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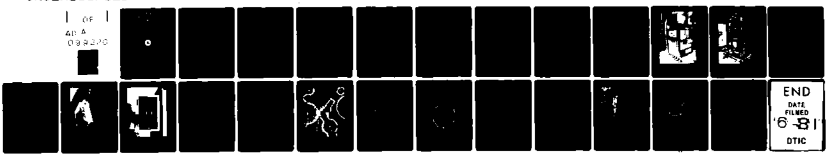

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FAA-CT-80-52

LEVEL III

TEST AND EVALUATION OF REMOTE AREA PRECISION POSITIONING SYSTEM (RAPPS) PHASE 1

Matthew Naimo

FEDERAL AVIATION ADMINISTRATION TECHNICAL CENTER
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FINAL REPORT

MARCH 1981

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16. Abstract

Described is the test and evaluation of an airborne multilateration-distance measuring equipment (DME) position reference system to be used with a long range navigation (LORAN)-C data collection system. The system, Remote Area Precision Position System (RAPPS), was developed by Amex Systems, Incorporated under an Federal Aviation Administration (FAA)/Systems Research and Development Service (SRDS) contract.

In August 1979, the FAA Technical Center determined system accuracy using a Convair 580 aircraft as a test platform. Space position measurement of the aircraft was determined by the Center Nike-Hercules radar. When the range biases of the four DME ground stations were removed by postflight computation, flight test results from orbits about the Atlantic City DME beacon indicated a standard deviation error of 256 feet about a mean range error of +345 feet.

Operational evaluation of the RAPPS airborne and ground subsystems was conducted during the winter in Vermont. The field evaluation determined that both the ground and airborne subsystems have significant design deficiencies of the hardware/software.

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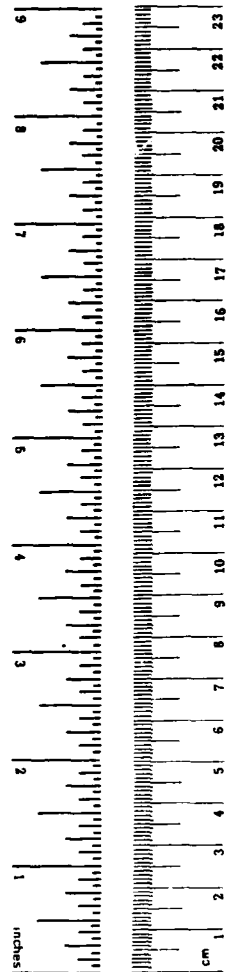
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

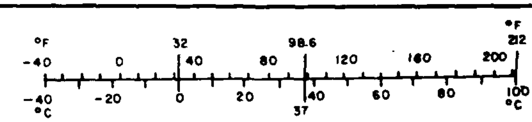
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ACKNOWLEDGEMENT

The author wishes to acknowledge Lorraine Rzonca, LORAN-C Project Manager, for her cooperation and assistance during the field evaluation effort. The assistance and efforts of the personnel of the Federal Aviation Administration New England Region and Mr. W. Polhemus, Consultant for the State of Vermont, was greatly appreciated.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

PURPOSE.

The purpose of this project was to conduct a test and evaluation of the Remote Area Precision Position System (RAPPS), Phase 1, to determine the system accuracy and capability to operate in a field environment.

BACKGROUND.

The Systems Research and Development Service (SRDS) awarded a contract in October 1978 to Amex Systems, Incorporated for an airborne data acquisition and position reference system, RAPPS. The contract is a multiyear funded award under which a subcontractor, Sierra Nevada Corporation (SNC), developed RAPPS, Phase 1. The Phase 1 system was designed for field testing of long range navigation (LORAN)-C airborne receiver accuracy. Future RAPPS', Phases 1.5 and 2, are to provide more accurate, more ruggedized, and improved performance systems for tests of LORAN-C and Global Position System receivers, respectively.

Champlain Technology, Incorporated (CTI), under an SRDS contract to collect LORAN-C data, operated the RAPPS 1 on the west coast. (Reference FAA-RD-80-120, "Evaluation of the Performance of the Remote Area Precision Positioning Systems (RAPPS)," dated October 1980.) Following system operations by CTI in California, RAPPS 1 was delivered to the Technical Center on July 31, 1979.

SYSTEM DESCRIPTION.

The RAPPS airborne subsystem collects multiple-distance measuring equipment (DME) data and records it with LORAN-C position data on magnetic tape. The RAPPS ground subsystem provided portable L-band transponders, which could be deployed as required in the geographical testing area to supplement operational DME ground beacons.

AIRBORNE SUBSYSTEM. The airborne subsystem contains the following hardware components:

1. Intel 80/20-4 microprocessor (μp)

2. King KDM-7000 DME interrogator

3. LORAN-C TDL-424 and TDL-711 navigation sets

4. Tektronix 4051 smart terminal

5. Chrono-log model 70 digital clock

6. Narco model AR-500 altitude encoder

7. Tektronix 4923 cartridge tape recorder

8. Tandberg SCDR-3000 cartridge tape recorder

9. Tektronix hard copy unit

The block diagram of the subsystem elements is shown in figure 1. The configuration of the hardware components in the racks is shown in figures 2 and 3.

The single DME interrogator is sequentially scanned to six preselected ground beacon frequencies to determine distance, which is inputted to the microprocessor (μp). Additional data sent to the μp are time, altitude, and LORAN-C data. The data are controlled and formatted by the p for input to the magnetic tape and "smart" terminal, Tektronix 4051. The Tektronix 4051 can optionally plot in real-time the non-filtered, DME multilateration, determined aircraft position and overlay it with LORAN determined position. A hard copy unit can record the display.

When delivered, the RAPPS 1 was not equipped with the Tandberg magnetic tape recorder; consequently, a Kennedy 9-track magnetic tape recorder was interfaced to parallel the Tandberg RS-232 port. All data were collected on the Kennedy magnetic tape recorder and used for postflight data analysis on the Center's Honeywell 66/60 computer.

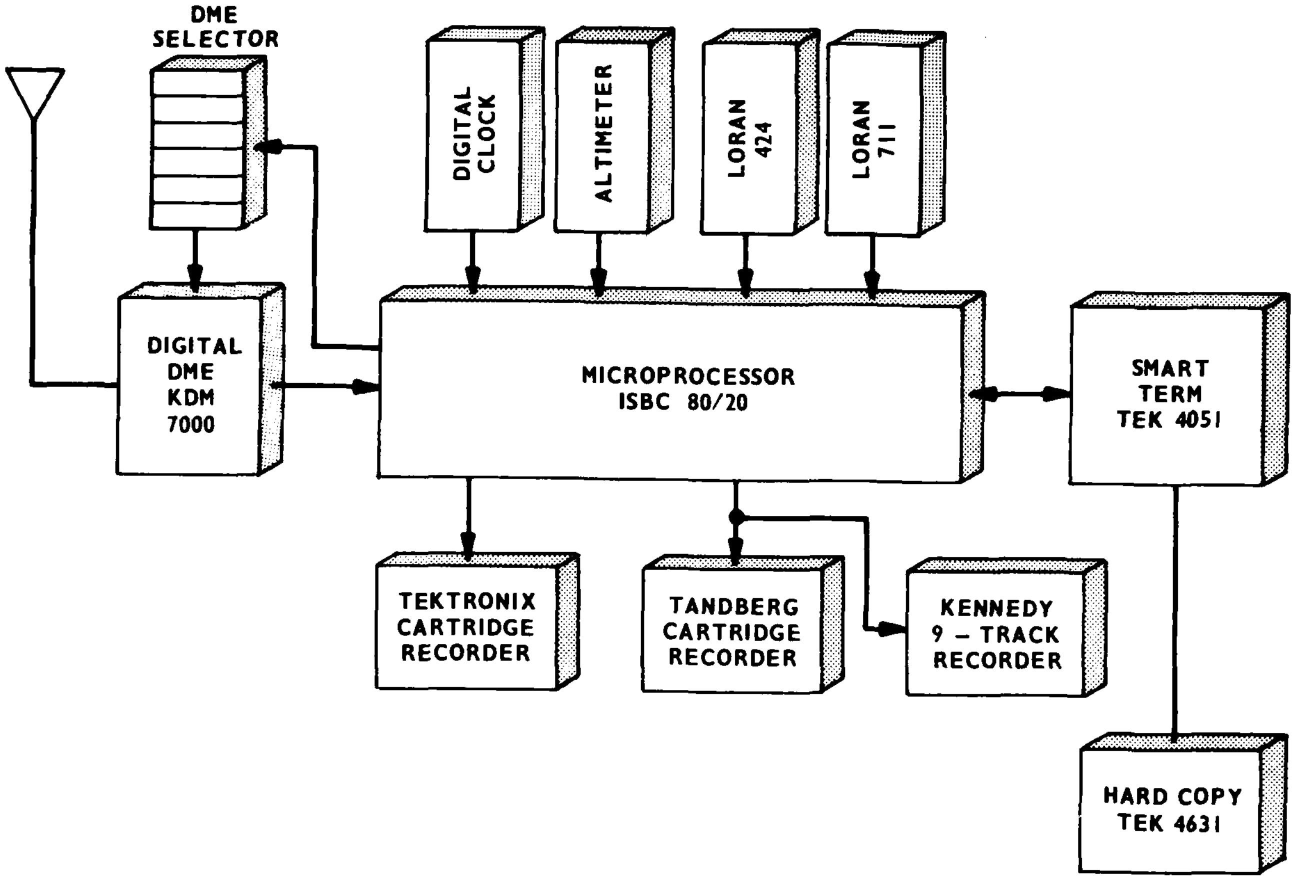


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FIGURE 1. RAPPS 1 BLOCK DIAGRAM

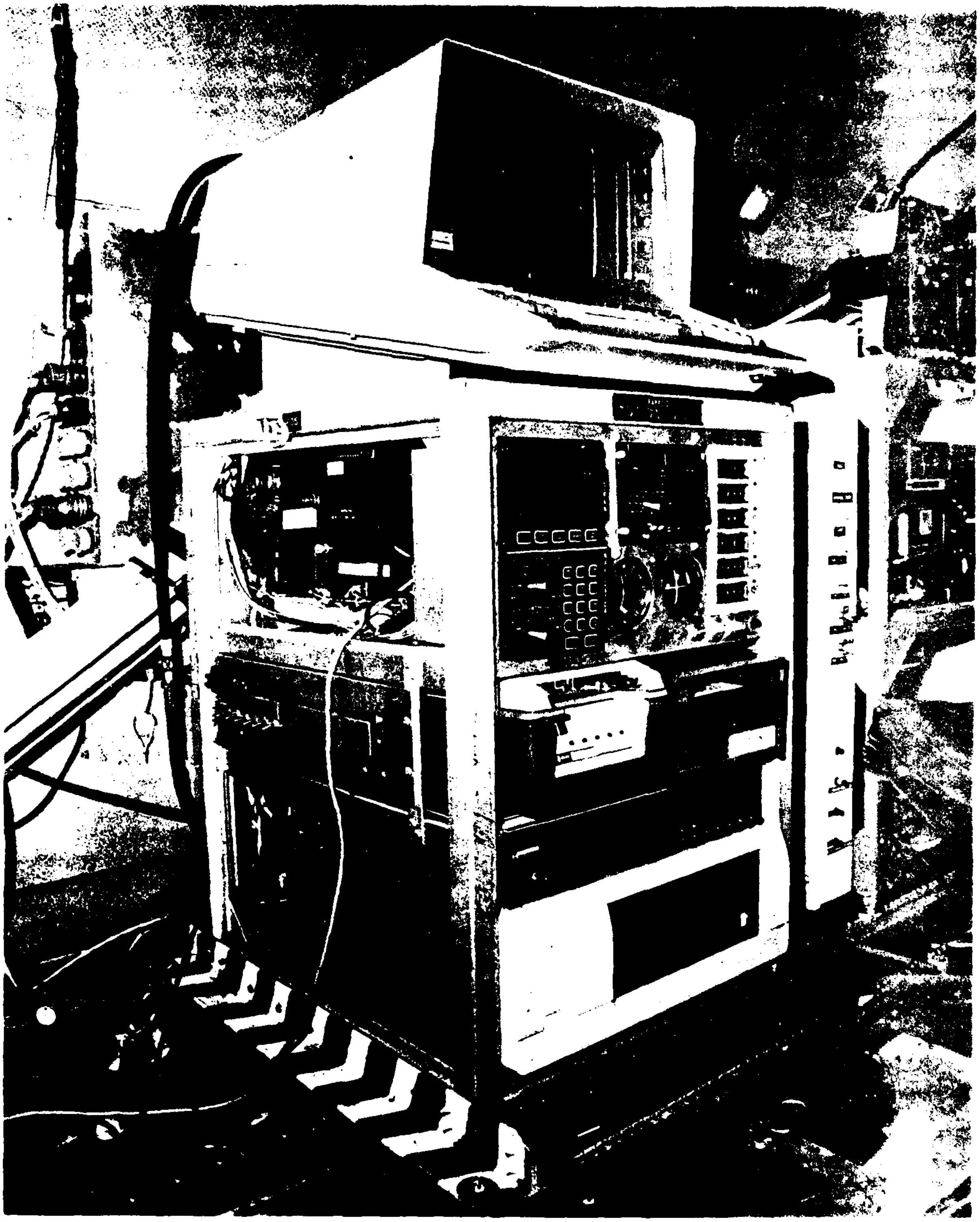

FIGURE 2. RAPPS 1 AIRBORNE RACK

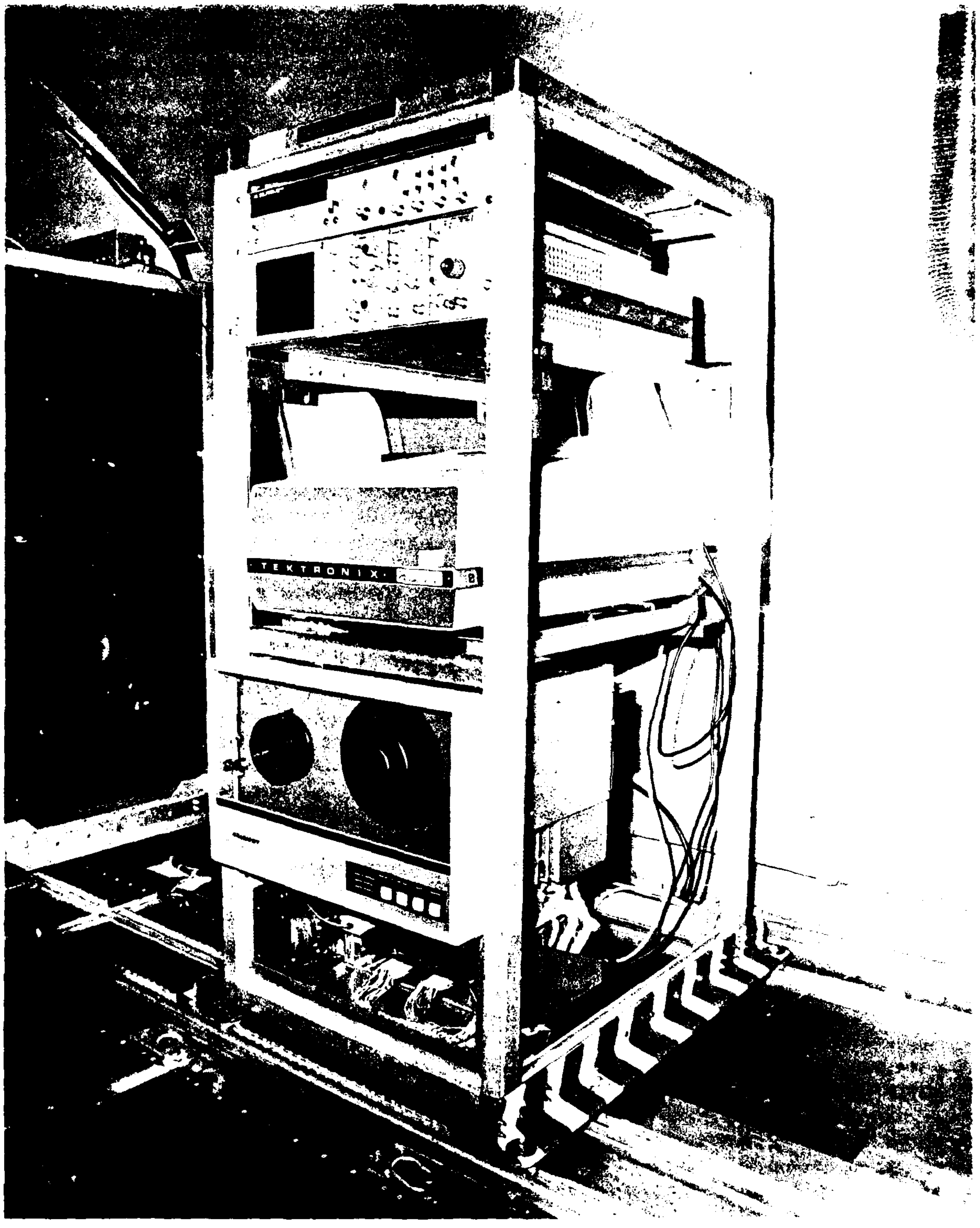

FIGURE 3. RAPPS I AIRBORNE RACK (RECORDING)

GROUND SUBSYSTEM. The ground subsystem consists of two types of beacon transponders: (1) contractor procured Vega units, and (2) GFE Butler transponder units from FAA DME stations. Table 1 is a summary of the specifications of the Vega and Butler transponders.

The Vega model 316L (see figure 4) is an Air Traffic Control Radar Beacon System (ATCRBS) that has been modified to operate as a DME transponder. It is a compact, fast rise-time pulse transponder designed for use in missiles and aircraft.

Three Butler DME transponders were also employed as portable ground beacons: two Butler model 1020's (one rated at 1,000 watts and the second at 100 watts), and a Butler model 1066 unit (rated at 100 watts). The Butler transponders are part of standard FAA DME ground stations. The transmitter is crystal controlled. The Butler model 1020 DME is shown in figure 5.

DISCUSSION

The test and evaluation of RAPPS 1 consists of static ground tests, flight test, and field evaluation. System position accuracy was determined by postflight analysis of the flight test data.

GROUND TESTS.

The RAPPS was placed in operation in the laboratory to familiarize personnel with the operational procedures, and to observe the real-time position solution as displayed by the terminal. A low loss 250-foot cable provided the radio-frequency (RF) connection between an airborne DME antenna, mounted on the building roof, and the RAPPS interrogator. The LORAN-C TDL 711 receiver was connected to a long-wire antenna, also on the building roof.

Subsequent to the laboratory checkout, static ground tests were conducted at the Center with the airborne subsystem operating in a van. The ground subsystem beacons were deployed to supplement the existing DME facilities for multilateration position solution. The van was moved to several surveyed sites to confirm system performance.

FLIGHT TESTS.

Flight tests of the RAPPS 1 were conducted at the Technical Center aboard a Convair 580, with the Nike-Hercules radar used as the position reference. Technical Center time synchronized the RAPPS clock with radar track data for postflight merge of data. (Reference Report: NA-80-32-LR, "Data Reduction and Analysis Techniques used in Determining the Accuracy of the Remote Airborne Precision Positioning System (RAPPS)," dated February 1980.)

During the flights the RAPPS TEK 4051 terminal display plotted real-time nonfiltered DME track data and LORAN-C position data to monitor system operation. In two test flights, the aircraft flew 10 nautical mile (nmi) radius orbits around the Atlantic City (ACY) DME, and radial DME tracks from ACY to Millville (MIV) to Coyle (CYN) to ACY. The flights were flown consecutively at altitudes of 6,500 and 5,500 feet mean sea level (m.s.l.) to insure signal reception from all ground stations.

Six ground transponder beacons were used during the flight tests, four of which were the operational facilities of ACY, CYN, MIV, and Sea Isle (SIE), and two portable beacons (a Butler model 1020 and a modified Vega model 316L) located at the Technical Center.

Antenna configurations for the RAPPS on the Convair 580 were as follows: an AS-133 blade antenna (mounted on the belly toward the rear of the aircraft) was connected to the DME interrogator,

TABLE 1. DME TRANSPONDER SPECIFICATIONS

Parameter	Butler 1020/1066	Vega 316L
Receiver		
Stability	±100 KHz	±2 MHz
Bandwidth (3 dB)	400 KHz	8 MHz ±2 MHz
Off Chan. Rej.	80 dB	60 dB
Sensitivity	-90 dBm	-70 dBm
Transmitter		
Type	Triode (1020)/Transistor (1066)	Triode
OSC	Crystal	Cavity
Power Output	1000 W (1020)/100 W (1066)	100 W - 300 W
Pulse Rise/Fall	2.5 μs	0.1 μs
Stability	0.002%	0.005%
Pulse Rate	950 pps	0 - 500 pps

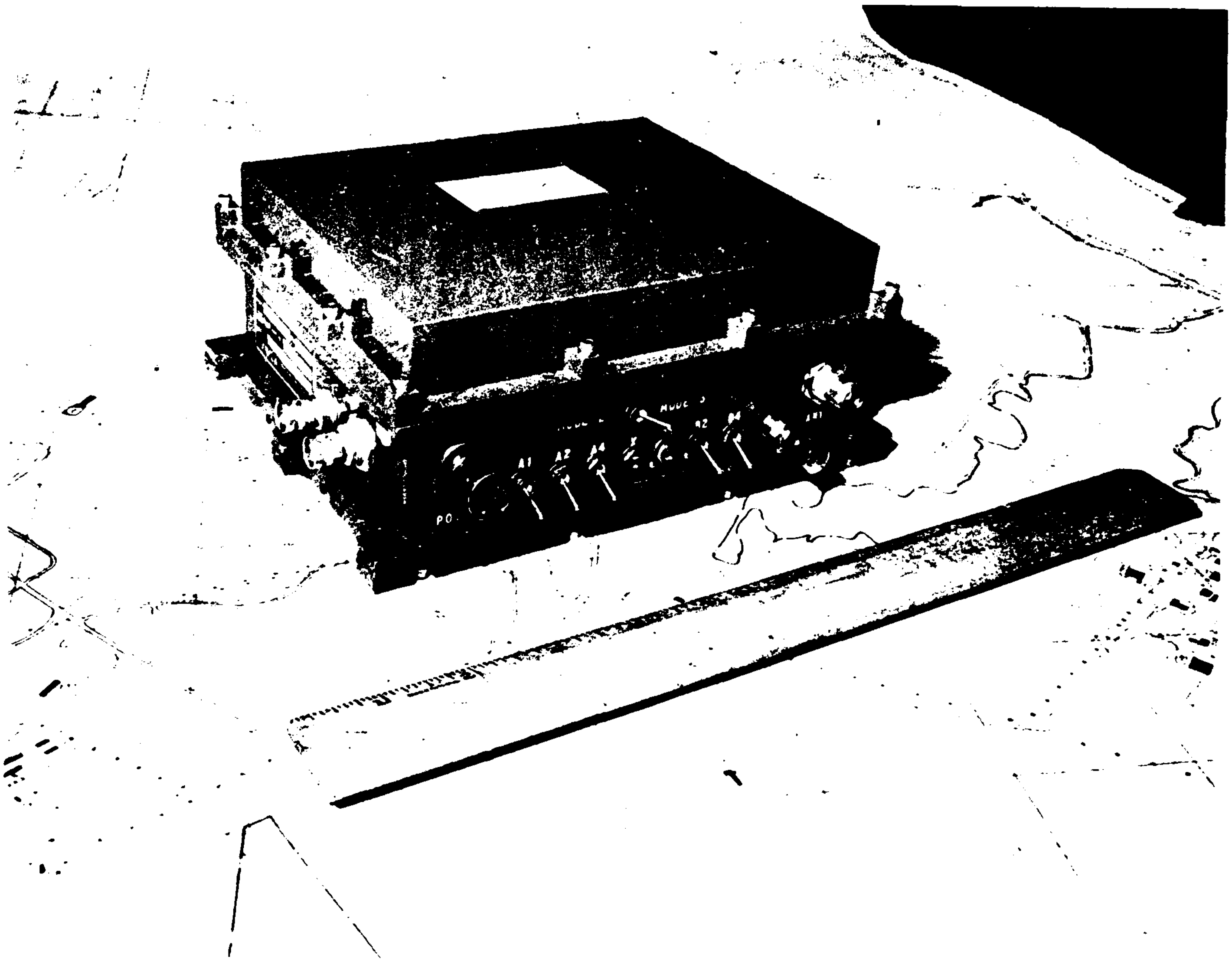

FIGURE 4. VEGA MODEL 316L GROUND BEACON

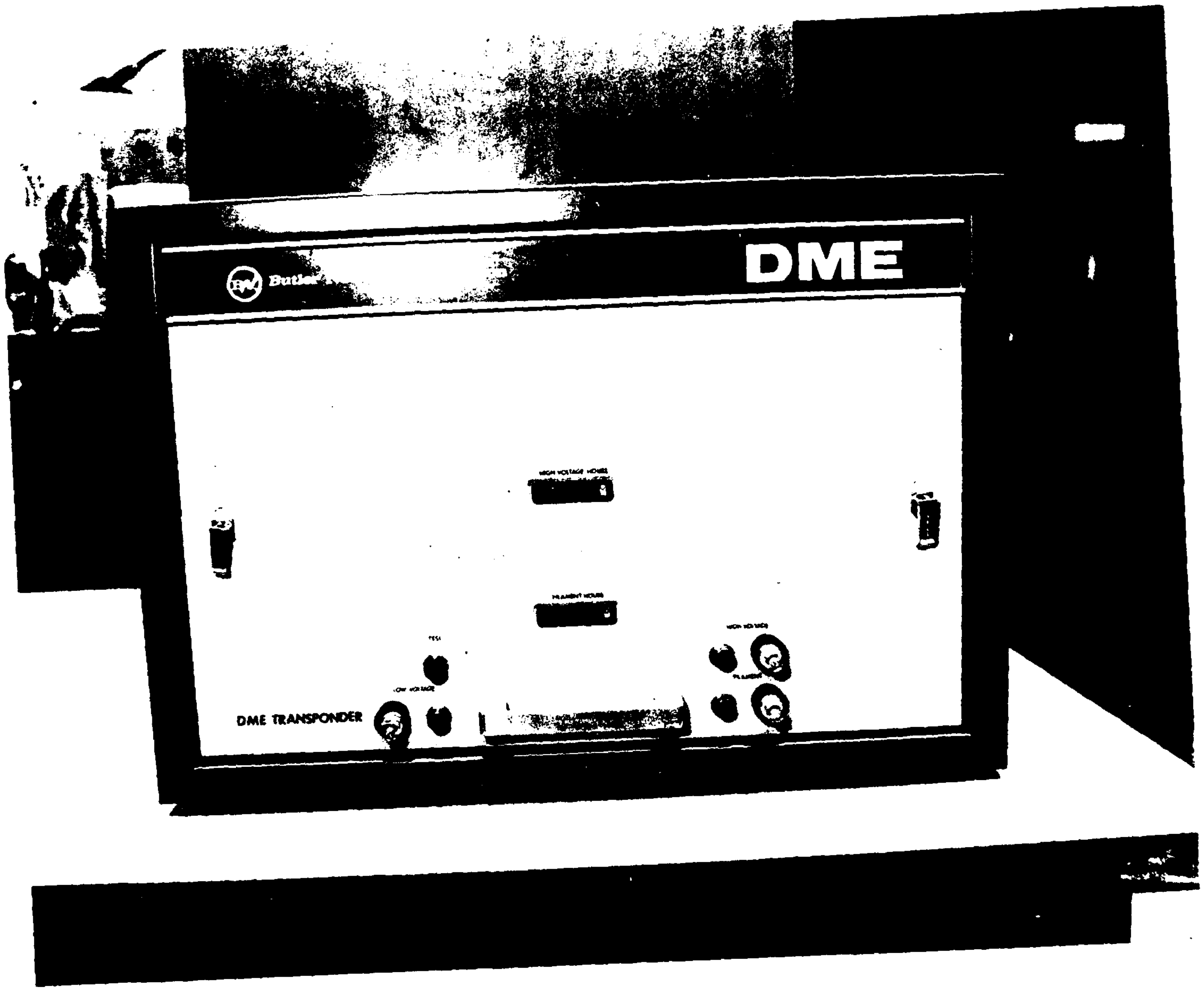

FIGURE 5. BUTLER MODEL 1020 GROUND DME

and a Teledyne whip antenna (mounted forward on the top of the fuselage) was connected to the LORAN-C TDL-711 receiver.

FIELD TESTS.

RAPPS 1 was field tested during support of Project No. 048-312-520, "Test and Evaluation of LORAN-C in Mountainous Areas." The designated test area was Vermont, from Rutland to the Canadian border. Because Vermont has only a single commissioned very high frequency omnidirectional radio range and tactical air navigation (VORTAC) facility, located 5 miles south of Burlington, the six portable RAPPS ground beacons were essential to provide adequate DME coverage for the tests. Three of the beacons were installed on mountain tops, while the other three were installed at the airports used. Table 2 lists the ground stations used during the Vermont tests. All units were housed in shelters (some heated) where 60 hertz (Hz) commercial power was available. The surveyed sites of the RAPPS beacons are shown in figure 6. Antennas installed for the beacons were AS-133 blade antennas having less than 0 decibels relative to isotropic (dBi) gain or disk-cone antennas with a gain of approximately 2 dBi.

During the field test a calibration procedure was followed to determine ground beacon distance errors. The procedure required the test aircraft to be positioned over a precisely surveyed bench mark. The distance to each beacon within line-of-sight was logged by the interrogator to the nearest 1/100 nmi. The data were used during postflight processing to initialize the iterative optimization program.

RESULTS

GROUND TESTS.

Ground test results indicated that the subsystems did function to input distance information from multiple DME ground stations and compute a position for display on the terminal cathode ray tube (CRT). Other data including time, altitude, and LORAN-C TDL 711 parameters were input and processed by the μp.

The static accuracy of the DME position solution was determined to be within 200 feet. This accuracy was extrapolated from the CRT terminal plot with the scale of 2,000 feet per inch. The origin of the plot was programmed to be the ACY VORTAC. The DME solution was repeatedly plotted as a dot on the CRT with no observable variation in position. The distances between surveyed sites and the ACY DME was readily measurable to within 1/8 inch on the CRT, making the comparison between actual and measured distance possible.

FLIGHT TESTS.

Flight test results are based on the Nike-Hercules radar tracked 10 nmi orbits around the ACY DME. No track data were accumulated on the radial flights; therefore, the expected poor geometry data of these flights were not analyzed. Figures 7 and 8 are comparative plots of the orbital data flights. Figure 7 is a Honeywell plot of the radar track of the aircraft. The plot distorts the orbit due to the unequal units of plot in X and Y. Figure 8 is a print of an inflight copy of the TEK 4051 terminal display, produced from a Tektronix hard copy unit, and shows a

TABLE 2. GROUND STATIONS IN VERMONT

Facility	Ident	Type	Channel	Elevation (ft)	Remarks
Burlington	BTV	VORTAC	122X	800	C
LeBanon	LEB	VORTAC	84X	600	C
Plattsburg	PTB	VORTAC	116X	400	C
St. Jean	YJN	VORTAC	105X	200	C
Sherbrooke	YSC	VORTAC	79X	1,000	C
Mansfield	MAN	Butler	35Y	4,300	P,M
Jay Peak	JAY	Butler	40Y	3,870	P,M
Sugarbush	SGR	Butler	90Y	3,990	P,M
Montpelier	MPV	Vega	105Y	1,190	P
Morrisville	MVL	Vega	50Y	750	P
Newport	EFK	Vega	20Y	945	P

C = Commissioned
P = Portable
M = Mountain-top

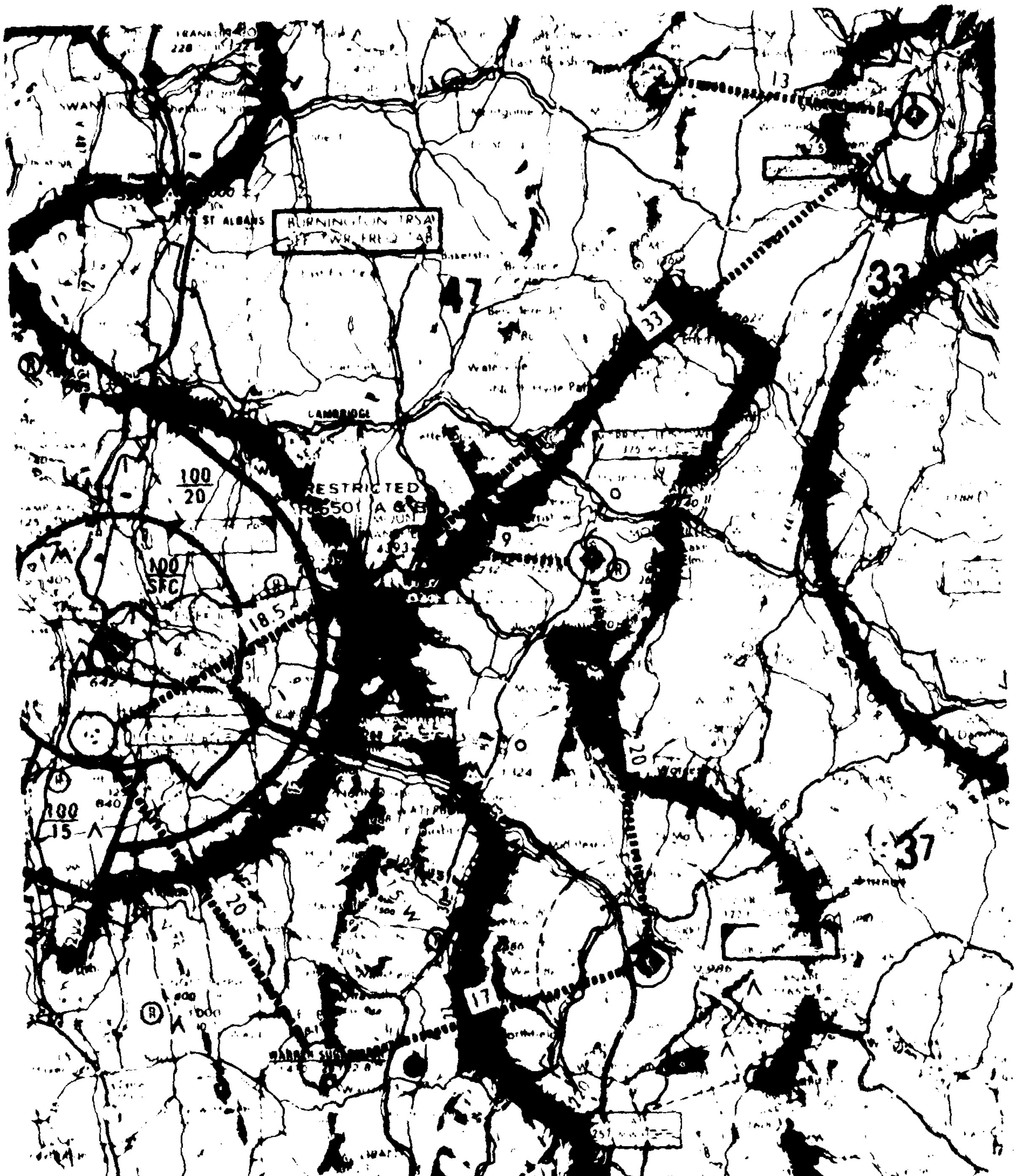

FIGURE 6. PORTABLE DME LOCATIONS IN VERMONT

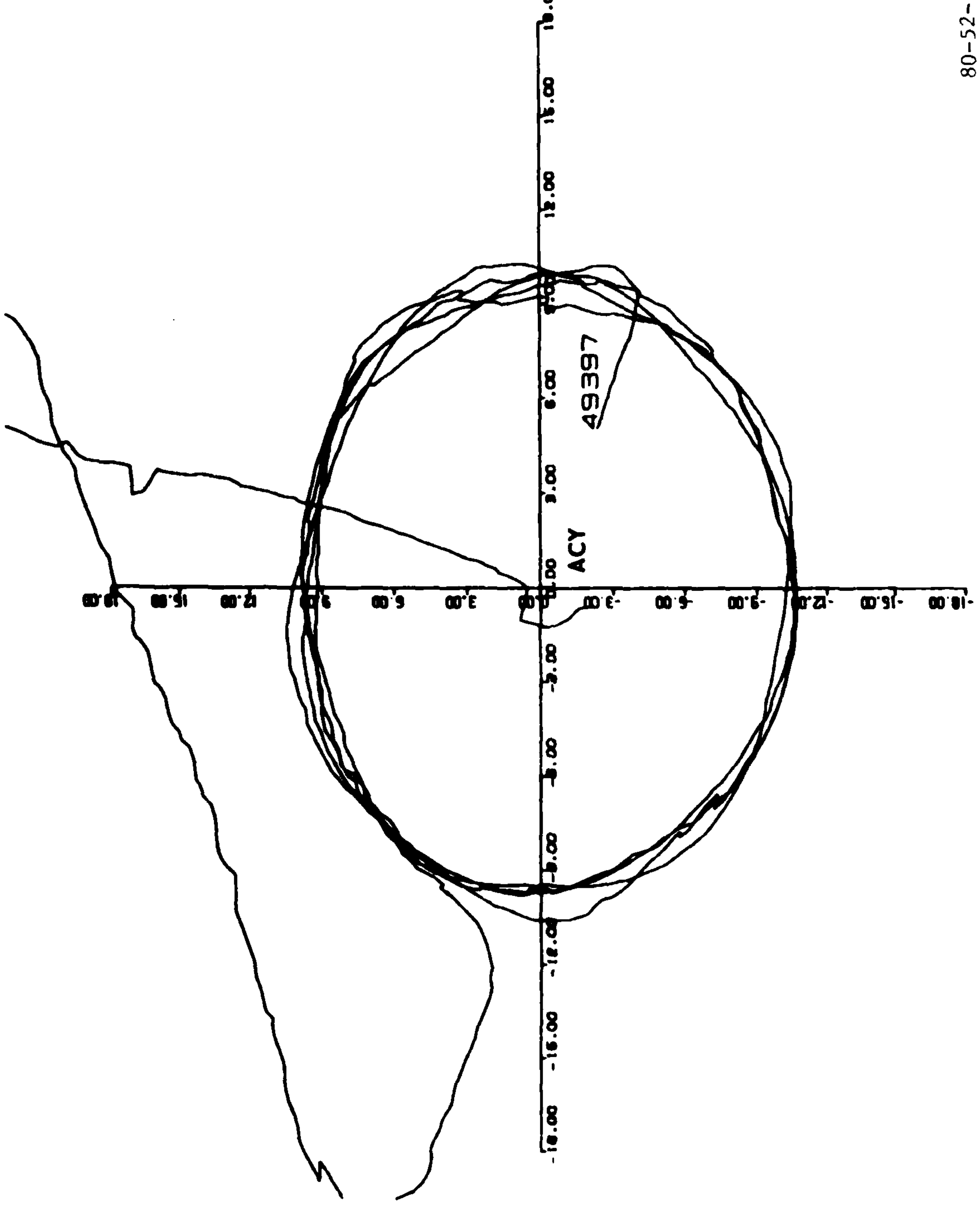

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FIGURE 7. NIKE RADAR PLOT — ORBITAL FLIGHT, SEPTEMBER 1, 1979

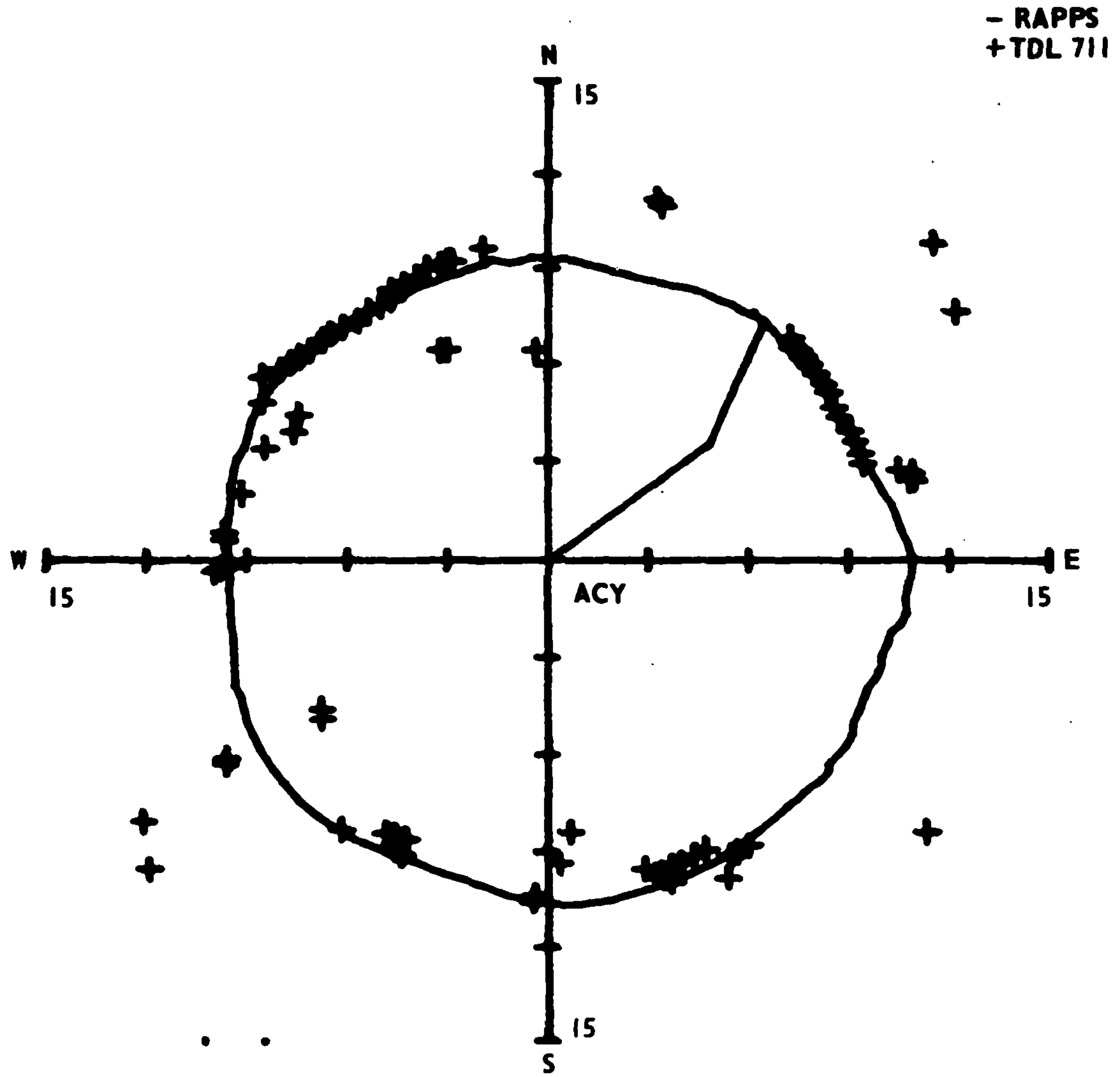

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FIGURE 8. RAPPS 1 REAL TIME PLOT — ORBITAL FLIGHT, SEPTEMBER 12, 1979

single orbit. The LORAN-C data are marked as "+" and show a close correlation with the DME track for several miles of the orbit. This was adequate to indicate that when the LORAN-C data were available the RAPPS processing and plotting routines performed properly. The LORAN-C points significantly off the DME track were due to interruptions of the signal or malfunction of the LORAN-C receiver.

Postflight data analysis resulted in a mean error of 890 feet and standard deviation of 467 feet for the range difference between the RAPPS 1 DME track and the reference radar track, based on a solution using all six ground stations. Independent computation of range bias for each station revealed an error for the coordinate used for one portable beacon and an out-of-specification tolerance range bias for a Vega beacon. A subsequent four station solution was computed without the two high error portable beacons. The error of the two beacons was too great to be fully corrected by the iterative processing routines. A least squares fit filtering technique of the data for range difference resulted in a mean error of 431 feet and a standard deviation of 307 feet. An iterative optimization procedure achieved further reduction to a mean error of 345 feet and standard deviation of 256 feet when the individual station coordinate errors/range biases were removed.

The lack of precise time tagging of the data caused by inadequate clock resolution, low interrogator sampling rate, and nonrigorous data acquisition software program contributed uncertainty to the DME derived aircraft position. A Technical Center Letter Report No. NA-80-32-LR details the analysis used in the computation of the RAPPS flight test accuracy.

FIELD TESTS.

The performance of RAPPS airborne and ground subsystem over the several months of operation in Vermont are listed below. The results include hardware failures and design deficiencies. Fourteen data flight hours were logged for both en route and nonprecision approach during the Vermont LORAN-C tests. The results of the LORAN-C tests, based on the RAPPS collected data, will be reported under Center Project 048-312-520.

GROUND SUBSYSTEM RESULTS.

1. The portable transponders had no built-in performance indicators to monitor radiation status or receiver performance.

2. The Vega transmitters with a ±2 megahertz (MHz) frequency stability are incompatible with the ±1 MHz DME interrogator channel spacing.

3. The voltage standing wave ratio (VSWR) overload protection of the Butler 1066 caused the beacon to be turned off most of the time because of icing of the unprotected antenna.

4. The Vega beacons lacked squitter which prevented proper automatic gain control (AGC) operation of the RAPPS airborne KDM-7000 interrogator.

5. The Vega receiver bandwidth of 10 MHz required channel selection of at least 10 MHz separation to avoid adjacent channel interference.

6. The Vega fast rise time transmitted radiofrequency (RF) pulses were a potential interference source for several adjacent channels.

7. The mountain top disk-cone antennas did not provide adequate signal levels to interrogators operating below the antenna horizontal plane.

8. The size, weight, and environmental susceptability of the Butler transponder made installation difficult at remote field sites.

AIRBOPNE SUBSYSTEM RESULTS.

1. The real-time plots showed DME position errors while the aircraft was maneuvering. The postflight data reduction showed that the errors were caused by dropout of one or more of the ground signals. Figure 9 shows a typical flight plan for en route data collection. Figure 10 is a real-time plot of the RAPPS DME and LORAN-C position. The straight-line deviation of DME position from the aircraft track are illustrative of maneuvering error.

2. The frequent failure and intermittent operation of subsystem elements were experienced such as: DME interface board, wiring and plugs, altitude decoder, and TEK 4051 terminal display.

3. The repeated reentry of initialization data was required upon aircraft power switchover or interrupt and was a nuisance factor.

4. The terminal software for real-time position plots, of the type shown in figure 10, was time consuming, error prone, and difficult to learn.

5. The initial terminal display lacked a monitor of real-time, numeric DME, and LORAN data such as ranges, latitude and longitude, altitude, and time.

CONCLUSIONS

1. Postflight analysis of distance measuring equipment (DME) and radar track data showed a standard deviation range error of 256 feet about a mean error of +345 feet, based on data from four commissioned DME ground stations.

2. The design deficiencies of hardware/software and operational problem areas required such extensive redesign that the present equipment could not be utilized to meet the RAPPS performance and accuracy objectives for future testing.

3. The RAPPS did provide an airborne data collection capability for LORAN-C Vermont flight testing, even though accuracy specification was not met nor operational performance suitable for future data collection.

RECOMMENDATIONS

It is recommended that the following improvements be made to the hardware and software of Remote Area Precision Position Systems (RAPPS's) 1.5 and 2.0 to increase its accuracy and reliability.

1. System: The RAPPS total system should provide an accuracy of 200 feet (1 sigma) when using the International Civil Aviation Organization (ICAO) signal format, and 50 feet (1 sigma) when 200 nanoseconds (ns) fast rise time pulse modulation is employed.

2. Ground Subsystem:

a. The portable RAPPS beacon transmitted pulses and signal format should conform to the normal ICAO pulse shape as specified in Federal Aviation Administration (FAA)-E-2444a, and have a switchable 200 ns rise time pulse modulation for increased accuracy.

b. The portable RAPPS beacons should have a built-in monitor to test system performance.

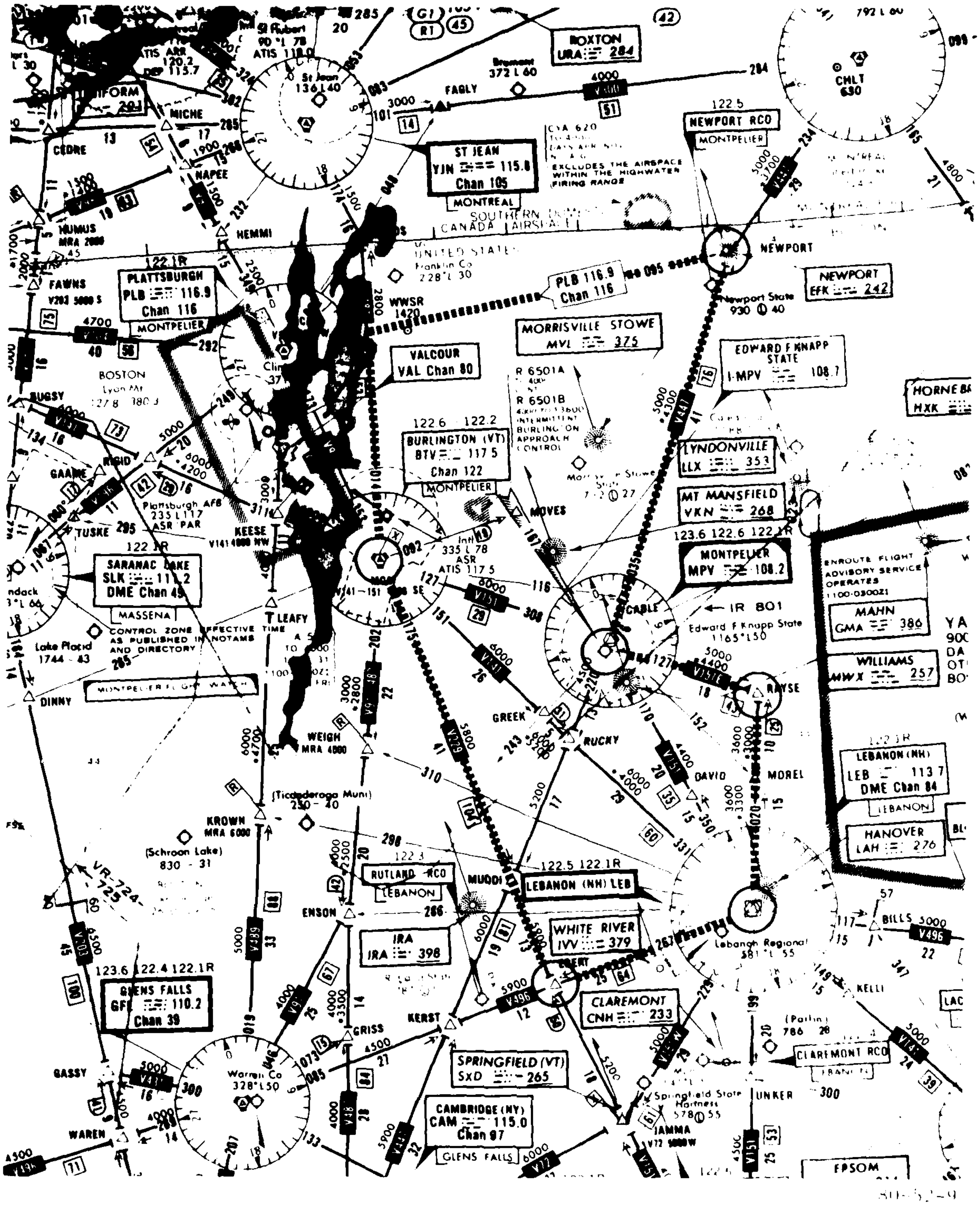

FIGURE 9. EN ROUTE "A" FLIGHT PROFILE IN VERMONT

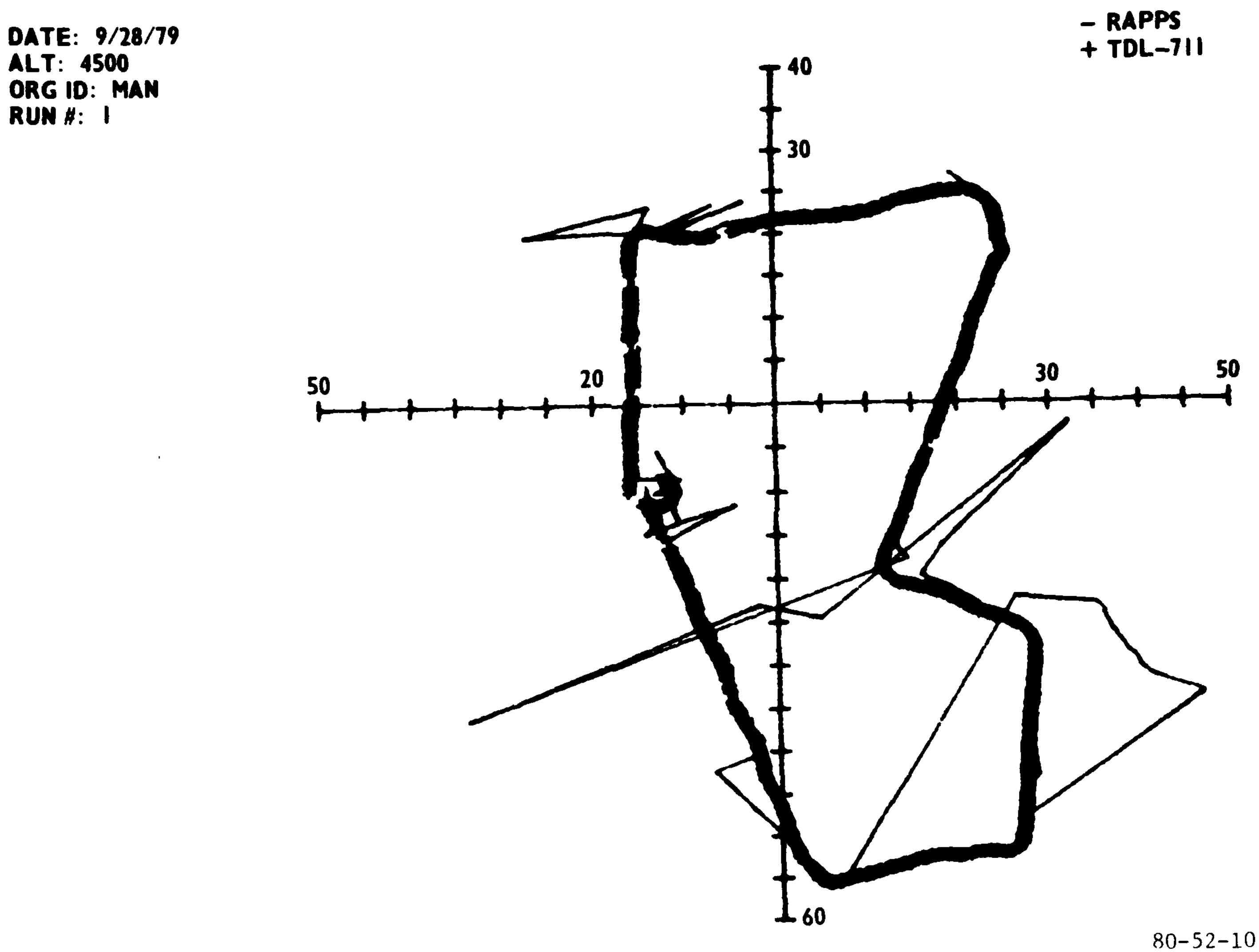

FIGURE 10. RAPPS 1 EN ROUTE "A" FLIGHT PROFILE

c. The portable RAPPS beacon should be a rugged, compact package capable of meeting the field environment over a temperature range of -40° C to +70° C with signal strength range of -80 to -20 decibels about 1 milliwatt (dBm).

3. Airborne Subsystem:

a. The airborne subsystem shall be compatible with the existing FAA distance measuring equipment (DME) stations, as specified in FAA-E-2444a, and be compatible with the portable RAPPS beacons having a 200 ns fast rise-time pulse.

b. The RAPPS airborne subsystem digital clock should have an accuracy of at least 1 millisecond and a resolution of 10 milliseconds to adequately time tag the DME data.

c. The scan rate of the airborne DME interrogator should be at least six times a second to provide sufficient DME data for improved filtering.

d. The RAPPS data acquisition software system should be based on an interrupt scheme for efficient handling of data and reduction of time tag errors.

e. The RAPPS system should be capable of withstanding power interrupts without system shutdowns. Further, the system should be capable of auto restart.

This project was accomplished under Technical Program Document (TPD) 04-309 subprogram 047-310-510. For further information contact Mr. Matthew Naimo, ACT-100B.1, or Mr. Edward Sawtelle, FAA Technical Center Program Manager, ACT-100B.1, telephone FTS 346-3913, commercial (609) 641-8200, extension 3913.

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-8