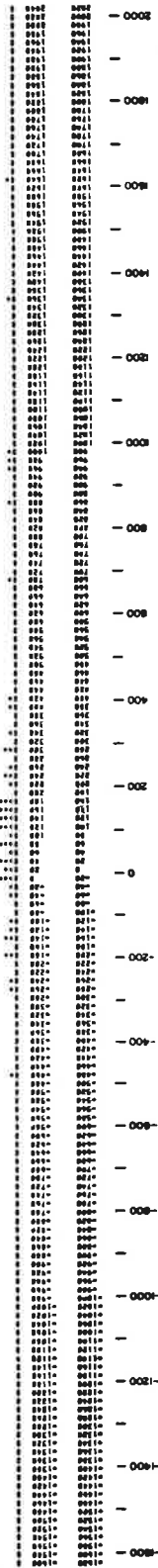
FIGURE 3. (cont.)



HISTOGRAM NO. 1

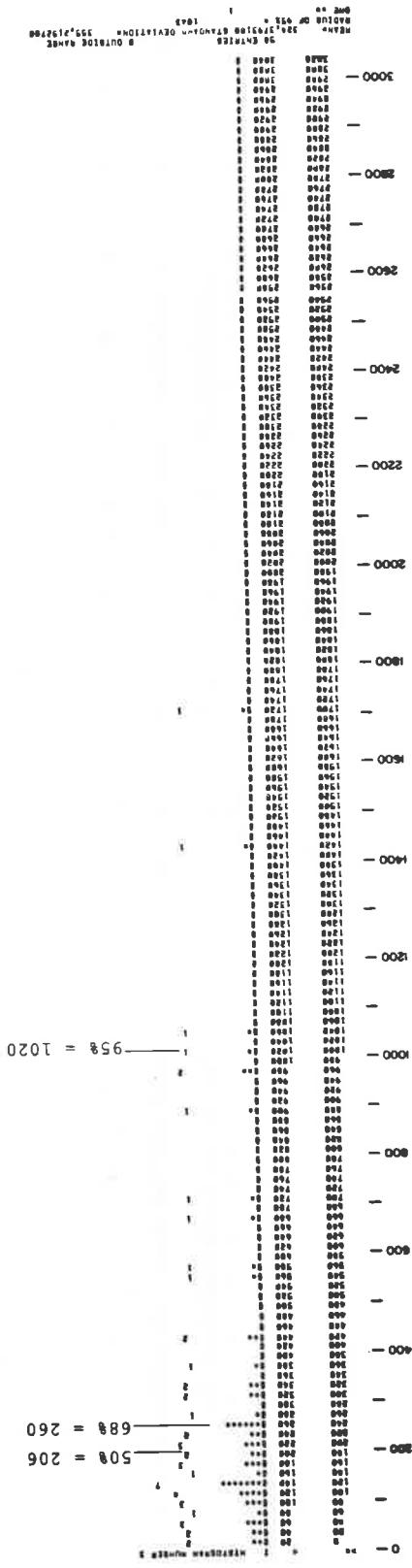


HISTOGRAM NO. 2



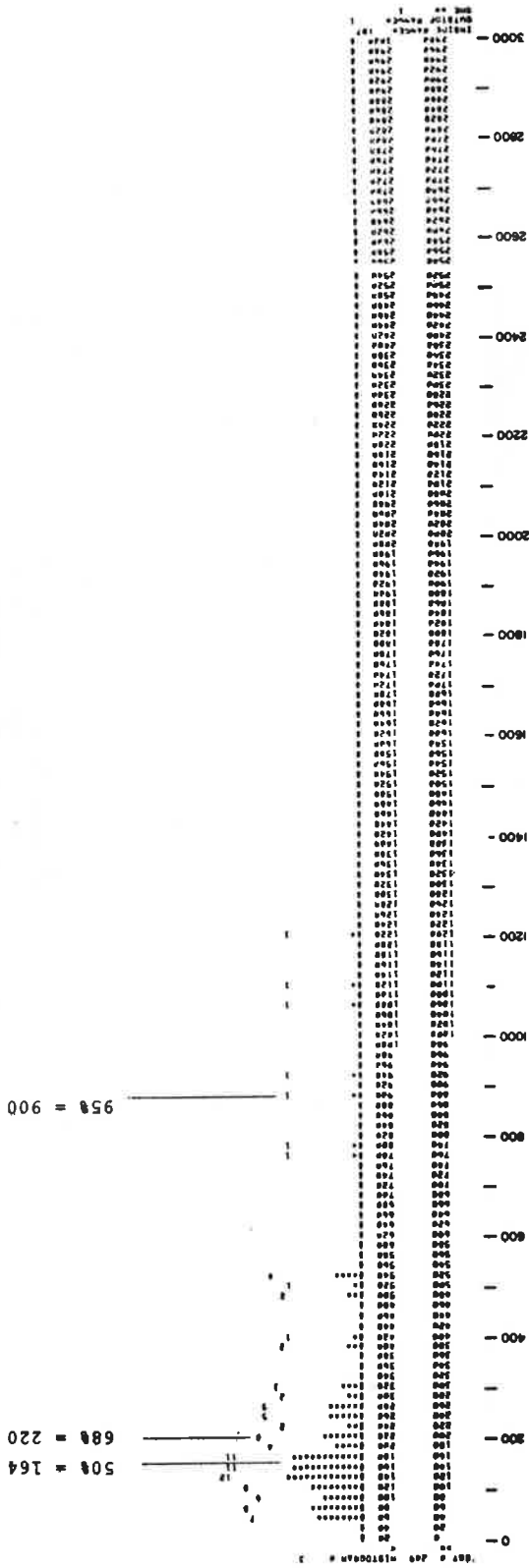
Fixed Route Location Accuracy Histogram, Large Triangle (HAC),  
 Subsystem Level, Check Points at 0.1-Second Update Rate, ID 219

FIGURE 4.



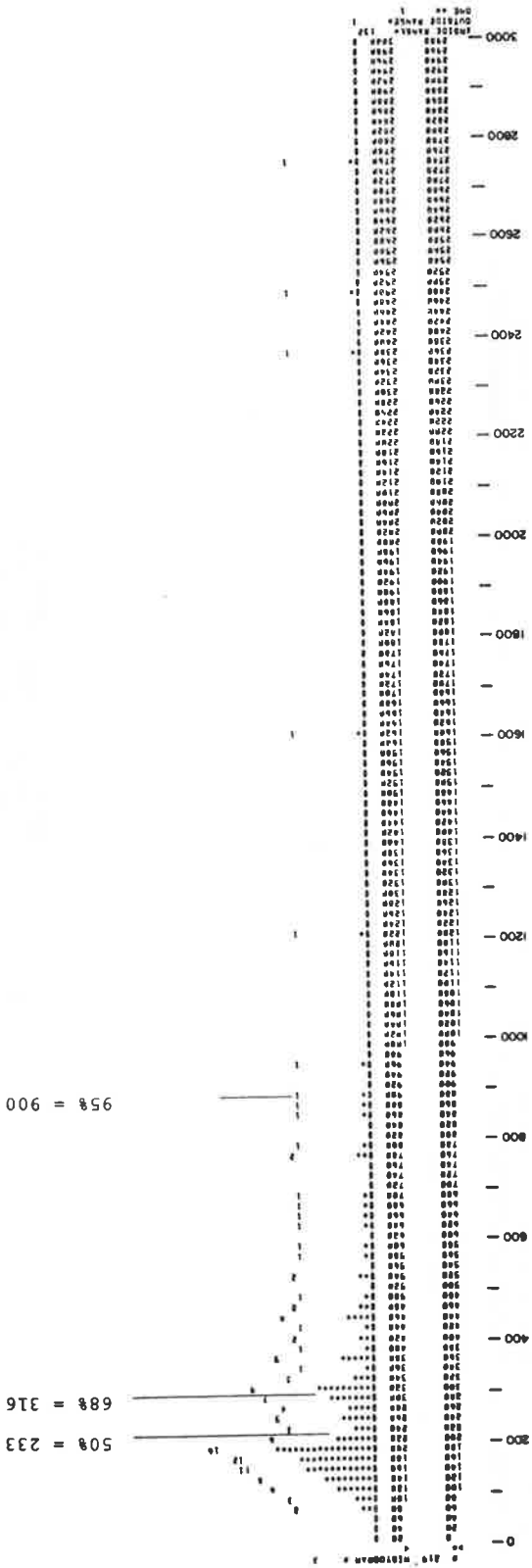
Fixed Route Location Accuracy Histogram, Large Triangle (HAC),  
 Subsystem Level, Check Points at 0.1-Second Update Rate, ID 219

FIGURE 4. (cont.)



Tenth Mile Average Radial Error Histogram,  
 Fixed Route, Large Triangle (HAC), System  
 Level, 10 Second Data, ID 249, Test 34

FIGURE 5.



Tenth Mile Average Radial Error Histogram,  
 Fixed Route, Large Triangle (HAC), Subsystem  
 Level, 0.1 Second Data, ID 219AV, Test 34

FIGURE 6.

FIXED ROUTE, SMALL TRIANGLE (LAC) HISTOGRAMS

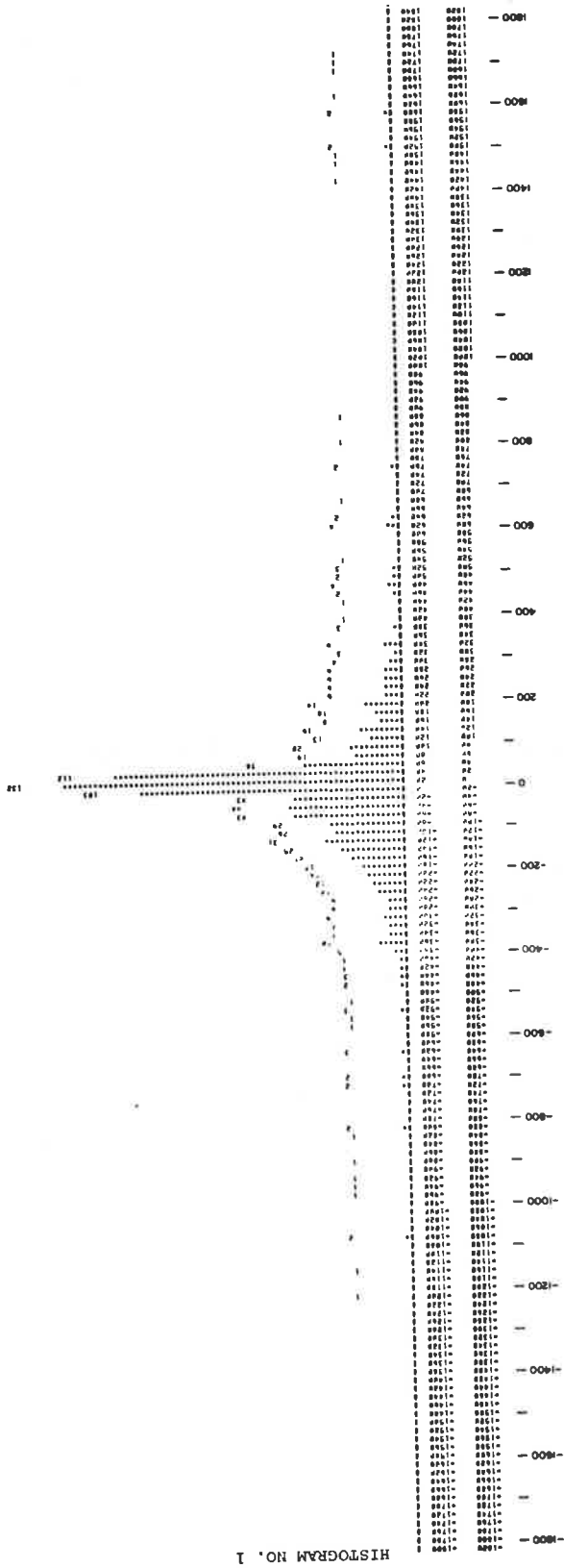
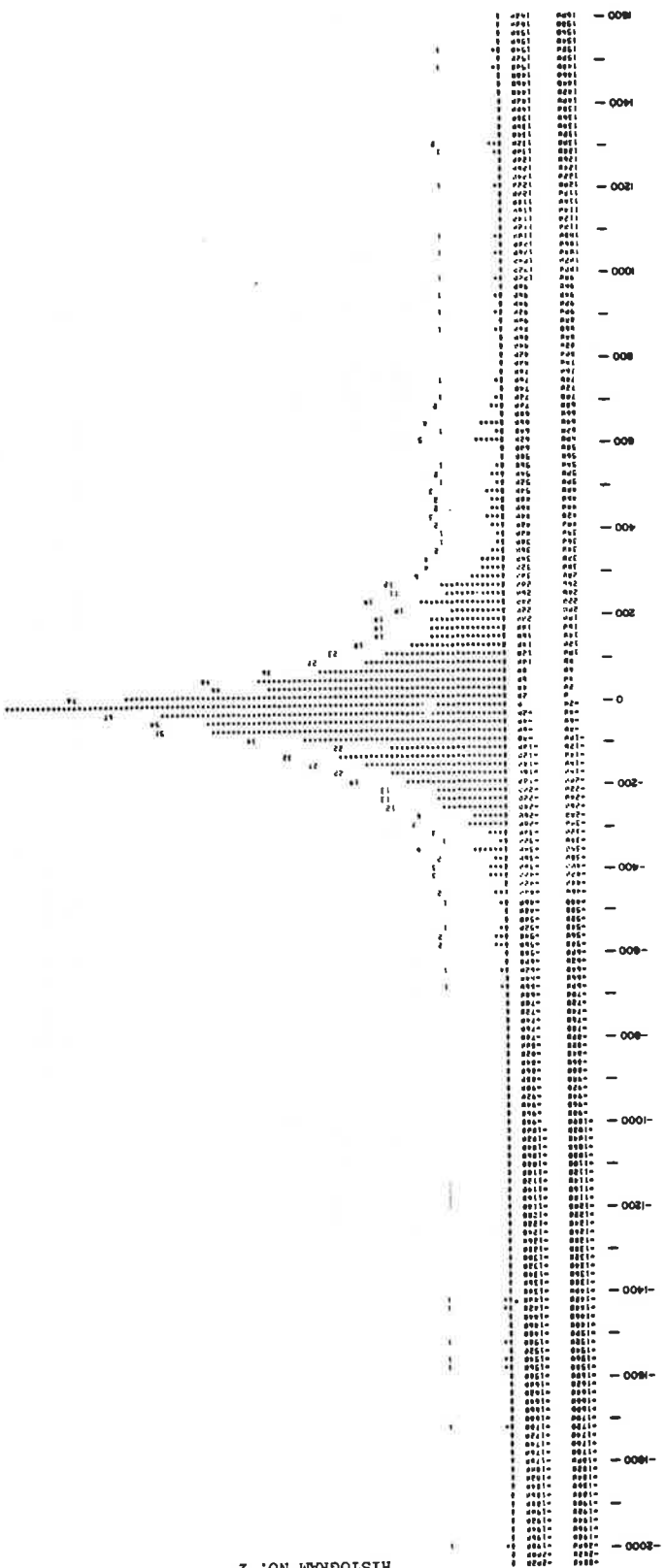
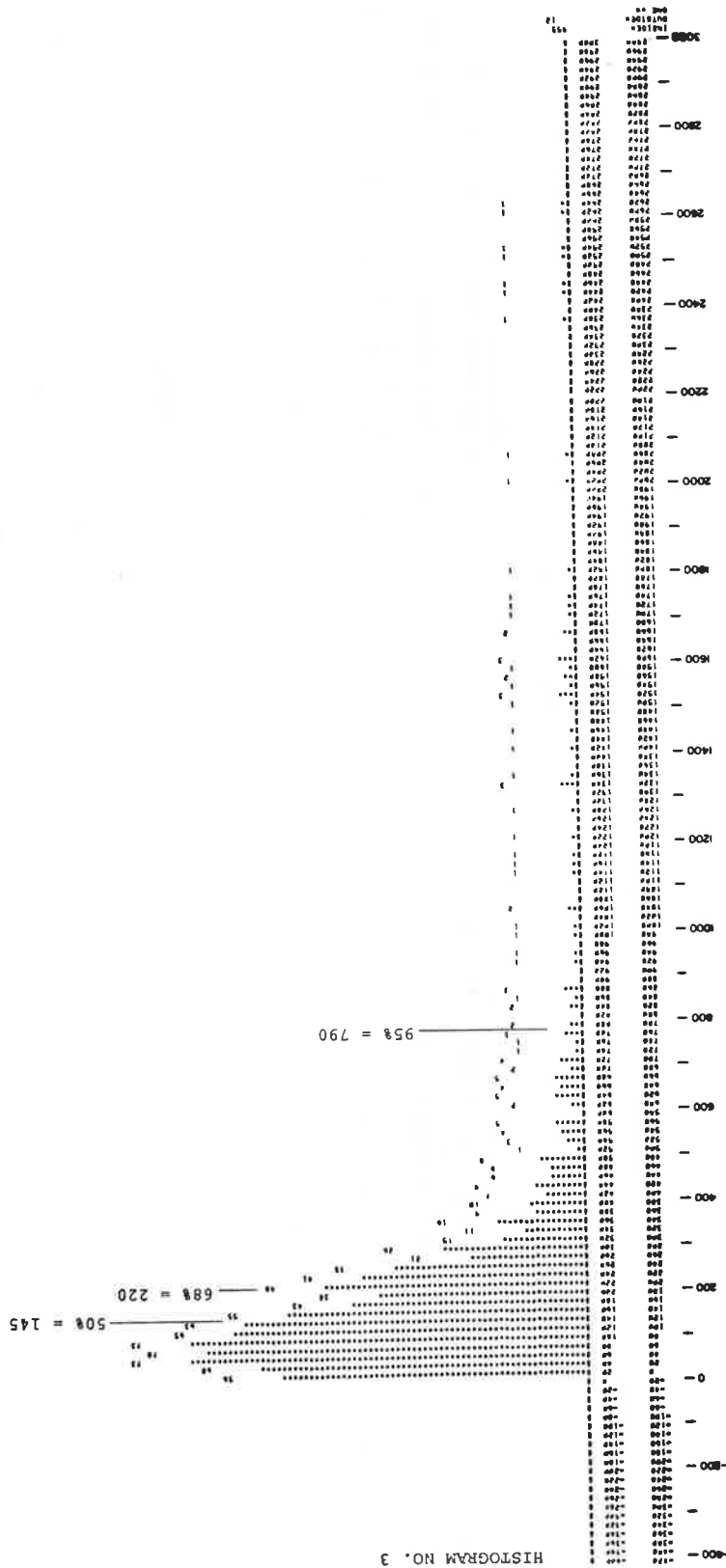


FIGURE 7.



Fixed Route Location Accuracy Histogram, Small Triangle (LAC),  
System Level, Check Points Plotted, ID 217

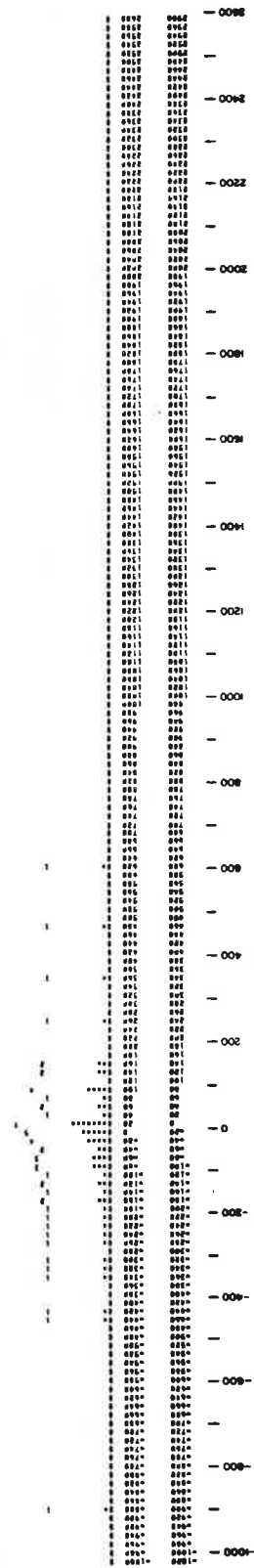
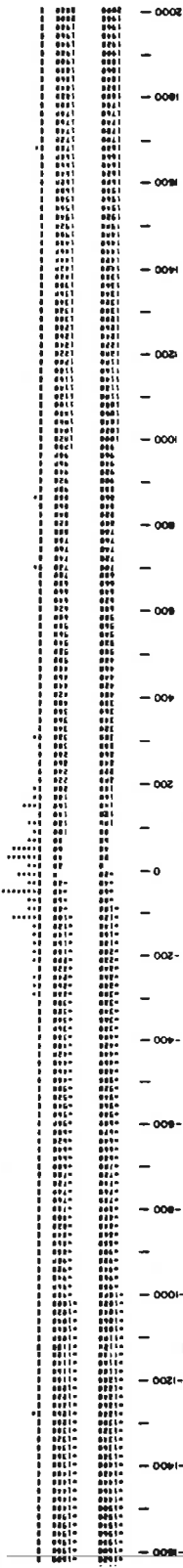
FIGURE 7. (cont.)



Fixed Route Location Accuracy Histogram, Small Triangle (LAC),  
System Level, Check Points Plotted, ID 217

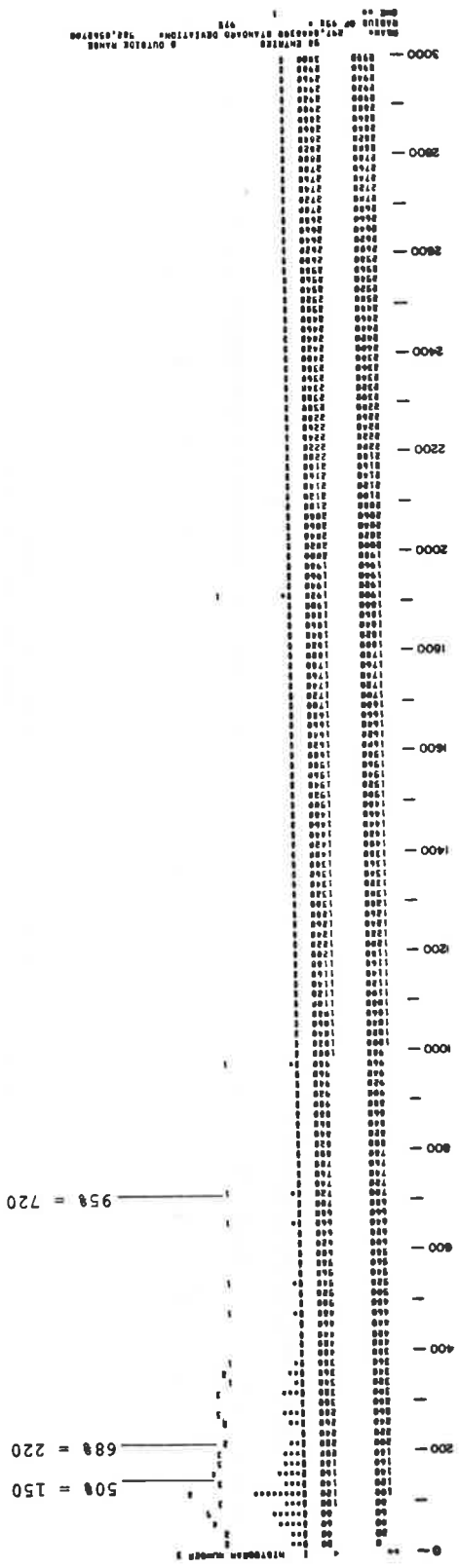
FIGURE 7. (cont.)





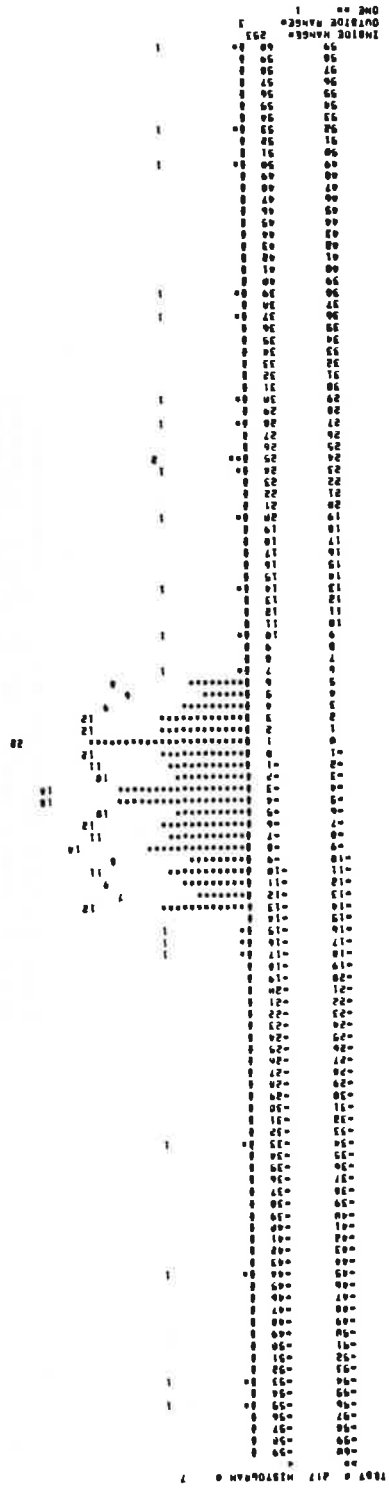
Fixed Route Location Accuracy Histogram, Small Triangle (LAC),  
 Subsystem Level, Check Points at 0.1-Second Update Rate, ID 218

FIGURE 8.



Fixed Route Location Accuracy Histogram, Small Triangle (LAC), Subsystem Level, Check Points at 0.1-Second Update Rate, ID 218

FIGURE 8. (cont.)



Fixed Route Time Point Accuracy Histogram, Small Triangle (LAC),  
System Level, Time Points Plotted, ID 217-TP

FIGURE 9.

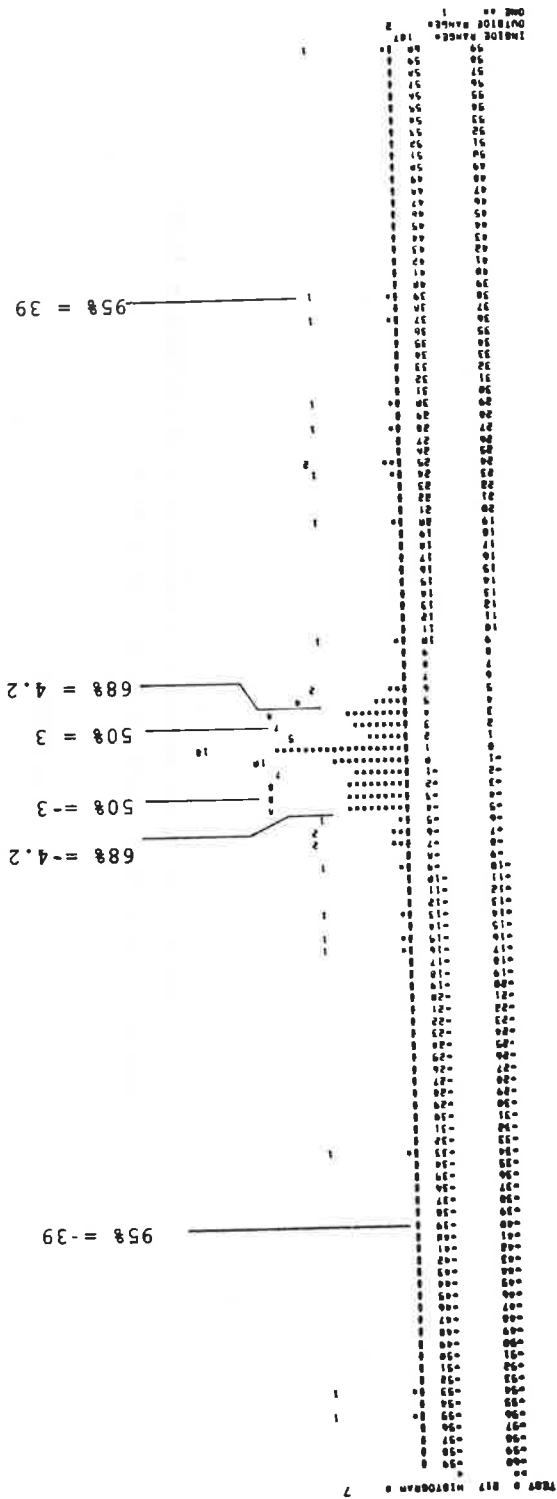
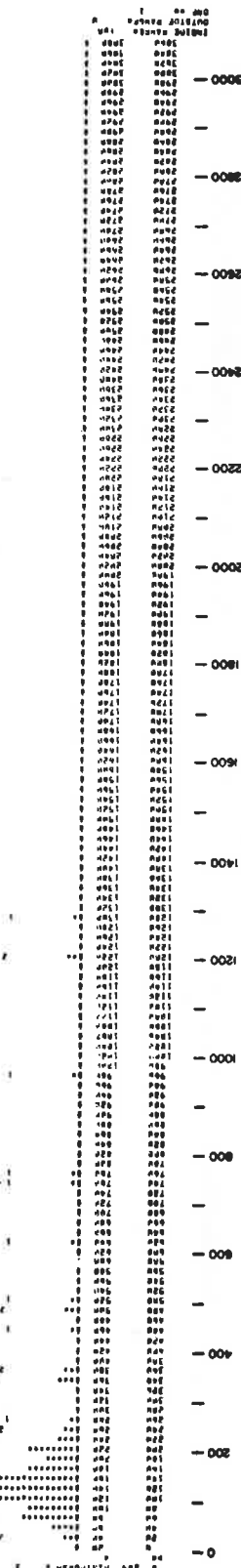


FIGURE 10.

958 = 760

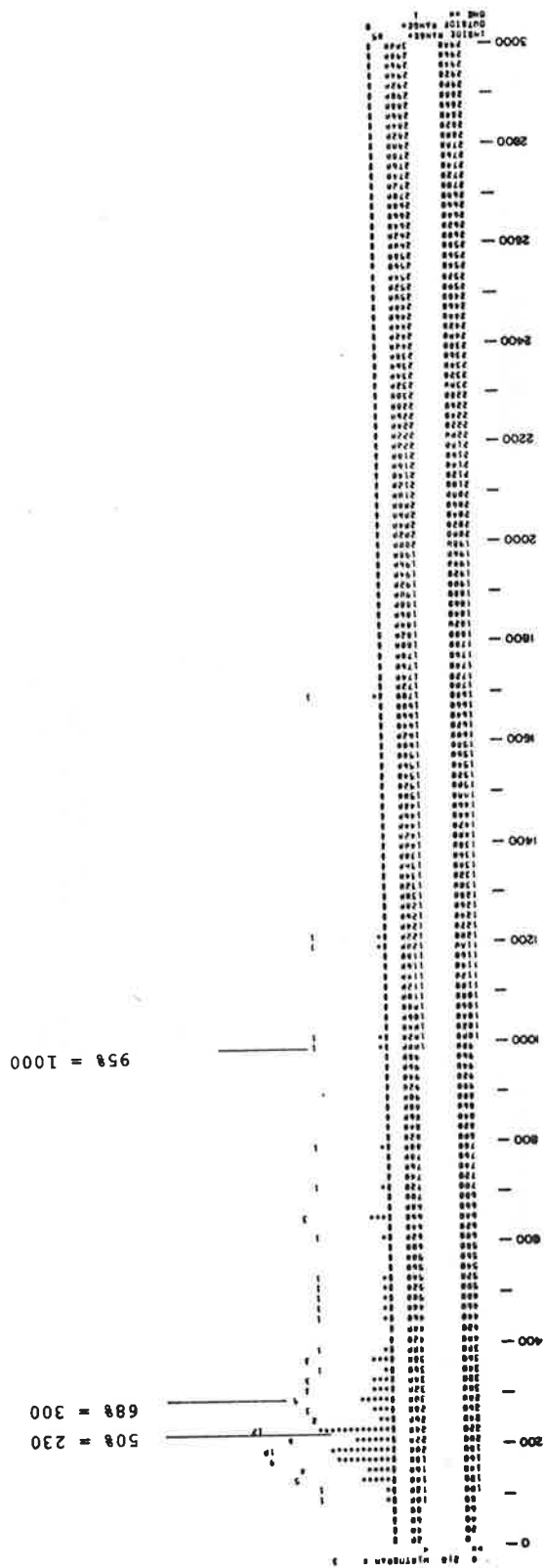
508 = 144

688 = 180



Tenth Mile Average Radial Error Histogram,  
 Fixed Route, Small Triangle (IAC), System  
 Level, 10 Second Data, ID 248, Test 34

FIGURE 11.

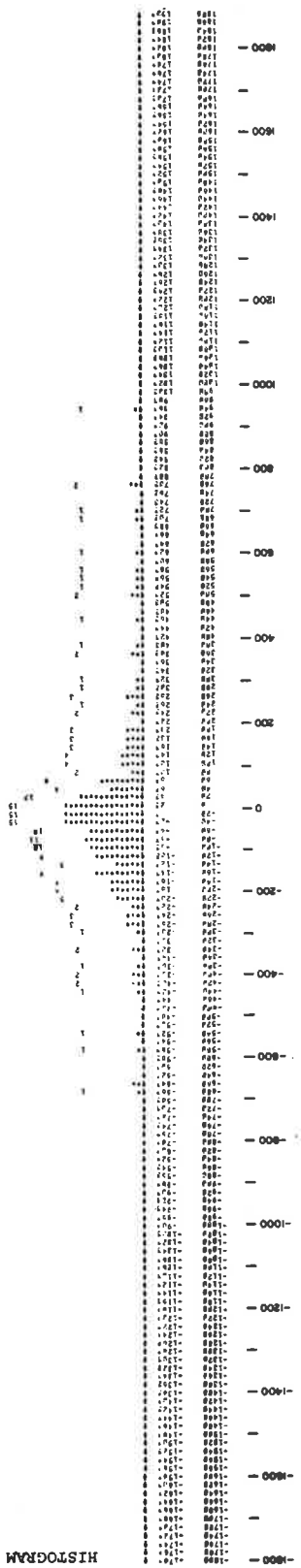


Tenth Mile Average Radial Error Histogram,  
Fixed Route, Small Triangle (IAC), Subsystem  
Level, 0.1 Second Data, ID218AV, Test 34

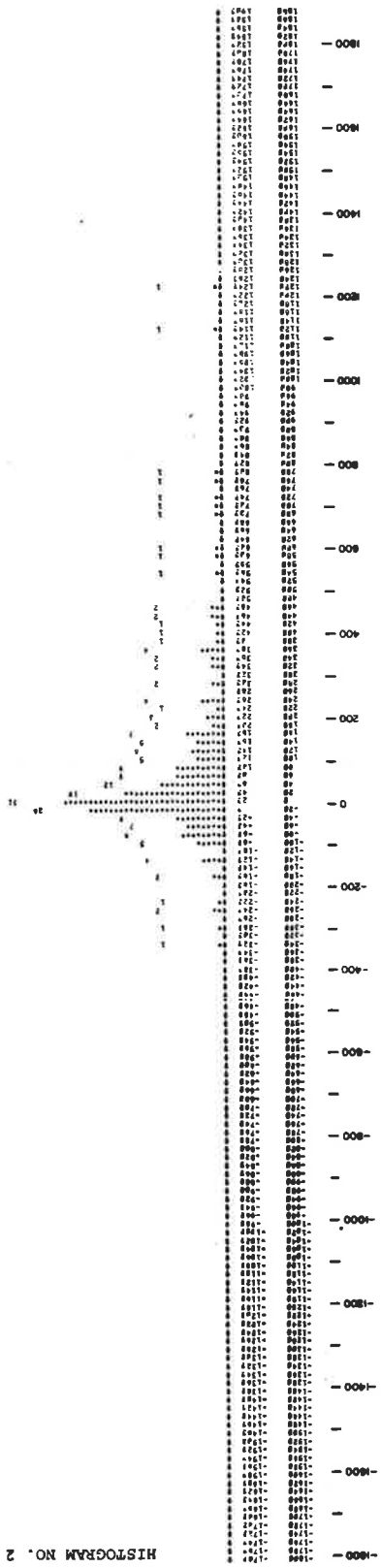
FIGURE 12.

SPECIAL FIXED ROUTES LOCATION ACCURACY HISTOGRAMS

HISTOGRAM NO. 1



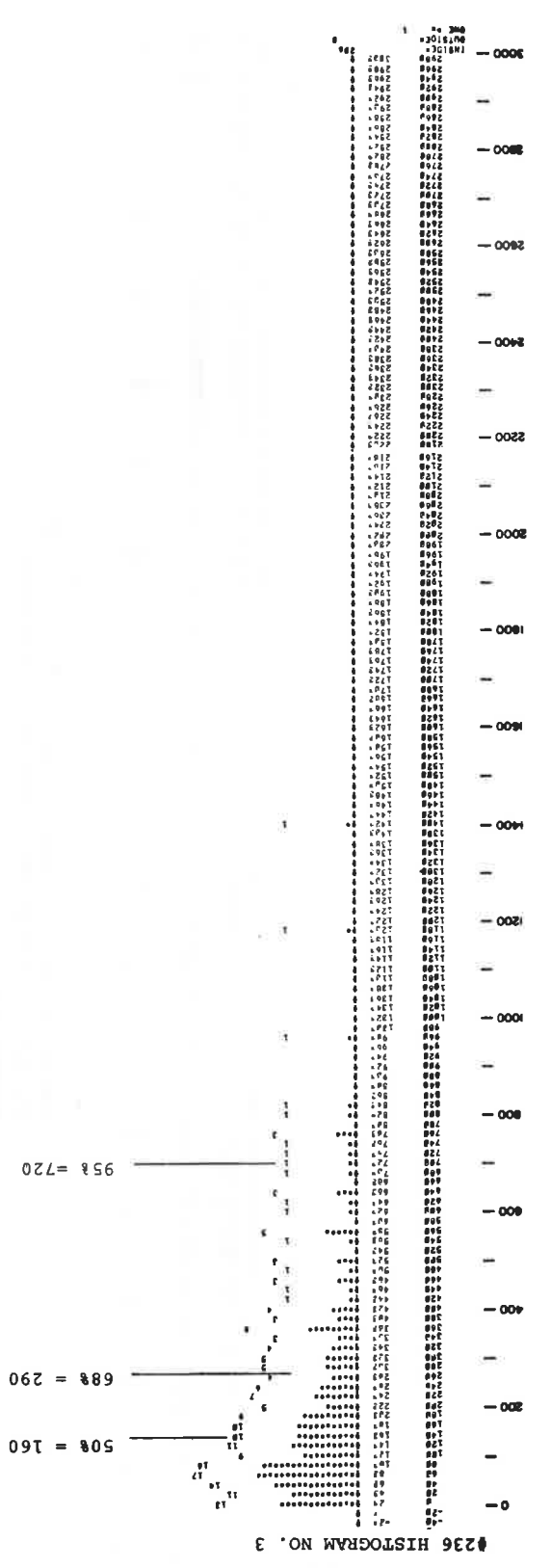
HISTOGRAM NO. 2



Special Fixed Route (A) Location Accuracy Histogram, Small Triangle (LAC), System Level, Check Points Plotted, ID 236

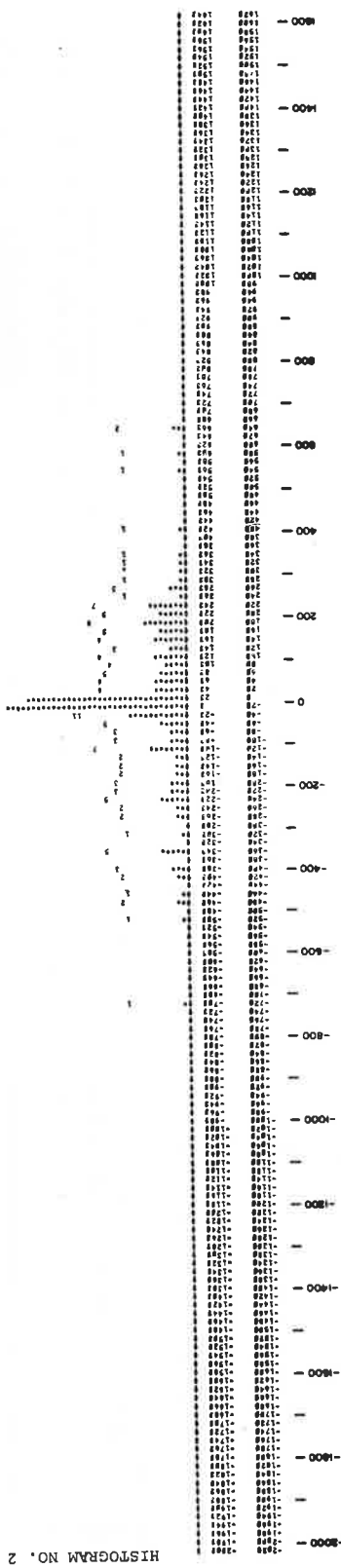
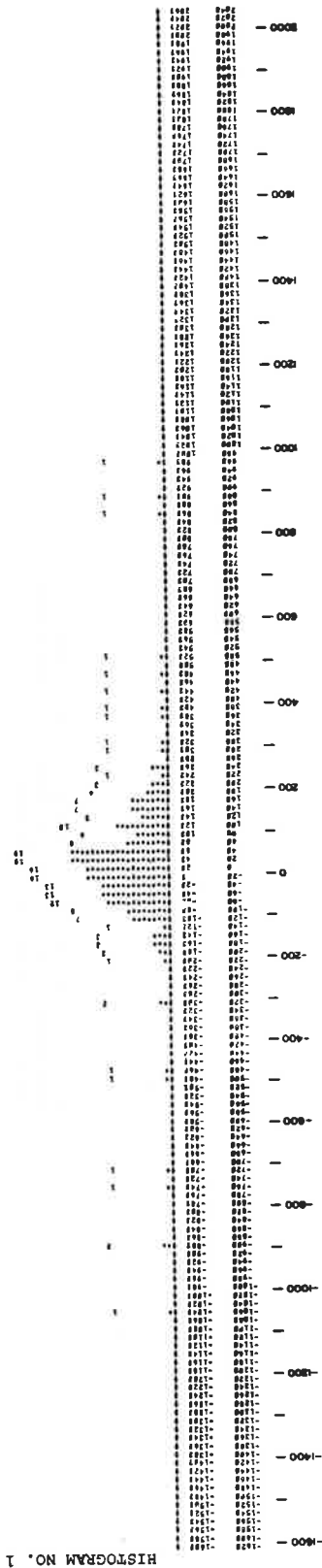
FIGURE 13.





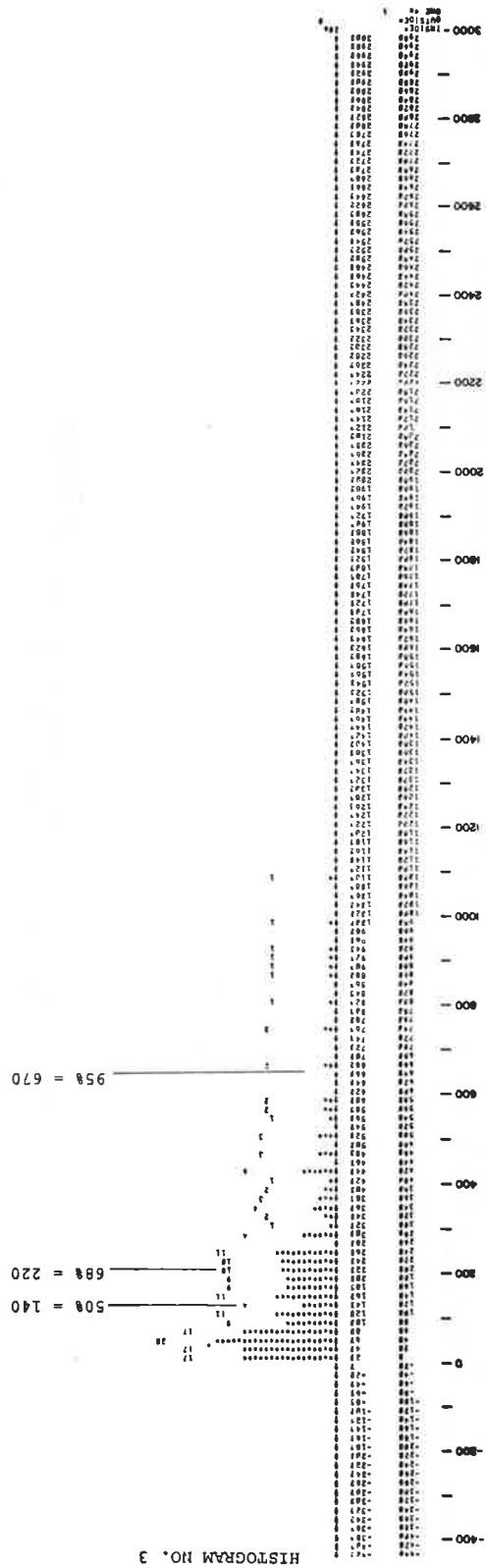
Special Fixed Route (A) Location Accuracy Histogram, Small Triangle (LAC), System Level, Check Points Plotted, ID 236

FIGURE 13. (cont.)



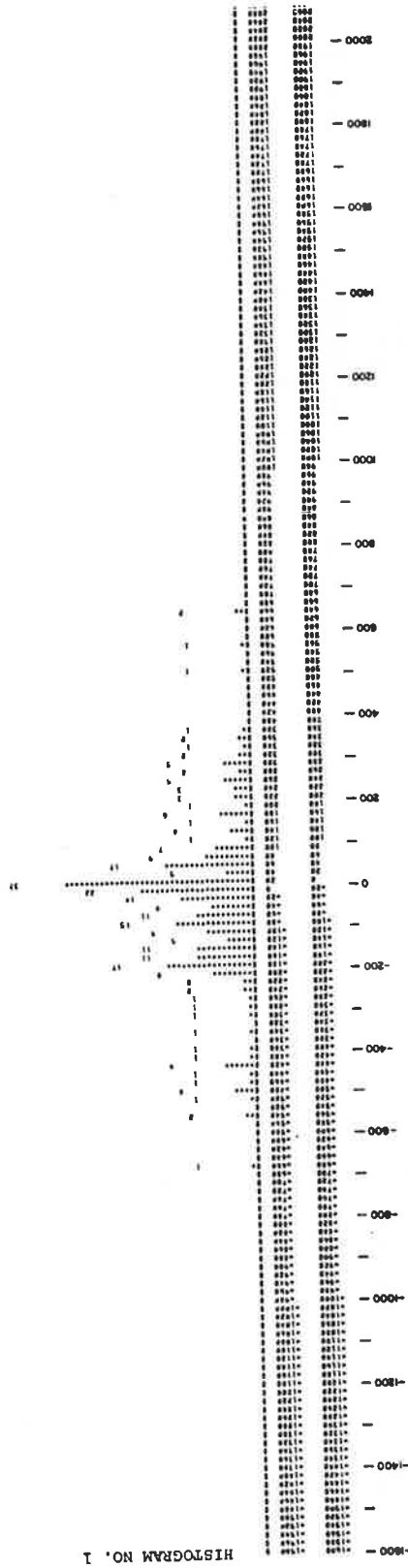
Special Fixed Route (A) Location Accuracy Histogram, Central  
 Downtown Site Triangle (PAC), System Level, Check Points  
 Plotted, ID 235

FIGURE 14.



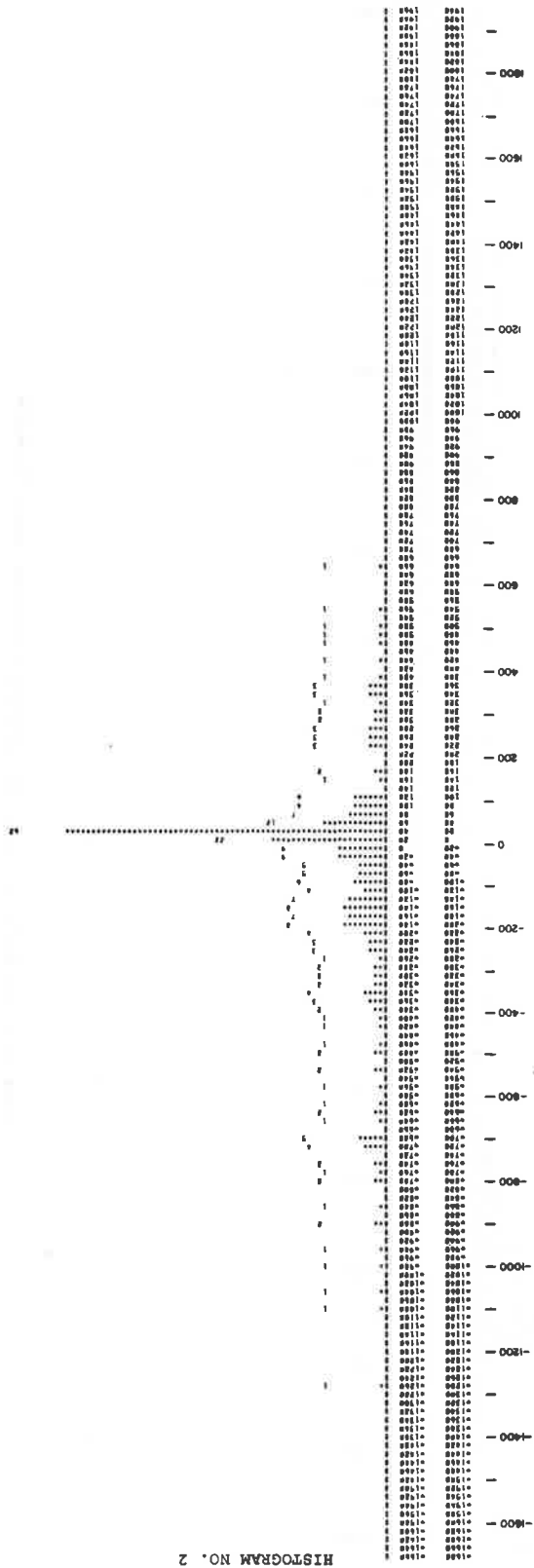
Special Fixed Route (A) Location Accuracy Histogram, Central  
Downtown Site Triangle (PAC), System Level, Check Points  
Plotted, ID 235

FIGURE 14. (cont.)



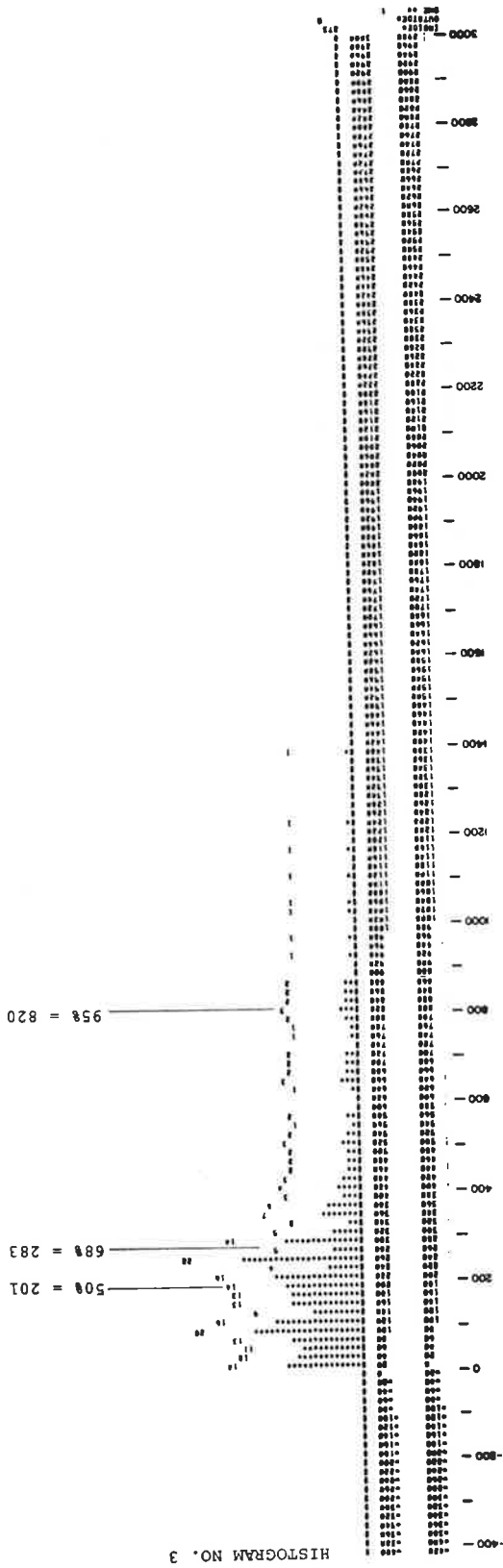
Special Fixed Route (B) Location Accuracy Histogram, Small Triangle (LAC), System Level, Check Points Plotted, ID 232

FIGURE 15.



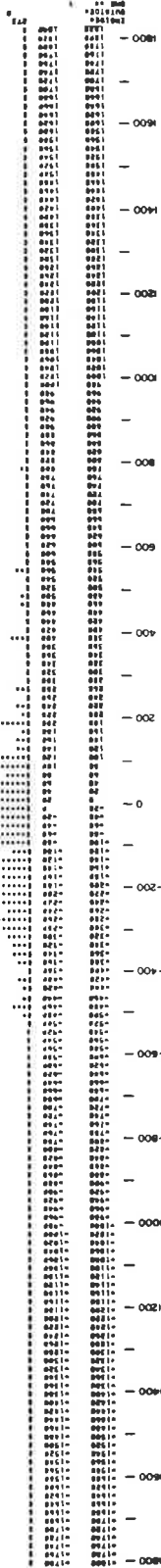
Special Fixed Route (B) Location Accuracy Histogram, Small Triangle (LAC), System Level, Check Points Plotted, ID 232

FIGURE 15. (cont.)



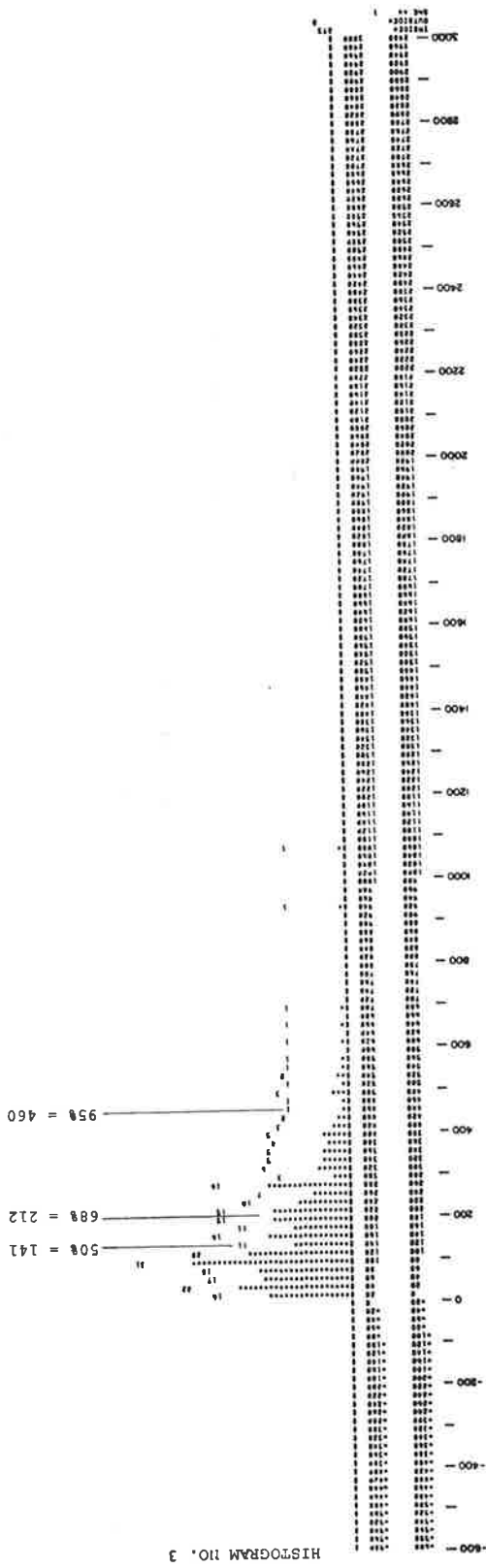
Special Fixed Route (B) Location Accuracy Histogram, Small Triangle  
(LAC), System Level, Check Points Plotted, ID 232

FIGURE 15. (cont.)



Special Fixed Route (B) Location Accuracy Histogram, Central Downtown Site Triangle (LPC), System Level, Check Points Plotted, ID 231

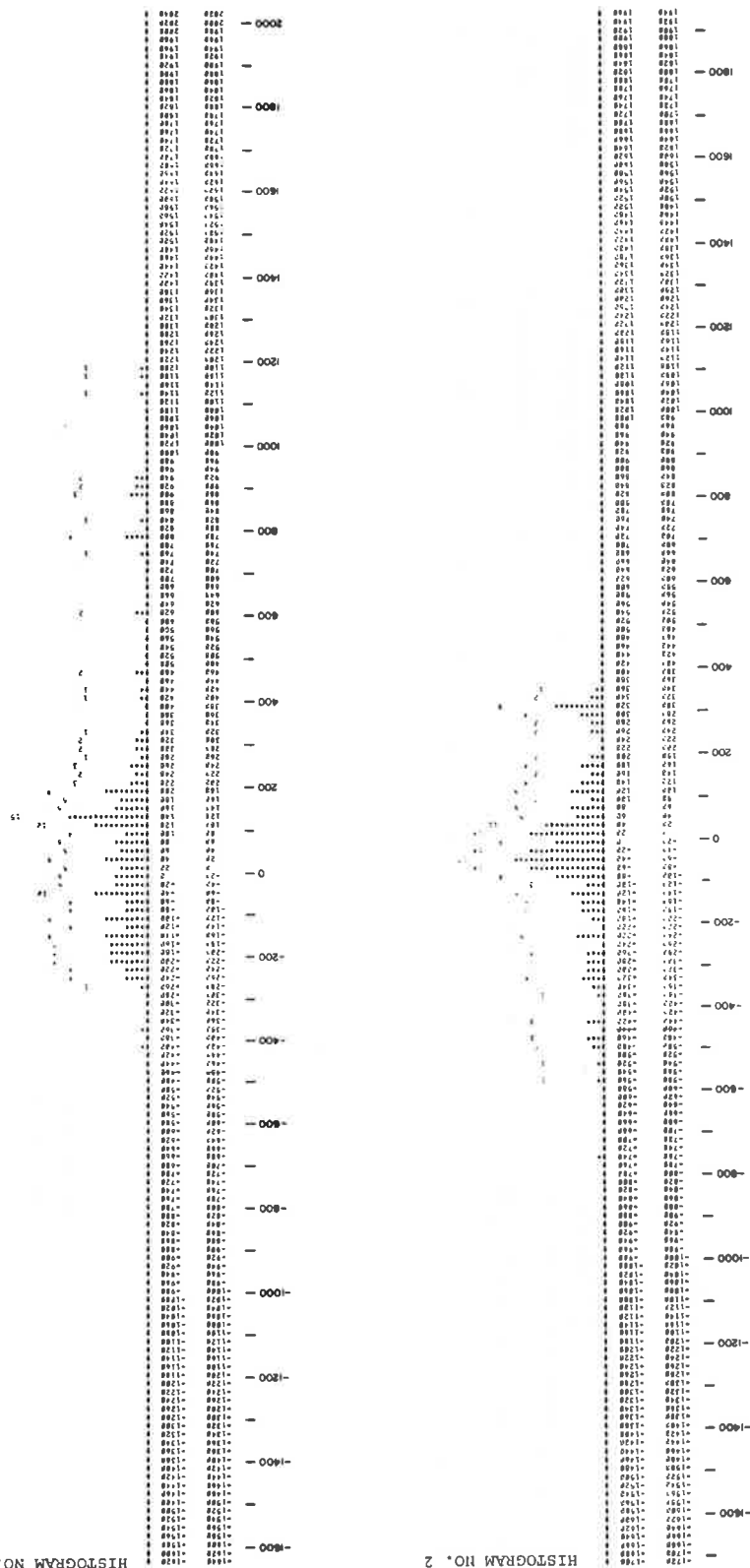
FIGURE 16.



Special Fixed Route (B) Location Accuracy Histogram, Central  
Downtown Site Triangle (LFC), System Level, Check Points Plotted, ID 231

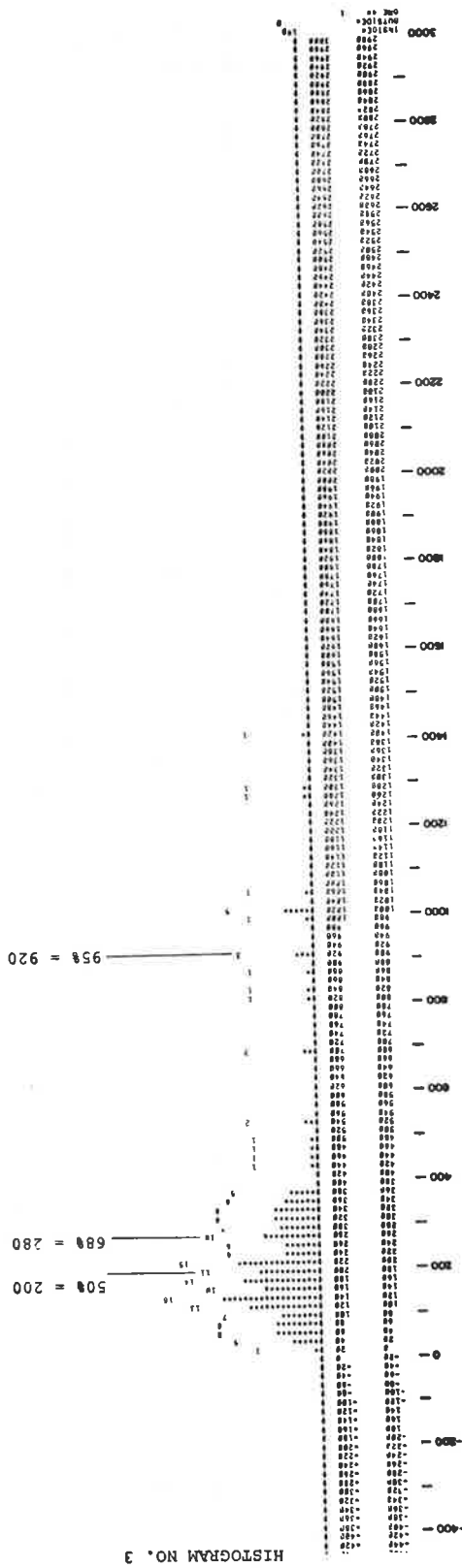
FIGURE 16. (cont.)





Special Fixed Route (C) Location Accuracy Histogram, Small Triangle  
(LAC), System Level, Check points Plotted, ID 230

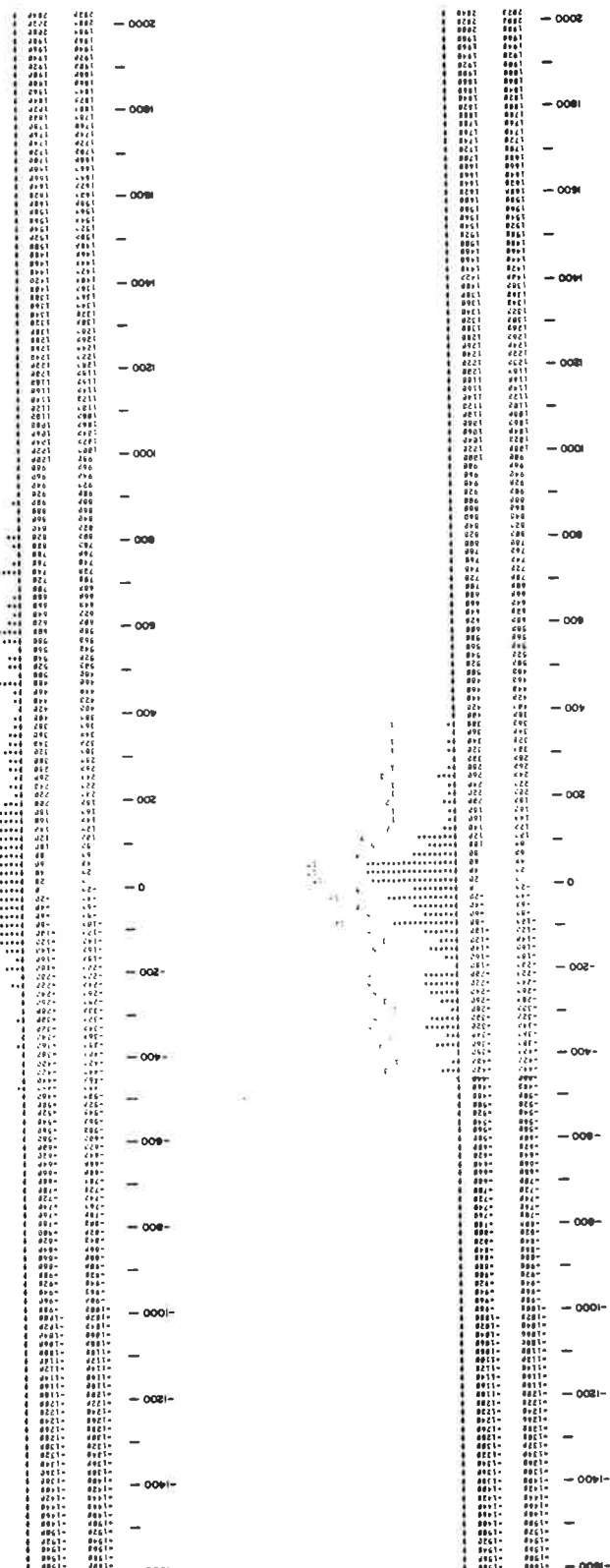
FIGURE 17.



Special Fixed Route (C) Location Accuracy Histogram, Small Triangle (LAC), System Level, Check points Plotted, ID 230

FIGURE 17. (cont.)

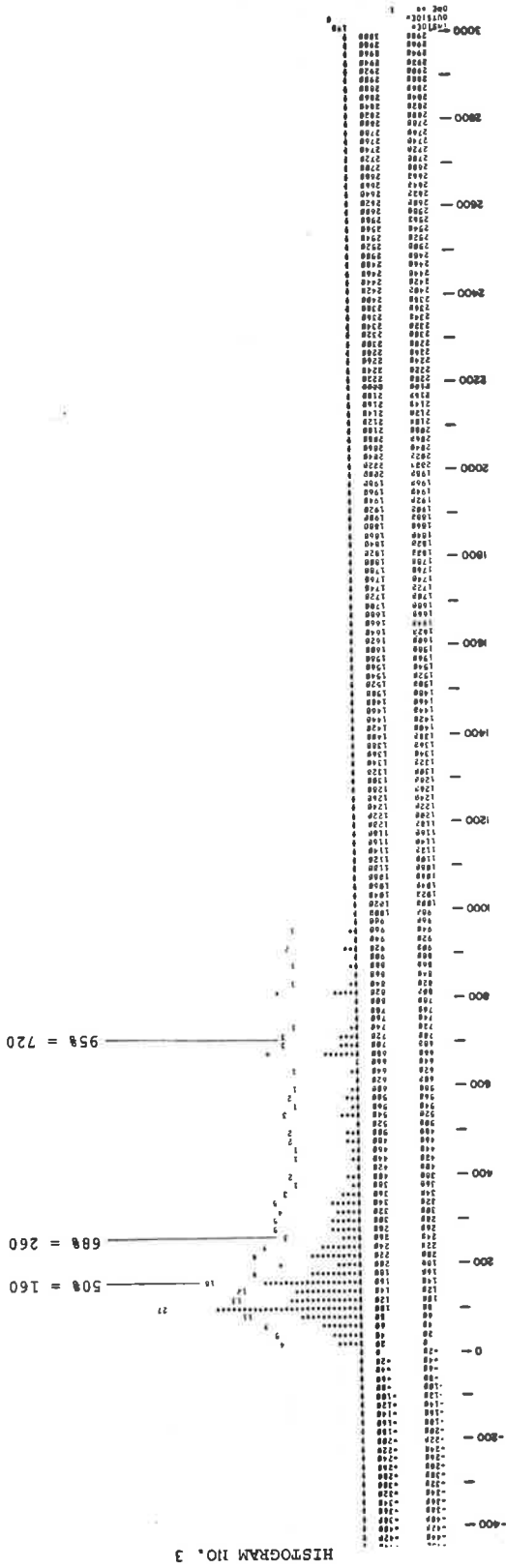
HISTOGRAM NO. 1



HISTOGRAM NO. 2

Special Fixed Route (C) Location Accuracy Histogram, Central Downtown  
 Site triangle (LAP), System Level, Check Points Plotted, ID 229

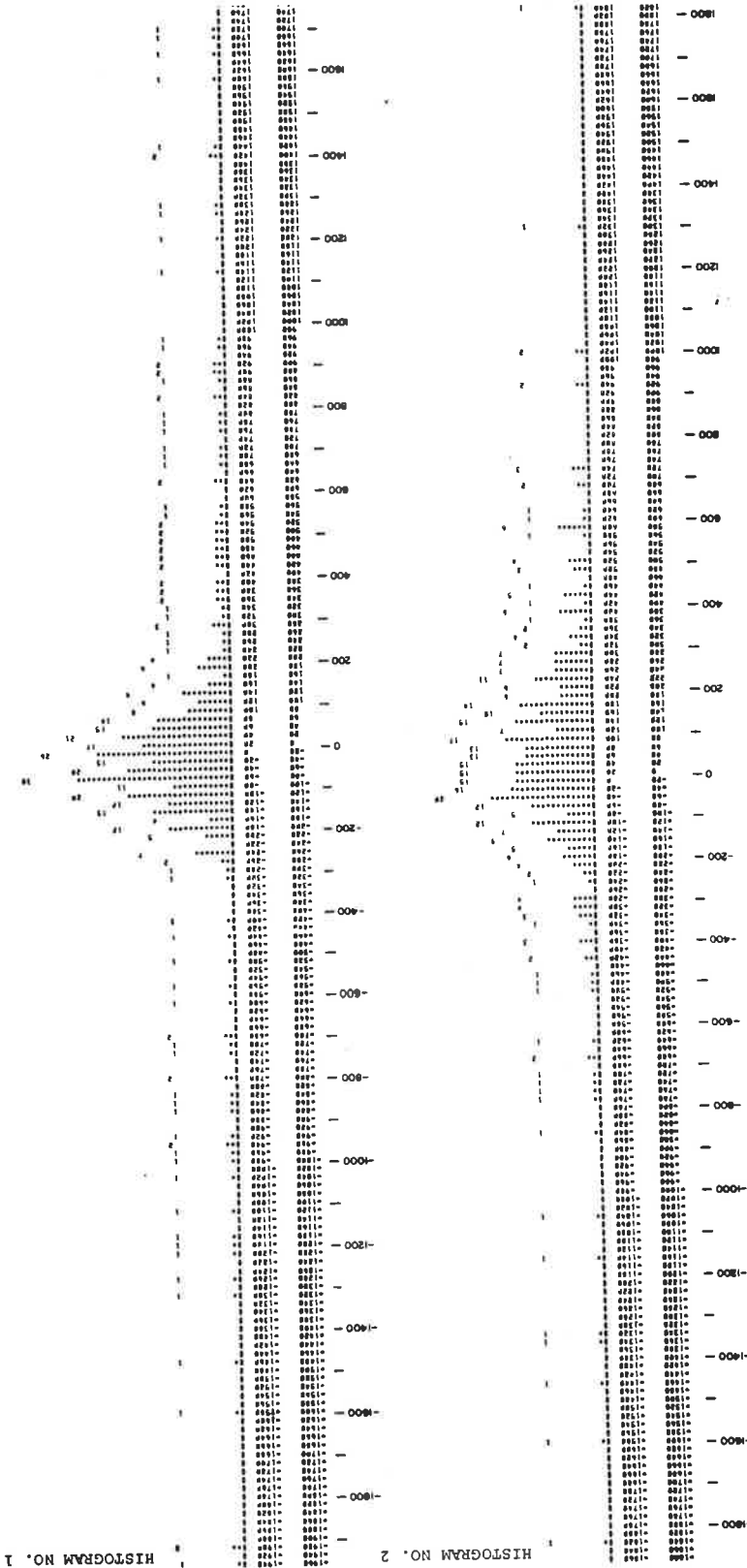
FIGURE 18.



Special Fixed Route (C) Location Accuracy Histogram, Central Downtown Site triangle (LAP), System Level, Check Points Plotted, ID 229

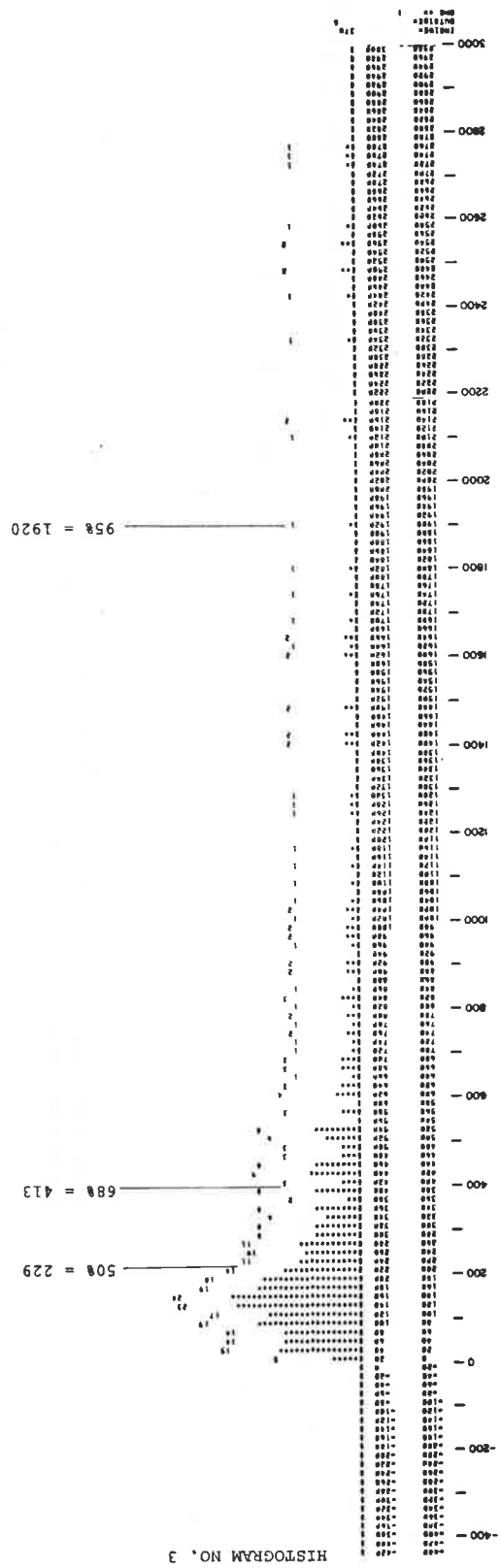
FIGURE 18. (cont.)

RANDOM ROUTE, LARGE TRIANGLE (HAC) HISTOGRAMS



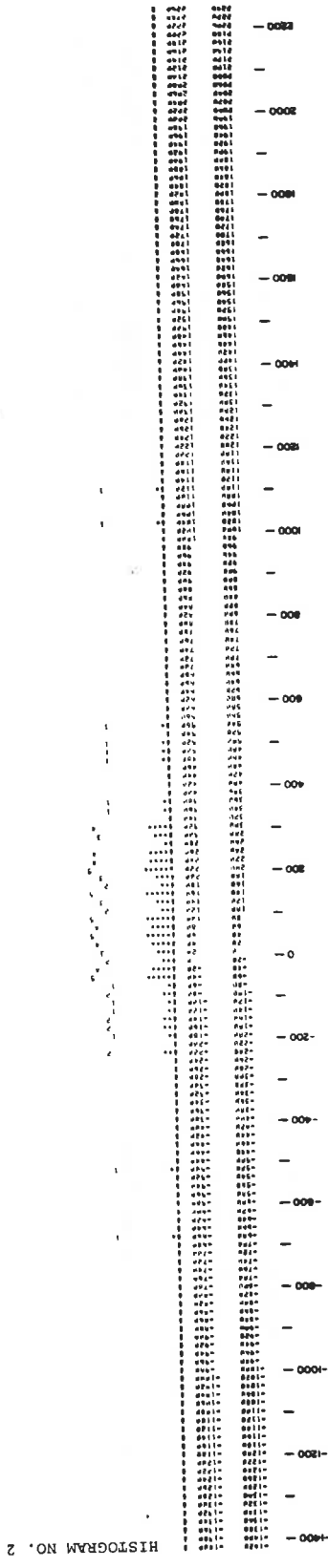
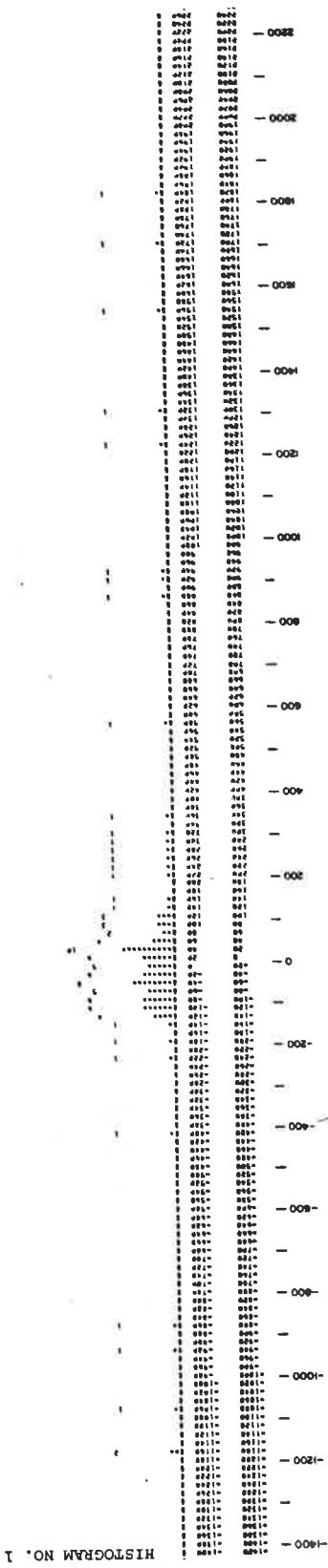
Random Route Location Accuracy Histogram, Large Triangle (RAC), System Level, Before Zero Fill, Check Points Plotted, ID215

FIGURE 19.



Random Route Location Accuracy Histogram, Large Triangle (RAC),  
System Level, before Zero Fill, Check Points Plotted, ID215

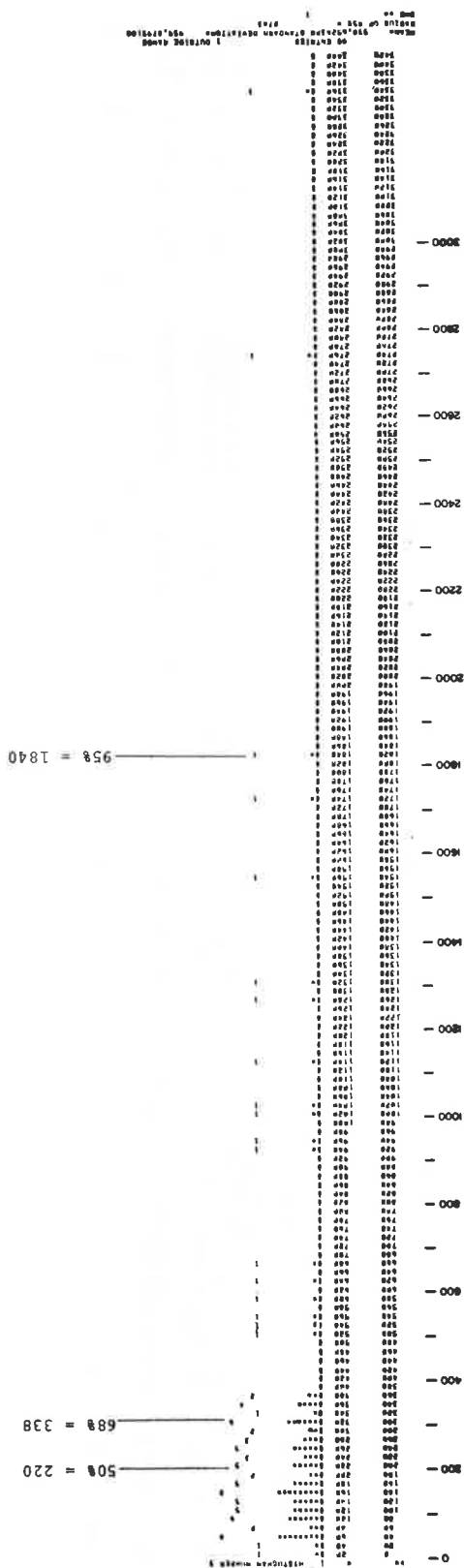
FIGURE 19. (cont.)



Random Route Location Accuracy Histogram, Large-Triangle (HAC),  
System Level, After Zero Fill, Check Points Plotted, ID214-CF

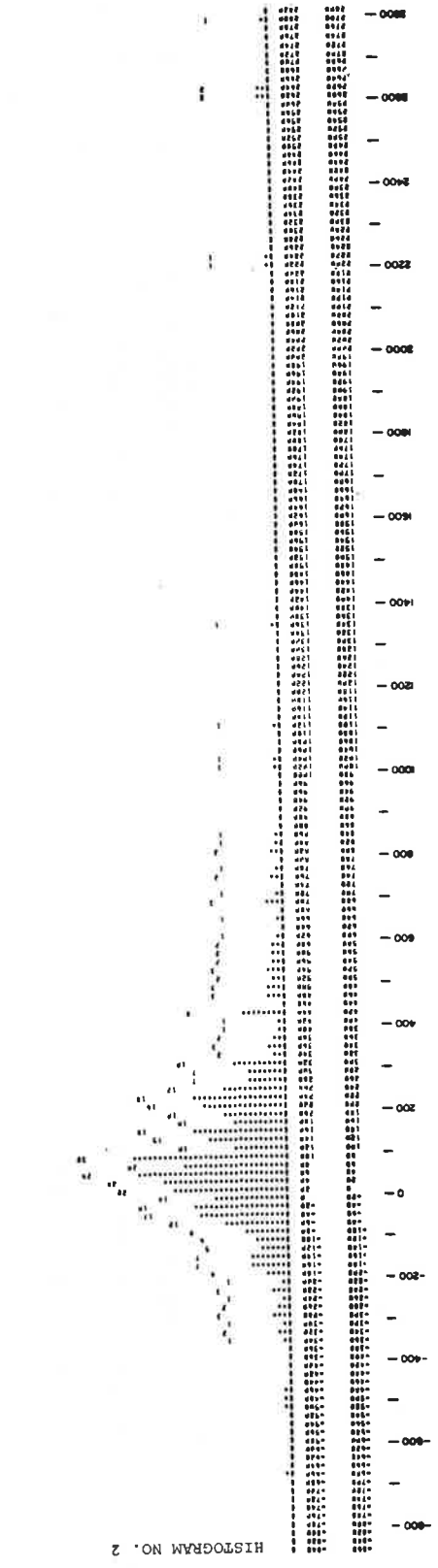
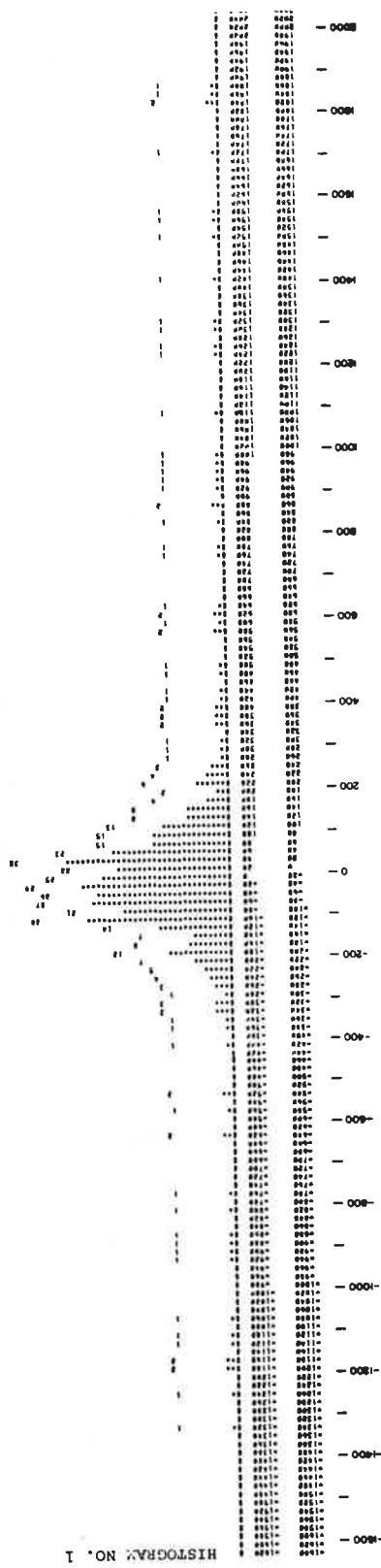
FIGURE 20.





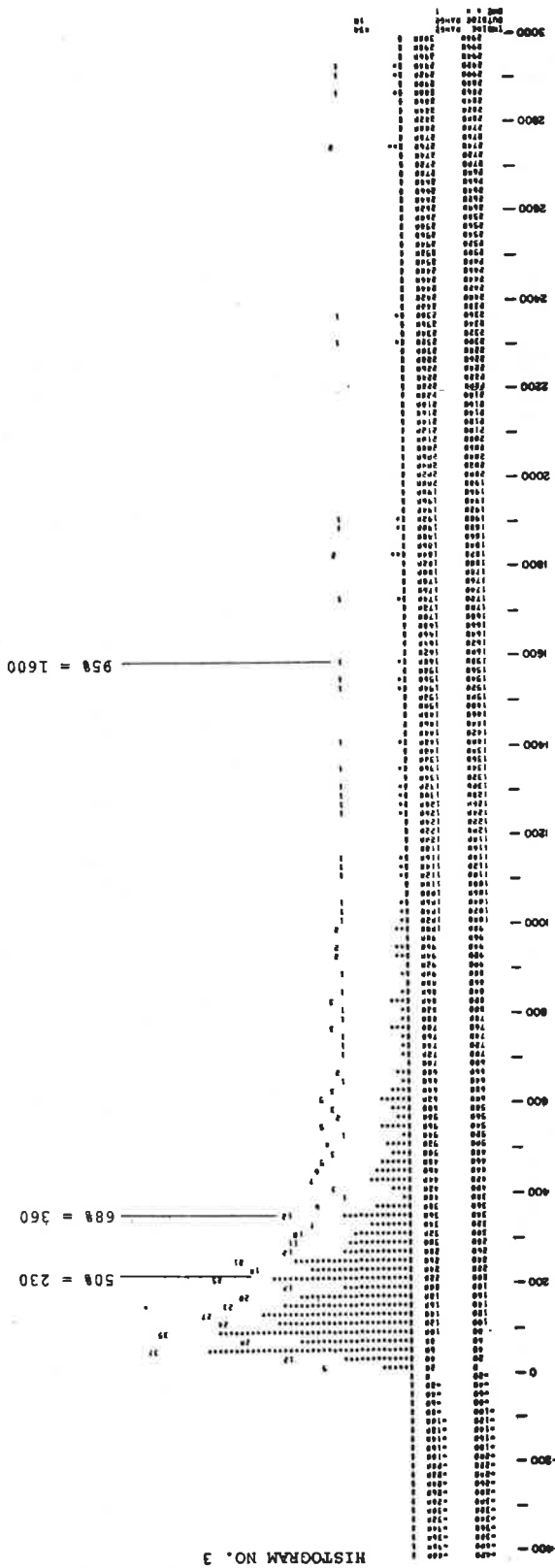
Random Route Location Accuracy Histogram, Large Triangle (RAC), System Level, After Zero Fill, Check Points Plotted, ID214-CP

FIGURE 20. (cont.)



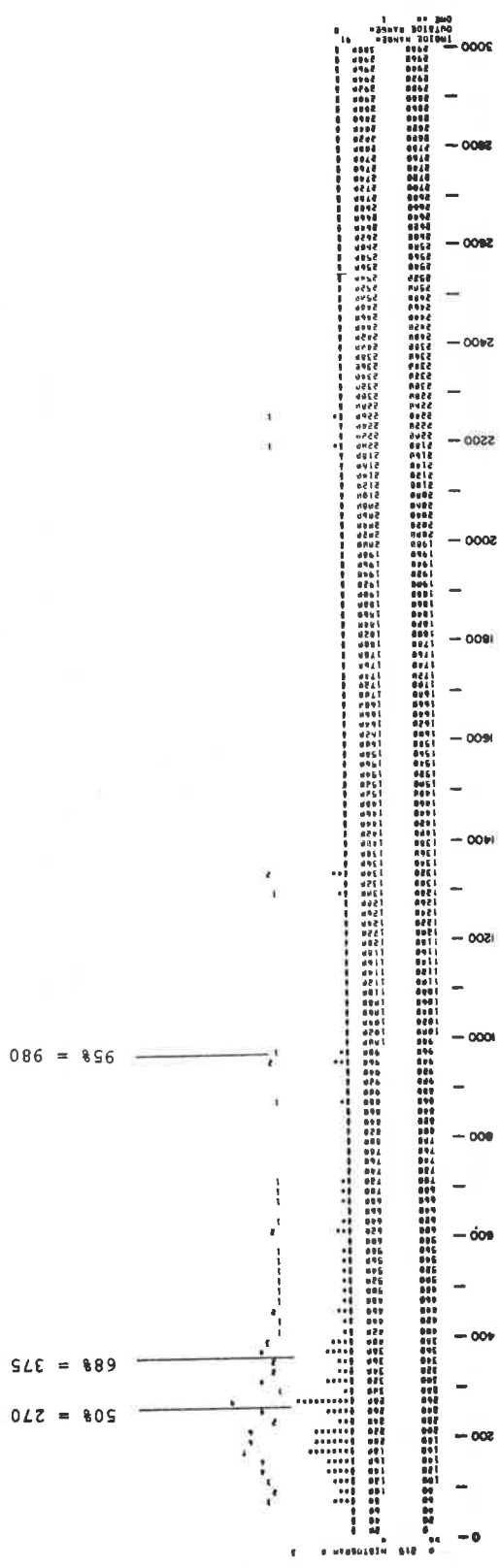
Random Route Location Accuracy Histogram, Large Triangle (HAC),  
System Level, After Zero Fill, All 10-Second Data Samples, ID214-EX

FIGURE 21.



Random Route Location Accuracy Histogram, Large Triangle (HAC),  
System Level, After zero Fill, All 10-Second Data Samples, ID214-EX

FIGURE 21. (cont.)



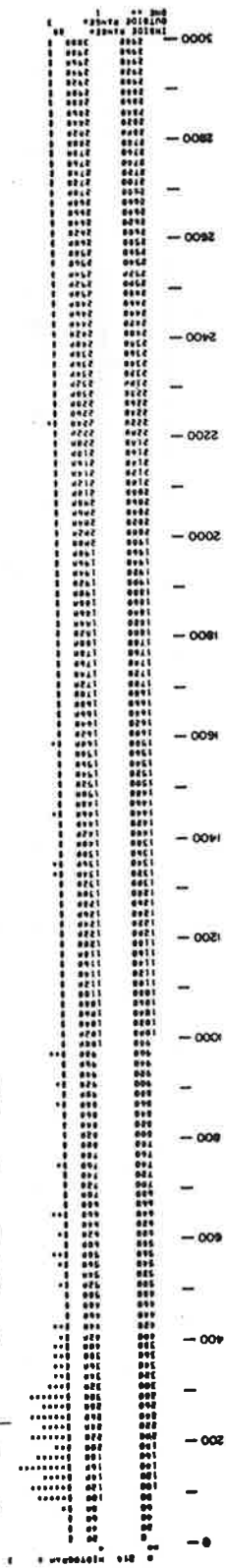
Tenth Mile Average Radial Error Histogram,  
 Random Route, Large Triangle (HAC), System  
 Level, 10 Second Data, Before Zero Fill,  
 ID 215AV, Test 3

FIGURE 22.

956 = 1460

688 = 340

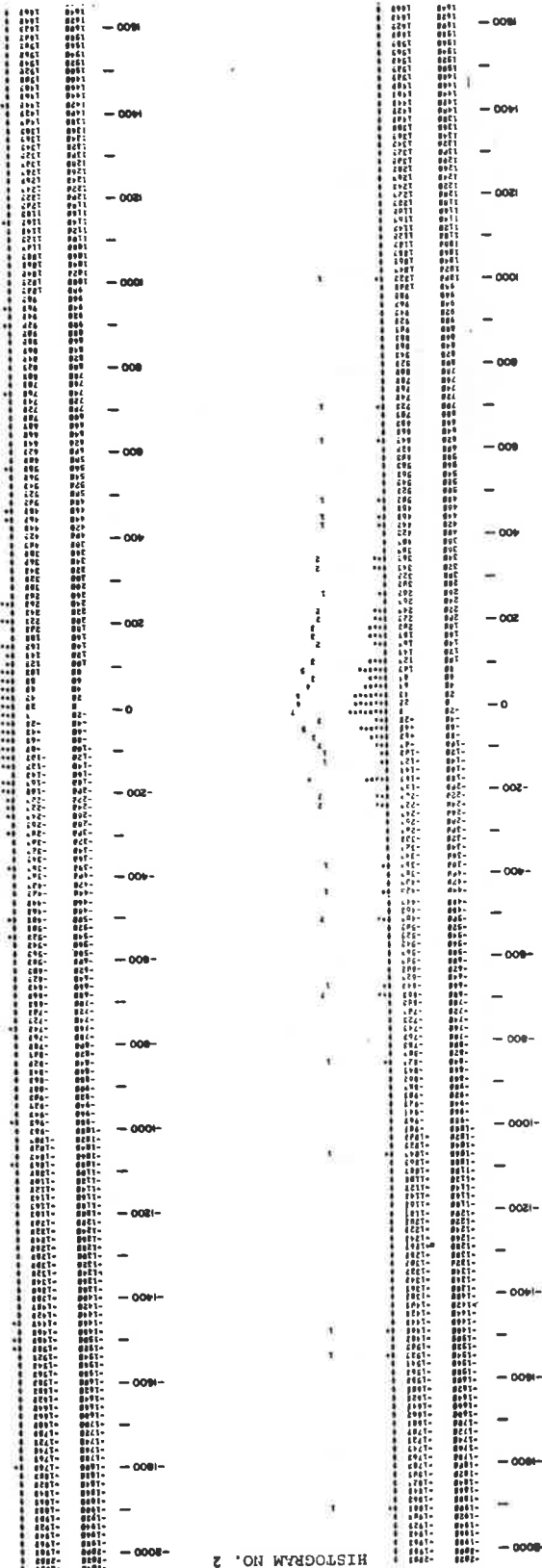
508 = 253



Tenth Mile Average Radial Error Histogram,  
Random Route, Large Triangle (HAC), System  
Level, 10 Second Data, After Zero Fill,  
ID 214AV, Test 6

FIGURE 23.

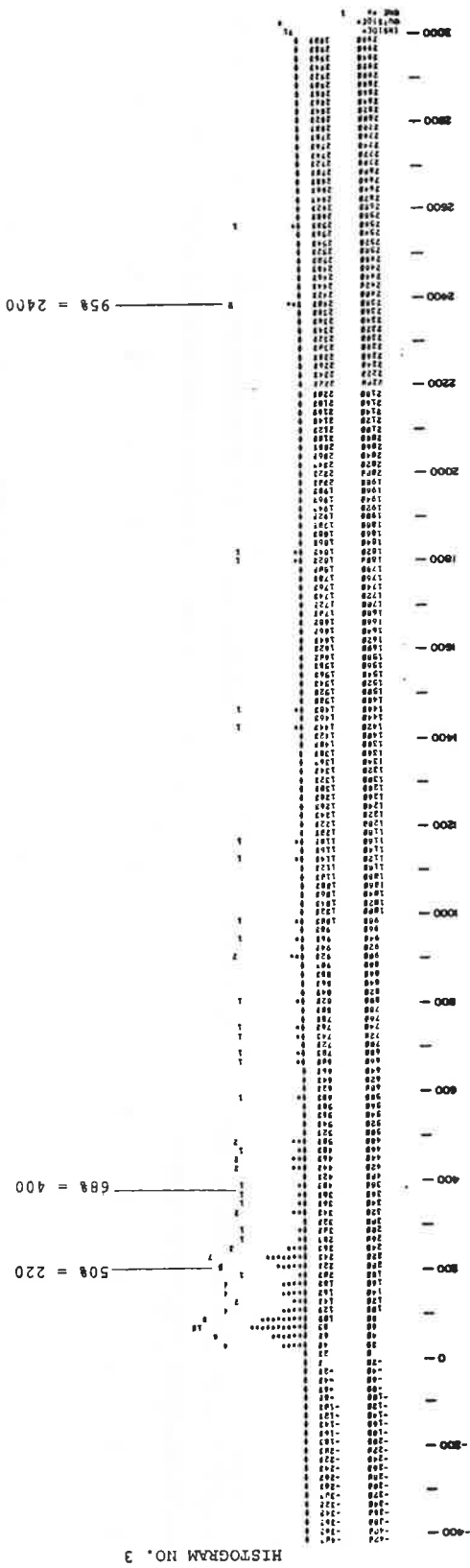
HISTOGRAM NO. 1



HISTOGRAM NO. 2

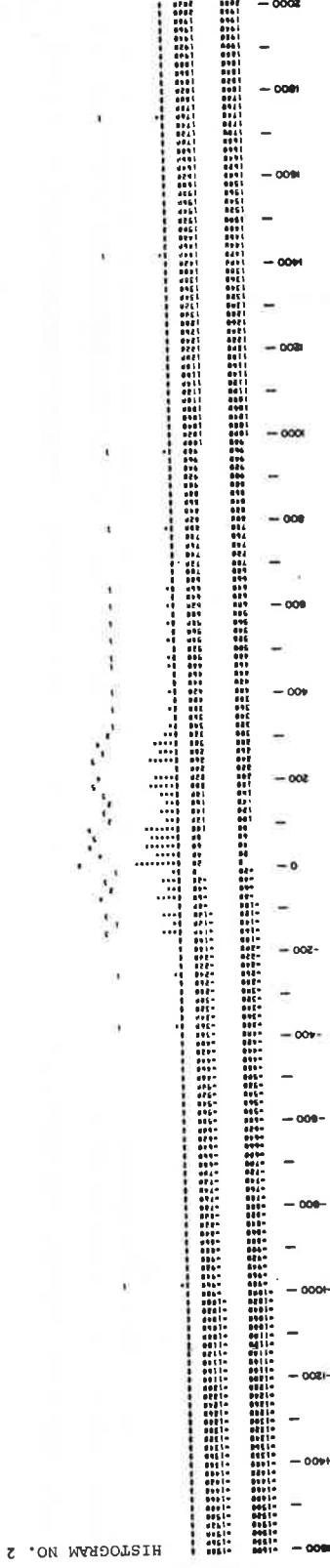
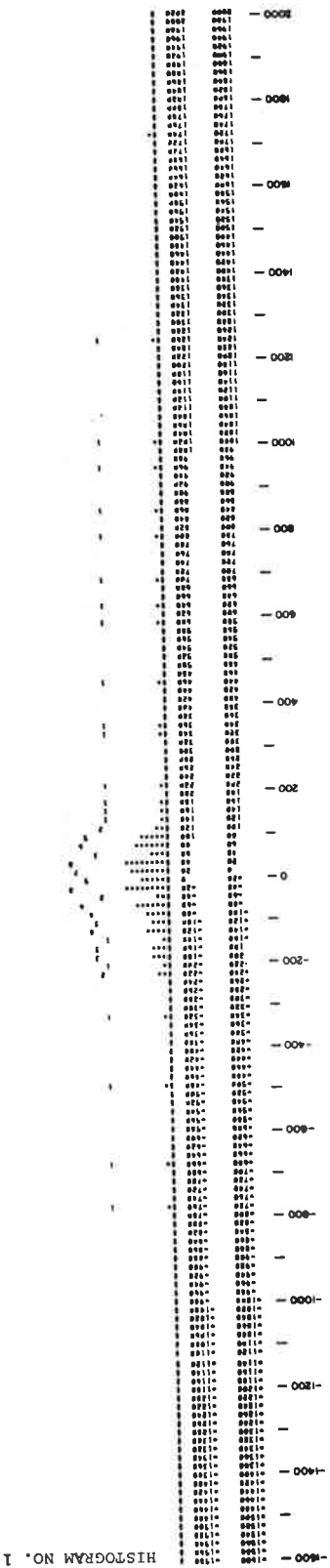
Random Route Location Accuracy Histogram, Large Triangle (HAC),  
 Subsystem Level, Before Zero Fill, Check Points at 0.1 Second  
 Update Rate, ID228

FIGURE 24.



Random Route Location Accuracy Histogram, Large Triangle (HAC),  
 Subsystem Level, Before Zero Fill, Check Points at 0.1 Second  
 Update Rate, ID228

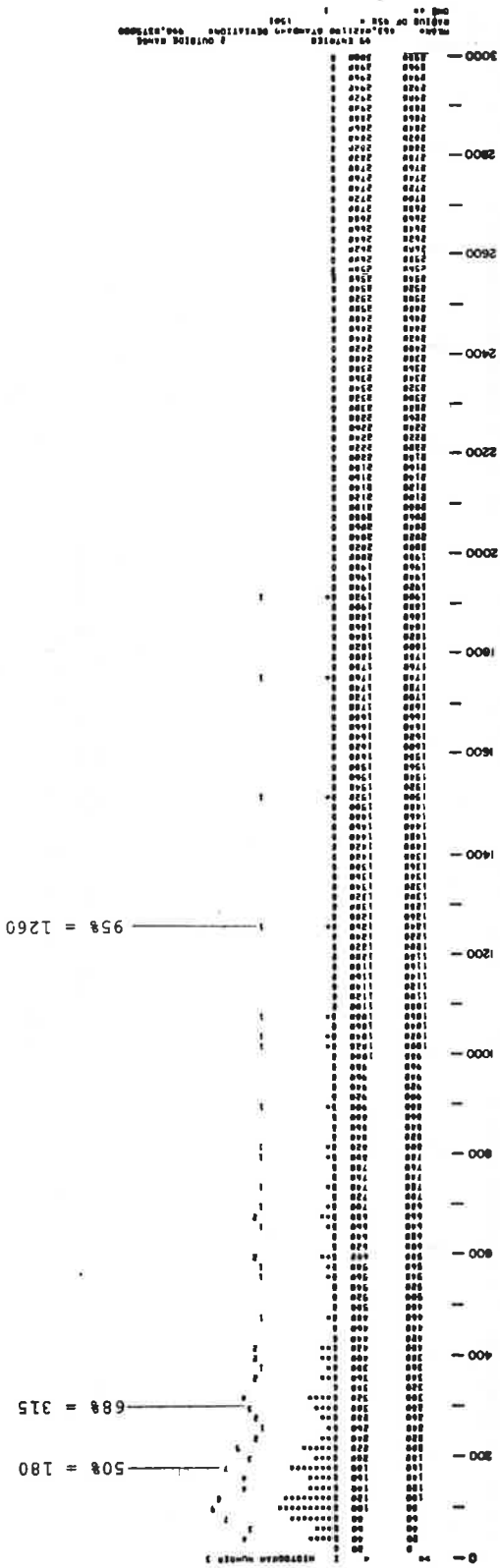
FIGURE 24. (cont.)



Random Route Location Accuracy Histogram, Large Triangle (HAC)  
 Subsystem Level, After Zero Fill, Check Points at 0.1 Second  
 Update Rate, ID221

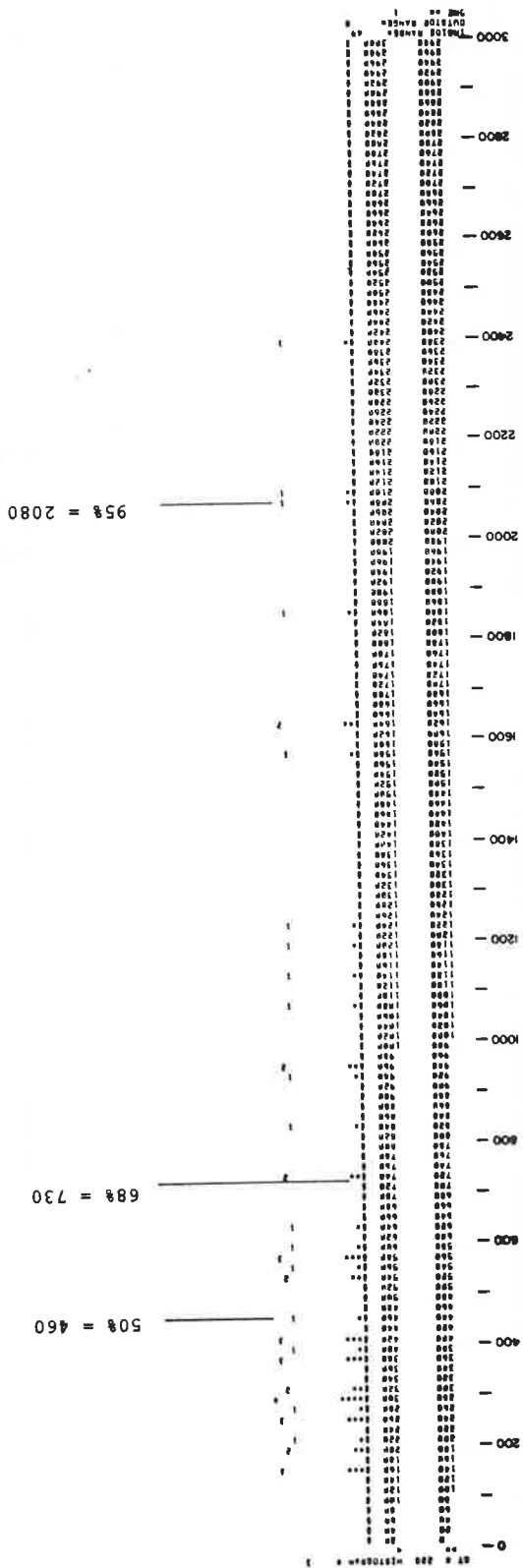
FIGURE 25.





Random Route Location Accuracy Histogram, Large Triangle (HAC)  
 Subsystem Level, After Zero Fill, Check Points at 0.1 Second  
 Update Rate, ID221

FIGURE 25. (cont.)



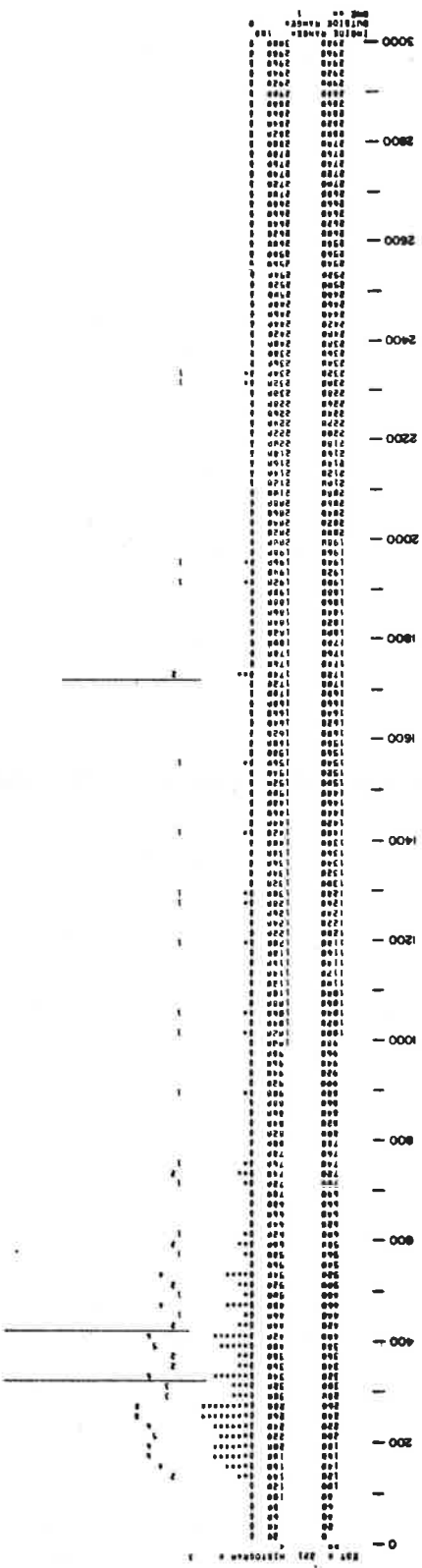
Tenth Mile Average Radial Error Histogram,  
 Random Route, Large Triangle (HAC), Subsystem  
 Level, 0.1 Second Data, Before Zero Fill,  
 ID 228AV, Test 1

FIGURE 26.

95% = 1730

68% = 430

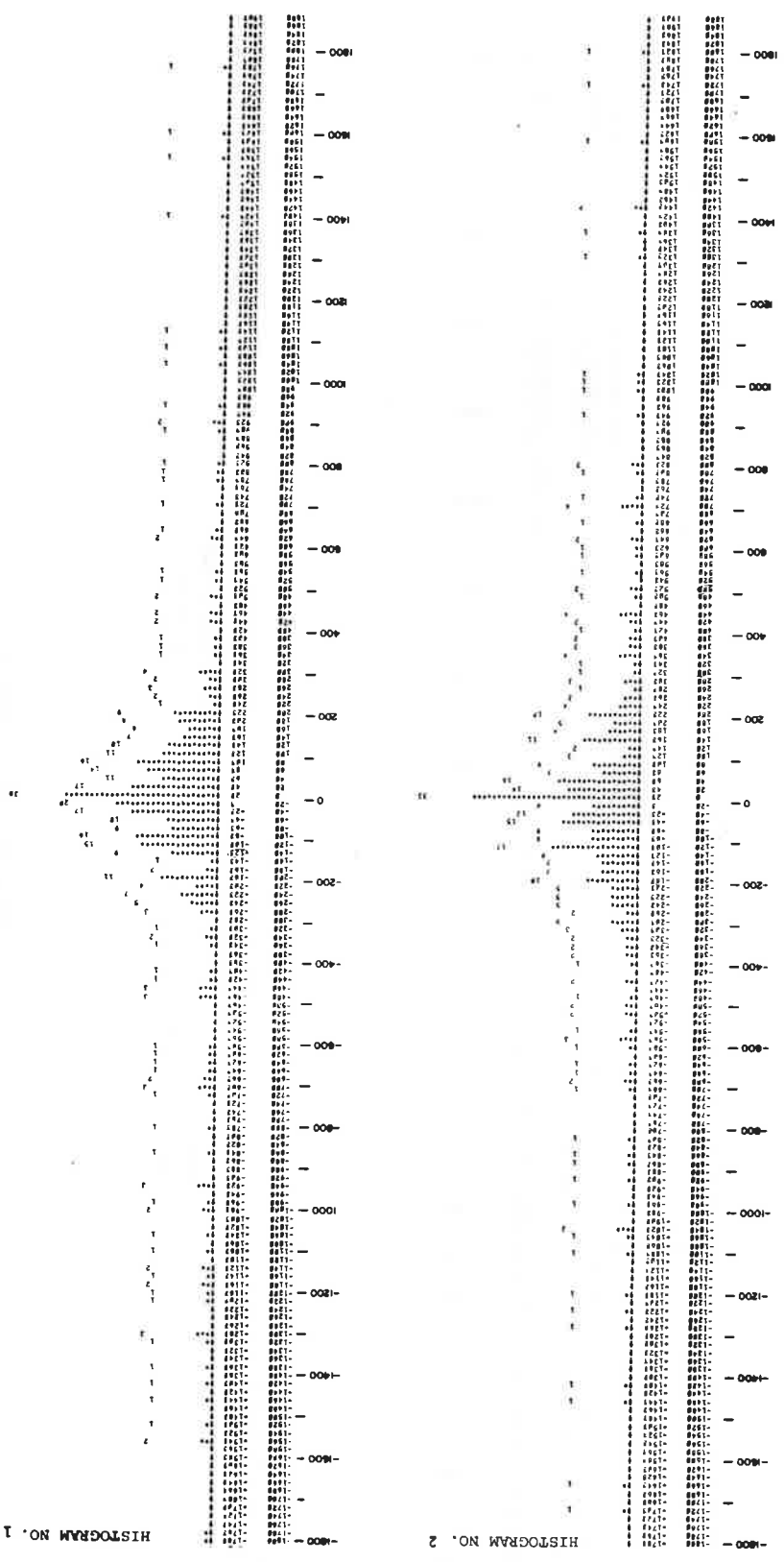
50% = 330



Tenth Mile Average Radial Error Histogram,  
 Random Route, Large Triangle (HAC), Subsystem  
 Level, 0.1 Second Data, After Zero Fill,  
 ID 221AV, Test 6

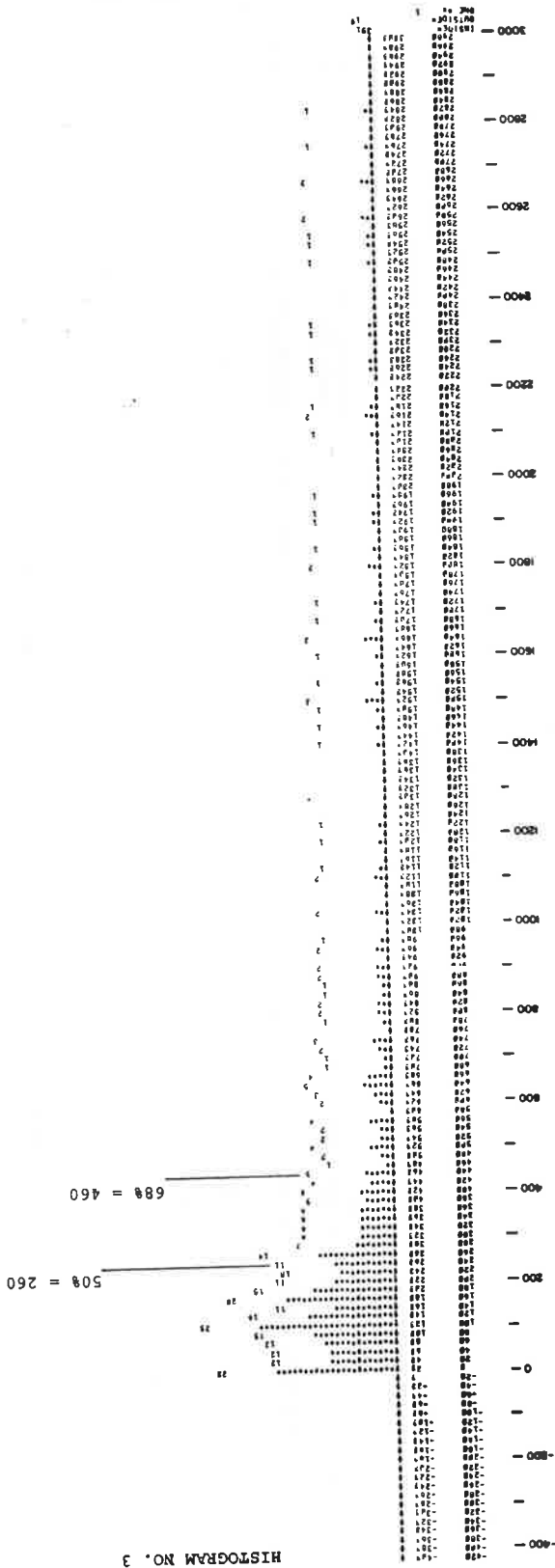
FIGURE 27.

RANDOM ROUTE, SMALL TRIANGLE (LAC) HISTOGRAMS



Random Route Location Accuracy Histogram, Small Triangle (IAC), System Level, Before Zero Fill, Check Point Plotted, ID 227

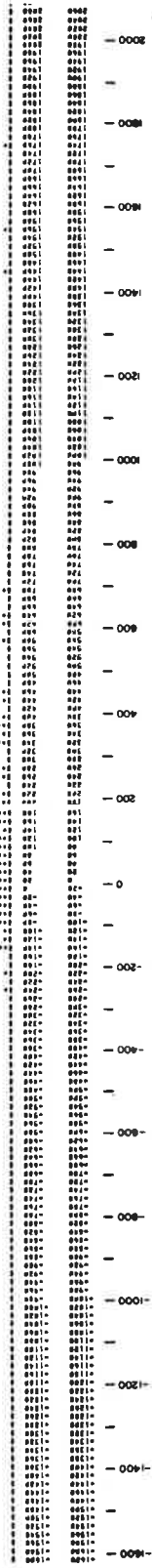
FIGURE 28.



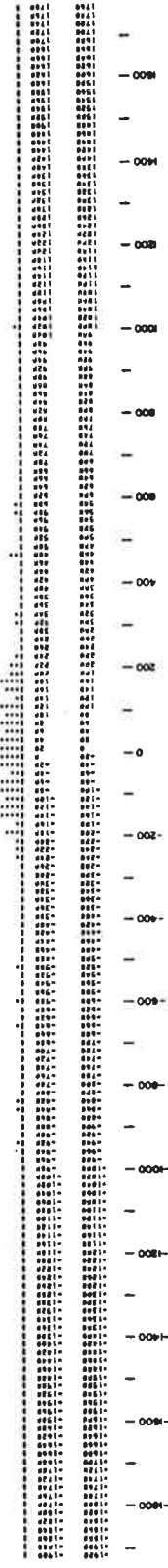
Random Route Location Accuracy Histogram, Small Triangle (LAC),  
System Level, Before Zero Fill, Check Point Plotted, ID 227

FIGURE 28. (cont.)

HISTOGRAM NO. 1

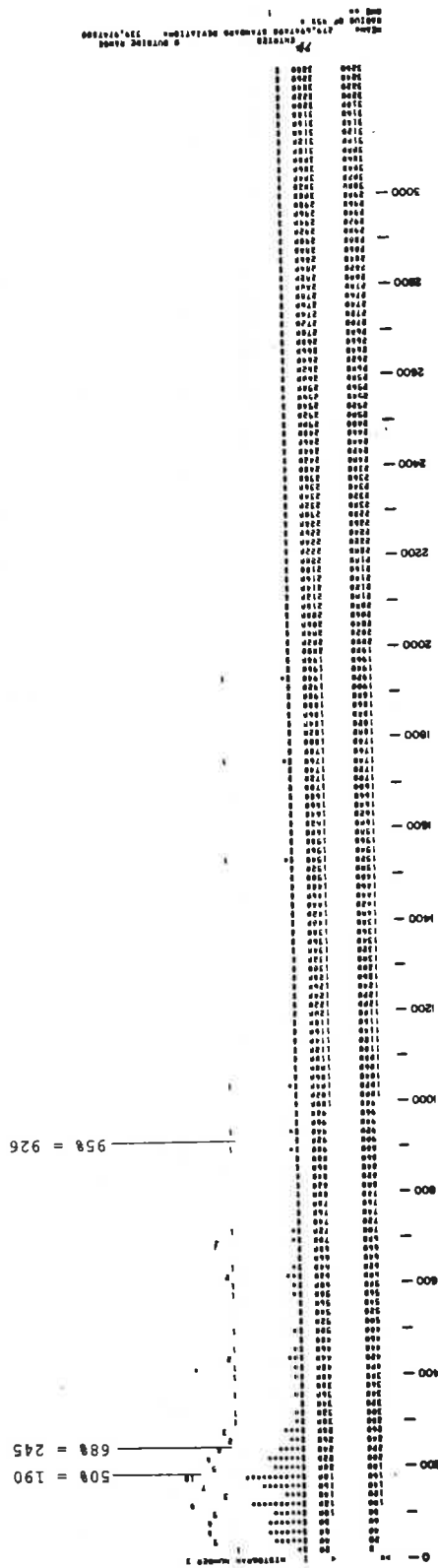


HISTOGRAM NO. 2



Random Route Location Accuracy Histogram, Small Triangle (LAC),  
System Level, After zero fill, Check Points Plotted, ID209-CP

FIGURE 29.



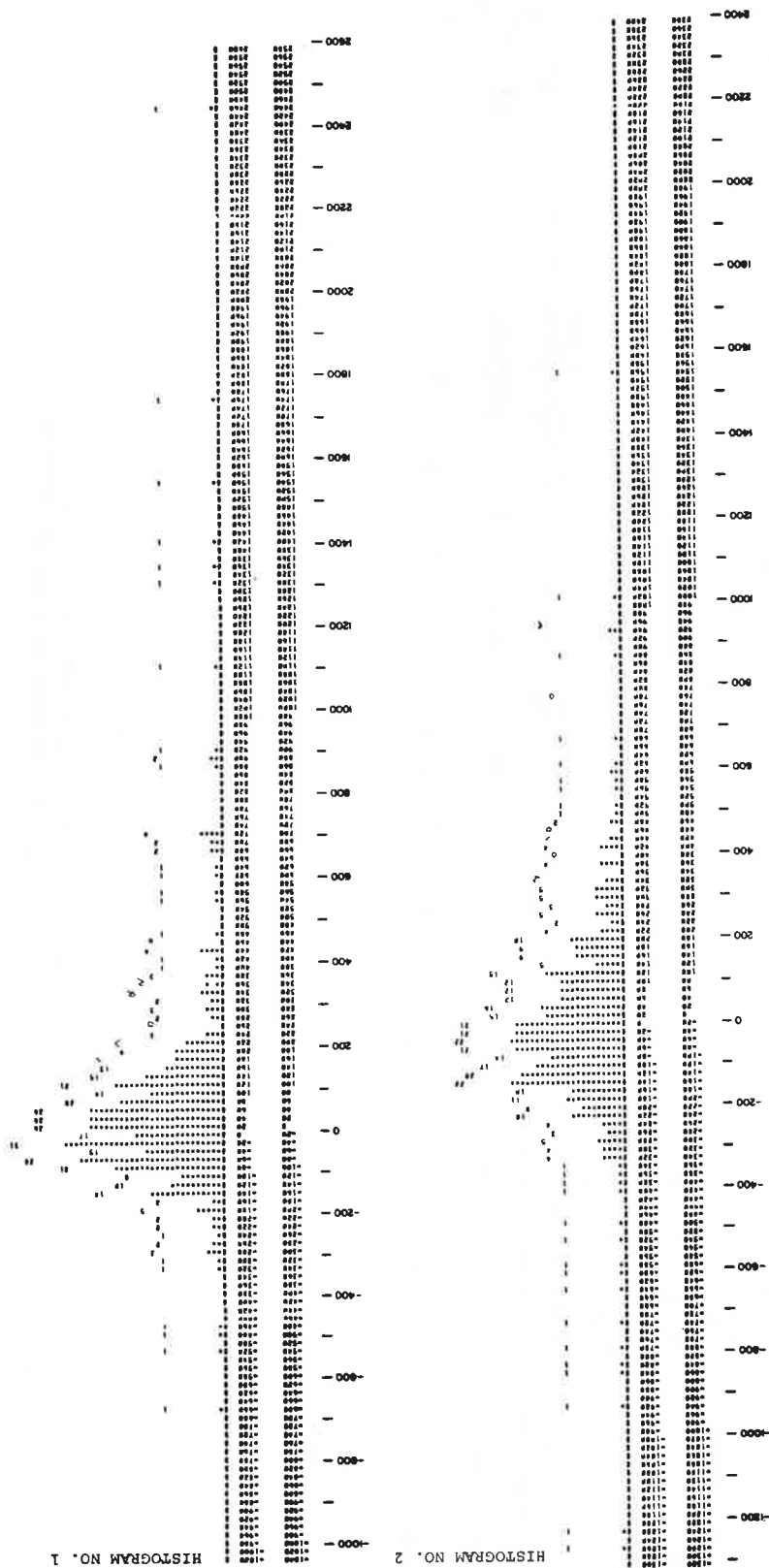
Random Route Location Accuracy Histogram, Small Triangle (LAC),  
System Level, After zero Fill, Check Points Plotted, ID209-CP

FIGURE 29. (cont.)



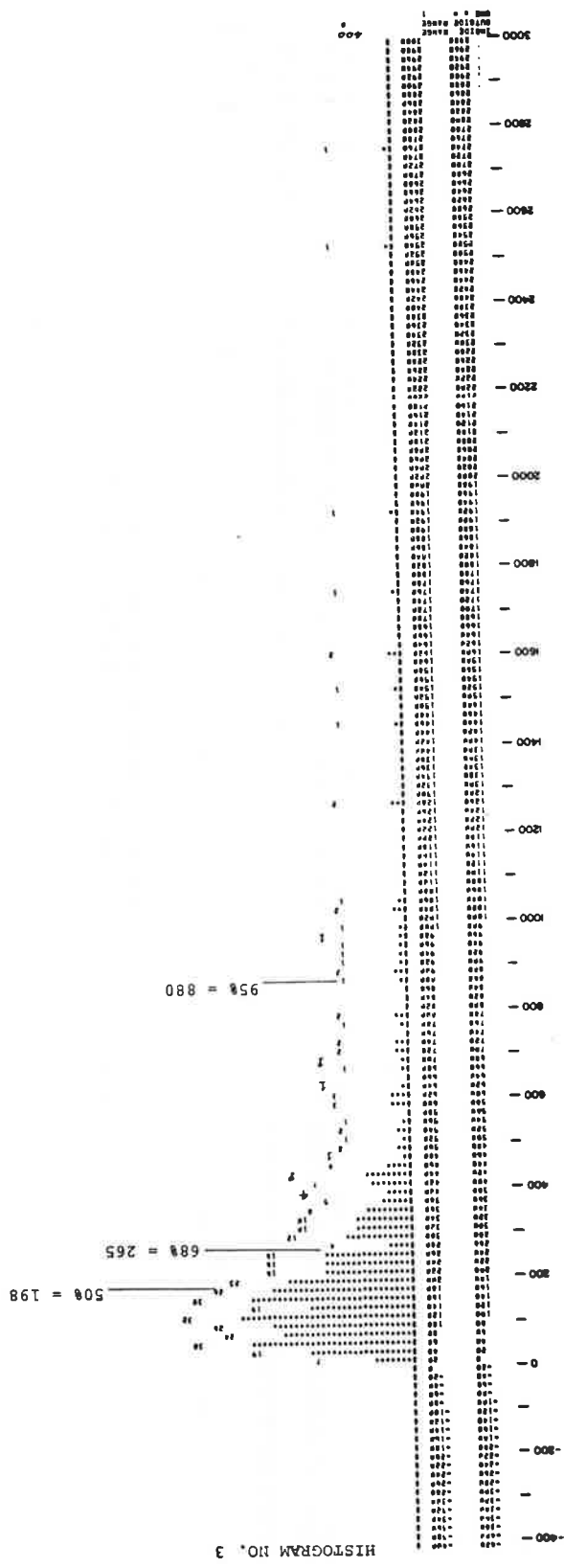
HISTOGRAM NO. 1

HISTOGRAM NO. 2



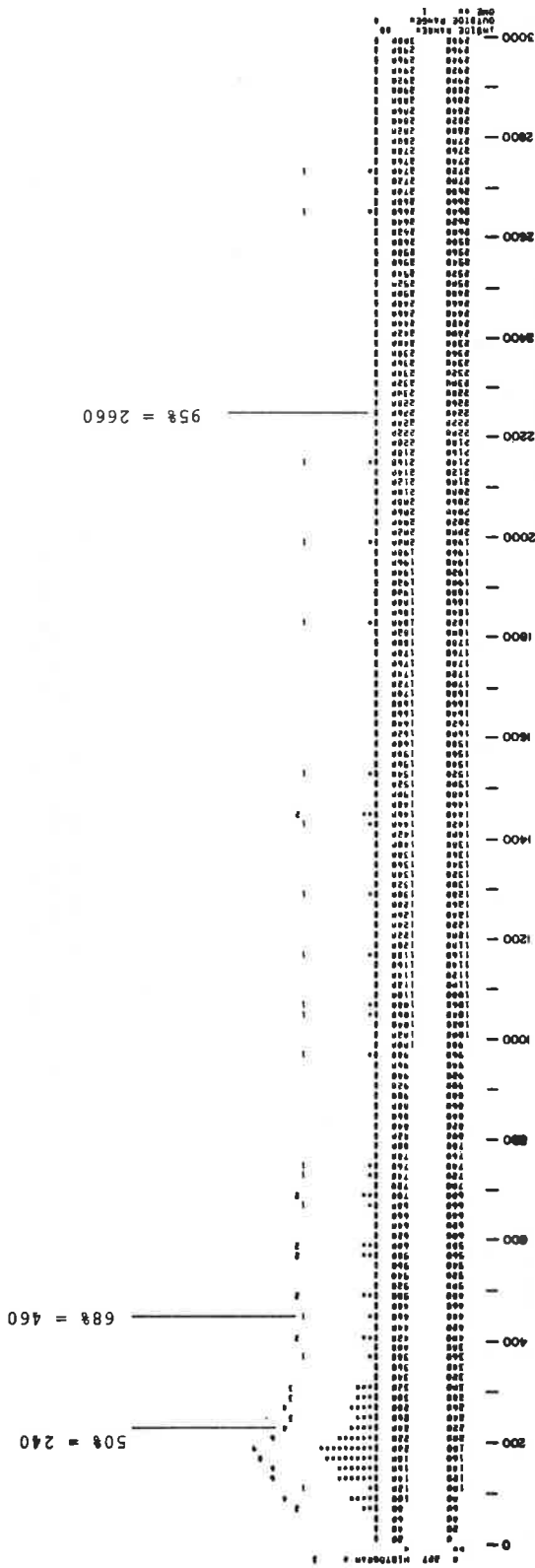
Random Route Location Accuracy Histogram, Small Triangle (LAC),  
 System Level, After Zero Fill, all 10-Second Data Samples, ID209-EX

FIGURE 30.



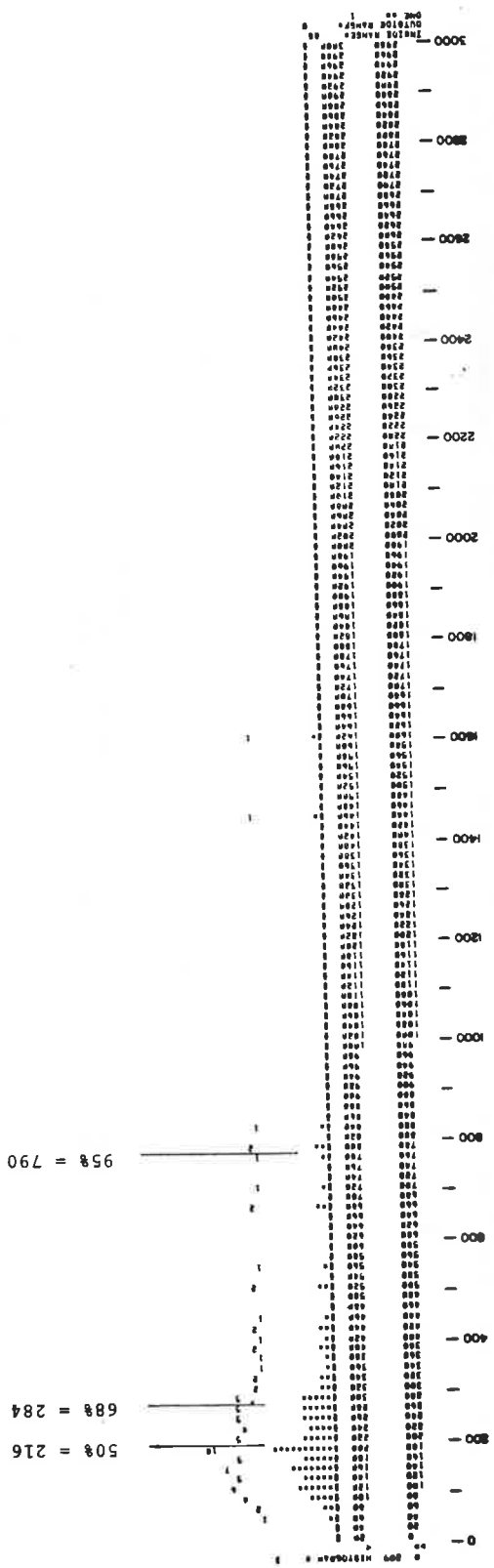
Random Route Location Accuracy Histogram, Small Triangle (LAC),  
System Level, After Zero Fill, all 10-Second Data Samples, ID209-EX

FIGURE 30. (cont.)



Tenth Mile Average Radial Error Histogram, Random Route, Small Triangle (LAC), System Level, 10 Second Data, Before Zero Fill, ID 227AV, Test 3

FIGURE 31.



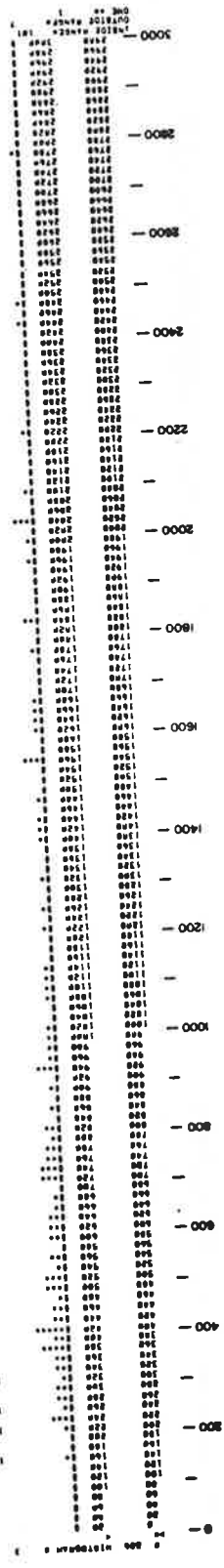
Tenth Mile Average Radial Error Histogram, Random  
 Route, Small Triangle (LAC), System Level, 1.0  
 Second Data, After Zero Fill, ID 209AV, Test 6

FIGURE 32.

950 = 4420

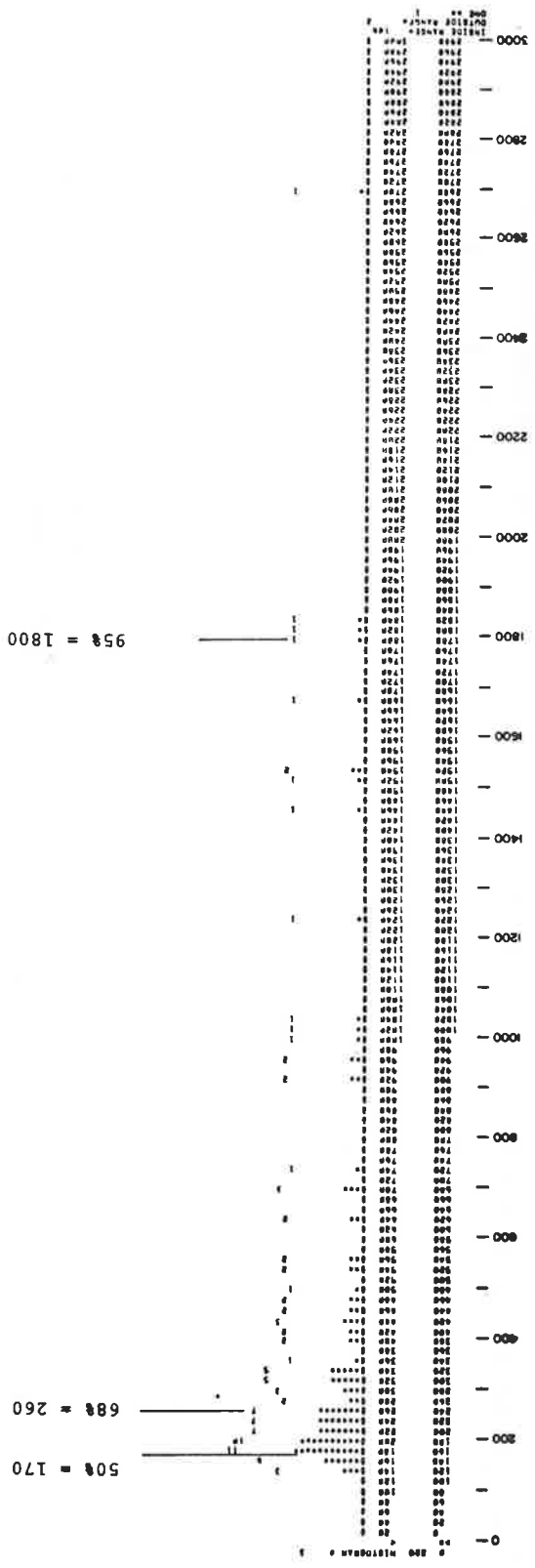
688 = 1400

508 = 320



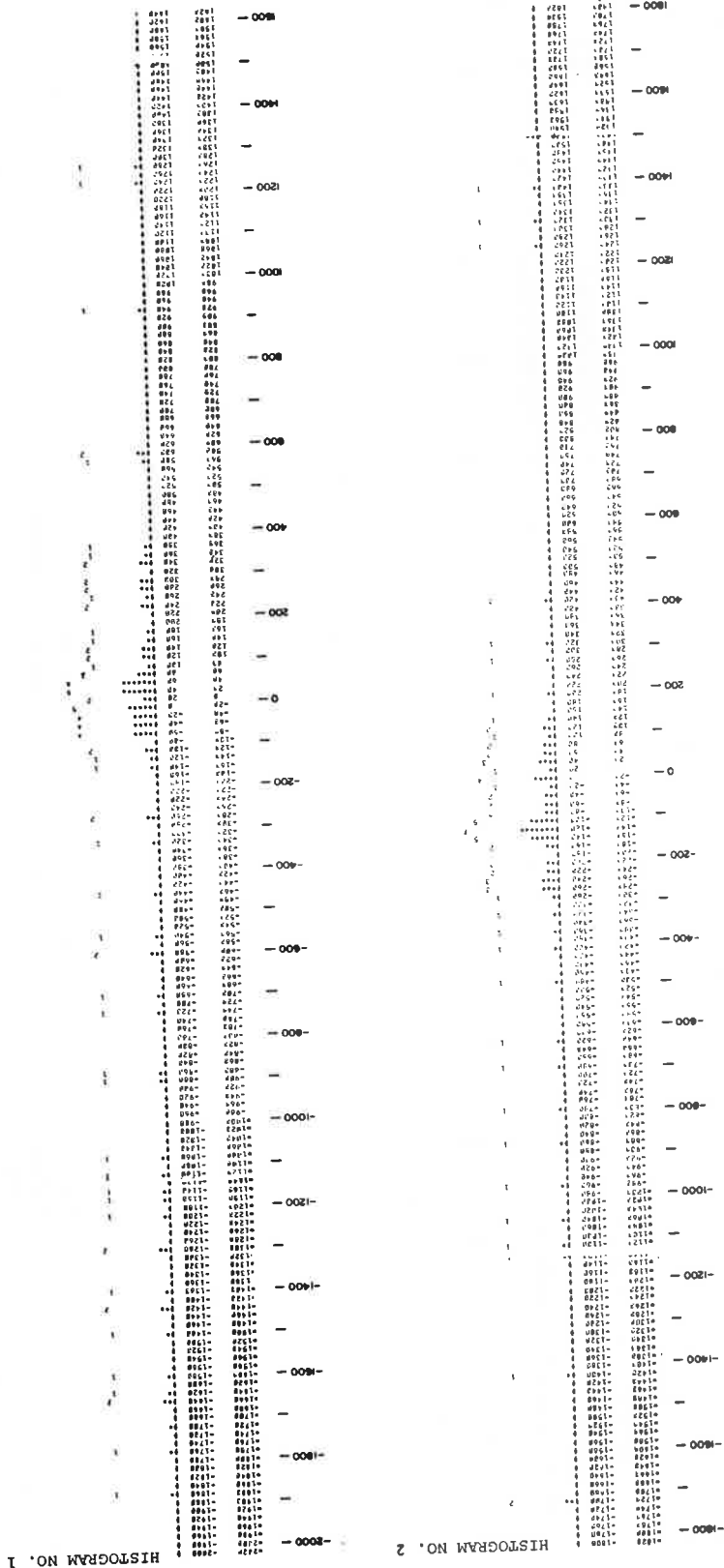
Tenth Mile Average Radial Error Histogram, Random  
 Route, Small Triangle (LAC), Subsystem Level,  
 0.1 Second Data, Before Zero Fill, ID 226AV, Test 1

FIGURE 33.



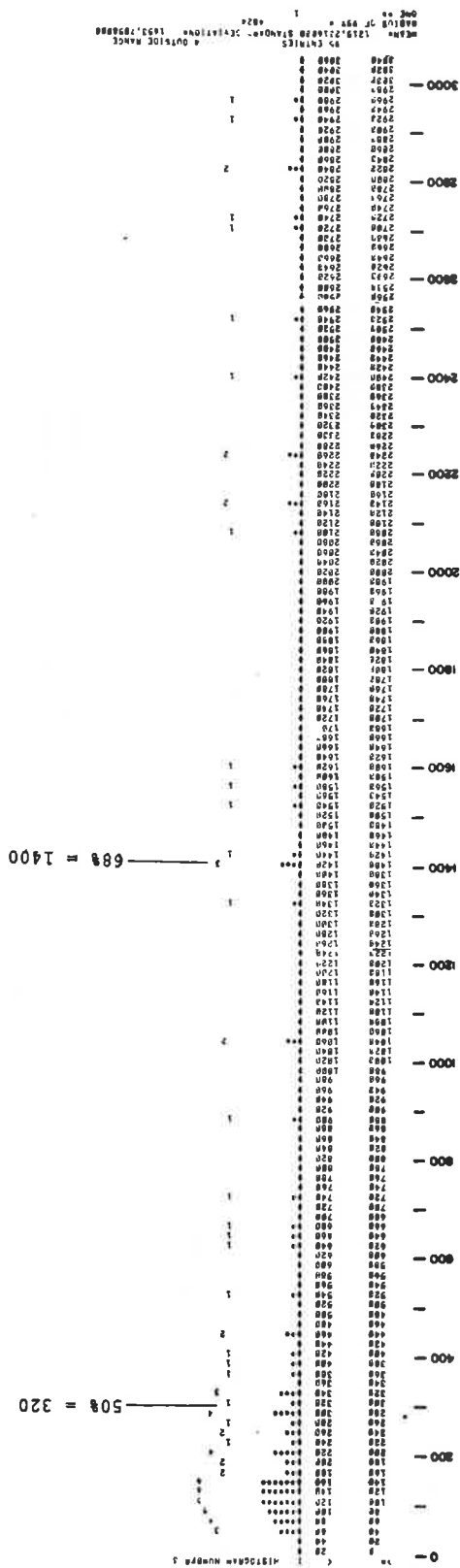
Tenth Mile Average Radial Error Histogram, Random Route, Small Triangle (LAC), Subsystem Level, 0.1 Second Data, After Zero Fill, ID 220AV, Test 6

FIGURE 34.



Random Route Location Accuracy Histogram, Small Triangle (LAC),  
 Subsystem Level, Before Zero Fill, Check Points at 0.1-Second  
 Update Rate, ID 226

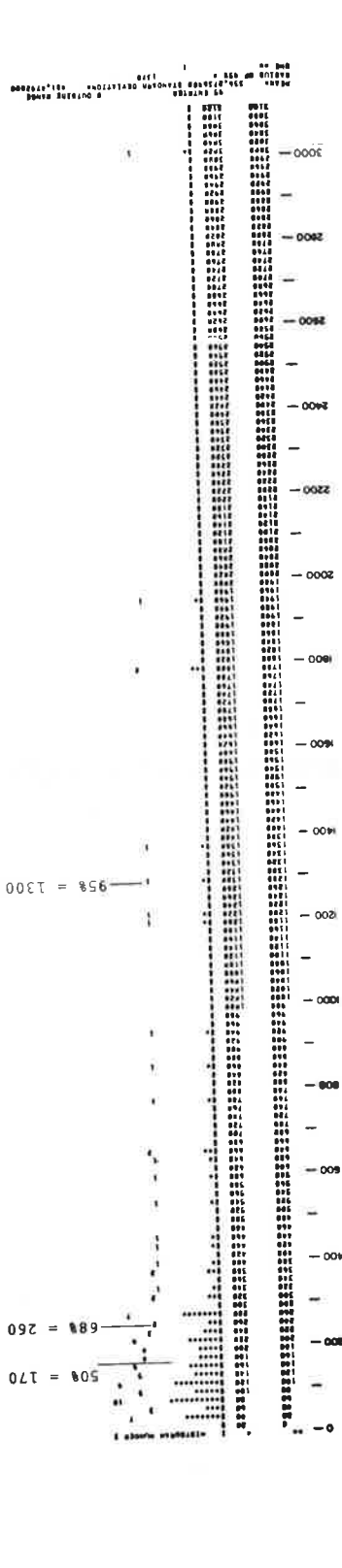
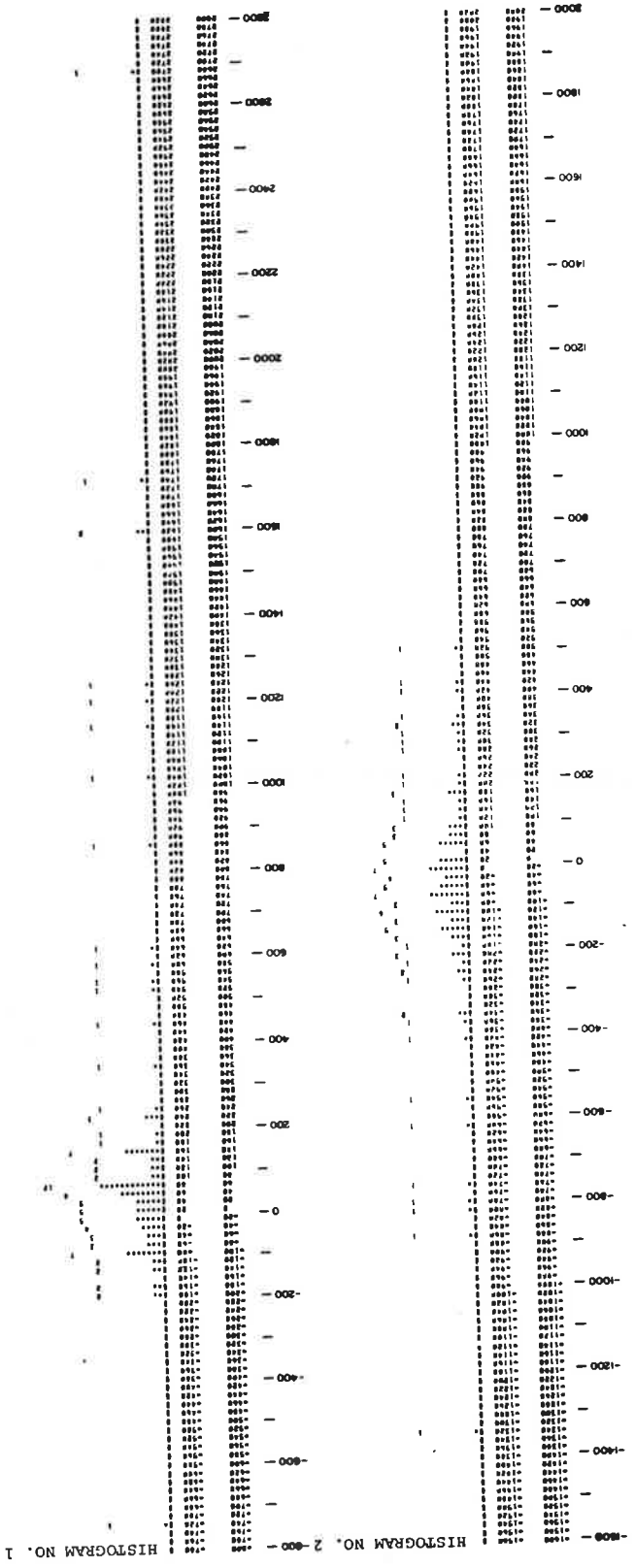
FIGURE 35.



Random Route Location Accuracy Histogram, Small Triangle (LAC),  
 Subsystem Level, Before Zero Fill, Check Points at 0.1-Second  
 Update Rate, ID 226

FIGURE 35. (cont.)

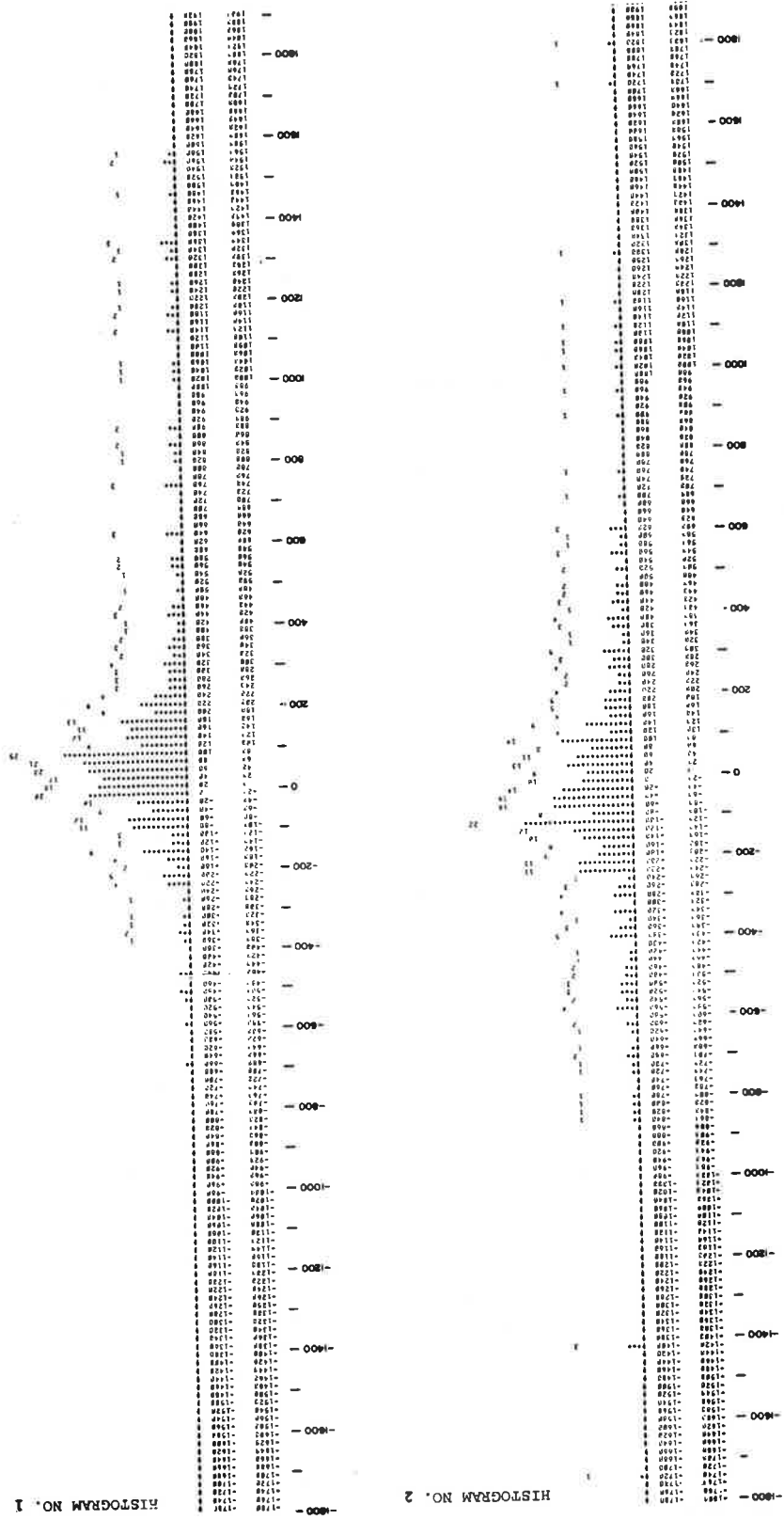




Random Route Location Accuracy Histogram, Small Triangle (LAC), Subsystem Level, After Zero Fill, Check points at 0.1-Second Update Rate, ID 220

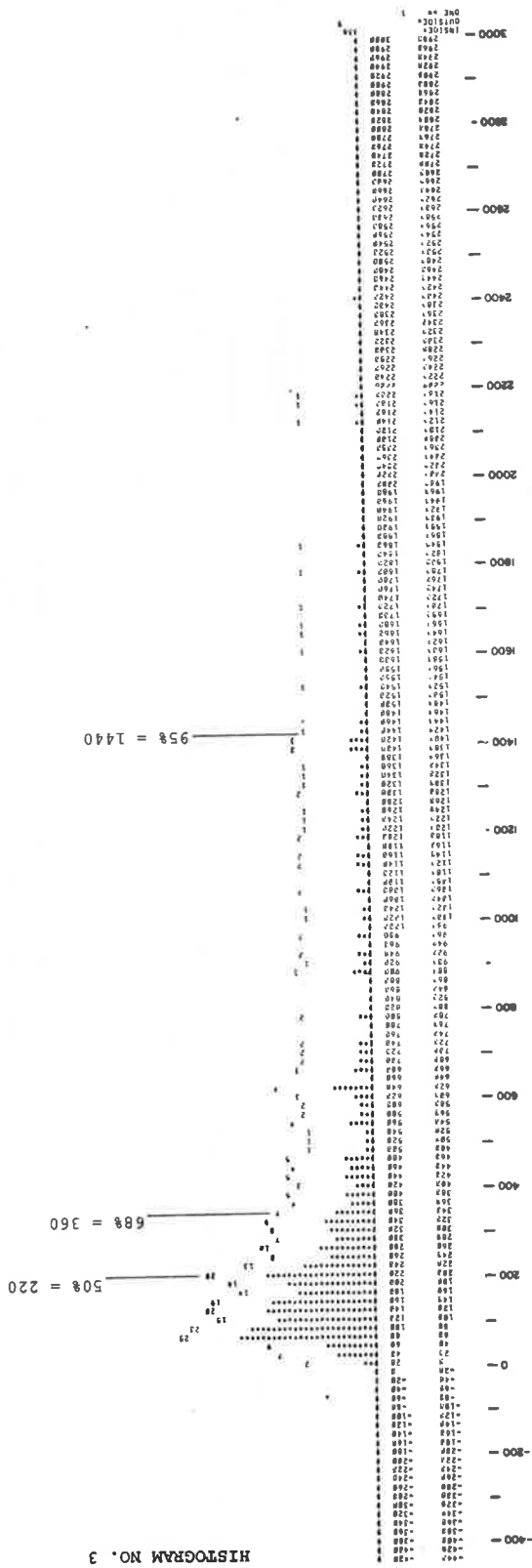
FIGURE 36.

SPECIAL RANDOM ROUTE LOCATION ACCURACY HISTOGRAMS



Special Random Location Accuracy Histogram, Small Triangle (IAC),  
System Level, After Zero Fill, Check Points Plotted, ID 234

FIGURE 37.



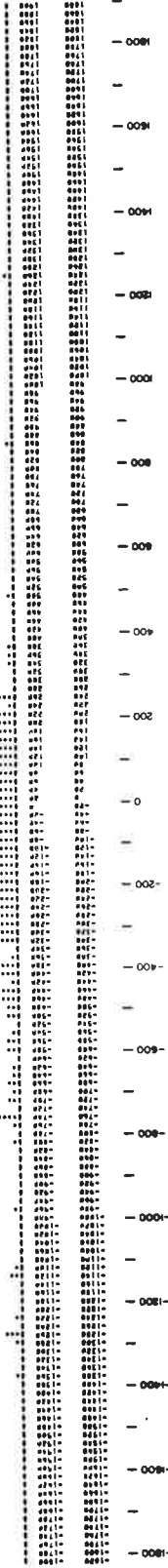
Special Random Location Accuracy Histogram, Small Triangle (IAC), System Level, After Zero Fill, Check Points Plotted, ID 234

FIGURE 37. (cont.)

HISTOGRAM NO. 1

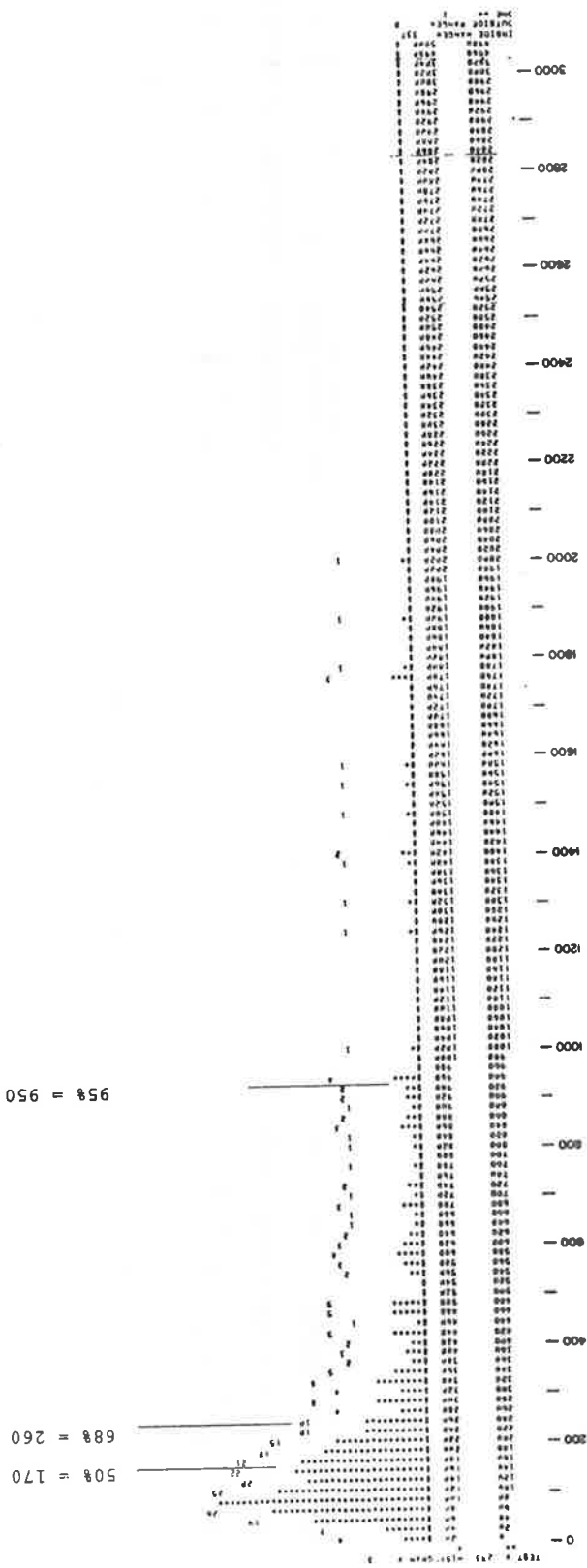


HISTOGRAM NO. 2



Special Random Route Location Accuracy Histogram,  
Central Downtown Site Triangle (LAF), System  
Level, Check Points Plotted, ID 233

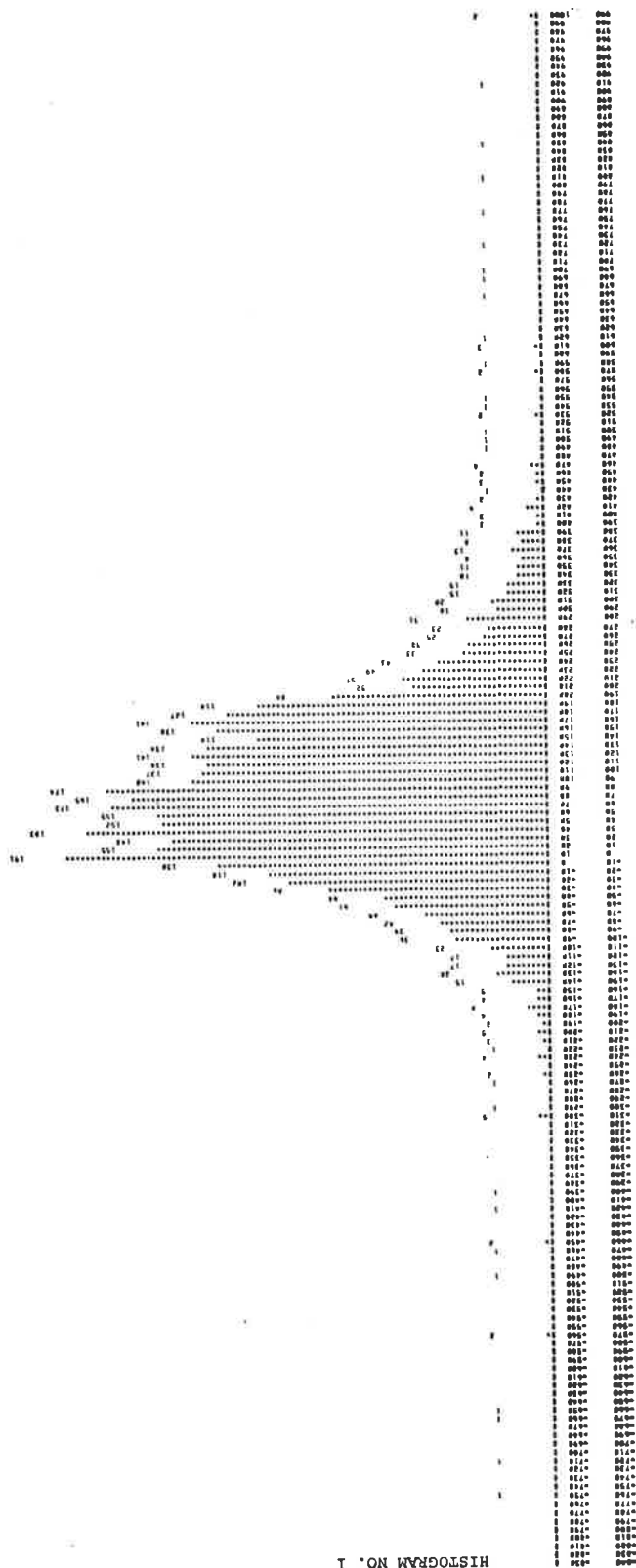
FIGURE 38.



Special Random Route Location Accuracy Histogram,  
Central Downtown Site Triangle (LAP), System  
Level, Check Points Plotted, ID 233

FIGURE 38. (cont.)

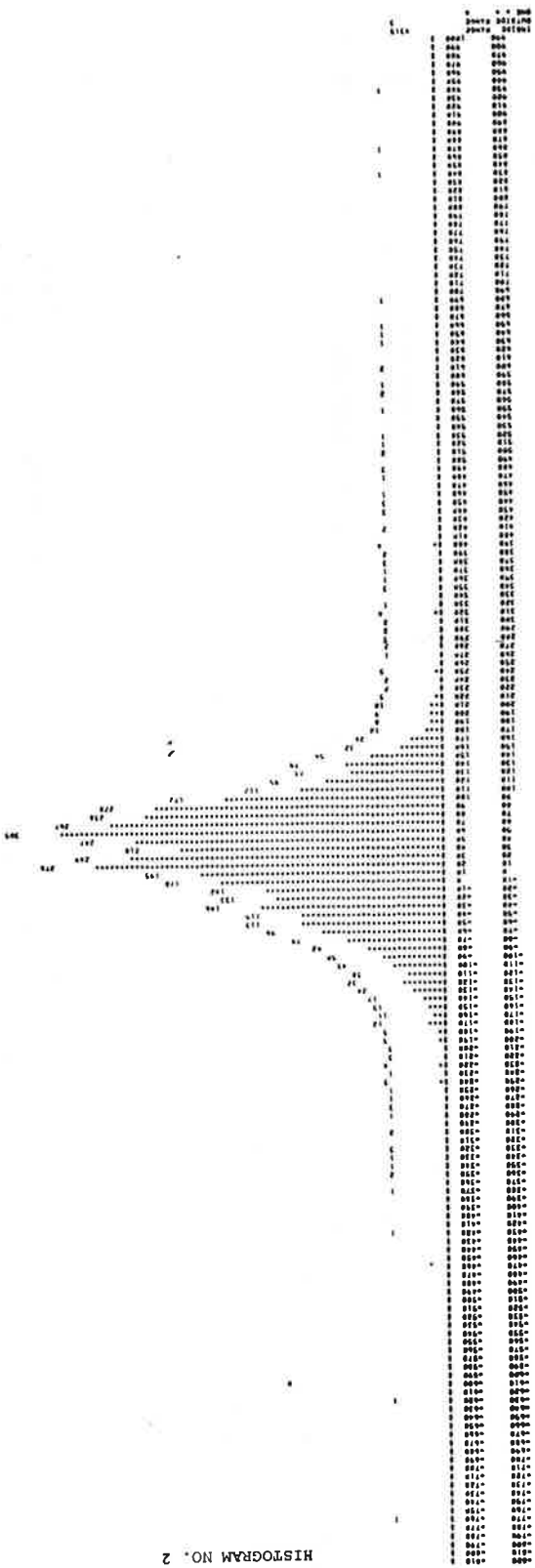
SUBURBAN ROUTE HISTOGRAMS



Suburban Route Location Accuracy Histogram, Large Triangle (HAC),  
 Subsystem Level, After Zero Fill, All 0.1-Second Data Samples for  
 First run, Before Bias Correction, ID 123

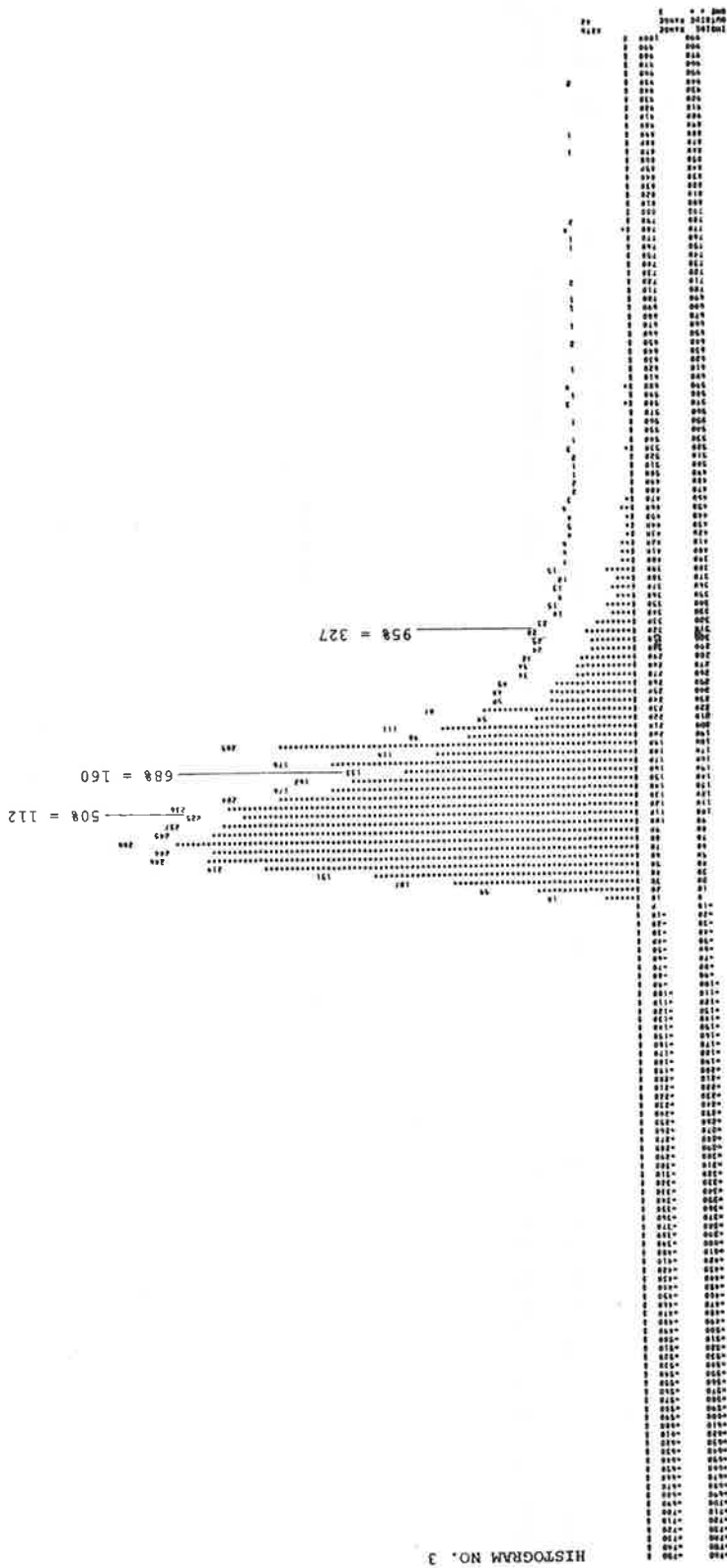
FIGURE 39.





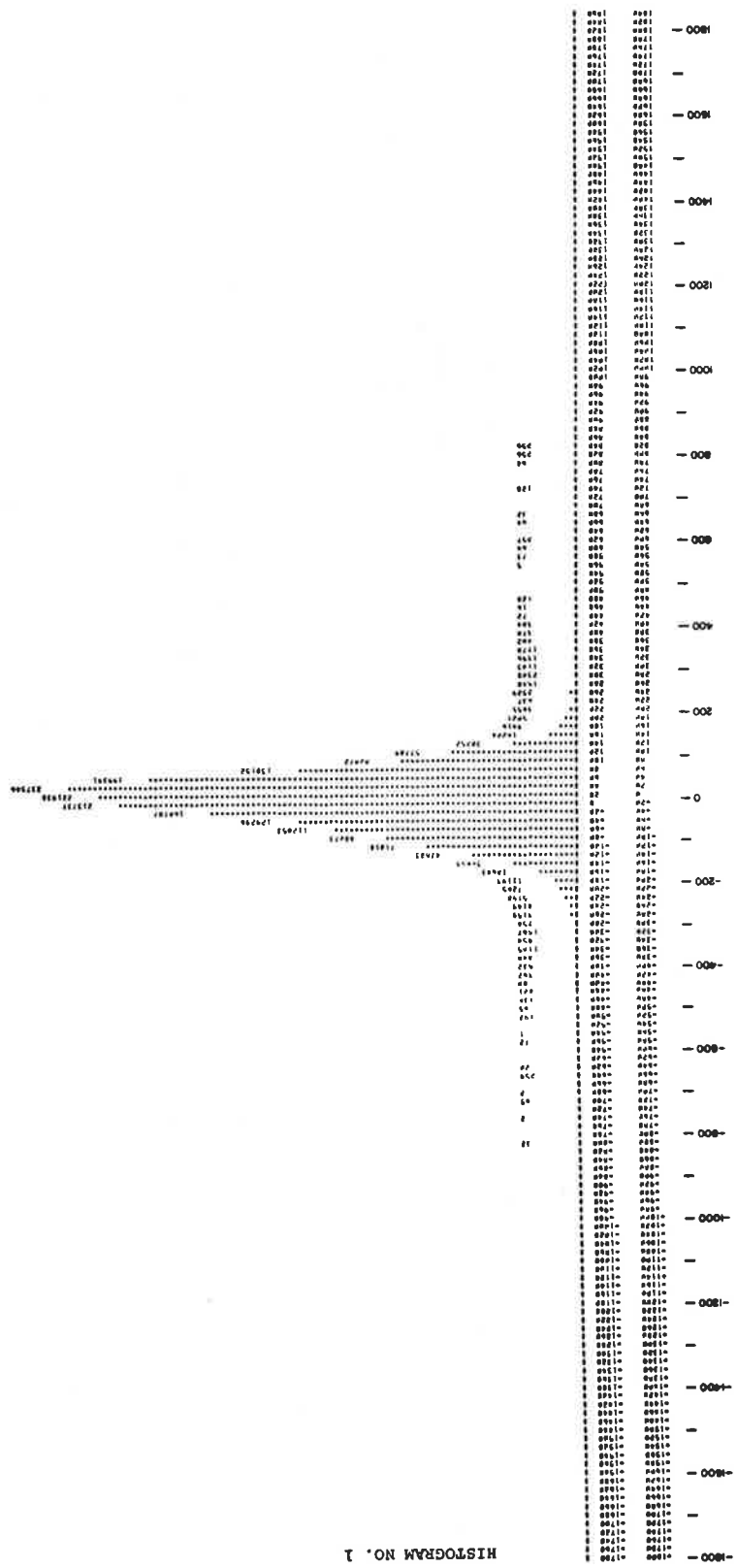
Suburban Route Location Accuracy Histogram, Large Triangle (HAC),  
 Subsystem Level, After Zero Fill, All 0.1-Second Data Samples for  
 First run, Before Bias Correction, ID 123

FIGURE 39. (cont.)



Suburban Route Location Accuracy Histogram, Large Triangle (HAC),  
 Subsystem Level, After Zero Fill, All 0.1-Second Data Samples for  
 First run, Before Bias Correction, ID 123

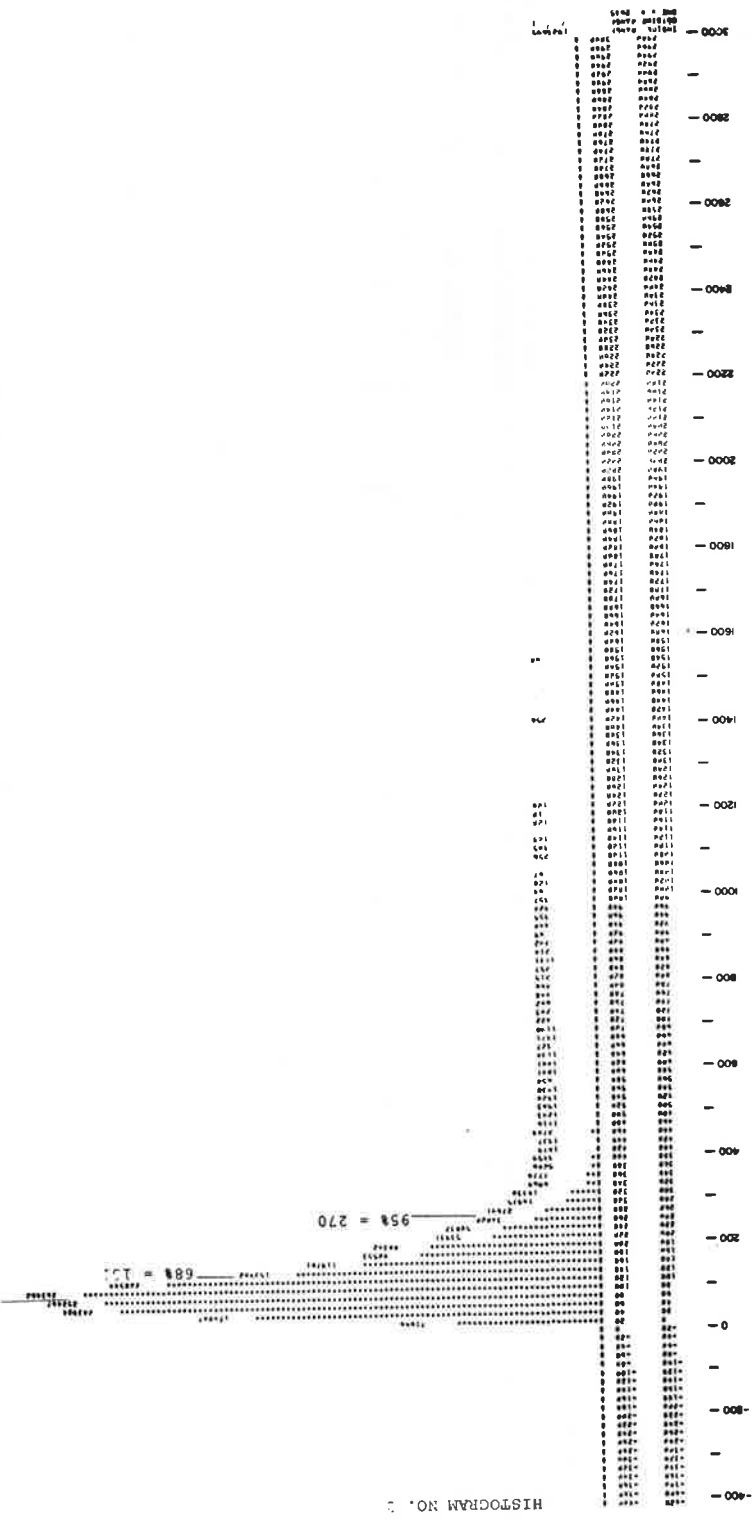
FIGURE 39. (cont.)



Suburban Route Location Accuracy Histogram, Large Triangle (HAC),  
 Subsystem Level, After Zero Fill, All 0.1-Second Data Samples for  
 all runs, after bias correction (derived from first run), ID 204

FIGURE 40.

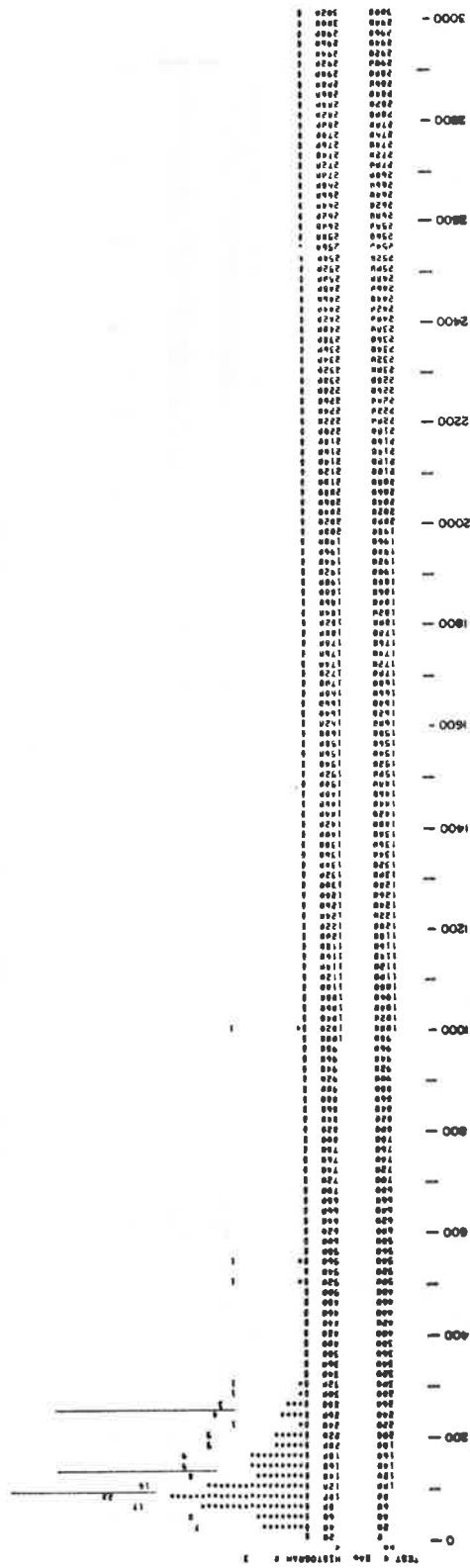




Suburban Route Location Accuracy Histogram, Large Triangle (HAC),  
 Subsystem Level, After Zero Fill, All 0.1-Second Data Samples for  
 all runs, after bias correction (derived from first run), ID 204

FIGURE 40. (cont.)

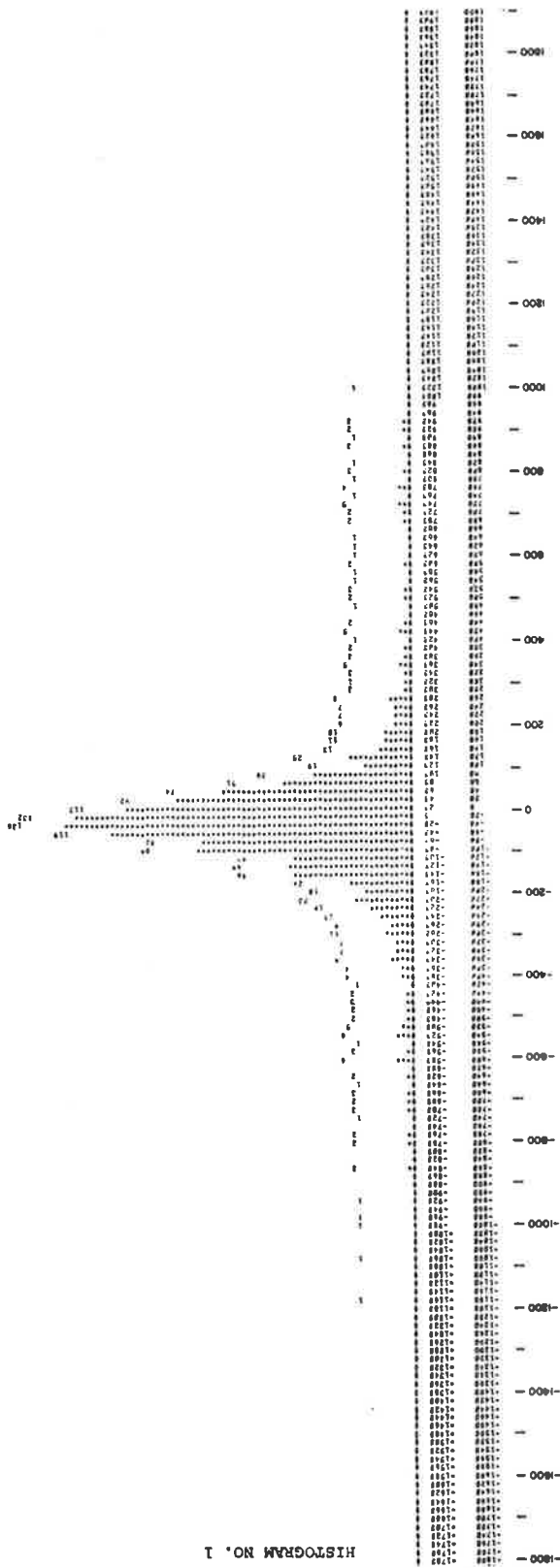
508 = 108  
 688 = 150  
 958 = 273



Tenth Mile Average Radial Error Histogram,  
 Suburban Route, Large Triangle (HAC), System  
 Level, 10 Second Data, After Zero Fill, ID 246

FIGURE 41.

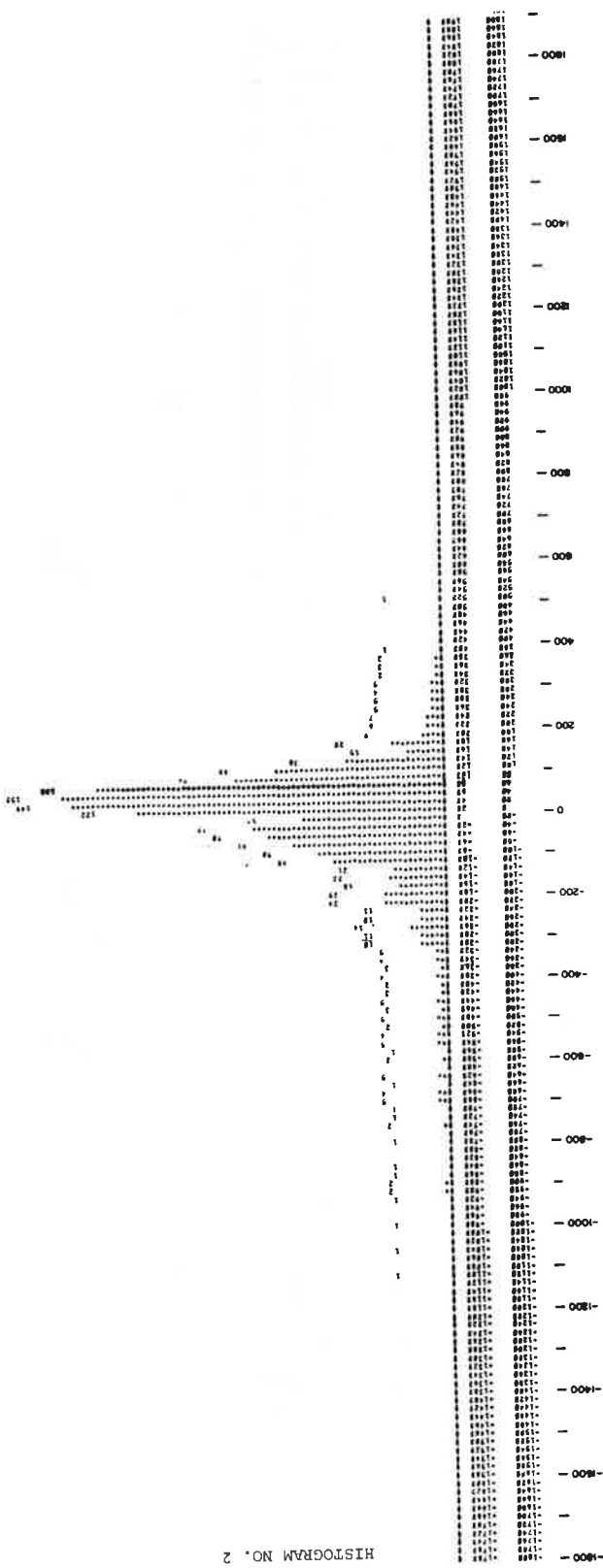
SPECIAL TESTS LOCATION ACCURACY HISTOGRAMS



Special High Speed Test, Location Accuracy Histogram, Large Triangle (HAC), Subsystem Level, All 0.1 Second Samples in Route Segment, ID 213

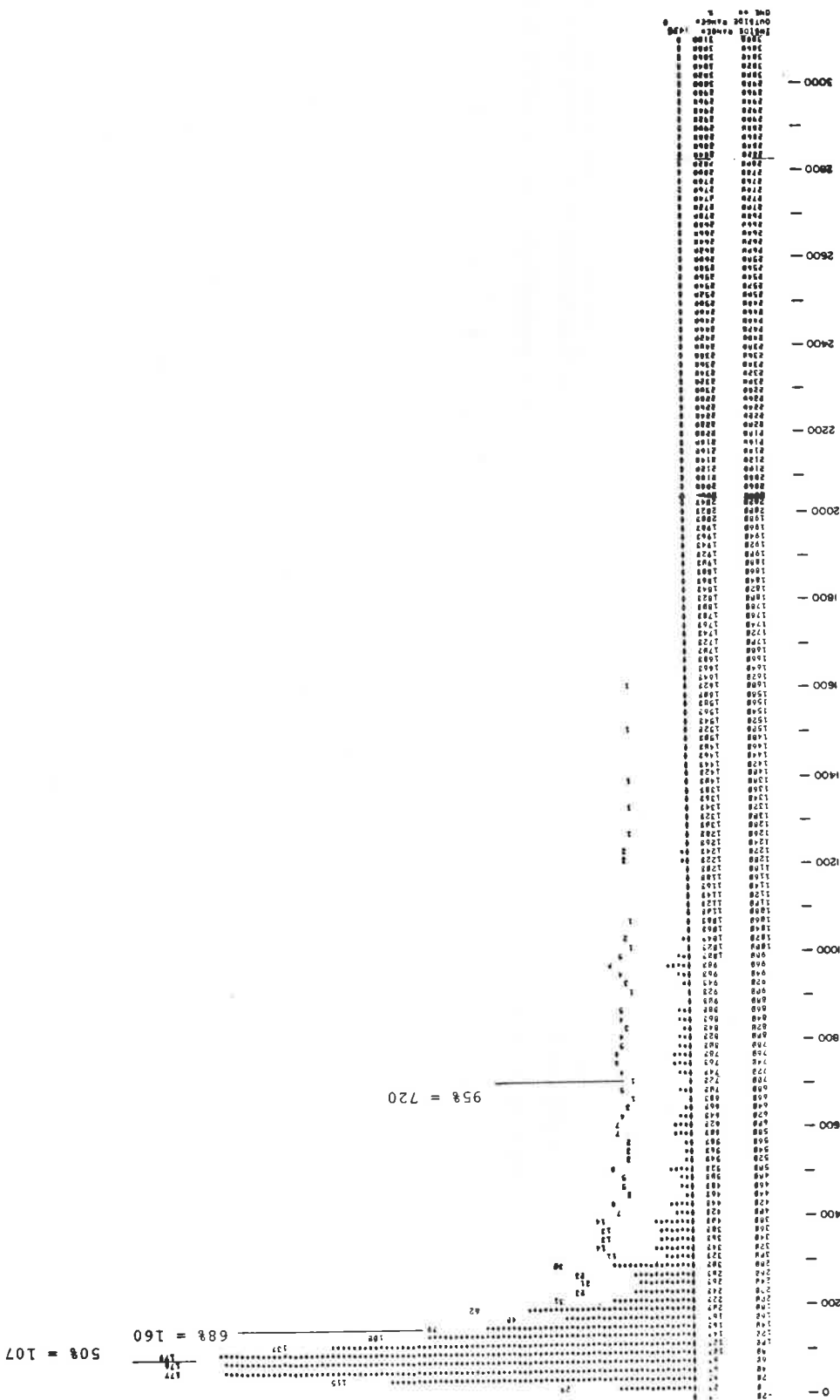
FIGURE 42.





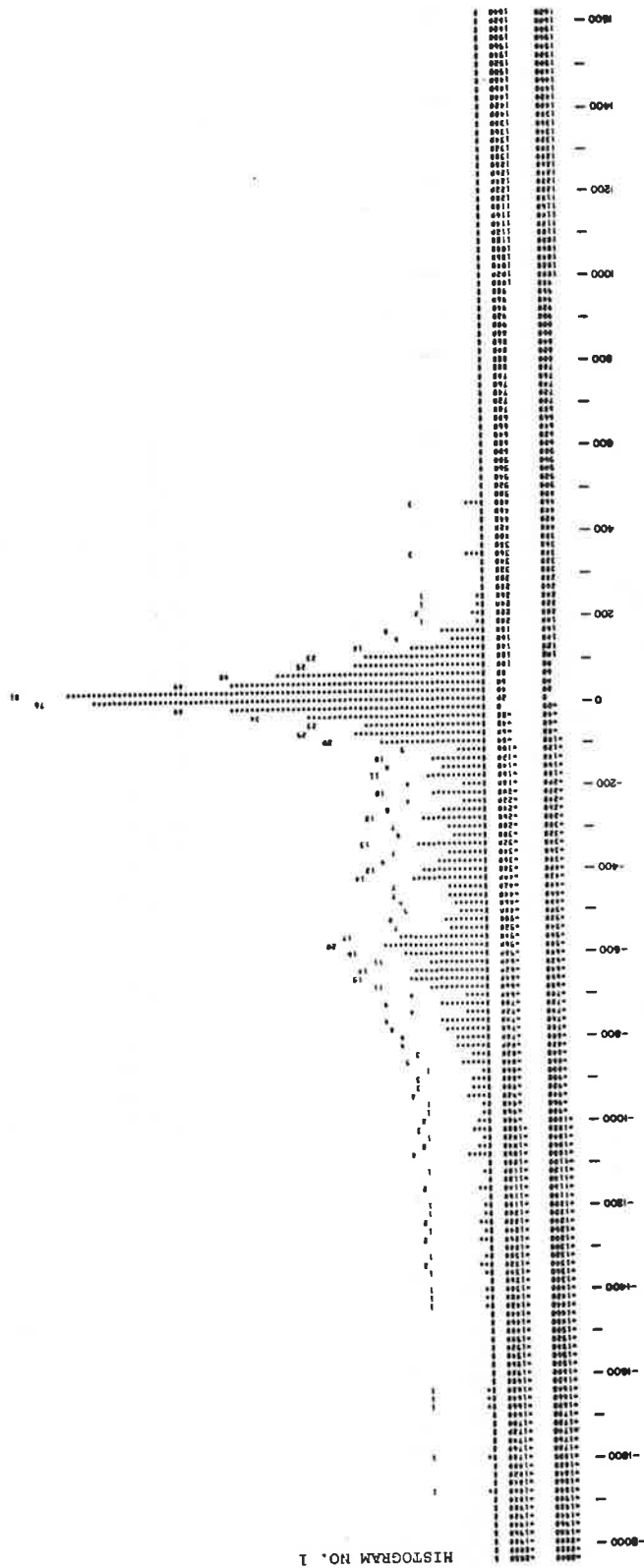
Special High Speed Test, Location Accuracy  
 Histogram, Large Triangle (HAC), Subsystem  
 Level, All 0.1 Second Samples in Route Segment,  
 ID 213

FIGURE 42. (cont.)



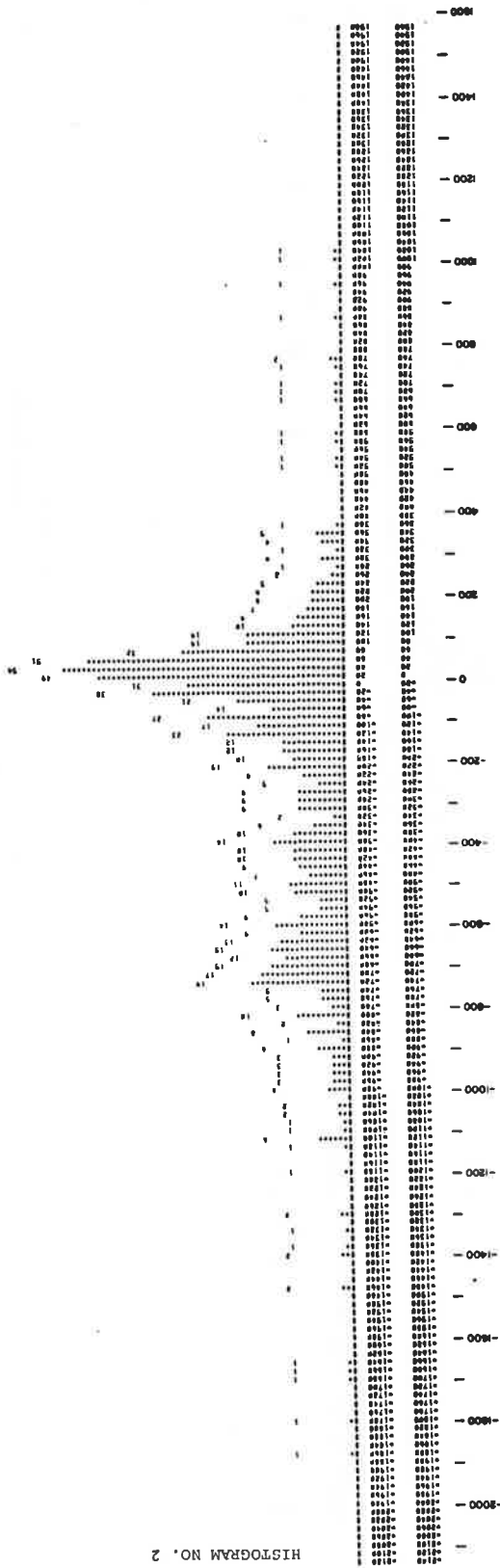
Special High Speed Test, Location Accuracy Histogram, Large Triangle (HAC), Subsystem Level, All 0.1 Second Samples in Route Segment, ID 213

FIGURE 42. (cont.)



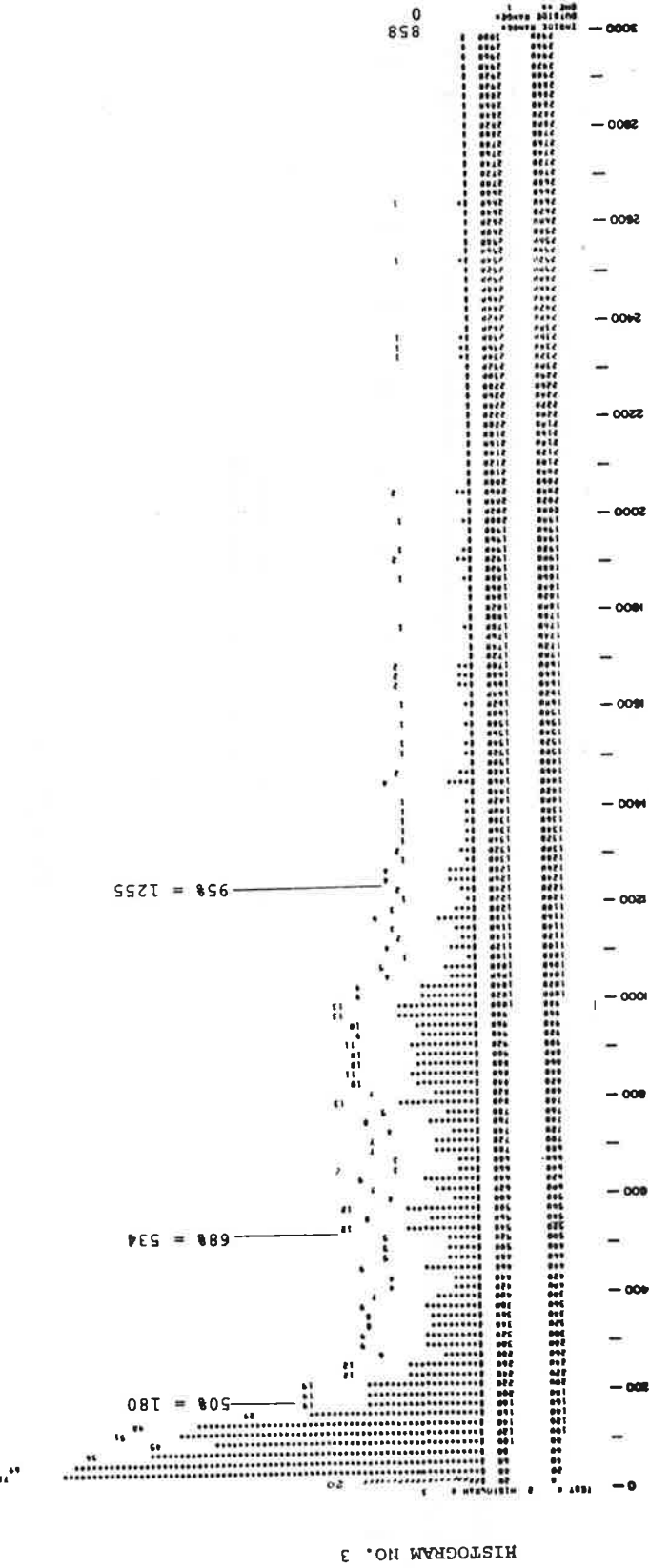
Special Underpass Test, Location Accuracy Histogram, Large  
 Triangle (HAC), Subsystem Level, only 0.1-Second Data Samples During  
 Underpass Intervals Plotted, ID 206-1

FIGURE 43.



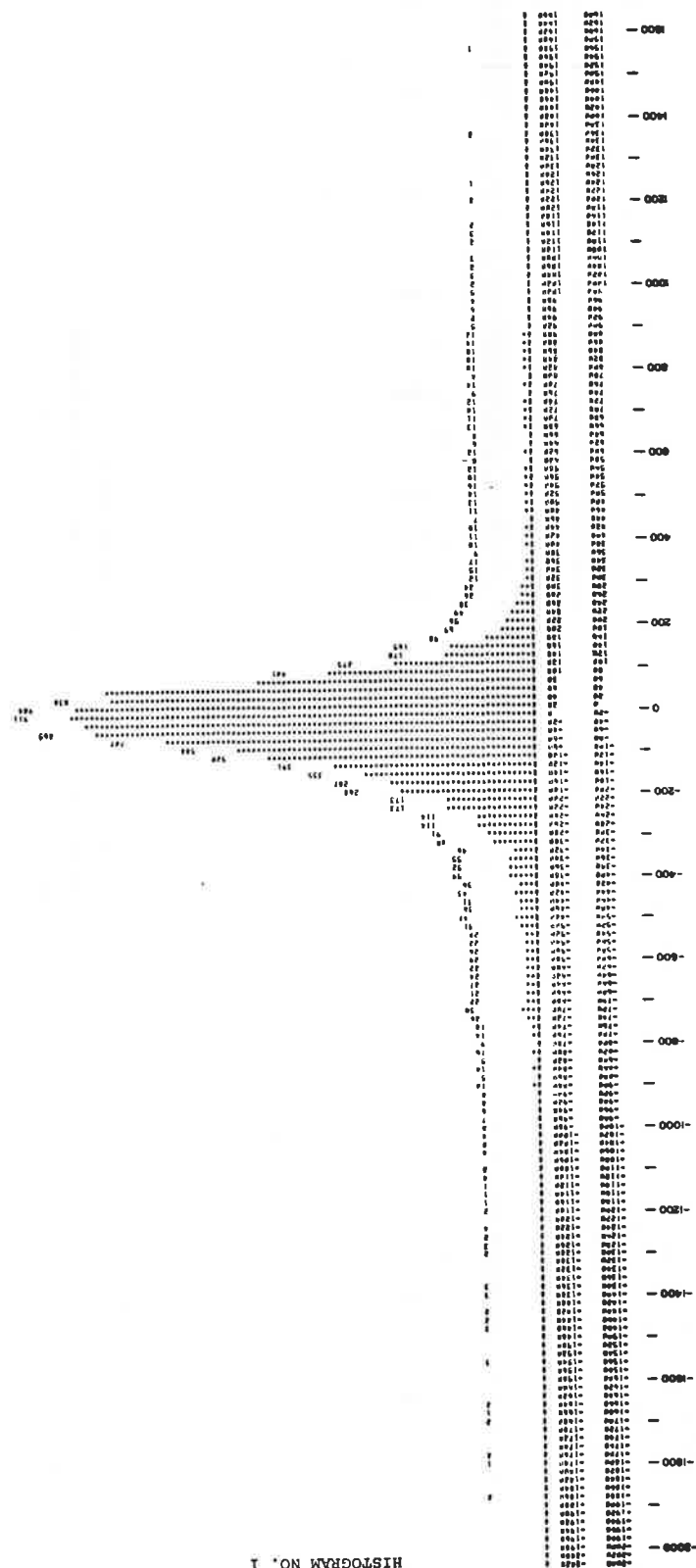
Special Underpass Test, Location Accuracy Histogram, Large Triangle (HAC), Subsystem Level, only 0.1-Second Data Samples During Underpass Intervals Plotted, ID 206-1

FIGURE 43. (cont.)



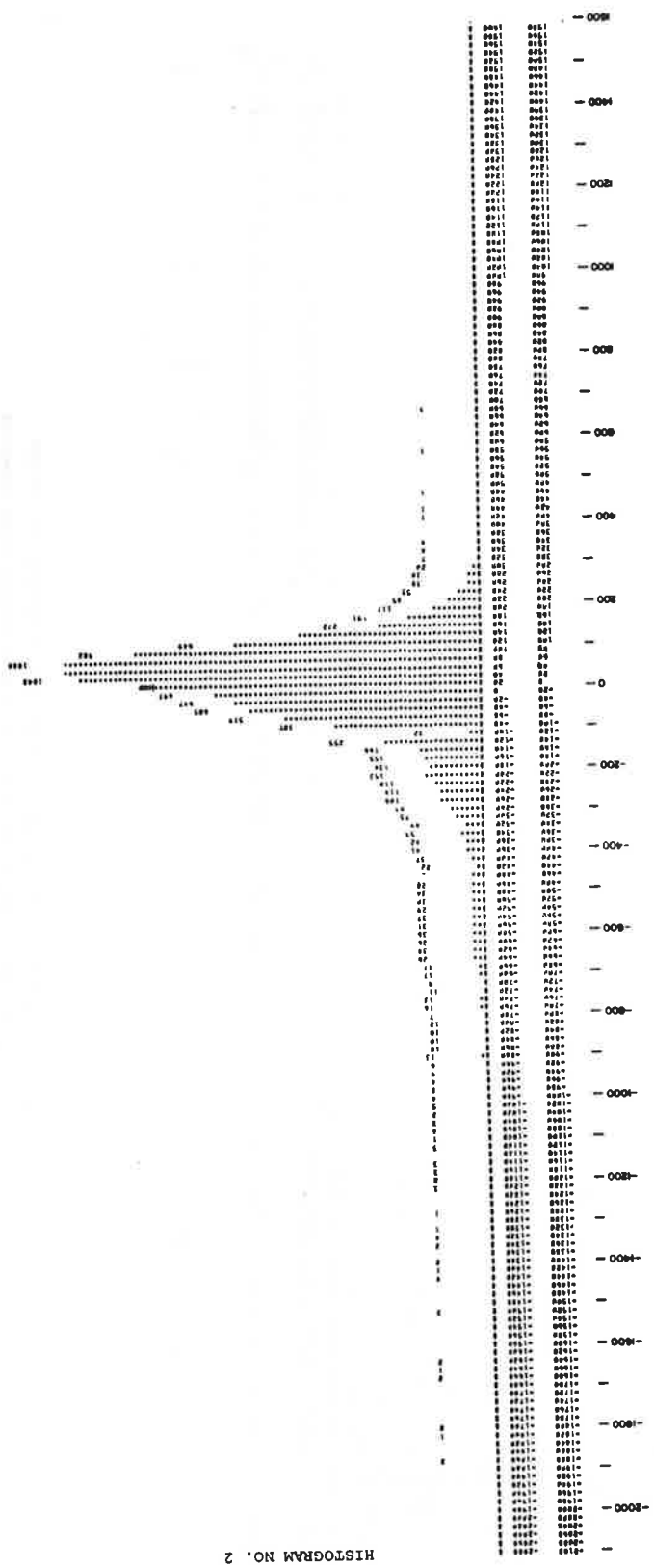
Special Underpass Test, Location Accuracy Histogram, Large Triangle (HAC), Subsystem Level, only 0.1-Second Data Samples During Underpass Intervals Plotted, ID 206-1

FIGURE 43. (cont.)



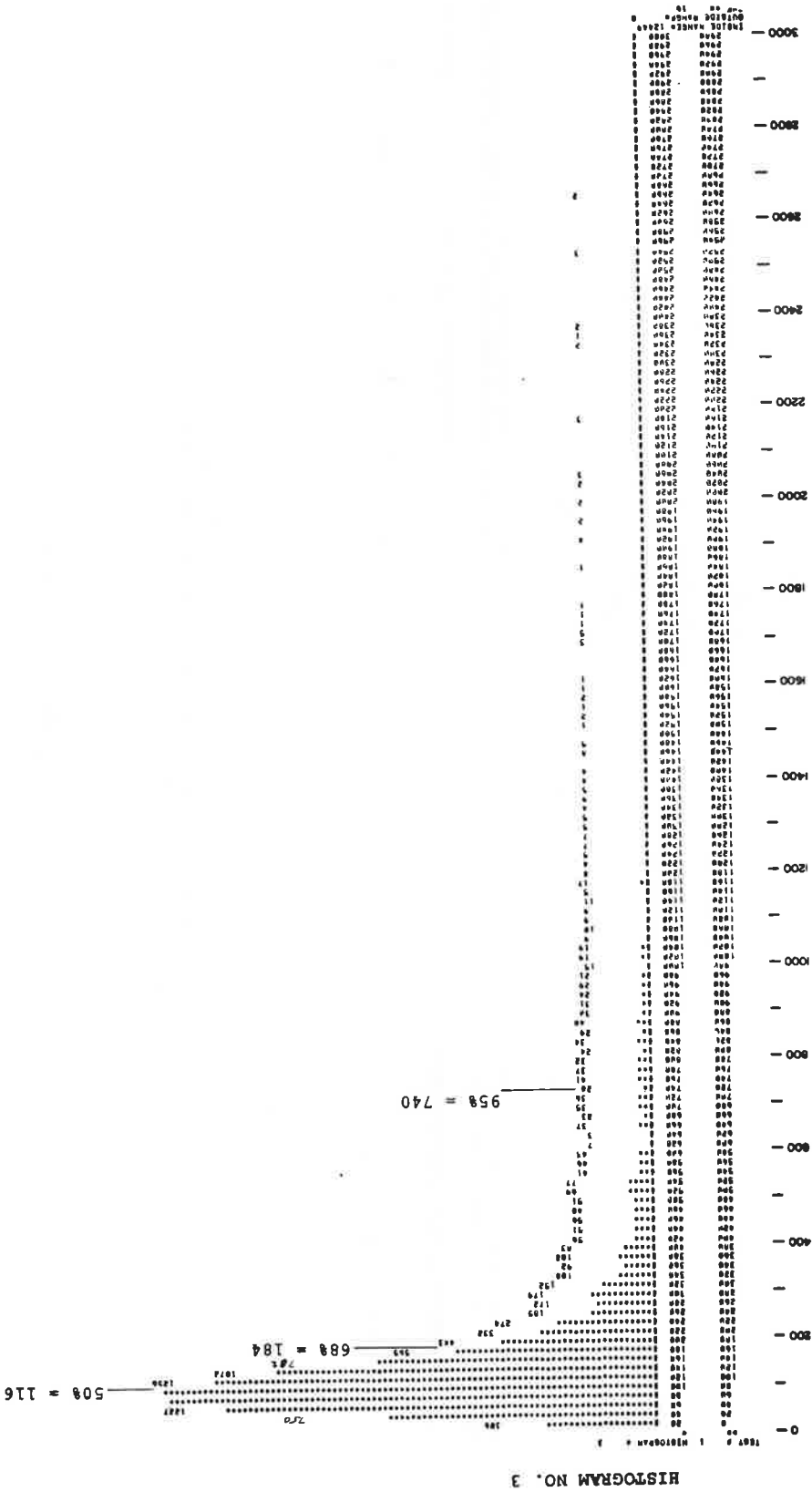
Special Underpass Test, Location Accuracy Histogram, Large Triangle (HRC), Subsystem Level, all 0.1-Second Data Samples of Run Plotted, ID 206-2

FIGURE 44.



Special Underpass Test, Location Accuracy Histogram, Large Triangle (HAC), Subsystem Level, all 0.1-Second Data Samples of Run Plotted, ID 206-2

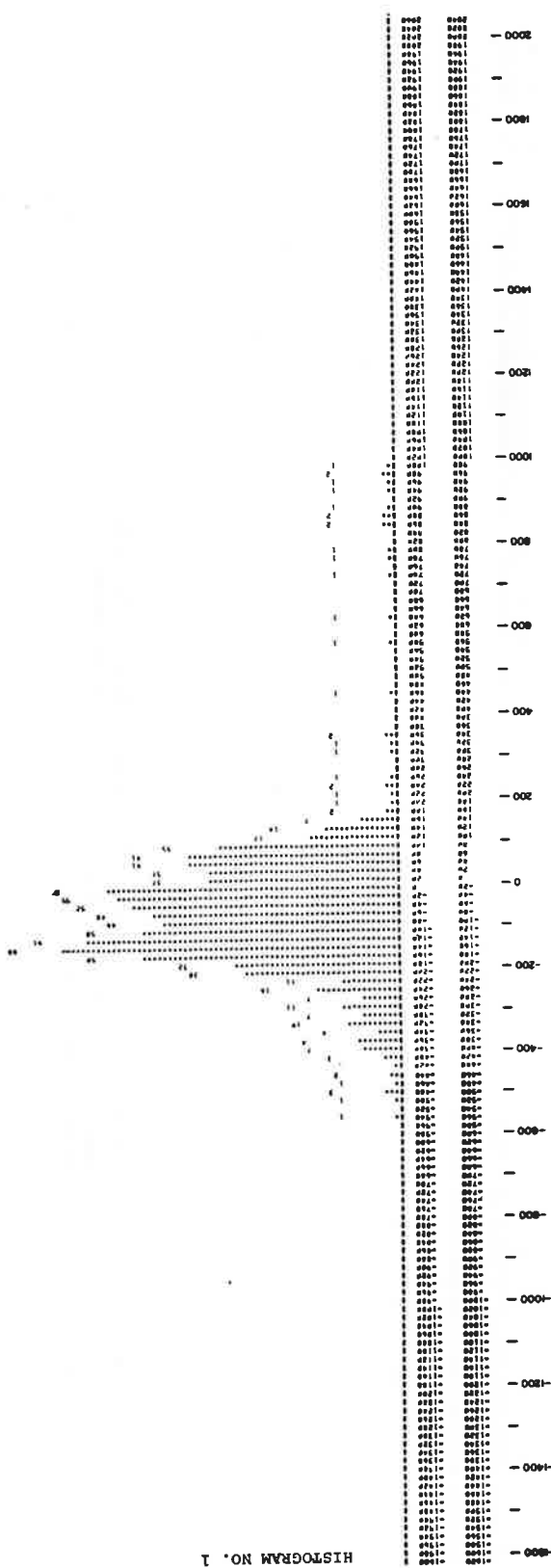
FIGURE 44. (cont.)



Special Underpass Test, Location Accuracy Histogram, Large Triangle (HAC), Subsystem Level, all 0.1-Second Data Samples of Run Plotted, ID 206-2

FIGURE 44. (cont.)

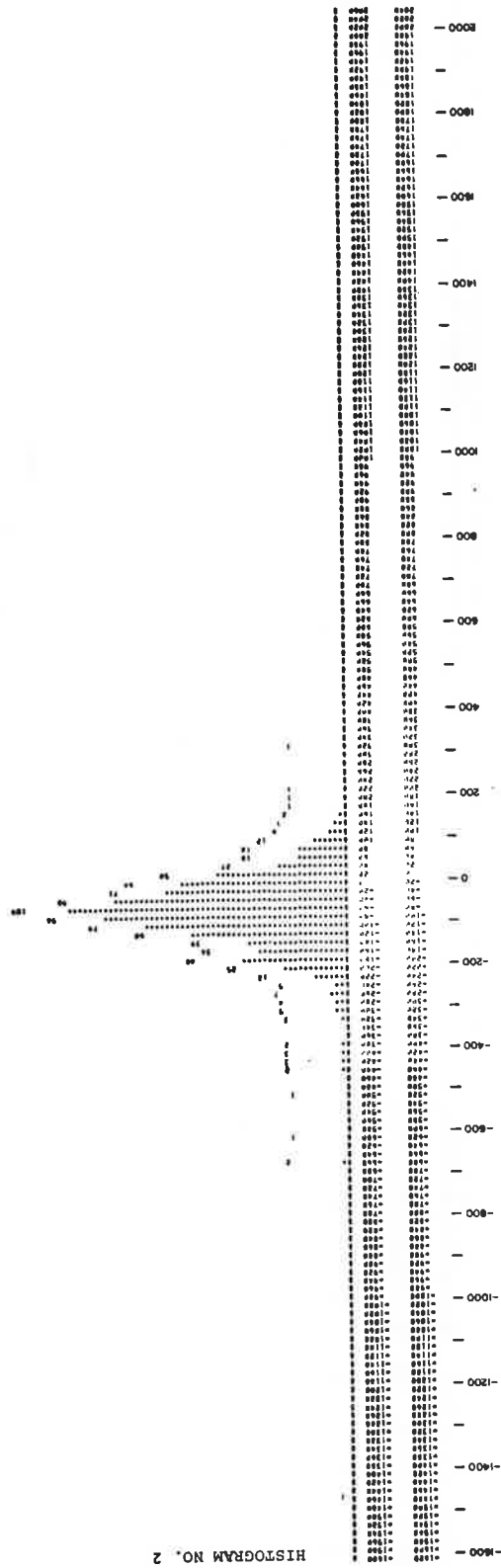




Special Power Line Interference Test, Location Accuracy Histogram,  
 Small Triangle (HAC), Subsystem Level, all 0.1-Second Samples  
 in Route Segment, ID 243

FIGURE 45.

HISTOGRAM NO. 2



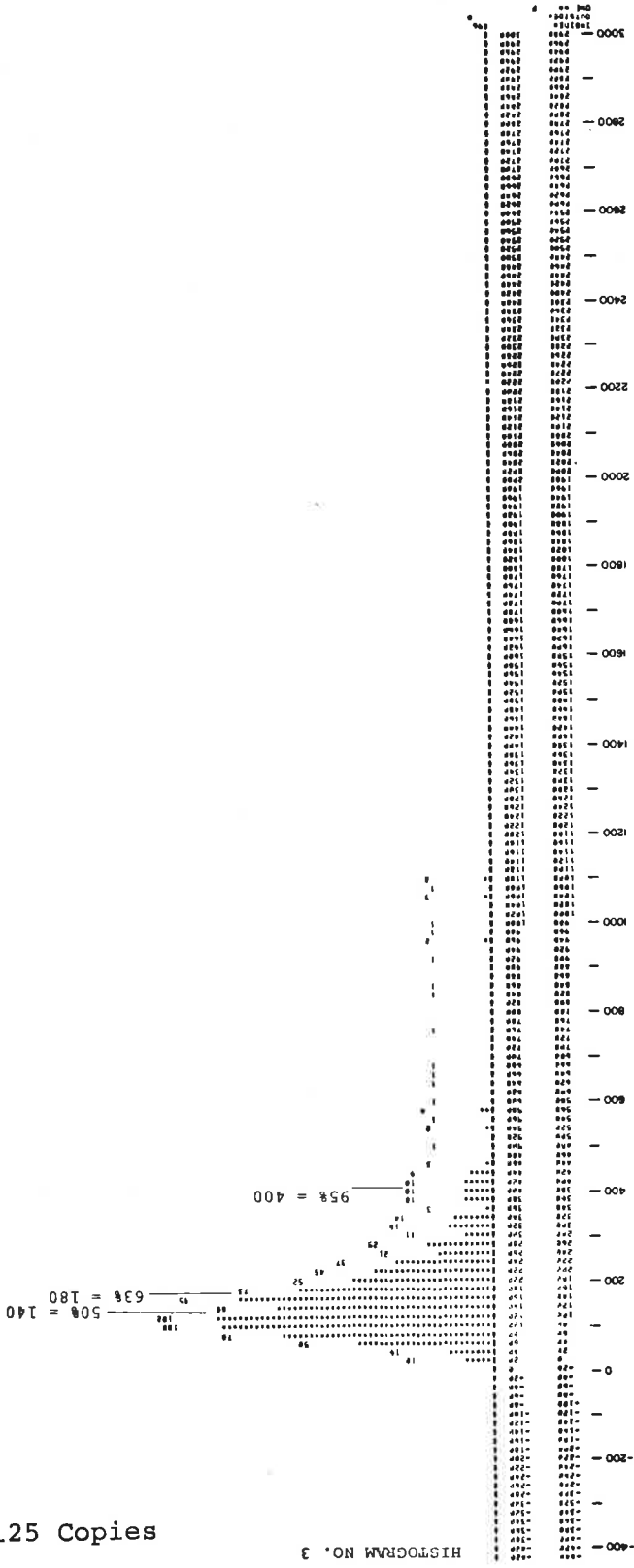
Special Power Line Interference Test, Location Accuracy Histogram,  
Small Triangle (HAC), Subsystem Level, all 0.1-Second Samples  
in Route Segment, ID 243

FIGURE 45. (cont.)

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HISTOGRAM NO. 3

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Special Power Line Interference Test, Location Accuracy Histogram,  
 Small Triangle (HAC), Subsystem Level, all 0.1-Second Samples  
 in Route Segment , ID 243

FIGURE 45. (cont.)





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