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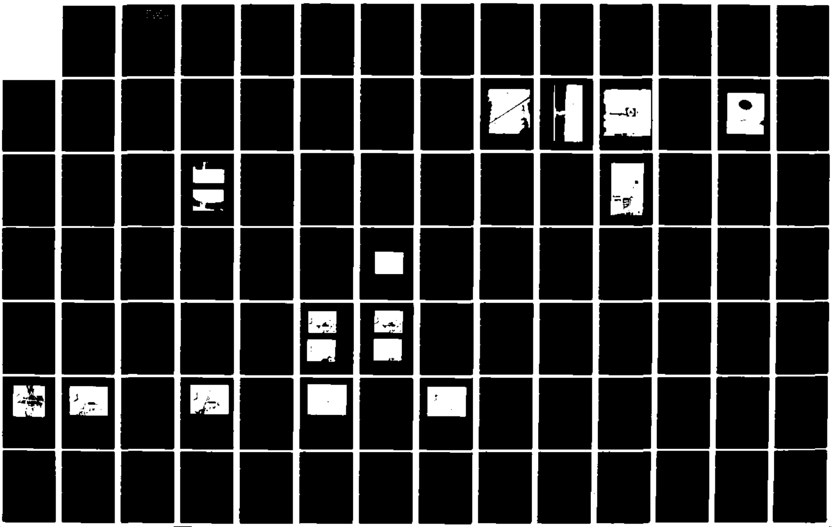

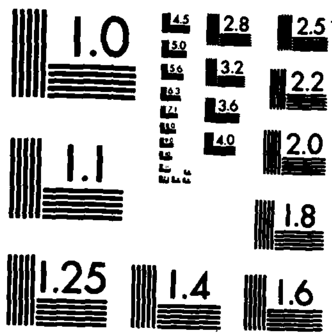

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Evaluation of a Marine Radar for Use as a Low Cost Runway Monitoring Radar at Non-ASDE Equipped, Category II Airports

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Cambridge MA 02142

June 1981
Final Report

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16. Abstract

A low cost, off-the-shelf, X-band marine radar coupled to an FAA BRITE display system was installed at Boston Logan International Airport for evaluation by the Department of Transportation/Transportation Systems Center. The radar was evaluated for use as a runway monitoring radar (RMR) for those airports that are equipped to conduct low visibility category II landings but do not have sufficient traffic levels to justify the cost of the ASDE-3 airport surveillance radar. At present there are 26 such airports where there is no direct visual means, in low visibility weather conditions, of confirming that the operational runway is clear before releasing it for the next arrival or departure. The number of airports of this type is expected to increase as the Category II runway certification program continues.

This report documents the radar unit evaluated, the evaluation conducted, the results of the evaluation, plus the results of a preliminary cost-benefit analysis.

The results of the evaluation indicate that the RMR, without further development, can fill a small, but potentially important, role in the safety of low visibility runway operations.

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Preface

This program was performed by the Department of Transportation, Transportation Systems Center (TSC), Cambridge, Ma, under the sponsorship of the FAA Systems Research and Development Service, Washington, D. C. Its purpose was to evaluate an off-the-shelf low cost, X-band marine radar for use as a runway monitor at non-ASDE-3 qualified, Category II airports.

The installation and evaluations were made at Logan International Airport, Boston, MA, because of the close proximity of Logan to TSC,. The cooperation of the Massachusetts Port Authority, FAA New England Region, FAA Boston Sector, and the radar manufacturer are gratefully acknowledged.

METRIC CONVERSION FACTORS

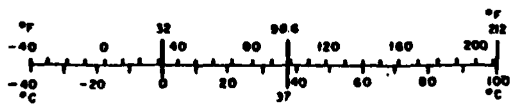
Approximate Conversions to Metric Measures

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



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EXECUTIVE SUMMARY

INTRODUCTION AND BACKGROUND

The purpose of this study is to evaluate an off-the-shelf, low cost, X-band marine radar for use as a runway monitoring system for non-ASDE-3 qualified, CAT II airports. Currently, there are twenty-seven airports of this type. The radar unit evaluated was installed at Boston Logan International Airport in October, 1980. Engineering and operational evaluations of the unit took place during the first quarter of CY1981.

Currently, there are over fifty airports in the United States that have one or more operational Category II runways. The Category II Instrument Landing System permits aircraft to land at visibilities down to 1/4 mile and ceilings down to 100 feet. At these low visibility conditions, the tower cab controllers have generally lost visual contact with all or part of the runway operation. At eleven of the busier CAT II airports, the local controller currently has ASDE-2, an airport surface surveillance radar, with which to monitor the runways. Over the next five years it is planned that a new airport surface surveillance radar, ASDE-3, will replace ASDE-2 and that the deployment will be expanded to cover twenty-seven airports. However, there is a growing number of intermediate sized CAT II airports that will not be able to justify the cost of ASDE-3. At these airports, local control has and will continue to have <u>no direct visual means</u> of confirming that a runway is clear of unexpected vehicles in CAT II weather conditions before releasing the next arrival or departure to use the runway. The Tenerife runway accident in

1977, involving two Boeing 747 aircraft, is the most disasterous example of a situation where a communications misunderstanding between a pilot and local controller in low visibility conditions led to an aircraft, both unexpected and unobserved by the local controller, being on the active runway at the time the controller released the next runway operation.

The engineering activities and evaluations performed at Logan in the first quarter of 1981 clearly indicated that the marine radar has the capability of detecting and displaying aircraft and vehicles over the radar ranges of interest. The operational evaluation demonstrated that the performance of the marine radar coupled to an FAA BRITE display would be of significant operational use to local controllers at non-ASDE equipped, CAT II airports.

EVALUATION

At the start of the evaluation it became apparent that the radar's Plan Position Indicator (PPI) was unsuitable for use in the high ambient brightness environment of a tower cab. At tower cab brightness levels, the PPI presentation was dim and exhibited a high degree of "white shirt" reflection. In the view of the evaluation team, the PPI would probably have to be used with a hood in an operational tower cab environment. This would be an undesirable situation that could compromise the radar's operational usefulness. For the evaluation, an FAA BRITE display was coupled with the marine radar, and the combination was presented as the Runway Monitoring Radar(RMR).

The first phase of the evaluation consisted of tuning the RMR in order to determine how well the unit could be made to both define an airport's runways and present the traffic on those runways. Based on a survey of the twenty-seven non-ASDE-3 qualified, CAT II airports, the maximum RMR range requirement was found to be 8600 ft. The results of the tuning phase were:

1) The RMR can be tuned to present clear, distinct targets out to 8600 ft even for small, fast moving targets,

2) In tuning the radar to provide good target definition out to 8600 ft, the ability of the radar to detect ground clutter from the airport surface and thereby depict a map of the runways and taxiways (as areas free of clutter) becomes severely compromised.

In response to this limited RMR mapping capability, the operational evaluation was expanded to include display formats that utilized two simple runway enhancement schemes. The runway enhancement schemes used either thread or tape on clear plastic overlays to clearly define the edges of the runways. The overlays were applied to the radar's PPI which was then viewed by the BRITE display camera. Thus on the BRITE display monitor, there was no evidence as to how the enhancement was accomplished (i.e., by physical or electronic means). However, the RMR format without enhanced runways remained as the primary format in the evaluation since the extent to which radar mapping is required for runway monitoring purposes was not known.

The first phase of the operational evaluation consisted of a simple target detection test which involved four subjects. The subjects were engineers, not controllers, with varying experience with ASDE displays. The results of the test were:

1) In the off-line operational environment tested, the RMR <u>without</u> enhanced runways permits an operator to have an excellent chance of detecting an unexpected target on a runway, regardless of whether the target is large or small, moving or standing while maintaining a low false alarm rate. The overall target detection performance was 98.5% and the overall false alarm rate was 2.5%,

2) All four subjects thought that enhanced runways would improve their ability to detect runway targets, and when tested, the use of enhanced runways was indeed found to improve an already impressive target detection performance.

The second and more critical phase of the operational evaluation was the evaluation by Boston Logan controllers as to the probable usefulness of the RMR in an on-line, operational environment. The results of this formal evaluation were:

1) The RMR without enhanced runways has a good chance of being of significant use to local controllers at non-ASDE equipped, CAT II airports,

2) The RMR with enhanced runways would be of significant use to local controllers at non-ASDE equipped, CAT II airports (Reason: enhanced runways would permit controllers turning their attention to the display to more quickly pick-out runway targets from the background clutter.),

3) The RMR format utilizing thread as an enhancement was clearly preferred by all the controllers,

4) If necessary, the display scale and offset can be fixed when the unit is first installed to keep down system cost. This becomes a requirement if a simple, inexpensive physical (versus electronic) implementation of the runway enhancement feature is to be used operationally.

The operational evaluation took place during good weather conditions. An engineering evaluation was conducted to assess the impact of rainfall on the quality of the RMR display presentation. Field observations of the unit's performance in rain supported the analysis findings. Specifically:

1) Since the RMR radome rotates with the antenna in contrast to the ASDE-2 radome, which is static, the RMR does not exhibit displayed target attenuation due to the sheeting of rain on the surface of the radome as is the case with ASDE-2,

2) In terms of radar performance alone (i.e., excluding the influence of radome design), the impact of rainfall on the RMR display presentation is similar to that of ASDE-2.

The performance of the RMR in rainfall is considered to be operationally acceptable in that it is equivalent to the performance of ASDE-2 out to 8600 ft, the radar range of interest relative to these non-ASDE-3 qualified, CAT II airports.

System Cost

The RMR, consisting of an off-the-shelf marine radar and an off-the-shelf monitor and camera of an FAA BRITE display, is a low cost system. June, 1981 GSA costs for the radar were obtained from Raytheon; costs for the FAA BRITE-4 system were obtained from ITT. The costs are summarized as follows but presented in more detail in Section 4.0.

1) Initial equipment cost	$52.9K
2) Installation cost by radar manufacturer	11.3K
3) Initial spares provisioning and site preparation	10.0K

Total cost not including Operation & Maintenance	$74.2K

Estimated annual O & M cost based on spares provisioning (with a MTBF of 600 hours and up to	0.5K

600 hours per year of operational use). Rationale for this value is provided in the tabulation of TABLE 4-1.

SYSTEM COST/BENEFIT JUSTIFICATION

The RMR provides a safety benefit in low visibility runway operations at non-ASDE equipped airports in that it provides local control with a direct means of confirming that a runway is clear of unexpected traffic before the runway is released to the next arrival or departure operation. A cost-benefit analysis was conducted as part of this study and was based on the following rationale:

1) One major CAT II runway accident involving air carrier aircraft occurred in the United States between 1969, when such operations started, and 1979, the last year for which airport traffic statistics are available - the 1972 Chicago O'Hare accident which involved $18.8M in damage and injury (1981 dollars),

2) From 1969 through 1979, an estimated 24,500 air carrier arrivals and departures took place in the United States under Category II weather conditions,

3) Assuming that one major runway accident over these 24,500 operations is typical for all CAT II operations, one can then calculate the potential for such an accident and the RMR B/C ratio for each airport based on the airport's annual number of CAT II air carrier operations. This assumption on safety benefits is considerably more conservative than that made in the ASDE-3 Establishment Criteria (Ref. 5-1).

The results of this analysis indicate that the probability of a major accident at a small Category II equipped airport is quite low (e.g. Tulsa International with a probability of 1% that a ground surveillance related accident will occur in the next 15 years) when compared with a large airport which is planned to receive ASDE-3 (e.g. Pittsburgh International with a probability for such an accident of 14%), but that never-the-less, due to its low cost, 22 of the 26 non-ASDE-3 qualified, CAT II airports currently in operation can justify the cost of the RMR with a benefit/cost ratio greater than one.

In addition, it was found that adding the RMR to the standard CAT II Instrument Landing System equipment package would only add 3.1% to the net present cost of that system. This small incremental cost increase would have little impact on the overall deployment of the CAT II ILS to these intermediate sized airports, even if the incremental RMR safety benefits were to be ignored.

SUMMARY OF FINDINGS

This study evaluated a low cost, off-the-shelf marine radar for use by local control to monitor runway traffic at airports with an operational CAT II runway that can not justify the cost of ASDE-3. It was decided that some modifications to the stand alone marine radar were required to make it operationally viable. An attempt was made to keep the modification costs to a minimum in order to permit the widest possible deployment of the evaluated system, if that configuration were chosen.

The first required modification was the incorporation of a BRITE display. An FAA BRITE display was selected as a suitable off-the-shelf unit. Only the display monitor and BRITE camera were used. It would have been impractical to incorporate the FAA Display Control Unit of the BRITE subsystem into the Logan installation. The chosen approach which was implemented with minimum cost provided limited flexibility in that the airport size and offset could not be controlled from the "control tower" location of the BRITE display. The RMR was therefore evaluated on the premise that the BRITE display range and offset would be fixed at the time of installation and could only be changed using the PPI controls located in the equipment room.

It is feasible however, in subsequent units, to achieve remote control of size and offset at the display console in the control tower. Technologically, it is not difficult but would require some design modification to the present radar. It is estimated that the additional cost for this optional feature would be between $500 and $1000.

A second possible modification identified during the evaluation was for artificial mapping, since the marine radar's inherent mapping capability is limited. With cost in mind, two simple runway enhancement techniques were included in the evaluation.

The enhancement techniques can be implemented quickly and cheaply. As demonstrated during the evaluation, they may be suitable for operational use.

The findings of the formal evaluation all indicate a strong rationale for the deployment of the RMR as an operational system:

1) The RMR was found equivalent to ASDE-2 in terms of displayed target definition, rainfall performance, and resolution for airports with a radar range requirement of 3600 ft or less (i.e., for the candidate RMR airports),

2) A test demonstrated that an operator using the RMR can readily detect unexpected runway targets - even small, standing targets,

3) Controllers readily accepted the RMR with enhanced runways as a system that would be of <u>significant</u> operational use to local control at non-ASDE equipped, CAT II airports,

4) The controllers thought that the runway enhancement feature was very desirable but may not be required for the RMR to be a viable operational system,

5) The RMR safety benefit justifies the cost of the unit at 22 of the current set of 26 non-ASDE, CAT II airports at current traffic levels,

6) The cost of the RMR is so low when compared to the Category II Instrument Landing System that it could be included in the deployment of that system to non-ASDE qualified airports with little adverse effect on the deployment of CAT II ILS to these intermediate sized airports.

These results indicate that the RMR can fill a small, but potentially important role in providing safety to low visibility runway operations. No further development is required. The next step is a decision regarding deployment. If deployment is decided upon, it is recommended that the RMR consist of: (1) the lowest cost off-the-shelf marine radar equivalent to the Raytheon Pathfinder Model 1250/18XR (i.e., the unit evaluated), (2) the FAA BRITE-4 display monitor and associated camera, and (3) the low cost implementation of the runway enhancement feature.

1.0 INTRODUCTION

1.1 BACKGROUND AND MOTIVATION FOR STUDY

There are 26 Category II airports in the United States which are not scheduled to receive an ASDE-3. Some of these airports have an appreciable number of operations per year. Many of these are international airports. Without a surface detection radar, the local and ground controllers are limited in poor visibility conditions to traffic management via voice communications only. Since the acquisition cost of an ASDE-3 will be considerable, it is unlikely that many if any of these airports will be eligible to receive an ASDE-3 radar in the future.

With the above as a major consideration and a conviction that an inexpensive surface radar could be better than no radar for providing a reasonable display of runways and taxiway cutoffs, the Transportation Systems Center (TSC) requested funding for a program to procure and evaluate a low cost marine radar as a runway monitor. As a result, a production X-band marine radar with relatively high azimuth and range resolution was purchased through the General Services Administration (GSA) from Raytheon Marine Company, Manchester, N.H. The radar was installed at Logan International Airport, Boston, Massachusetts by TSC, with the full and enthusiastic cooperation of the Massachusetts Port Authority (Massport). The marine radar was coupled to an FAA BRITE Display to provide an airport surface radar system which could be evaluated for use as a runway monitor for airports not eligible to receive an ASDE-3. The results of those evaluations are described in Sections 2 and 3.

1.2 DESCRIPTION OF MARINE RADAR

A Raytheon X-band marine radar was installed on top of the old control tower at Logan International Airport, Boston Massachusetts. The program was initiated by TSC under the sponsorship of the FAA Systems Research and Development Service, ARD-122. The purpose of the program was to provide an evaluation of this type of radar system as an inexpensive runway monitor radar (RMR). The radar configuration installed at Logan for evaluation purposes consists of four major subsystems: antenna/pedestal, modulator/transmitter/receiver (MTR), radar PPI display, and FAA BRITE display.

The antenna/pedestal subsystem was mounted above the roof of the "penthouse" of the Old Control Tower Building. Figure 1-1 is a photograph of the installation with the new 300 ft tower as a backdrop. The antenna, which is 18 ft long by 5 inches high, is situated 97 ft above the ground. Figure 1-2 is a view of the airfield taken from the "penthouse" rooftop. The antenna/pedestal is a production assembly specifically configured by the manufacturer for harbor surveillance operation requiring moderately high resolution at relatively short ranges. For the operational evaluation discussed in this report, the antenna was rotated at 20 rpm.

The modulator/transmitter/receiver (MTR) was mounted on the inside wall of the "penthouse" to provide a minimum length of waveguide run to the antenna/pedestal. A photograph of this installation is shown in Figure 1-3. The MTR contains most of the electronics required for transmitting the radar signal. All of the microwave components including the magnetron transmitter and the receiver front end are located in the MTR. The Log IF amplifier, video detector, and video buffer amplifier are also located in the MTR. The subsequent analog and digital video stages and timing and control generation circuits are located in the radar PPI display subsystem.

Figure 1-1. Antenna/Pedestal Installation with Logan Airport Tower as a Backdrop

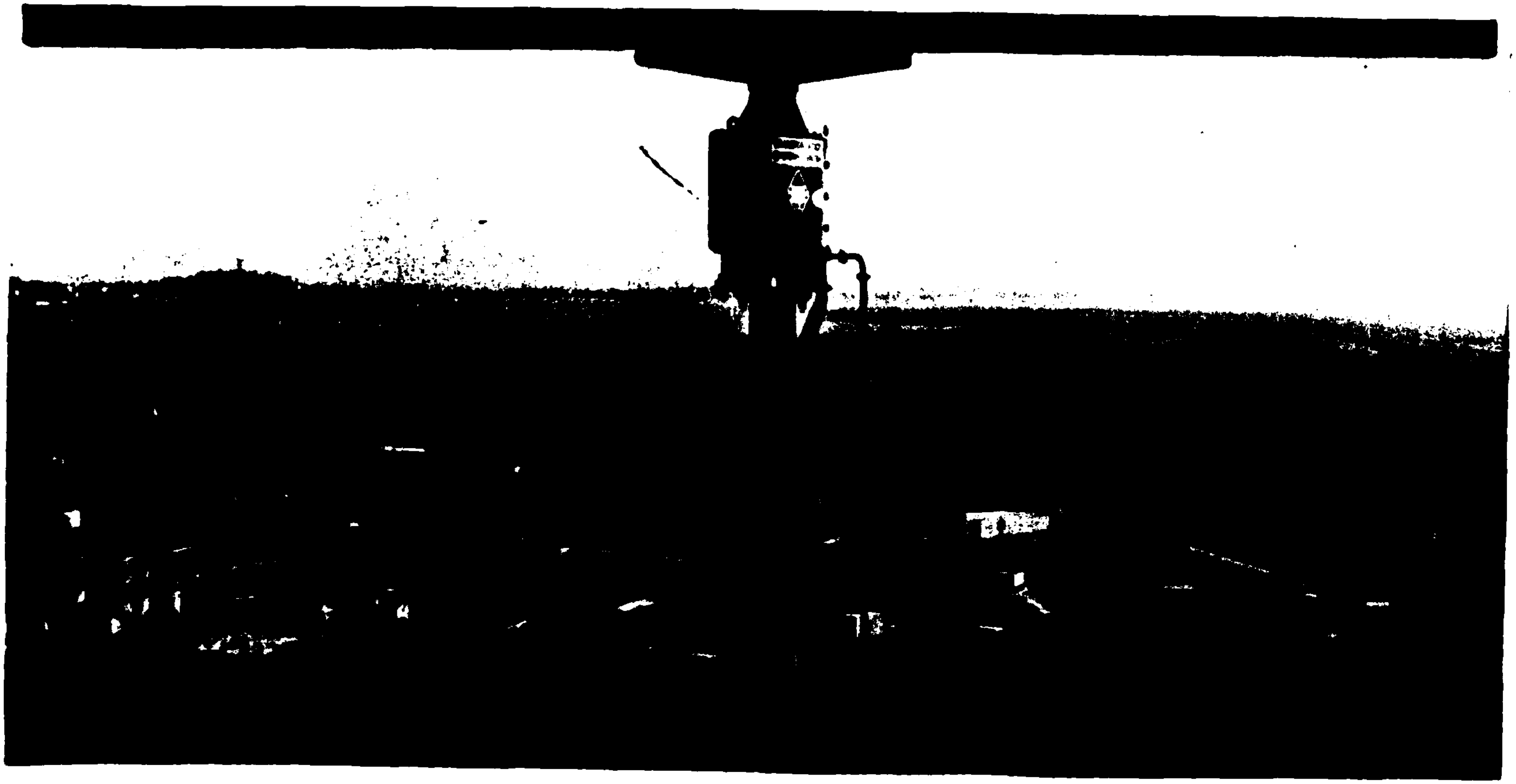


Figure 1-2. Antenna/Pedestal Installation Overlooking Logan Airport

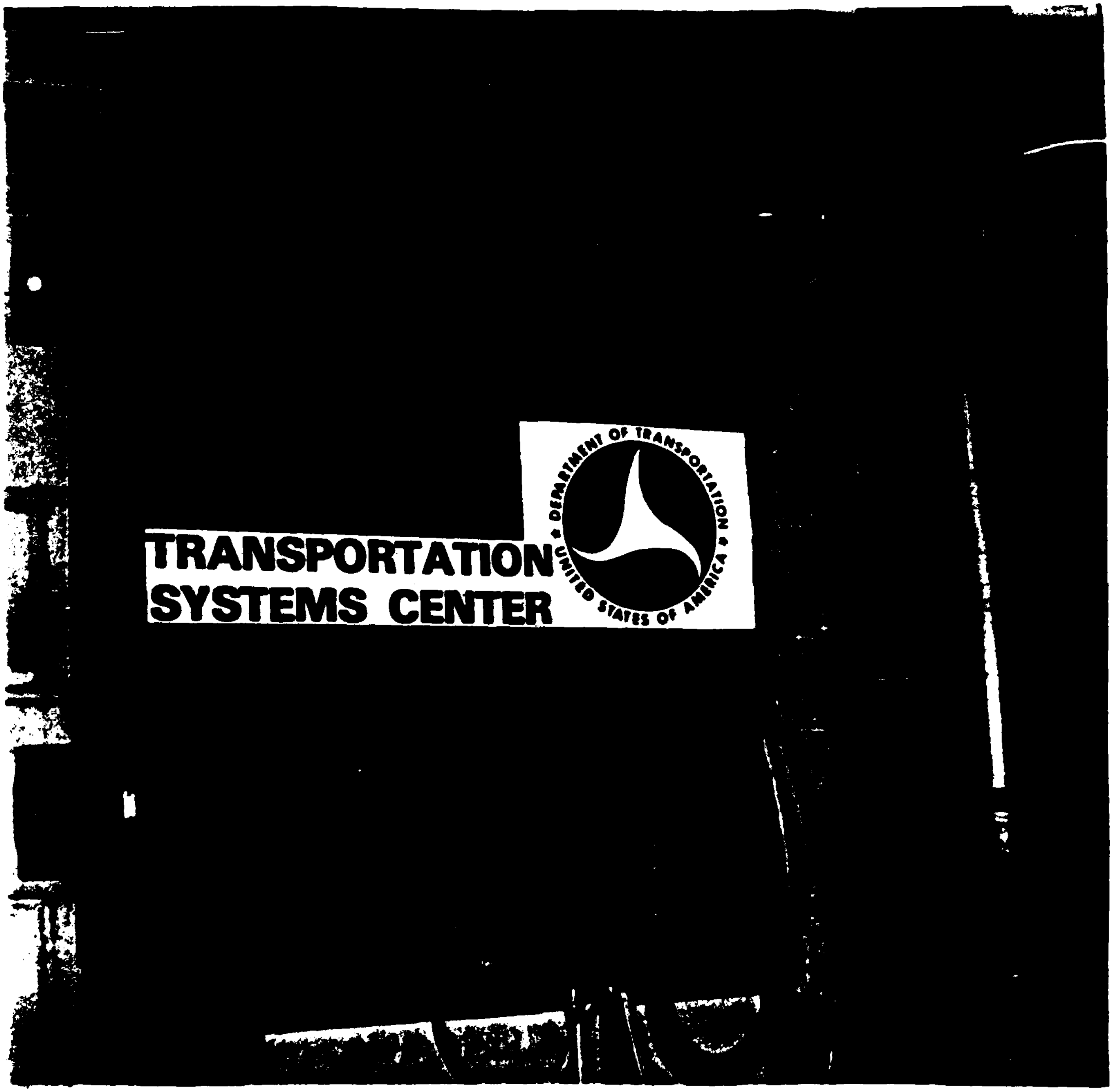


Figure 1-3. Modulator/Transmitter/Receiver (MTR) Installation at Logan Airport

The radar PPI display subsystem, shown in Figure 1-4, incorporates the 12 inch cathode ray tube supplied with the radar. The display is sufficiently light and compact to be conveniently located where desired. The primary purpose of this subsystem is to display the processed video at the proper bearing and range. The unit, however, contains the display control circuits, radar operating controls, analog video processing controls such as sensitivity time control (STC), fast time constant (FTC), and digital thresholding and amplification circuits. The cathode ray tube subsequently purchased and used for the operational evaluation incorporated an ambient light suppression filter which reduced the washout effect observed with the original CRT.

1.3 FAA BRITE DISPLAY SUBSYSTEM

Efforts were expended to set up the PPI display supplied with the radar in order to obtain acceptable performance for the runway monitoring application. The pertinent aspects of these efforts will be described in Section 2.2. At the conclusion of the radar set up and alignment procedures, TSC decided that the maximum update rate and persistence achievable, when viewing the direct display, would not be sufficient to yield satisfactory detection performance during runway monitoring operations. Consequently, a decision was made to incorporate an FAA BRITE display subsystem as part of the total radar system.

Incorporating the BRITE display not only improves detection capability but permits the use of relatively simple and low cost techniques that produce airport mapping effects at the BRITE display. These mapping techniques will be discussed in Section 3. All of the operational results and interview comments were obtained by observers when viewing the BRITE display with various types of airport mapping as well as with no mapping.

Figure 1-4. Radar PPI Display Subsystem

1.4 RADAR SYSTEM EVALUATIONS

The testing and evaluation activities performed at Logan Airport basically evolved into two major categories: engineering and operational. By their nature, some of the activities overlapped both categories. As an example, the radar was initially set up and aligned to produce optimum performance. Although these tests and adjustments were made to achieve engineering performance goals, comparisons were simultaneously being made to project their effect on the operational evaluation. Thus it was that two antenna rotation rates and two different types of displays were tried. As a consequence, an FAA BRITE display was added to the marine radar configuration.

Once the BRITE display was incorporated, the system was adjusted to produce the best results for the operational evaluation. Subsequently, no engineering changes or adjustments were made and the activities were exclusively oriented toward operational evaluation purposes.

Matters relating to the engineering evaluation such as rain performance, target return sensitivity and intensity, update rate, and airport imaging are discussed in Section 2. Information relative to the operational evaluation such as mapping, target definition, detection results, and controller interview comments are discussed in Section 3.

1.5 COST/BENEFIT ANALYSIS

Representative costs of the radar and BRITE display have been obtained. Installation costs have been developed for a quantity of 25 to 30 systems based on an average site similar to Logan International Airport. Maintenance costs have been projected for a single site based upon 25 to 30 sites in operation. These figures are included in Section 4.

A cost benefit analysis has been performed based on the safety benefit and the percentage increase in cost of a complete Category II installation as a result of including the marine radar/BRITE display into the total system. The analysis and results are presented in Section 5.

2.0 ENGINEERING EVALUATION

The RMP program consisted of two phases: the engineering evaluation and the operational evaluation. The pertinent aspects of the operational evaluation are given in Section 3. In this section, the installation and the radar are discussed in detail. During the engineering phase of the project, the installation was planned and coordinated, and the radar was installed, adjusted and evaluated by the engineering personnel.

The installation was completed, and the radar operation was initialized in the first couple of days at Logan. The basic capabilities and adjustments of the radar were then thoroughly explored in order to determine how to set the radar for this new airport application. At this time, a new reduced glare CRT was ordered to improve display characteristics in high ambient light. Although the new CRT was much better than the original one, it was deemed not good enough for tower use. Thus, the FAA BRITE display was subsequently added to the system.

During this engineering evaluation phase, the radar was operated in rain and snow conditions and movies and photographs made. It was apparent that the radar operated comparable to the Boston Logan ASDE-2 and would be acceptable for an airport with a maximum range 1.4 nm. The details of these efforts are described in the following subsections.

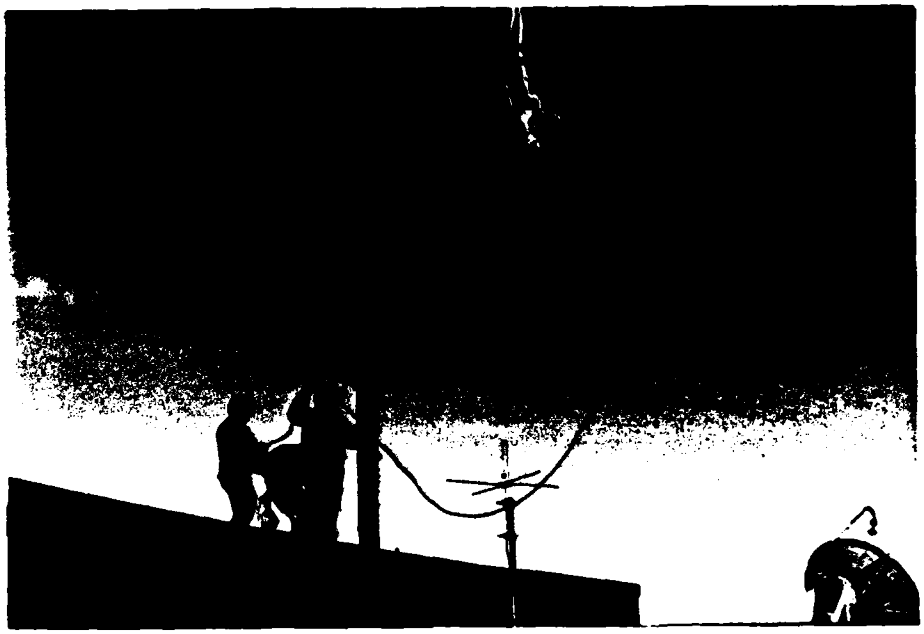
2.1 DESCRIPTION OF INSTALLATION

Logan International Airport was chosen as the site of the installation because of its close proximity to TSC (approximately 5 miles away). The near location permitted efficient utilization of time and funds since travel time and transportation costs were negligible. Logan was a very good choice for the type of evaluation that was planned. There is a great deal of traffic at Logan which provided many targets of opportunity.

The radar was installed on top of the "Old Tower Building" which is situated between the new tower and the airfield, as shown in Figure 3-2. The X-band antenna, mounted on its pedestal, is located 97 ft above the ground within 20 ft of the former location of the ASDE-2 radar, before it was moved onto the top of the 300 ft tower. A 200 ft crane was used to lift the combined antenna/pedestal, weighing approximately 300 pounds, to the roof top for installation onto the mast platform. Figure 2-1 (a) views the airfield with the antenna/pedestal combination on the way up. Figure 2-1 (b) shows the unit as preparations were made for its descent to the roof for final attachment. The pedestal was fastened to a 1 inch thick platform which was attached to a 10 inch diameter, 3/8 inch wall thickness mast. The platform top of the mast is 5 ft above the "penthouse" roof. The 18 ft by 5 inch antenna is situated 8 ft above the "penthouse" roof eliminating physical danger to anyone while rotating.

The mast support consisted of two 10 inch pipes, one outside and one inside the "penthouse". The pipes were connected together at two heights by pairs of 3 x 3 inch angle irons welded to the pipes. The inside pipe visible in Figure 1-3, was secured to a plate which was bolted onto the concrete floor. The top of that pipe was secured to a structural, reinforced concrete beam by two heavy steel brackets. The installation, which was approved by the Massport Construction Coordinator was designed by a professional engineer in TSC's Facilities Branch. It was very strong and unconditionally stable. Evidence of this was often demonstrated in windy weather. The PPI display was always stable and unwavering, even during the worst wind conditions that were encountered during the operations at Logan.

(a) 200 ft Crane Lifting Antenna/Pedestal



(b) Crane Letting It Down onto Roof Mount

Figure 2-1. Logan Airport Installation Process

The modulator/transmitter/receiver (MTR) was mounted as shown in Figure 1-3 on the inside surface of the "penthouse" wall adjacent to the pipe support structure. This area was a seldom used corridor leading to the roof of the main building. This location was ideal because it minimized the length of waveguide run and thus the microwave loss between the MTR and the antenna/pedestal. The two were interconnected by the appropriate multiconductor cable which also contained three AC cables for carrying the pedestal motor current.

The MTR was interconnected to the PPI display through another multiconductor cable which contained three coaxial cables. All cables are available from the radar manufacturer in any desired length. The display was mounted on a rolling dolly so it could be conveniently moved depending on the particular need. The MTR-display interconnection cable was long enough to serve this purpose. The general location for the display was in a small room down the corridor about 20 feet away from the MTR.

2.2 DETAILED DESCRIPTION OF RADAR SYSTEM USED IN THE OPERATIONAL EVALUATION

The radar installed at Logan International Airport is a low cost, solid state, production model marine radar available from the General Services Administration (GSA) Federal Supply Service. It is designed with standardized, modular components which provide maximum interchangeability, shorter mean time to repair (MTTR), and ultimately reduced spares requirements for a given service area. The radar operated in X-band with sufficient transmitter power to produce acceptable radar returns at the 8000 ft radar range of the airport. The radar provides good range and azimuth resolution and produces a well defined image on the CRT for reproduction on the BRITE display. A simplified block diagram of the overall radar system is shown in Figure 2-2. The pertinent aspects of the design as well as the factors related to

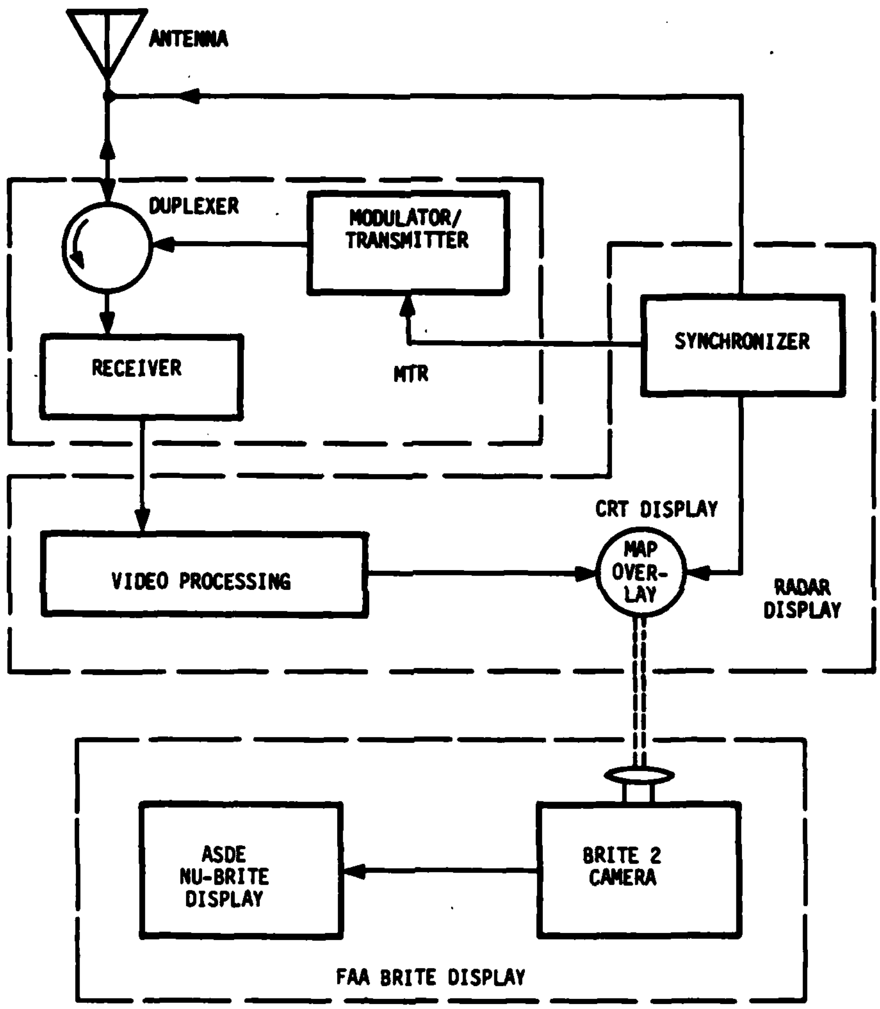


Figure 2-2. Simplified Block Diagram of Overall Radar System

set up, alignment and performance, will be discussed in the following subsections.

2.2.1 Antenna/Pedestal Subsystem

The antenna pedestal subsystem is composed of the two separate and distinct elements. The antenna was designed by the manufacturer to be used with the X-band shipboard radar in a harbor surveillance application. It became available for purchase in 1980. The antenna weighs approximately 50 pounds and is 18 ft long by 5 inches high. It produces a beam having a 3 dB vertical beamwidth of 18 degrees. The 3 dB horizontal beamwidth is 0.4 degrees. With a pulse repetition frequency (PRF) of 3600 Hz, and scan rate of 20 rpm, the system produces 12 hits per beamwidth.

The narrow horizontal beamwidth provides very satisfactory target resolution particularly considering the low cost of the antenna and system. The wide vertical beamwidth, a by product of a low cost system, is an undesirable feature. Two disadvantages of this wide vertical beamwidth are (1) a large amount of energy is directed toward the ground (compensation for this is provided in the receiver by the STC) (2) the rain clutter volume is large compared to that obtainable with an expensive shaped antenna. Although it is feasible to redesign the antenna to reduce the vertical beamwidth by 25 to 50 percent, it is not considered necessary to satisfy the range requirements of the 26 Category II, non-ASDE-3 qualified airports listed in Table 2-1. This opinion is based upon the performance observed at Logan using the controls available in the display subsystem.

The antenna which is secured to the top of the pedestal has an X-band waveguide flange interconnection. The radiating element is a slotted waveguide array enclosed in an aluminum extrusion flared housing. The X-band energy is radiated from the slotted array in a narrow unidirectional horizontally polarized

TABLE 2-1. Signal to Noise Plus Clutter Ratios for Twenty Six Category II, Non-ASDE Airports and Logan (ASDE) Airport

Airport	Maximum Range Ft	Tower Instl. Height Ft	S/(N+C) in 15mm/hr dB	S/(N+C) Zero Rainfall dB
Anchorage Intl(AK)	7000	158	14.6	45.9
Balt/Wash. Intl (MD)	5500	151	15.6	50.1
Birmingham Mun.(AL)	6000	117	16.0	48.6
Bristol Tri-City (TN)	5500	108	15.8	50.1
Buffalo Intl(NY)	4800	89	18.0	52.5
Greater Cincinnati(KY)	6600	172	15.0	46.9
Columbia Metro(SC)	5600	126	15.5	49.8
Dayton Intl (OH)	7200	117	14.5	45.4
Fairbanks Intl(AK)	5200	78	17.5	51.4
Indianapolis Intl(IN)	5200	180	16.7	51.0
Jackson Mun(MS)	6800	177	14.8	46.3
Jacksonville Intl(FL)	4900	154	17.5	52.1
Louisville Standiford(KY)	5300	117	17.0	50.8
Milwaukee Mitchell(WI)	5800	58	16.5	49.2
Nashville Metro(TN)	5000	81	17.7	51.8
Oakland Intl(CA)	8100	171	13.4	43.4
Omaha Eppley(NB)	4900	107	17.7	52.4
Orlando Intl(FL)	7400	106	14.3	45.0
Richmond Byrd Intl(VA)	8600	89	13.1	42.3
Sacramento Metro(CA)	6800	158	14.8	46.4
Salt Lake City Intl(UT)	8000	126	13.6	43.6
San Antonio Intl(TX)	6100	71	15.1	48.3
Shreveport Regional(LA)	7400	80	14.4	45.0
Spokane Intl (WA)	6700	152	15.0	46.7
Tulsa Intl (OK)	5300	179	16.7	50.7
W.Locks Bradley Intl(CT)	7200	105	14.5	45.4
Logan Intl(MA),Reference	8000	100	13.7	43.6

beam. The slotted array is enclosed top, bottom, and rear by an aluminum housing. The front of the array is covered with a flat section of radome material, thus making a compact, self contained, rotating structure.

Some thought has been given to the need for de-icing. However, since this same type of construction is used operationally on ships and for harbor surveillance in icy conditions with no apparent target detection problems, a decision has been made not to pursue the matter further.

The antenna is rotated at a uniform rate by the motor and drive system located in the pedestal. The rotation rate depends upon the particular set of pulleys in the drive system. At Logan, the antenna was rotated both at 34 and 20 rpm. As delivered, the radar was set up by the manufacturer to rotate at 20 rpm. They chose this speed because the antenna could conservatively operate at higher wind velocities at the lower rotation rate. With hardware supplied by the manufacturer and with their tacit approval, TSC increased the rotation rate to 34 rpm. At this time the radar PPI was used for direct viewing of target returns. From an operational perspective, the usefulness of the display was increased at 34 rpm. The radar was operated for about three months at this speed with no apparent adverse effects.

After the BRITE display was installed, and prior to the operational evaluation, the rotation rate was reduced to 20 rpm. This was done to permit operation of the antenna at the highest possible wind velocities. Observations were made of the BRITE display to determine the consequent effect on the displayed radar returns. It appeared that the quality and usefulness of the display was not diminished by changing from 34 to 20 rpm. In fact, it may be that the observable tracks of taxiing aircraft were better defined with the reduced update rate in that discrete rather than merged images were displayed. Some of the explanation for this lies in the high persistence of the RMR CRT. The radar tracking of aircraft on takeoff and landing was considered to be satisfactory with 34 rpm.

The pedestal basically is an S-band pedestal whose design was modified for X-band in order to provide production units capable of turning the 18 ft antenna in high winds. Although formal wind tunnel tests were not made on the 18 ft model, the radar manufacturer subsequently performed a computer analysis which indicated that at 20 rpm the antenna can be turned in winds up to 65 knots with gusts up to 130 knots without damage to the system.

The pedestal is approximately 12" x 24" x 36" high and weighs approximately 280 pounds. It is powered from contactor switches and fuses located in the MTR. There is an antenna safety switch on the pedestal which stops antenna rotation and turns off the transmitter so that maintenance can be safely performed. The pedestal is fitted with a waveguide input, output, and low loss rotary joint. Waveguide is used to interconnect the pedestal to the MTR discussed in the next subsection.

2.2.2. Transmitter/Receiver Functional Description

The modulator/transmitter/receiver (MTR) is contained in a single enclosure, 26" H 20" W, 13" D, and weighing 50 pounds. An interior view of the MTR is shown in Figure 2-3. It is easily transportable and can be installed on a wall by two people if the height of the installation is no greater than 5 or 6 feet.

The unit contains the usual microwave components such as the magnetron, duplexer, TR limiter, mixer, GUNN local oscillator and required lengths of WR-90 waveguide. The transmitter tube is a standard readily available conventional magnetron. Likewise, the duplexer, TR limiter, mixer, and GUNN oscillator are standard components available from either the component or radar manufacturer. A functional block diagram of the MTR is given in Figure 2-4 and discussed in this subsection.

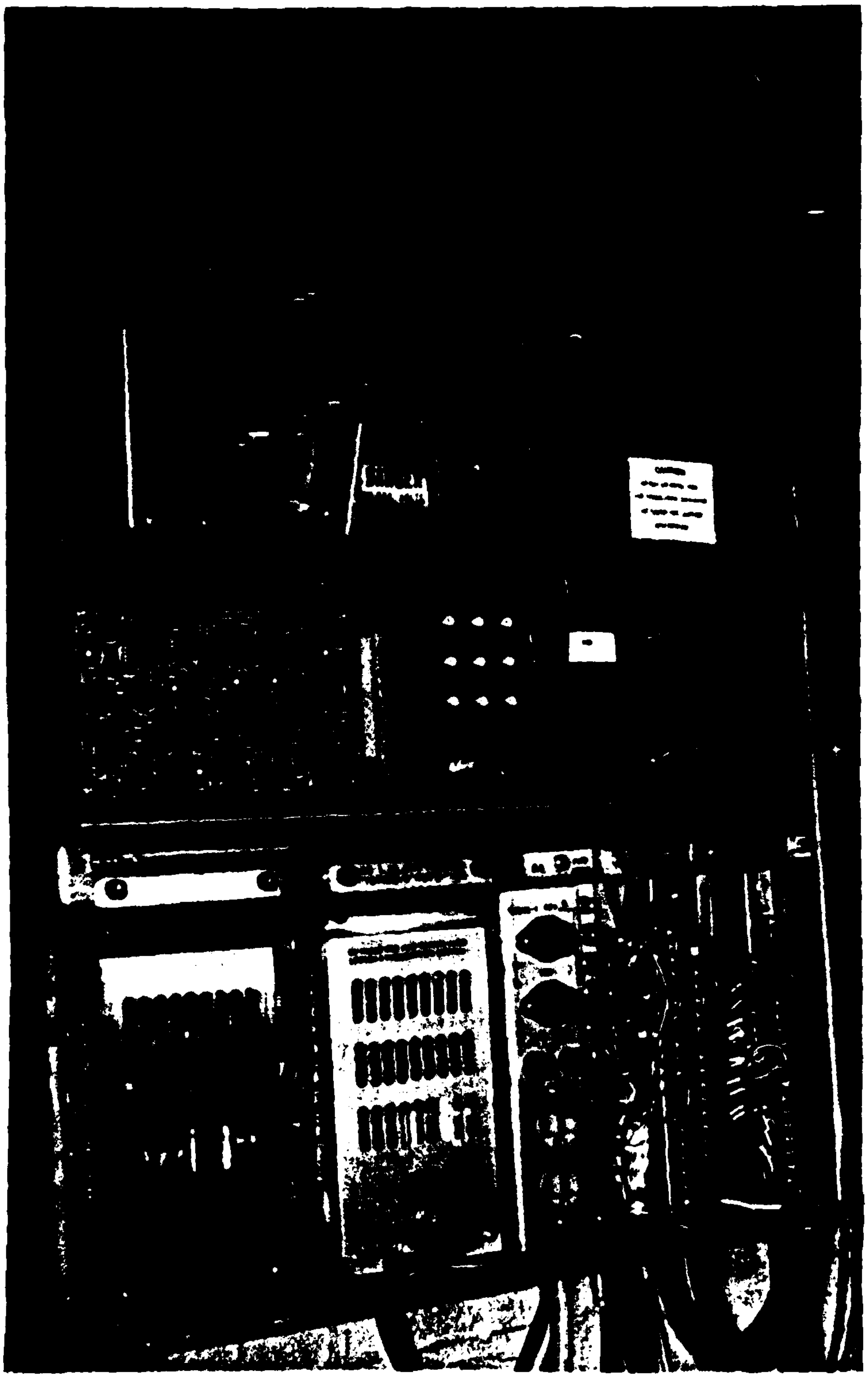


Figure 2-3. Internal View of MTR

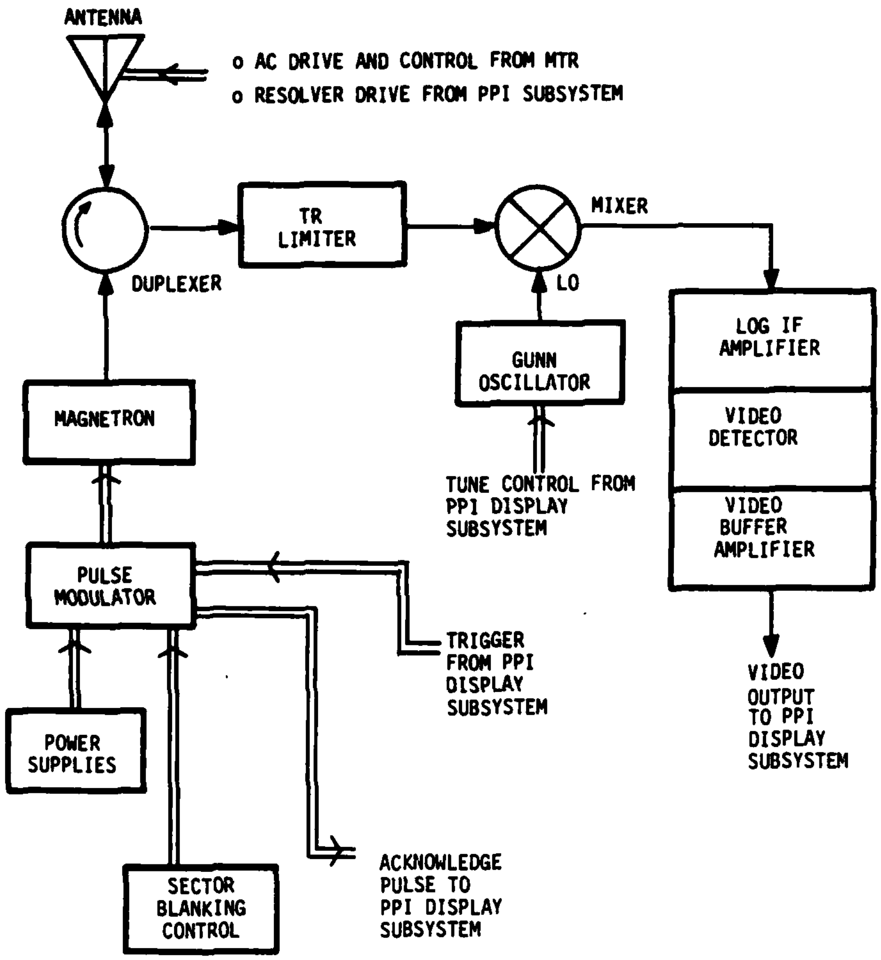


Figure 2-4. Functional Block Diagram of MTR

The microwave components are all solid state and as such should have high reliability and long life. The system has been operating at Logan for 400 hours without a component failure. The mean time to repair would be minimal since replacement of any of the aforementioned is straightforward and should be readily achievable by a technician with some experience in maintaining any radar.

The radar installed at Logan incorporates a sector blanking option which permits the transmitter to be disabled over a portion of the 360 degree scan. The inhibit sector can be adjusted by mechanical and electrical means to begin anywhere on the field. The angular extent of the inhibited area is adjustable from 60 to 225 degrees. This feature can be used to eliminate undesirable radiation in one selected angular sector. Although not essential, it can also be used to reduce ground clutter returns in areas that do not have runways or taxiways.

An all solid state modulator is readily available from the manufacturer as a production item. The MTR also contains the transmitter pulse logic control, low and high voltage power supplies with monitor points, switchable meter for monitoring important functions, elapsed operating time meter, and local controls for the transmitter operation and antenna rotation.

The MTR inputs are: the trigger and control signals from the display, the microwave signal returns from the antenna; and the AC power source. The MTR outputs are: The transmitter pulse to the antenna; the video output and the acknowledge pulse to the display; the fused AC power to the antenna motor; and the resolver drive to the pedestal.

The primary functions of the MTR are to:

1) generate and send to the antenna the short X-band pulses,
2) down convert the radar returns to an IF of 45 MHz,
3) amplify and detect the IF signals, and
4) send the video signals to the radar display where they are processed to provide range compensation, rain clutter reduction, additional amplification, and digital display format.

The transmitter produces a 50KW peak power pulse at 9410 MHz at a nominal pulse repetition frequency (PRF) of 3600 Hz. The magnetron output is coupled through the circulator duplexer to the external waveguide which routes the pulse energy to the antenna. The basic radar was purchased for Logan with the capability of operating at 9410 ± 7 MHz as well as 9375 ± 30 MHz. This was done to preclude any interference problems. None occurred and the second magnetron was returned to the manufacturer for credit.

The marine radar is inherently capable of operating at three distinct pulse widths for the 10 range settings available. The 3/4 and 1 1/2 mile settings were primarily used at Logan. The short pulse width was automatically selected by the indicator based on the Logan range settings. The short pulse was adjustable in the MTR from 50 to approximately 150 nanoseconds. It was adjusted to 70 nanoseconds at Logan as a compromise between resolution of targets and display characteristics on the PPI indicator. The PRF generation and triggering were provided to the MTR by the radar display subsystem. When the magnetron fired, the modulator generated an acknowledge pulse and sent it to the display subsystem which synchronized the display with transmitted pulse.

The radar returns are routed from the antenna to the receiver by the MTR three port circulator. The received signals pass through the circulator and TR limiter to a balanced mixer for down conversion to the 45 MHz IF frequency. Local oscillator for the mixer is supplied by a GUNN oscillator. Although set to the proper frequency at the factory, it can be adjusted on site, if required.

The down converted signals are amplified in a log amplifier with 24 MHz bandwidth suitable for passing the short pulse widths involved. In a log amplifier, a weak signal is amplified much more than a strong signal so that the output is proportional to the log of the input. Logarithmic amplification provides improved detectablilty for small aircraft and vehicular targets. The video detector and video buffer amplifier are included in the log IF amplifier assembly in the MTR. The output of the video buffer is cabled to the printed circuit boards contained in the display subsystem.

Sensitivity Time Control (STC) and video gain adjustment circuitry are incorporated into the display subsystem since they would be ineffective if placed in front of the log IF amplifier. Circuitry for control of the Fast Time Constant (FTC) function is also included in the display subsystem. They will be discussed in more detail in the next subsystem section.

2.2.3 Radar PPI Display Subsystem

The primary purposes of the subsystem are to process the video returns and display them on the CRT at the proper bearing and range. Either a 12 or 16 inch diameter display is available from the manufacturer. The 12 inch display purchased for Logan is a relatively low cost digital display designed to provide enhanced brightness and contrast. The analog video is processed, then thresholded and converted to three digital levels: high, medium, and zero. The process is implemented so that digital bits are developed in real time, amplified, stored in a shift register, and read out to a CRT over an extended time period compatible with one pulse repetition time.

All of the operating video and display controls are located on the top surface of the unit as shown in Figure 1-4. A functional block diagram of the subsystem is shown in Figure 2-5. The circuits basically fall into two categories: video amplification/processing and display control.

The radar video enters the display subsystem at the video amplifier printed circuit board (PCB). This PCB contains circuitry which provides FTC, STC and video amplification. The FTC (labeled anti-clutter rain) performs the function indicated by the manufacturer. It is a high pass filter which differentiates the received pulses, passing the leading edge and attenuating the low frequency components of the pulses. The FTC is a CFAR (constant false alarm rate) type circuit which reduces the extent to which the clutter appears on the PPI depending upon the setting of the anti-clutter control knob. The FTC maintains the clutter output of the receiver at a value below the lower intensity threshold, thereby suppressing it on the display. Without it, rain clutter could mask desired targets in the areas of interest.

Simultaneously, FTC operates in the same manner on large targets. Thus it is desirable to be able to adjust the FTC to suppress rain clutter to the extent needed to reduce interfering clutter effects on the PPI only. The radar as originally purchased incorporated an FTC control which had a switch-like action, essentially on or off. When the FTC was on, too much was applied to the video. Although rain clutter was suppressed, there was a somewhat degrading effect on the definition of large targets which, although tolerable, was undesirable. To reduce undesirable effects, Raytheon designed a new video PCB which

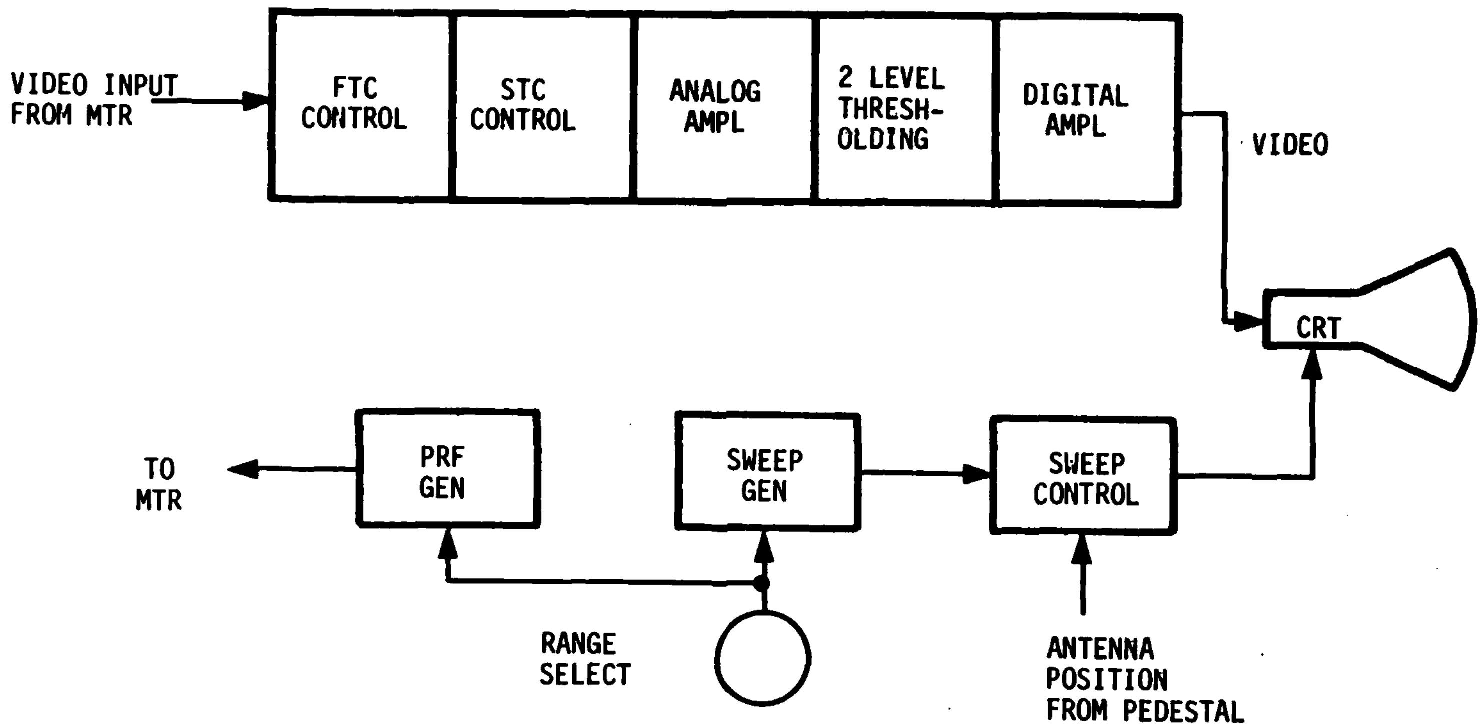


Figure 2-5. Functional Block Diagram of Radar Display Subsystem

permits vernier adjustment of the FTC from off to whatever level is required to reduce rain clutter effects. One of these boards has been provided to TSC and will be incorporated into the radar as time permits. The new circuit design is to be incorporated into all radars manufactured in the future.

After FTC, the video passes through the STC circuitry. The STC, an auxiliary gain control operating on the video signal returns, is extremely important in this radar. It is designed to operate at video rather than at IF because it would be ineffective if applied to the logarithmic IF amplifier. Normally in a ground surveillance radar, the STC would be used to provide a constant signal to noise, S/N, to compensate for range return effects not perfectly provided by a shaped antenna. Since the vertical beam of this radar is unshaped and the beamwidth is very large, the STC is the major factor which prevents saturation and blooming of targets at close ranges up to about one half mile. This STC circuit although designed for long range sea and not short range land applications is nevertheless very effective in providing signal control which permits satisfactory display of near-in targets including vehicles and aircraft in the gate areas just below the radar installation.

Several STC related adjustments are provided on the printed circuit boards to set up the radar for each particular tower installation. Once these adjustments are made, they would probably not have to be touched again. There is one major STC control located on the display control panel. It is not certain at this time whether it should be adjusted once to compensate for most weather conditions or whether it would have to be adjusted more often depending upon the level of rainfall. The matter of remoting this and the FTC control is being investigated with the manufacturer.

After FTC, the range adjusted video is passed through circuitry which amplifies signals uniformly, so that the compensation applied by STC is maintained. Basically, two gain controls are available, one on the control panel for adjustment by the facility radar technician and one inside the cabinet on the PCB for adjustment by the radar installer. After initial setup, the latter adjustment will not be changed. The former one is generally set to a given level and adjustment is seldom required.

The analog signals are then transferred to a data storage PCB where the signals in a single sweep are sampled into discrete increments and compared with thresholds in two parallel circuits. The thresholds would be pre-set at the factory and could be fine tuned during the radar installation. The setting of the two thresholds determines which radar returns will appear as high intensity signals and which will appear as medium intensity signals on the PPI.

These settings determine the quality of the presentation. Ideally, it is desired to illuminate aircraft and vehicular targets as high intensity signals, airfield grass as medium intensity background and runways/taxiways with zero intensity. A great deal of time was spent at Logan with these adjustments in combination with others to try to obtain the best possible compromise between grassy areas and desired targets.

Unfortunately, these two threshold controls are a little interactive. The aircraft and vehicular targets can be adjusted to produce high intensity signals. The grass can not be made perfectly uniform at low intensity because of the variety of return levels from the grass. The runway and taxiway lights are sharp returns and tend to give the effect of narrowing the runways and taxiways. Although all of the taxiways can not be adjusted to produce zero intensity, the thresholds were adjusted so that aircraft moving through these areas were readily distinguishable from the low intensity clutter. Because of the compromised natural mapping quality produced on the PPI, mapping techniques were developed which were effective when used with the FAA BRITE display subsystem.

After thresholding, the high and low intensity bits of each radar sweep are stored in two separate 512 bit storage registers. Each bit corresponds to a range interval that depends upon the radar range setting. After each sweep is sampled, thresholded, and stored in a range bin of the appropriate shift register, the bit train is transferred back to the video PCB and amplified. The bit train is then read out to the PPI CRT at a much slower rate during the remaining time available prior to the next pulse transmission. The slower rate permits greater excitation of the scope phosphor and consequently increased brilliance. For example, with a radar range setting of 1.5 nm the radar returns are received and stored during an 18 microsecond time period. For a centered display, the three hundred range bins, each for 30 ft, are read out onto the PPI in a time period of 111 microseconds. Thus the CRT sweep time is 6 times longer than it would be on a conventional analog display.

With a standard radar feature called interference reject (IR), a second set of 512 bit storage registers is used to store adjacent radar sweeps. The radar returns from each of the sweeps are compared for each range interval (shift register bit). If the return appears on both sweeps at the same intensity, it is accepted and will be displayed on the CRT. If it does not appear on both sweeps, it will not appear on the CRT. The IR feature provides a means of rejecting radar non-synchronous interference from other radar transmitters which may be operating within the reception range.

Figure 2-6 is a sample of one of the PPI displays obtained early in the adjustment process. Because of a combination of reasons, it was decided that an FAA BRITE display subsystem had to be included as part of the tower display. These reasons will be discussed in the next subsection. Pictures of the results obtained with the FAA BRITE display are shown in Section 3.

Figure 2-6. PPI Presentation of Logan Airport During Light Wet Snow

Relative to display control, many interesting circuits operate during each antenna scan. However, the explicit details are not pertinent to an overall understanding of the radar operation. It is sufficient to mention that the master clock and the PRF generator/trigger are located on display subsystem PCBs. The trigger is sent to the MTR which causes the transmitter to fire. This causes an acknowledge pulse, generated in the MTR, to be sent back to the display subsystem where timing and control signals operate to read out the digitized video onto the PPI CRT.

Controls for brightness and contrast are located on the control panel of the radar display. After initial setting, they rarely need readjustment. At 3600 pulses per second, 20 rpm antenna rotation, and the range settings appropriate to any airport, the display will read out 10,800 sweeps per 360 degree scan. Of these, 4 sweeps will be read out on each azimuth position of the PPI resulting in 2700 separate azimuth increments per rotation of the PPI cursor.

2.2.4 FAA BRITE Display Subsystem

The radar was delivered with Raytheon's standard P19 phosphor 12 inch CRT PPI. The illumination is yellow and the persistence is fairly long with a decay time constant of 220 milliseconds. One of the early photographs of the radar PPI presentation taken on this CRT is shown in Figure 2-5.

At tower cab ambient light conditions, the standard PPI CRT suffered a severe loss of contrast, and the display face exhibited a high degree of "white shirt" reflection. The evaluation team concluded that the display would have to be used with a hood in the operational tower cab environment and viewed the need for a hood as highly undesirable. A similar CRT, except for a color selective filter and antireflective coating, was then evaluated. The filters helped the "white shirt" reflection problem but did not adequately increase the display contrast. At tower cab illumination levels, the targets on the unhooded display were difficult to see except for the brief moment when the rotating cursor passed over them. At the antenna rotation rate of 34 rpm, the targets were updated every 1.76 seconds. This glimpse of the targets every 1.76 seconds would make locating expected targets time consuming and monitoring the runways for unexpected targets difficult. An FAA BRITE display was obtained for use with the marine radar. The use of the BRITE display also permitted the antenna rotation rate to be reduced to the value recommended by the manufacturer, 20 rpm.

The BRITE subsystem consisted of standard FAA equipment. A BRITE-2 camera, borrowed from the Logan Airport FAA radar maintenance group, was placed about 2 ft from the Raytheon PPI. The radar range was set to 1.5 nm and the image centered on the PPI in order to provide an image at the same location each and every time the radar was turned on. The location of the PPI image was unconditionally stable.

A BRITE-4 display was borrowed from the FAA Technical Center, Atlantic City Airport, N.J. and interconnected to the BRITE-2 camera. Appropriate adjustments were made and the radar system was ready for the operational evaluation.

2.3 SYSTEM ENGINEERING ASPECTS

Indirectly, many of the system engineering aspects of interest have been covered in the foregoing description of the radar. In this section, an effort will be made to correlate them by discussing some of the functional requirements and how the radar performance compares with these requirements.

This radar was, of course, installed and evaluated to determine its usefulness as a runway monitor at Category II airports which would not be eligible to receive an ASDE-3.

Therefore, the maximum range requirement should be commensurate with the airport which has the maximum distance from the control tower to the furthest end of the Category II runway. That distance is 8200 ft at Richmond Byrd International Airport in Richmond, Virginia. However, the furthest point on the taxiway leading to the runway is at a range of 8600 ft.

In deciding what the other requirements will be, a very important consideration is whether a production radar of this type should be bought or whether relatively costly modifications should be permitted. Certainly from a consideration of factors such as cost, delivery schedule, time to complete deployment, spares availability and cost, and maintenance experience, TSC believes that an unmodified marine radar of this type should be the approach used if a decision were ultimately made to deploy this radar.

The radar installed at Logan International Airport was bought on a competitive basis from the GSA Federal Supply Service. It is certain that at least one other company is a competitor on that 1980 list. Based upon TSC's discussions with the antenna subcontractor, there are an additional two companies which are ordering the same 18 foot antenna, which suggests that they are in the business of making this type of radar. Table 2-2 is a listing of the technical requirements which would be recommended as a basis for an operational RMR system.

In order to operate this X-band system on the surface of Logan International Airport, a frequency allocation permit was obtained through the FAA Frequency Management personnel in AAF-730. If a decision were made to deploy this system at Category II airports which were not eligible for ASDE-3, the FAA would, of course, have to make appropriate provisions to operate in this portion of X-band which is normally used for marine radar.

TABLE 2-2. Marine Radar Minimum Technical Requirements

A. TRANSMITTER

1. Frequency: 9375 ± 30 MHz

2. Power Output: 50 KW peak, nominal
   20 watts average, maximum

3. Pulse width/PRF: 0.05-0.10 microsec adjustable/3500 PPS minimum

B. RECEIVER

1. Overall noise figure: 10 dB (balanced mixer) maximum

2. IF bandwidth: 24 MHz

3. Video bandwidth: 20 MHz

4. Vernier adjustment of Sensitivity Time Control (STC) for maximum ranges up to 1.5 nm

5. Selectable false target elimination capability (dual or staggered PRF)

6. Vernier adjustment of Fast Time Constant (anti-rain clutter) capability

7. Input Power Requirements for pedestal/receiver/transmitter Unit: 115 v, 60 Hz, less than 15 amp, 24 OV, 60 Hz, less than 10 amp

C. ANTENNA

1. 3 dB Beamwidth:
   a. Horizontal: 0.45 degrees, maximum
   b. Vertical : 10 degrees, nominal
   20 degrees, maximum

2. 20 dB Beamwidth, Horizontal: 1.2 degrees, nominal

3. 28 dB Beamwidth, Horizontal: 1.9 degrees, nominal

TABLE 2-2. (Con't)

4. Azimuth Sidelobes:
   a. Within ± 10 deg. of mainbeam: better than 28 dB down
   b. Outside ± 10 deg. of mainbeam: better than 30 dB down.

5. Elevation Sidelobes:
   a. Within ± 90 deg. of mainbeam: better than 22 dB down
   b. Outside ± 90 deg. of mainbeam: better than 30 dB down

6. Gain: 34 dB Minimum

7. VSWR: Better than 1.2:1

8. Array weight: 100 lbs. maximum

9. Swing Circle (diameter): 10 ft, maximum

10. Operating temperature range: -25^{o} C to $+55^{o}$ C

11. Humidity: 95% at 40^{o} C

12. ICE Loading: $5lb/Ft^{2}$

13. Wind speed loading without damage
    a. not rotating: up to 100 knots
    b. rotating at 20 rpm: up to 65 knots with gusts up to 130 knots

14. Salt spray: 5% continuous

15. Water: wind driven rain, 1 inch per hour at 65 knots

D. PEDESTAL

1. Rotation speed: 20 rpm, nominal
2. Weight: not to exceed 250 lbs.
3. Height of Pedestal: approximately 36 inches
4. Capable of rotating the antenna at 20 rpm under environmental conditions listed for the antenna

E. DISPLAY

1. Type: 12 inch bright display
2. Input power requirements: 115 v, 60 Hz, less than 15 amp.
3. Height: approximately 36 inches
4. Range Selections Required: (all with 0.66 microsec nominal pulse 0.5, 0.75, 1.5, and 3 nm
5. Off centering capability: name on standard equipment

TABLE 2-2. (Con't)

F. GENERAL 1. All solid state except for a. PPI CRT display b. Magnetron

The reader may well deduce from what has been written that this radar has many adjustments. The variety of adjustments were a key factor in being able to set up the marine radar to operate satisfactorily as a short range airport surface radar. TSC believes it understands the operational circuitry sufficiently to prescribe factory settings and provide guidance information for on site installation. In addition, the manufacturer provides technical training courses at the factory or at the customer's facility.

The many adjustments are generally advantageous. One example of an advantage is that the receiver STC adjustment is so effective that it provides adequate compensation to overcome the adverse effects of the large vertical beamwidth of the low cost antenna. Another advantage is in the thresholding circuitry. The low intensity threshold can be set to reduce the display of medium level rainfall clutter on the PPI without significantly affecting the high intensity display of aircraft and vehicular targets.

It is useful to look at the calculated range capability of the radar independent of thresholding and FTC to see what is basically achievable. The calculations can also provide a comparison with comparable radars when the same frame of reference is applied.

The range capability of the radar at any level of rainfall rate can be calculated from

$$\frac{S}{(N+C)} = \frac{[P\lambda^2\ Lw\ L_\alpha\ I_\sigma\ G^2\ (\theta)]}{[(R^4\ (4\pi)^3\ KTBF) + (P\lambda^2\ Lw\ L\alpha\ ILP\ \eta R^2\ (C\frac{\tau}{2})\ \Delta\phi \int_{\theta_0}^{\theta_1} \overline{G}^2\ (\theta)\ d\theta)]}$$

(Ref. 1)

where:

$P = 5 \times 10^4$ watts (transmitter power)

$\lambda = 3 \times 10^{-2}$ meters (wavelength for a frequency of 9.41 GHz)

$Lw = 0.63$ (system and waveguide loss factor for -2 dB)

$L_\alpha = 2.8 \times 10^{-4}$ (one way rain attenuation per meter) (Ref. 2)

$I = 4$ (integration factor in PPI)

$\sigma = 3$ meter^2 (assumed radar cross section for all calculations)

G = antenna gain for signal power portion of calculation

R = radar range in meters

K = Boltzman's Constant

$T = 290^oK$ (reference temperature)

$B = 24 \times 10^6$ Hz (receiver bandwidth)

$F = 10$ (receiver noise factor)

$Lp = 1$ (due to linear polarization)

η = backscatter cross section per unit volume in m^2/m^3 (Ref. 3)

$C = 3 \times 10^8$ m/sec (speed of light)

$\tau = 70 \times 10^{-9}$ sec (pulse width)

$\Delta_\phi = 7 \times 10^{-3}$ radians (azimuth beamwidth of 0.4 degrees)

$\int_{\theta_0}^{\theta_1} \overline{G}^2\ (\theta)\ d\theta$ = product of [1] vertical angular extent of beam between ground (θ_0) and upper 3 dB point (θ_1) and [2] antenna gain calculated for the extent.

Curve A of Figure 2-7 is a plot of the ratio of signal to noise plus clutter with no rainfall. Curve B which is a plot of the same ratio during 16 mm/hr rainfall does not take thresholding and FTC into account. The actual performance of the radar in rainfall appears to fall somewhere between these two levels because of the application of thresholding and the operation of the FTC circuit. The FTC does not increase the received signal level, but it does reduce the effect of the rain by suppressing the clutter level appearing on the display. Analytically determining that effect is unnecessary and beyond the scope of this report. However, the calculations suggest that the radar is capable of operating satisfactorily on a field whose maximum range is 1.4 nm.

The plots of Figure 2-7 were made for an installation which was 100 feet above the ground. Of the 26 Category II airports in the United States which do not appear to be eligible for an ASDE-3, the installation height ranges from approximately 50 to 180 ft and the maximum ranges vary from 0.8 to 1.4 nm. Table 2-1 lists the airports with projected installation heights (tower height plus 8 ft) and maximum ranges from the tower to the furthest end of the Category II runway. For each of the 26 airports the table presents the calculated ratio of S/(N+C) at that maximum distance for rainfall conditions of zero and 16mm per hour. At worst, the ratios are comparable to Logan Airport.

The engineering observations and evaluations made at Logan under conditions of fog, driven snow, rain, and clear air tend to confirm the 1.4 nm capability of the radar, at least to the satisfaction of the TSC project engineer.

Moving pictures were also taken of the PPI presentation in rain and snow. The movies depict the clutter effect of the rain or snow. They also clearly demonstrate substantial reduction of the clutter on the display because of application of FTC. The targets in the movies are more visible because of the reduction/elimination of clutter. In fact, snow plows, that were scurrying back and forth, clearing inactive runways and taxiways were significant high intensity level targets.

The photograph of Figure 2-6 was taken on December 15, 1980 during a period of light wet snow when the visability was "not great". A 727 aircraft is landing on runway 4R. A larger aircraft probably a DC-10 is on taxiway S ready to move onto runway 9 for takeoff. A smaller aircraft is on taxiway S behind the larger aircraft. The snow banks along the runways and taxiways provide a natural outline for them.

On another occasion when it was raining fairly hard and aircraft were landing on runway 27, an experiment was performed to see how far out beyond the airport that various aircraft, which were in the approach mode, could be seen on the PPI presentation. The radar range was set so that the 5 mile mark was at the edge of the PPI. Large aircraft like DC-10s and L-1011s could be clearly observed over water without loss of target from scan to scan as they entered the edge of the display at 5 miles. A small general aviation aircraft was picked up on most scans as far out as 3 1/2 miles and could be observed on every scan after it reached the 2 1/2 mile mark. This experiment was not intended to suggest that this radar is a 2 1/2 mile radar. The purpose of the experiment was to see if there was an adequate target detection margin at the 1.4 nm distance. It was performed to get a qualitative level of confidence that the 8000 ft maximum range of Logan was not the maximum range of the radar. Unfortunately, since there was no quantitative measure of rainfall available, hard numbers cannot be attached to the results.

After the FAA bright display was incorporated, observations by the TSC project engineer were performed in two types of inclement weather on April 24, 1981. In the first case, the airfield was totally and completely blanketed with heavy fog. None of the runways or taxiways could be visually observed from the roof of the Old Control Tower Building. The aircraft were landing on the Category II runway 4R and taking off on runway 9. Approach control was simultaneously being monitored by the observer. While listening to the approach controller and watching the bright display, the pattern of operation on the airfield was completely discernible. Takeoffs were authorized on runway 9 as soon as the aircraft landing on 4R had cleared the intersection (assuming another aircraft was not following on 4R). Targets were well displayed and detectable.

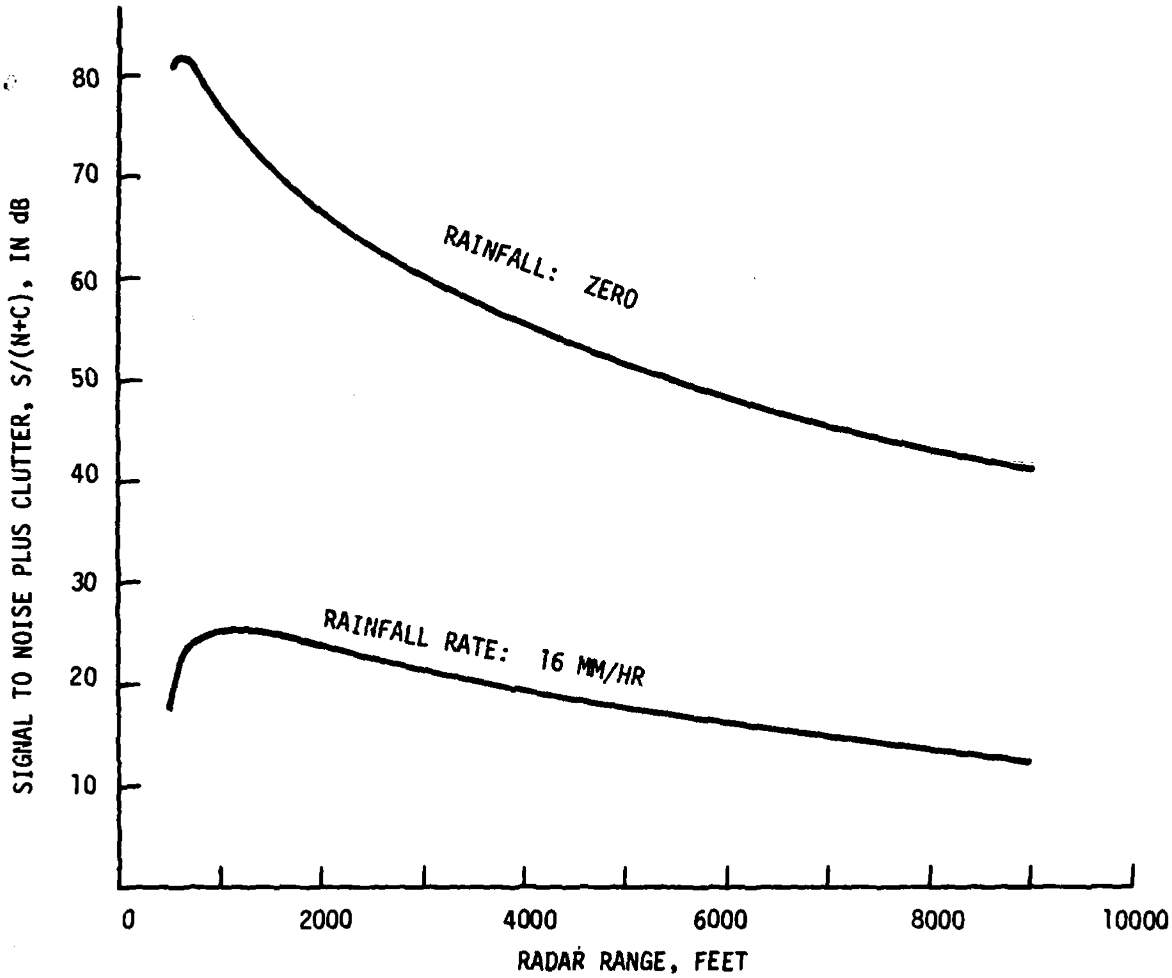


Figure 2-7. Theoretical Signal to Noise Plus Clutter Versus Range for Logan Airport at Zero and 16mm/hr Rainfall

Figure 2-8 presents two photographs of this time period. Figure 2-8(a) shows a 727 taking off on runway 9. Figure 2-8(b) shows a small general aircraft taking off. The aircraft which were monitored taking off on runway 9 were visible and detectable up through the approach lights on the other end (runway 27).

Later in the afternoon, the fog lifted and a rainstorm developed and passed through the area. Rainfall data was obtained from the National Weather Service (NWS)from a tipping bucket located about one half mile from the radar and about one mile from the region on the field which displays the heaviest clutter during rainy periods. The measured rainfall rate at NWS varied from 4 to 16 mm/hr. During that period, pictures of the display were taken.

The pictures in Figure 2-9 indicate how clutter appeared on the bright display of the X-band radar and the effect of the FTC. Figure 2-9(a) displays clutter as it appeared on the BRITE display. Figure 2-9(b) indicates the suppression of clutter. The picture of Figure 2-9(b) was taken 1 1/2 minutes after 2-9(a) in order to allow the illumination persistence of the bright to decay. Some of the residual map between runways 4R and 4L may be due to lag in the vidicon. Targets were detectable and trackable with the FTC on. The off/on switch type FTC control is discussed in Section 2.2.3. A vernier controlled FTC is much more desirable and will be available from the manufacturer in subsequent production units. If radars are procured, for runway monitor application, vernier control of the FTC will be a requirement in the technical specification.

One last word about rain clutter on the radar displays deals with the effect observed on the ASDE-2. On another occasion when it was raining the TSC project engineer visited the ASDE-2 equipment room in the Logan tower. Rain clutter was also observed on the ASDE-2 Conrac display. It had a different

a) 727 Taking Off on Runway 9

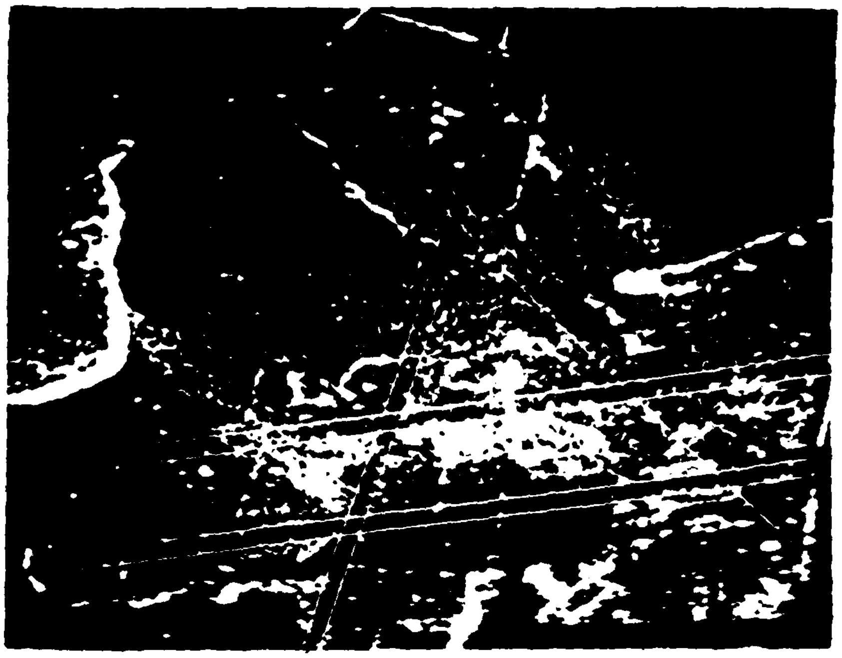
For Both (a) and (b):

(1) **Aircraft queued on** taxiway S

(2) An aircraft is crossing runway 4L

(b) Small General Aviation Aircraft Taking Off on Runway 9

Figure 2-8. Bright Display Photographs of Logan Airport Operation in Heavy Fog



(a) Typical Clutter Produced by Rainfall

(b) FTC Switched on to Reduce Clutter

Figure 2-9. Suppression Effect of FTC on Rain Clutter character in that rain clutter looked more like thin cotton on the ASDE-2, whereas at X-band it looked more like popcorn. The rain clutter effects on ASDE-2 were effectively suppressed when the radar technician turned on the FTC. Although these are impressions and are subjective, it is felt that the FTC effects on the X-band marine radar and the K-band ASDE-2 are relatively similar.

With regard to the X-band radar resolution capability, no formal quantitative tests were made. However, many observations were made of aircraft, large and small, taxiing or standing in line. The individual aircraft were always clearly discernible regardless of size or position on the field. Another type of observation involved watching tow vehicles relative to the aircraft at 500 to 1000 ft range from the radar. When attached to the aircraft, the tows generally produced a display image with a noticeable protrusion in front of the aircraft. As the tow separated and moved away from the aircraft, it could be seen as a separate entity when the distances were at an estimated 40 or 50 feet.

3.0 OPERATIONAL EVALUATION

The Runway Monitoring Radar, RMR, has been evaluated as a runway monitoring system for non-ASDE equipped, CAT II airports. It has not been evaluated relative to any other ASDE function. The operational evaluation took place at Boston Logan Airport during April of 1981. The evaluation consisted of determining:

1) How well the marine radar/BRITE display could be made to present both airport surface traffic and the runway/taxiway network by means of tuning the system.

2) How well the unit should permit an operator to detect runway targets by means of a test,

3) Probable controller acceptance of the system by means of controller interviews.

At the very start of the evaluation it became apparent that the marine radar's plan position indicator (i.e., PPI) was unsuitable for operational use in the high ambient brightness environment found in the tower cab. At tower cab brightness levels, the PPI display presentation has little contrast and the display face exhibits a high degree of "white-shirt" reflection. In the view of the evaluation team, the PPI would probably have to be used with a hood in the operational tower cab environment - an undesirable situation that would compromise the radar system's usefulness. At present, the FAA uses BRITE raster display subsystems for its tower cab surveillance systems (i.e., the NUBRITE for ASDE and the BRITE-4 for the ARTS local control presentation). In the operational evaluation, a BRITE-4 subsystem was coupled with the marine radar, and the combination was presented as the RMR system.

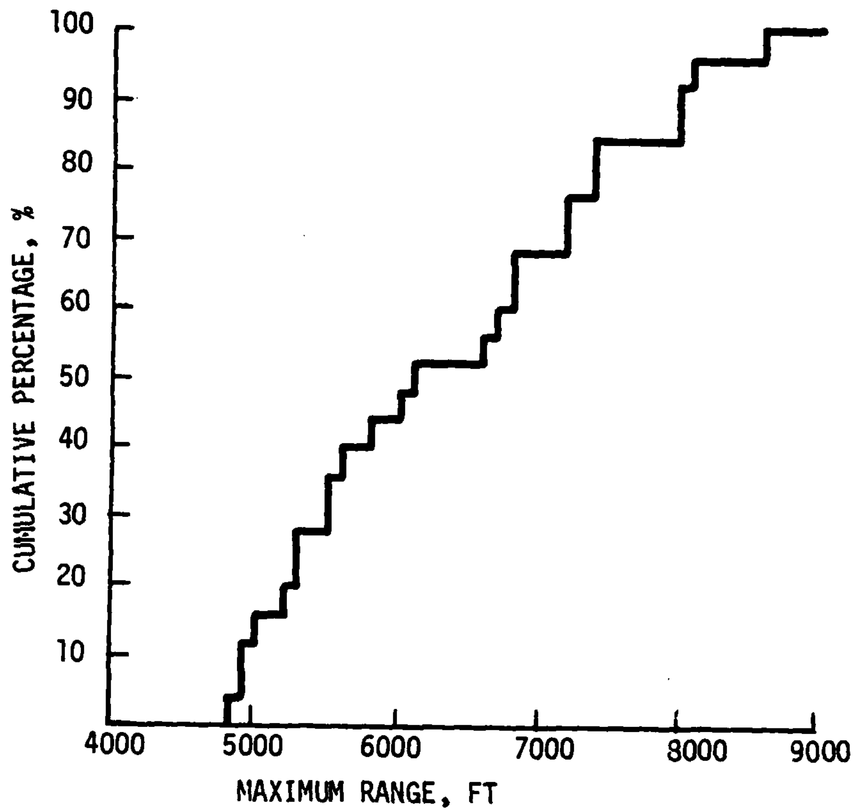
3.1 RMR TUNED FOR OPERATIONAL EVALUATION

Both target image definition/strength and the ability of radar to map an airport's runways and taxiways, by means of showing the grass areas adjacent to the aircraft movement areas, deteriorate with radar range. In order to estimate the overall range requirement on the RMR, and the range for which the Logan test unit should be tuned, the range requirement was determined for each candidate RMR site (i.e., all airports with a Cat II runway that do not have ASDE-2 and do not qualify for ASDE-3 on a cost/benefit basis). For this estimate it was assumed that the RMR would be mounted on top of the airport's control tower and that the radar should distinctly display all targets out to the most distant part of the airport's Cat II runway. Table 3-1 presents the results. It is seen that the range over which the RMR will operate at these 26 airports is from 4800 to 9500 ft The information in this table is reorganized in Figure 3-1 in the form of a cumulative distribution. The cumulative distribution shows the RMR range requirement on an airport by airport basis, versus the percentage of the current number of non-ASDE equipped, CAT II airports that would be satisfied by such an RMR range requirement.

Figure 3-2 shows the layout of Boston Logan Airport, the location of the RMR test site on the airport surface, and range rings relative to that site. Boston Logan's CAT II runway, Runway 4R, with an RMR range of 6300 ft, represents the 50th percentile RMR range requirement case among the 26 potential RMR candidate sites, Figure 3-1. However, it was decided that a better test situation would result from assuming that either Runway 9/27 or 33L/15R were CAT II equipped. Both runways have an RMR range requirement of 8000 ft, which represents the 90th percentile case among the 26 potential candidate RMR sites. Consequently, the RMR was tuned to clearly display all targets, including small, fast moving targets, out to a range of 8000 ft for the operational evaluation.

TABLE 3-1. RMR Range Requirements Based on the Current Airports with an Operational CAT II Runway that Are not Expected to Qualify for ASDE-3

Airport	Range From Control Tower to Most Distant Part of the CAT II Runway
1) Anchorage International (AK)	7000 ft
2) Baltimore/Washington Intl.(MD)	5500
3) Birmingham Municipal (AL)	6000
4) Bristol Tri City (TN)	5500
5) Buffalo International (NY)	4900
6) Cincinnati Greater (KY)	6500
7) Columbia Metropolitan (SC)	5600
8) Dayton International (OH)	7200
9) Fairbanks International (AK)	5200
10) Indianapolis International (IN)	5200
11) Jackson Municipal (MS)	6800
12) Jacksonville International (FL)	4900
13) Louisville Standiford Field (KY)	5300
14) Milwaukee Mitchell(WI)	5800
15) Nashville Metropolitan (TN)	5000
16) Oakland International (CA)	8100
17) Omaha Eppley (NB)	4900
18) Orlando Jetport Intl.(FL)	7400
19) Richmond Byrd Intl.(VA)	8600
20) Sacramento Metropolitan (CA)	6800
21) Salt Lake City Intl. (UT)	8000
22) San Antonio Intl. (TX)	6100
23) Shreveport Regional (LA)	7400
24) Spokane International (WA)	6700
25) Tulsa International (OK)	5300
26) W.Locks Bradley Intl. (CT)	7200



RMR Range Requirement (Maximum Range From a Control Tower Mounted RMR to Most Distant Part of airport's CAT II runway)

NOTES: CAT II AIRPORTS THAT DO NOT HAVE ASDE-2 AND DO NOT QUALIFY FOR ITS REPLACEMENT, ASDE-3

Figure 3-1. Cumulative Distribution of the RMR Range Requirement on an Airport by Airport Basis Versus the Percentage of the Current Number of Non-ASDE Equipped CAT II Airports that Would be Satisfied by Such a Range Requirement

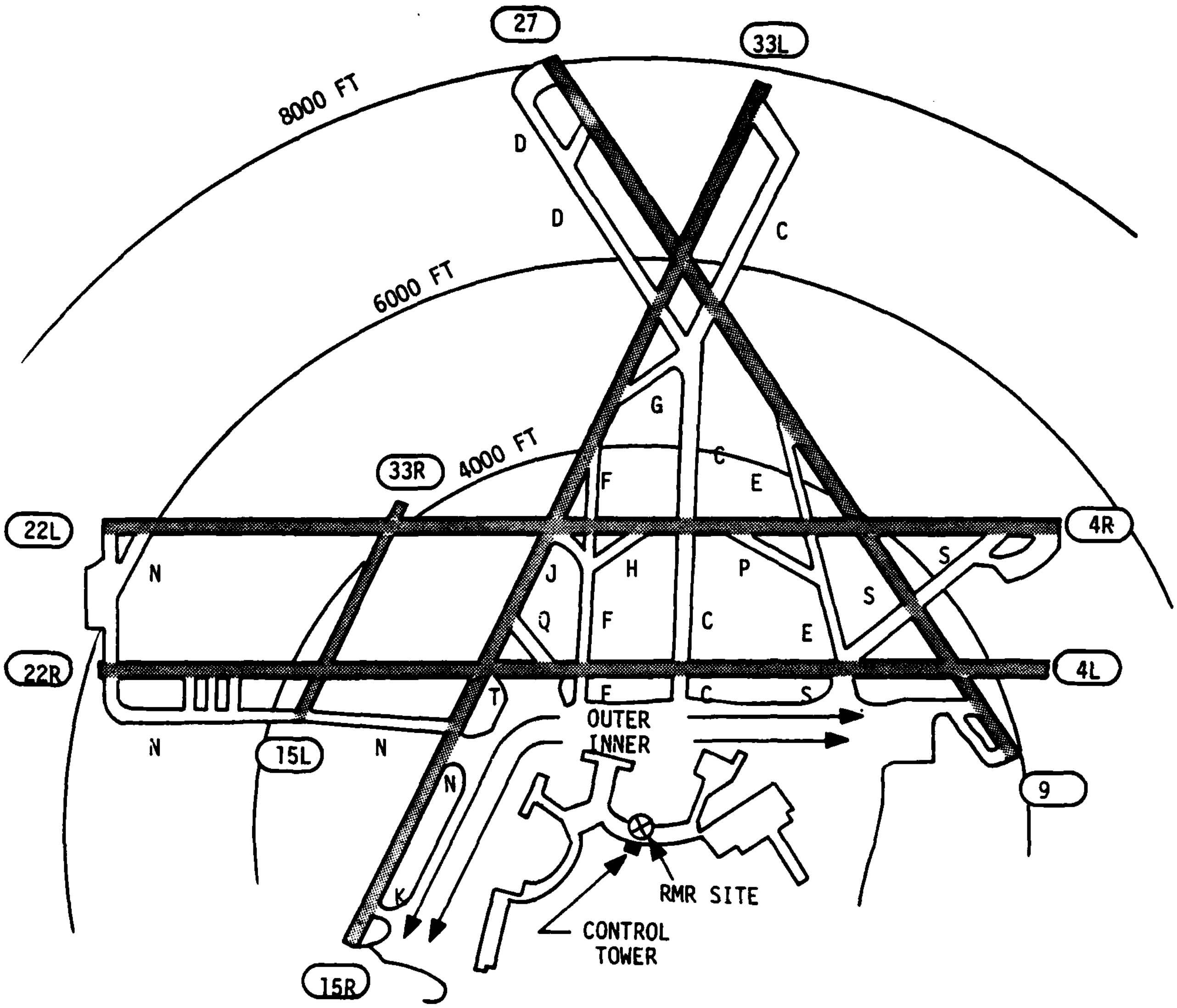


Figure 3-2. General Purpose Map of Boston Logan Airport Showing the RMR Test Site Location, Range Rings Relative to That Site, and Identifying the Airport's Runways and Taxiways

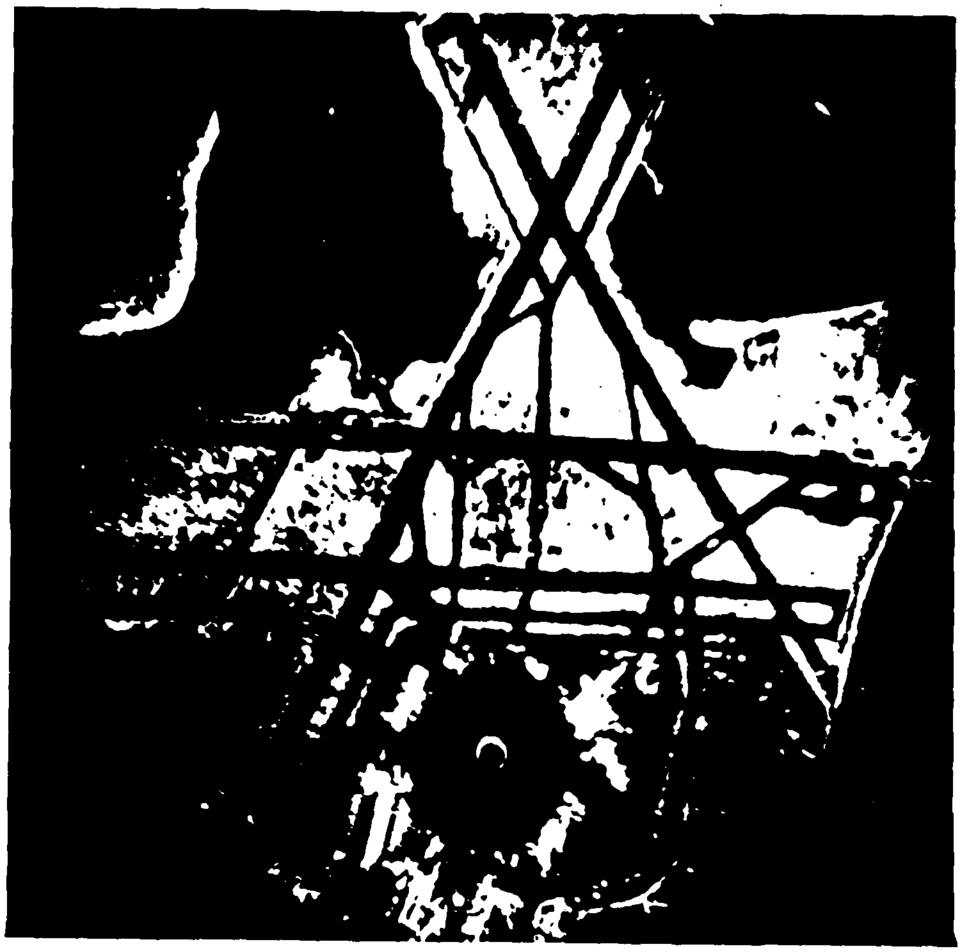
In tuning the RMR, the Boston Logan ASDE presentation was used for comparative purposes. The quality of the ASDE presentation is shown in Figure 3-3. Targets of all sizes are clearly presented and the radar's mapping quality, which is based on radar return from the airport's grass areas, is excellent. Moving targets exhibit trails, which are helpful for both target detection and for quickly determining the movement status of the targets.

In tuning the RMR test unit, it was found that the system could provide an airport mapping quality nearly equal to that of ASDE out to the 8000 ft range if small targets were ignored. However, when the condition was imposed that small targets had to be displayed as clearly visible images out to the range of 8000 ft, the retuning severely compromised the radar's mapping capability. Figure 3-4 shows the results of that retuning. At this setting, there is some target fade of small, fast moving targets on the runways beyond the 6000 ft range, yet these targets remained clearly visible on the BRITE display even in bright daylight conditions. Overall target definition with the RMR is comparable to that of ASDE, at least out to the 5000 ft range; however, little mapping is in evidence beyond the 4000 ft range and within that range the radar map is incomplete with a patchy appearance.

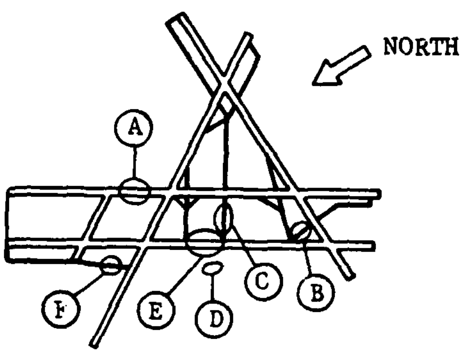
At the conclusion of the radar tuning phase of the operational evaluation, it was felt that:

1) The RMR could be tuned to display distinct targets with trails over all ranges of interest,

2) At an RMR range of 8000 ft, the radar's mapping capability is limited. However, since a full map presentation is of less concern for runway monitoring purposes than for other ASDE functions for which the RMR is not being proposed, the RMR with limited mapping might

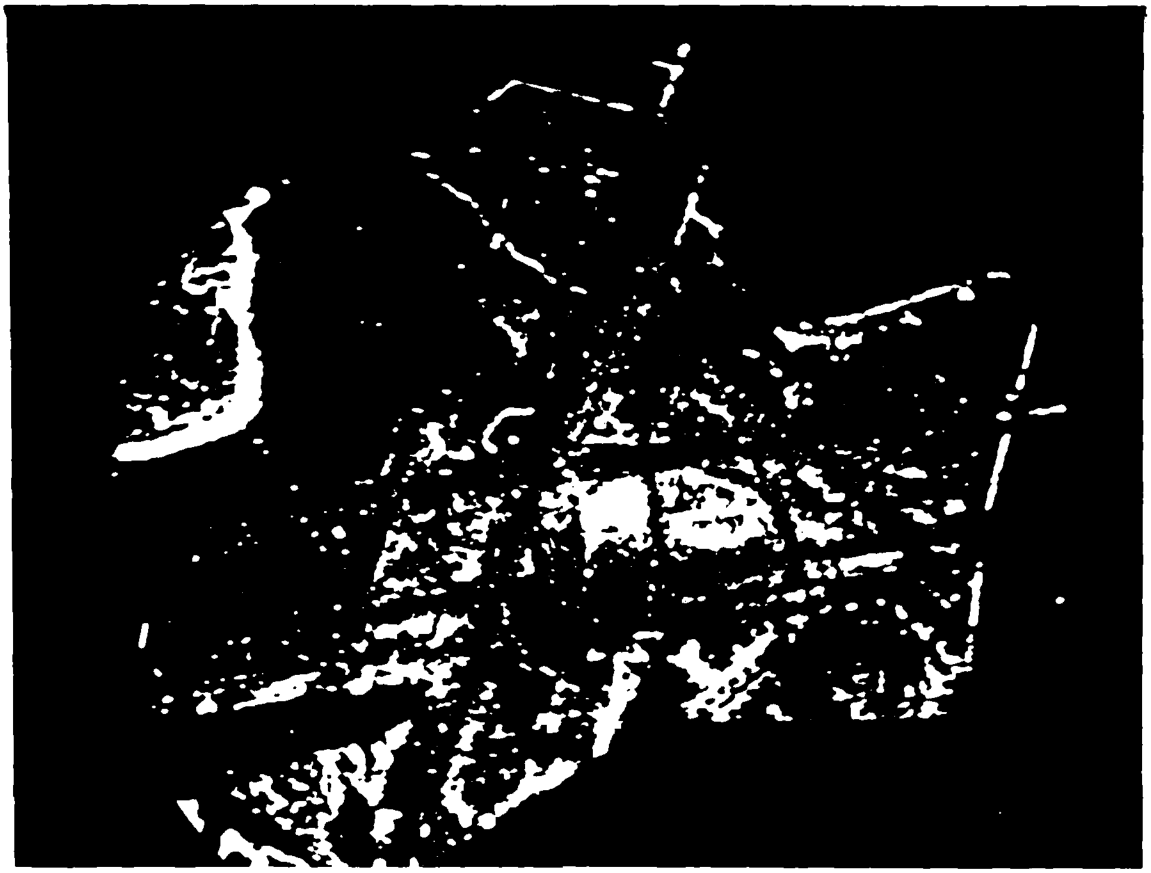


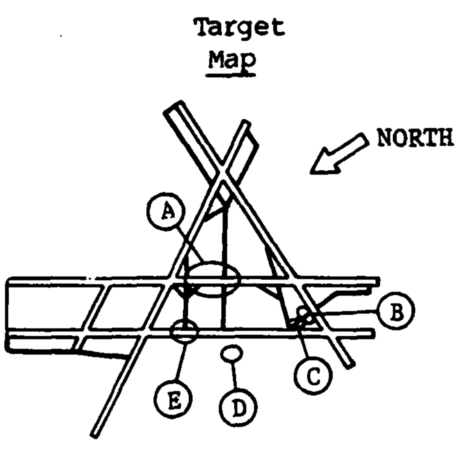
Target Map



Target Letter	Target Location	Target Type	Target Length
A	4R	B-727	133/153 ft
B	S	DC-9	104/125/133
C	C	Maint cars/ trucks	15 to 25
D	Inner	DC-9	104/125/133
E	4L	Gen Av. aircraft	35
F	N	DC-9	104/125/133

Figure 3-3. Boston Logan ASDE Display Presentation





Target Letter	Target Location	Target Type	Target Length
A	4R	DC-9	104/125/133 Ft
B	S	DC-9	104/125/133
C	S	B-727	133/153
D	Outer	FH-227	83
E	Crossing 4R	Convair	79

Figure 3-4. Basic FMR Display Presentation

still be operationally useful to local control and its operational evaluation should continue,

3) A simple means of enhancing the outline of the runways might significantly improve the operational usefulness of the system for monitoring runways.

3.2 RUNWAY ENHANCEMENT SCHEMES GENERATED FOR INCLUSION INTO THE OPERATIONAL EVALUATION

ASDE-3 will have an electronic mapping unit that will outline the airport's runways and taxiways and suppress returns from the grass areas. The production cost of the unit is expected to approach $50K. A mapping unit of this complexity for the RMR would put the viability of the system into doubt:

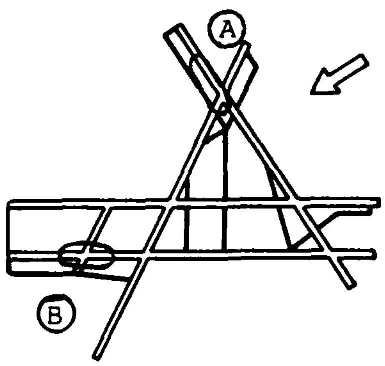
1) The $53K production cost of the RMR (i.e., $28K for the marine radar and $25K for the BRITE-4 display) would approximately double,

2) The RMR, which is available off-the-shelf, would now require some form of development activity adding cost to the system and delay in its deployment.

Two simple runway enhancement schemes were generated for inclusion into the operational evaluation. These schemes can either be implemented electronically or made-up quickly and cheaply as masks that are taped down onto the radar's PPI, as was done in this evaluation.

The first mask consisted of outlining Runway 33L with reflective tape placed on a clear plastic overlay on the PPI face. Figure 3-5 shows the impact of this "broad-line" runway enhancement on the RMR presentation. The tape defines the runway edge where the radar map is weak, masks the clutter along the runway edge, where the background clutter might be distracting,

Target Map



Target Letter	Target Location	Target Type	Target Length
A	27	L-1Ø11	177 Ft
B	22R	Twin Otter	51

Figure 3-5. RMR Display Presentation with the "Broad-Line" Runway Enhancement

and clearly shows the runway exits. This enhancement can be used on all the runways or reserved for the CAT II runway.

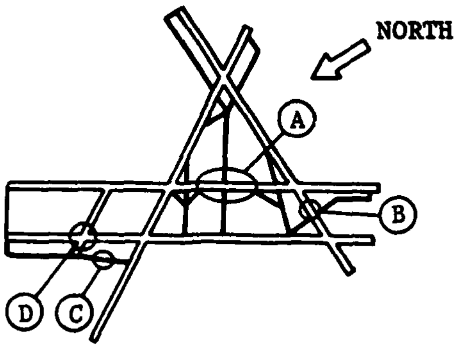
One possible drawback with this enhancement, is the fact that the tape can mask the wings of large targets, as can be seen in Figure 3-5. A much more serious problem would be drift of the radar image on the PPI. Drift could make this type of runway enhancement unusable. However, no drift was observed during the one month operational evaluation. A discussion on drift is presented in Section 2.

The second enhancement scheme consisted of outlining the 4 primary Logan runways (i.e. 4L/22R, 4R/22L, 9/27, 33L/15R) with thread. Figure 3-6 shows the impact of this "thin-line" runway enhancement on the RMR presentation. Except for Runway 33L/15R, the runways are shown without exits. As a result of the controller interviews, described in Section 3.4, Runway 33L/15R was modified to show its exits. The exits were implemented simply by means of inking the thread at the exits using a black marker.

This second scheme enhances the runways without masking the radar presentation. Not even the smallest targets were observed to be entirely lost to view when under one of the thread-lines due to the physical thinness of the thread used. In addition, long term drift, if present, should not cause any significant operational problems due to masking parts of a runway. If drift ever became noticeable, it could be easily accommodated by the thread-map by simply realigning the threads.

During the evaluation, and particularly during the photographing, the brightness of both the tape and thread maps were controlled by a dimmed light source that uniformly lit the maps from above the PPI. In operation, the lights that illuminate the bearing scale around the perimeter of the marine radar's PPI could provide this light source.

Target Map



Target Letter	Target Location	Target Type	Target Length
A	4R	B-727	133/153 Ft
B	9	B-707	145/152
C	N	B-737	94/100
D	Crossing 4L	FH-227	83

Figure 3-6. RMR Display Presentation with the "Thin-Line" Runway Enchancement

The final RMR format generated is the same as in Figure 3-6 except that the radar's Fast Time Constant, FTC, was turned "on". This scheme, shown in Figure 3-7, eliminates all radar mapping and thus emphasizes the targets. FTC, which was fully discussed in Section 2, passes the initial portion of long radar return pulses and attenuates the remainder of these pulses with the results:

1) Grass clutter returns, which tend to appear as very long pulses where clutter density is high and the radar mapping is good, are now eliminated,

2) Large targets tend to appear in a somewhat abbreviated form (compare the B-707 landing on 4R in Figure 3-7 with FTC "on" with the B-727 landing on 4R in Figure 3-6 with FTC "off", a similar sized aircraft),

3) Small targets are relatively unaffected.

The resulting emphasis of targets in the taxiways approaching an active runway could be important for runway monitoring purposes.

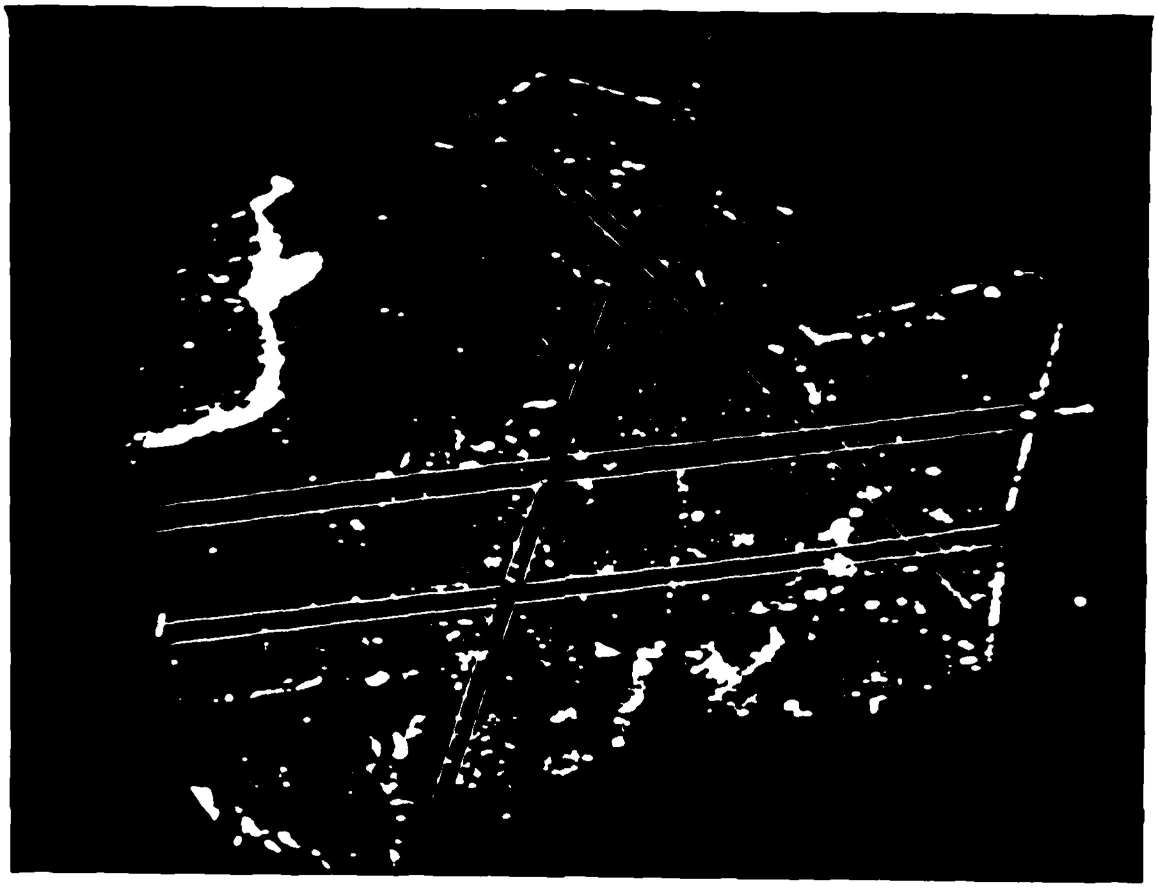
In summary, four RMR display formats were selected for inclusion into the operational evaluation. They are the:

1) Basic RMR presentation shown in Figure 3-4,

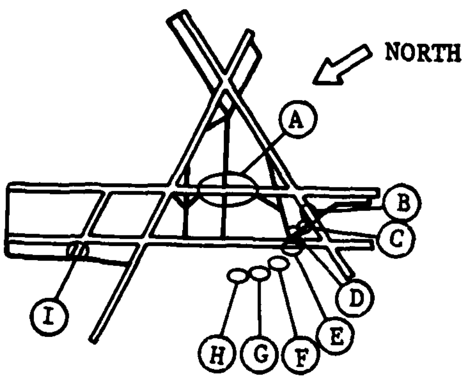
2) RMR presentation with the "broad-line" runway enhancement shown in Figure 3-5,

3) RMR presentation with the "thin-line" runway enhancement shown in Figure 3-6,

4) RMR presentation with the "thin-line" runway enhancement and enhanced taxiway targets shown in Figure 3-7.



Target Map



Target Letter	Target Location	Target Type	Target Length
A	4R	B-707	145/152 Ft
B	9	B-727	133/153
C	S	B-727	133/153
D	S	DC-10	182
E	Crossing 4L	B-727	133/153
F	S	B-727	133/153
G	Inner	B-727	133/153
H	Inner	DC-9	104/125/133
I	33R	DC-9	104/125/133

Figure 3-7. RMR Display Presentation with the "Thin-Line" Runway Enhancement and Enhanced Taxiway Targets

All these photographs (i.e., Figure 3-4 through Figure 3-7) were taken of the RMR display presentation as it appeared on an ASDE NUBRITE display operating with a BRITE-2 camera producing 945 raster lines.

3.3 TARGET DETECTION TEST

In low visibility conditions, surveillance by both ground and local controllers at non-ASDE equipped, CAT II airports is currently conducted by means of verbal position reports from pilots. This type of surveillance works well in low volume traffic situations when everything proceeds as expected by the controllers. However, the unforeseen can occur, and if it involves an unexpected vehicle on an active runway, the consequences can be disastrous. An unexpected vehicle on an active runway can come about in either of two ways. For example, the driver of an uncontrolled car/truck on an airport service road can become confused in low visibility conditions and proceed to blunder onto an active runway. A much more serious situation can occur when a misunderstanding takes place between the pilot of an aircraft in the runway/taxiway network and the tower cab controllers where the pilot proceeds in a manner unexpected and unobserved by the controllers. In this situation, a large aircraft can be the unexpected vehicle travelling along or across an active runway. The purpose of the RMR is to permit the local controller to visually verify that the operational runways are, in fact, clear of all unexpected vehicles before clearing the next operation (i.e., arrival or departure) to use the runway.

In tuning the radar, the RMR was found to be equivalent to ASDE-2 in terms of target presentation over the ranges of interest, but to be distinctly inferior to ASDE-2 in terms of mapping an airport's runway and taxiway network (e.g., compare Figure 3-4 to Figure 3-3). To determine if this lack of distinct runway edges would compromise the operational usefulness of the radar for runway monitoring purposes, a simple target detection test was devised.

3.3.1 Description Of Test Set-Up

The target detection test conducted at Boston Logan International Airport was devised to determine how well operators using the RMR could detect unexpected runway targets in an off-line, operational environment. The operators consisted of four non-controllers. Non-controllers were used because (1) it was felt by the evaluation team that the successful use of the RMR by non-controllers to detect unexpected runway targets would demonstrate the radar's potential for use by controllers, who are more familiar both with radar displays and with their airport's runway operation, and (2) to minimize the evaluation's requirement for controllers. All four test subjects were familiar with the general air traffic control operation of airport runways, and three of the four subjects had some previous experience with ASDE and so were at least somewhat familiar with the radar presentation of airport surface traffic.

For each subject, the test started about 9 a.m. and was completed by 2:30 p.m. During the test, the subject was seated before the BRITE RMR display with the display being at eye level and being illuminated by daylight coming in over the subject's right shoulder. The display face was fully illuminated by daylight, but direct sunlight never fell on the display face. The morning was spent becoming familiar with the radar presentation, the airport layout, and using the display to monitor runway traffic activity. This training session lasted about two hours. After lunch, the formal target detection test was conducted.

The test was performed with the RMR format shown in Figure 3-5. This format, which shows Logan with only one enhanced runway, permitted performance data to be obtained for the RMR format of primary interest (i.e., the RMR presentation without enhanced runways), and yet permitted the subject to formulate an opinion as to the possible usefulness of enhanced runways in the target detection task.

During the test, the subject did not look at the display until asked for a response (e.g., "Is there a target on Runway 4R?"),and then looked away from the display after making his response. Typically, three runways are in operation at Logan at any one time. By having the subject not look at the display unless requested and by having three runways generating a variety of runway traffic situations, careful management of the response requests could keep the subject from anticipating the traffic situations. This lack of anticipation was confirmed by each subject at the end of the test and permitted the results of the test to be associated with the detection of unexpected targets on a runway.

Target performance data were collected so the impact of two parameters on target detection performance could be investigated: target size and target motion (i.e., moving versus standing targets). Specifically, data were collected relative to the following nine runway situations:

1) Moving aircraft the size of a BAC 111 (i.e., 94 ft long) or larger. (These vehicles are of a size to make good sized targets on an airport radar display),

2) Moving aircraft smaller than the BAC 111 but longer than 50 ft in length (e.g., the Twin Otter which is commonly used as an air taxi is 51 ft in length),

3) Moving aircraft shorter than 50 ft in length. (These vehicles tend to appear as point targets on an airport radar display.),

4) Moving car or truck

5) Standing aircraft longer than 90 ft

6) Standing aircraft from 50 to 90 ft in length

7) Standing aircraft under 50 ft in length

8) Standing car or truck

9) No target on the runway

3.3.2 Test Results

The results of the target detection test are presented in Table 3-2, the highlights of which are:

1) Subject A correctly identified the 98 situations involving a target moving on a runway, the 16 situations involving a target standing on a runway and the 66 situations in which no target was present on the runway.

2) Subject B missed only one target, a small GA aircraft crossing a runway at an unusual location, and, incorrectly called 2 of the 70 situations in which no target was present on the runway,

3) Subject C missed two standing targets and incorrectly called 3 of the 67 situations in which no target was present on the runway,

4) Subject D missed 3 targets and incorrectly called 1 of the 41 situations in which no target was present on the runway,

5) Since the field test only involved targets of opportunity, some of the less common runway situations have smaller than desirable sample sizes on an individual by individual basis (e.g., almost all the standing target situations involving targets less than 90 ft in length have sample sizes of less than 5). However, in totalling the results over all four subjects, the sample sizes become meaningful in all but one of the nine runway situations of interest (i.e., in the case of a car or

TABLE 3-2. Results of Runway Target Detection Test
Runway Situations Involving a Moving Target

AIRCRAFT LENGTH				
SUBJECT	OVER 90 FT.	50 TO 90 FT.	UNDER 50 FT.	CARS/TRUCKS
A[2]	$\frac{49}{49}$ = 100%	$\frac{14}{14}$ = 100%	$\frac{28}{28}$ = 100%	$\frac{7}{7}$ = 100%
B[2]	$\frac{63}{63}$ = 100%	$\frac{10}{10}$ = 100%	$\frac{17}{18}$ = 94%	$\frac{3}{3}$ = 100%
C[2]	$\frac{35}{35}$ = 100%	$\frac{12}{12}$ = 100%	$\frac{17}{17}$ = 100%	$\frac{2}{2}$ = 100%
D[3]	$\frac{29}{29}$ = 100%	$\frac{11}{11}$ = 100%	$\frac{24}{27}$ = 89%	$\frac{3}{3}$ = 100%
TOTALS	$\frac{176}{176}$ = 100%	$\frac{57}{57}$ = 100%	$\frac{86}{90}$ = 96%	$\frac{15}{15}$ = 100%
DETECTION OF MOVING TARGETS = $\frac{334}{338}$ = 98.8%				

RUNWAY SITUATIONS INVOLVING A STANDING TARGET				RUNWAY SITUATIONS INVOLVING NO TARGET
AIRCRAFT LENGTH				
SUBJECT	OVER 90 FT.	50 TO 90 FT.	UNDER 50 FT.	
A[2]	$\frac{12}{12}$ = 100%	$\frac{2}{2}$ = 100%	$\frac{2}{2}$ = 100%	$\frac{66}{66}$ = 100%
B[2]	$\frac{10}{10}$ = 100%	$\frac{1}{1}$ = 100%	$\frac{4}{4}$ = 100%	$\frac{68}{70}$ = 97%
C[2]	$\frac{8}{9}$ = 89%	$\frac{1}{1}$ = 100%	$\frac{6}{7}$ = 86%	$\frac{64}{67}$ = 96%
D[3]	$\frac{6}{6}$ = 100%	$\frac{1}{1}$ = 100%	$\frac{1}{1}$ = 100%	$\frac{40}{41}$ = 98%
	$\frac{36}{37}$ = 97%	$\frac{5}{5}$ = 100%	$\frac{13}{14}$ = 93%	$\frac{238}{244}$ = 98%
DETECTION OF STANDING TARGETS = $\frac{54}{56}$ = 96.4%				
OVERALL DETECTION OF UNEXPECTED TARGETS ON RUNWAYS = $\frac{388}{394}$ = 98.5%				
OVERALL FALSE ALARM RATE OF $\frac{6}{244}$ = 2.5%				

NOTES 1. DENOMINATOR = THE NUMBER OF SITUATIONS PRESENTED TO THE SUBJECT
NUMERATOR = THE NUMBER OF SITUATIONS CORRECTLY IDENTIFIED BY THE SUBJECT
PERCENTAGE = PERCENTAGE OF SITUATIONS CORRECTLY IDENTIFIED

2. ASDE EXPERIENCE

3. NO ASDE EXPERIENCE

truck standing on a runway, not one such occurrence was observed during the test period, as one might expect). These composite results show that target detection performance remains high relative to unexpected targets regardless of the size of the vehicle involved or whether it is standing or moving,

6) Of the 338 total runway situations involving a moving target, only 4 were missed for an overall moving target detection rate of 98.8%,

7) Of the 56 total runway situations involving a standing target, only 2 were missed for an overall standing target detection rate of 96.4%,

8) Of the 244 runway situations involving a runway free of all targets, only 6 were missed for an overall false alarm rate of 2.5%.

As previously mentioned, in order to get an early indication of the possible usefulness of enhanced runways before discussing them with controllers, one of the five Logan runways was enhanced during the test. During the test, each subject was presented with detection situations from 3 runways. For subjects A and B, the airport operation permitted one of those 3 runways to be the enhanced runway. The two subjects had a total of 99 target situations and 43 non-target situations presented to them on the enhanced runway. Based on this sample, the target detection performance with enhanced runways approaches 100% (i.e., no targets were missed) and the false alarm rate approaches 0% (i.e.,no false targets were claimed). In addition, all four subjects liked the enhancement and thought that it would improve their ability to detect targets.

Subtracting out the enhanced runway sample, associated with subjects A and B, does little to change the overall test results (e.g., the overall target detection performance decreases from 98.5% to 98.0% and the overall false alarm rate increases from 2.5% to 3.0%). For the purpose of this study, the results presented in Table 3-2 are to be associated with the basic RMR format without enhanced runways.

At the conclusion of the target detection phase of the operational evaluation, it was felt that:

1) In the off-line operational environment tested, the RMR format without enhanced runways permits an operator to have an excellent chance of detecting an unexpected target on a runway, regardless of whether the target is large or small, moving or standing. The RMR format without enhanced runways would be included in the controller evaluation,

2) The concept of enhanced runways was well received by the subjects, and when tested, improved an already excellent target detection performance. The enhanced RMR display formats would be included in the controller evaluation.

3.4 CONTROLLER EVALUATION

The last and most critical element of the operational evaluation was the evaluation by controllers of the probable usefulness of the RMR in an on-line, operational environment. Four Boston Logan controllers volunteered to participate in the formal evaluation, and the controllers evaluated the RMR unit on an individual basis.

3.4.1 Information On Which Controllers Based Their Evaluation

A controller's reaction to a new surveillance system, like the RMR, is influenced by both what he is shown and what he is told concerning the system. Each controller was told about the RMR in a briefing given just prior to the controller's formal evaluation of the unit. The briefing went as follows:

"We are evaluating a low cost radar for possible deployment to non-ASDE equipped, CAT II airports for use as a runway monitoring system. At present there are over twenty such airports including Bradley, Buffalo, and Baltimore/Washington. The unit being evaluated consists of an off-the-shelf marine radar coupled with a standard FAA BRITE display. Deployment of this unit depends on (1) keeping the unit cost down which means accepting the system essentially as is and (2) controller reaction. The controls that will be made available to controllers in the tower cab will be: an on/off switch and the display brightness and contrast controls. To keep the price of the system down, the controller will not be able to change the display scale/offset directly. The best overall airport scale and offset settings will be setup at the time of installation. Once installed, a radar technician will be able to change the settings if it becomes necessary. Finally, the RMR is not meant for an airport like Logan that has ASDE-2 and that will have ASDE-3. I would like you to try to put yourself in the place of a controller at an airport like Bradley, who will never have an ASDE with which to monitor the runways in low visibility conditions, but could have this unit instead of nothing at all."

3.4.2 Results Of The Controller Evaluation

After the introductory briefing, each controller was shown the RMR presentation without runway enhancements, Figure 3-4. Afterwatching a few runway operations, the controller was asked the question, "Would this unit be of significant use to local control at non-ASDE equipped, CAT II airports?" Remembering that their experience was with the ASDE presentation shown in Figure 3-3, each controller took several moments to answer. Three of the controllers thought that the RMR would be of significant operational use and one controller was unsure, but tended to be doubtful. To the question "Do you have any problems with the unit?" the controllers tended to feel that it would be difficult to use the RMR as a quick-look display, which is important since the controller would not be able to watch the RMR for extended periods of time but would have to continue to time share his attention among various other displays, flight strips, etc.

The controller was then told that the evaluation team thought that the very limited mapping capability of the RMR might prove to be a problem and that we would like his opinion of several low cost fixes. The controller was shown the RMR presentation with the "broad-line" runway enhancement, Figure 3-5. To the question "Is this runway enhancement helpful?", all four controllers agreed that it was; and the one controller that expressed doubt concerning the operational viability of the basic RMR presentation, Figure 3-4, now thought that the RMR with runway enhancements would be of significant use to local control at non-ASDE equipped, CAT II airports.

Next, the RMR presentation with the "thin-line" runway enhancement was shown to the controllers. Figure 3-6 represents what was shown to the controllers except that the enhancement on Runway 33L was shown as two solid lines without gaps at the turnoff locations. All four controllers thought that this enhancement was a distinct improvement over the previous case provided that the turnoff locations are shown. They preferred this format since it did not mask the radar presentation. In order to see what gaps in the line at the turnoff locations would look like, the Runway 33L enhancement was modified as shown in Figure 3-6.

Figure 3-7 represents the last display format shown to the controllers, the "thin-line" enhancement with reduced grass return providing enhanced taxiway targets. All four controllers preferred this display format over the previous alternatives because the reduction in clutter would quicken the display for local control purposes.

To the final question "In conclusion, are there significant benefits to be obtained from deployment of this unit to non-ASDE CAT II airports?", the four controllers, without hesitation, gave strongly positive responses.

This brief discussion has highlighted the main points coming out of the controller evaluation. A complete description of the sequence of questions asked of the controllers and their individual responses is presented in Table 3-3.

Following the formal evaluation, the RMR was shown to a number of Boston Logan shift supervisors and one former controller from Bradley Airport, a candidate RMR site. At the end of each RMR demonstration, each individual was asked, "Would deployment of the RMR at non-ASDE equipped, CAT II airports be of significant use to local control?" The answers added up to a unanimous "yes".

3.5 OVERALL RESULT OF THE OPERATIONAL EVALUATION

The RMR was evaluated as a runway monitoring system for non ASDE equipped, CAT II airports. It was not evaluated relative to any other ASDE function. The primary results of the operational evaluation are:

1) The maximum RMR range requirement is 8600 ft. The unit can be tuned to give clear, distinct targets out to this range even for small, fast moving targets,

2) Tuning the radar to provide good target definition out to 8600 ft severely diminishes the radar's basic ability to map an airport's runways and taxiways,

TABLE 3.3. Results of Interviews with Logan Controllers

RADAR PRESENTATION FORMAT	QUESTION	CONTROLLER RESPONSES			
		CONTROLLER I	CONTROLLER II	CONTROLLER III	CONTROLLER IV
BASIC RMR FORMAT (NO RUNWAY ENHANCEMENT) (FIG. 3-4)	(1) WOULD THIS UNIT BE OF SIGNIFICANT USE TO LOCAL CONTROL AT NON-ASDE EQUIPPED CAT II AIRPORTS?	YES	YES, FOR ONE OR TWO RUNWAY OPERATIONS	YES	UNSURE BUT DOUBTFUL
	(2) ANY PROBLEMS ABOUT USE OF THIS UNIT?	DIFFICULT TO PICK OUT RUNWAY TRAFFIC	NO	PROBLEM USING DISPLAY ON A QUICK LOOK BASIS	PROBLEM USING DISPLAY ON A QUICK LOOK BASIS
FORMAT WITH "BROAD LINE" RUNWAY ENHANCEMENT (FIG. 3-5)	(3-a) IS THIS RUNWAY ENHANCEMENT HELPFUL?	YES, IT IS VERY GOOD	YES	YES	YES
	(3-b) WHY?	(1) REDUCES CLUTTER (2) HELPS TO FOCUS SCAN	(1) DEFINES RUNWAY (2) SHOWS TURNOFFS	(1) REDUCES CLUTTER (2) SHOWS RUNWAY/TURNOFFS	(1) REDUCES CLUTTER (2) QUICKENS DISPLAY
	(3-c) ANY PROBLEMS WITH THIS ENHANCEMENT?	STILL SEE SOME CLUTTER ON RUNWAY	NO	NO	IF DRIFT OCCURS, ENHANCEMENT COULD CAUSE PROBLEM
	(3-d) IF ANSWER TO QUEST. (1) NO, WOULD UNIT NOW BE OF SIGNIFICANT USE TO LOCAL CONTROL AT NON-ASDE CAT II AIRPORTS?	NA	NA	NA	YES
FORMAT WITH "THIN LINE" RUNWAY ENHANCEMENT (FIG. 3-6)	(4-a) IS THIS ENHANCEMENT AN IMPROVEMENT OVER THE PREVIOUS CASE?	YES	YES	YES, ONLY IF TURNOFFS SHOWN AS GAPS IN LINE	YES, ONLY IF TURNOFFS SHOWN AS GAPS IN LINE
	(4-b) WHY?	PREFER NOT TO HAVE ANY OF THE RADAR PRESENTATION MASKED			
	(4-c) ANY PROBLEMS WITH THIS ENHANCEMENT?	WOULD LIKE TO SEE THE RUNWAY TURNOFFS	WOULD LIKE TO SEE THE RUNWAY TURNOFFS	NEED TO SEE THE RUNWAY TURNOFFS	NEED TO SEE THE RUNWAY TURNOFFS
FORMAT WITH "THIN LINE" RUNWAY ENHANCEMENT AND ENHANCED TAXIWAY TARGETS (FIG. 3-7)	(5-a) IS THIS DISPLAY FORMAT TO BE PREFERRED OVER PREVIOUS ALTERNATIVES?	YES, FOR LOCAL CONTROL	YES, IF TURNOFFS SHOWN AS GAPS IN LINE	YES, IF TURNOFFS SHOWN	YES, IF TURNOFFS SHOWN
	(5-b) WHY?	REDUCTION IN CLUTTER WOULD QUICKEN THE DISPLAY			
	(5-c) ANY PROBLEMS WITH FORMAT?	GROUND CONTROL MAY ONLY BE ABLE TO USE UNIT AT AIRPORTS WITH SIMPLE TAXIWAY STRUCTURES	GROUND CONTROL MAY ONLY BE ABLE TO USE UNIT AT SMALL AIRPORTS	NO	NO, BUT WOULD LIKE FTC ON CONTROL PANEL IN TOWER CAB
IN GENERAL	(6) IN CONCLUSION, ARE THERE SIGNIFICANT BENEFITS TO BE OBTAINED FROM DEPLOYMENT OF THIS UNIT TO NON-ASDE, CAT II AIRPORTS?	YES	DEFINITELY	YES	YES

3) In a simple test of non-controllers using the basic RMR without enhanced runways at Logan, it was found that unexpected targets on the runways could be readily detected regardless of target size and motion status (i.e., standing or moving) and that the false alarm rate with the unit is very low (i.e., under 3%)

4) In a formal evaluation of the RMR by Boston Logan controllers, it was found that:

   a) The RMR display presentation without any additional mapping capability has a good chance of being of significant use to local controllers at non-ASDE equipped, CAT II airports.

   b) The RMR display with enhanced runways would be of significant use to local controllers at non-ASDE equipped, CAT II airports, (reason-the enhanced runways would quicken the display).

   c) The clearly preferred RMR display format was the "thin-line" runway enhancement with turnoffs shown and with enhanced taxiway targets, Figure 3-7.

   d) Display scale and offset can be fixed when the unit is first installed if this is necessary to keep the system cost down.

4.0 SYSTEM COST

The marine radar used in this project was obtained "off the shelf" from Raytheon Marine Company, Manchester, N.H. Except for the 18 ft antenna, the radar was essentially GSA listed. The total cost of the marine radar was $21,000 with features deemed suitable for an RMR. Although the GSA purchase price is not yet finalized, TSC was able to secure projected radar costs in June 1981 dollars. These cost estimates are presented in Table 4-4 for:

1) The equipment, radar and BRITE display
2) Installation
3) Initial spares provisioning
4) Operation and Maintenance

The projected cost of the radar has risen by about $7000 since the original procurement in 1980. Of the total increase, Raytheon has indicated that $3000 is due to inclusion of antenna development costs which were not in the original procurement. Of the remaining $4000 increase, the display and antenna/pedestal went up 23 percent each while the MTR increased by 7 percent. The net av=erage increase not including the antenna development cost was about 20 percent which is about 8 percent above inflationary effects. The causes for the 8 percent additional increase are not clearly understood.

The information from Table 4-1 is used in Section 5 in the development of a cost benefit study.

TABLE 4-1. Estimated Costs of an RMR in June 1981 Dollars

EQUIPMENT		
Radar delivered to destination	$27.9K	
BRITE-4 camera and display	25.0K	
Total Equipment Cost		$52.9K
INSTALLATION		
Installation services (vendor)	9.8K	
Installation materials	1.5K	
Total Installation Cost		$11.3K
INITIAL SPARES PROVISIONING		
PCB and other radar spares	6.7K	
Training course (1 Tech. per site)	0.3K	
Training labor (1 man week)	1.0K	
Training travel (average)	1.0K	
FAA labor (1 man week)	1.0K	
Total spares provisioning		$10.0K
Total Initial Radar System Costs		$74.2K
Operation and Maintenance, for each failure		
PCB or other part replacement	0.25K	
Repair labor, 4 hrs at $30/hr	0.12K	
Miscellaneous	0.13K	
Total O & M cost per year		$0.5K

Based on: (1) 600 hrs MTBF and 1.6 hours use per day, 584 hrs per year, (2) one failure per year, (3) use of PCBs and spares to minimize MTTR.

5.0 RMR COST/BENEFIT ANALYSIS

At present there are 26 airports with a Category II equipped runway that cannot justify the cost of installing ASDE. As the Category II Instrument Landing System deployment continues, this number will increase. The brief analysis described in this section addresses two issues:

1) To what extent can the current set of non-ASDE equipped Cat II airports justify the deployment of the RMR?

2) For those non-ASDE airports that will get a CAT II ILS in the future, can the inclusion of the RMR into the basic CAT II ILS equipment package be justified?

5.1 ESTIMATION OF RMR BENEFITS

ASDE has both a safety benefit (i.e., ASDE permits the local controller to verify that an active runway is clear of unexpected vehicles before clearing the next operation to use the runway) and a delay benefit (i.e., ASDE increases the local control runway capacity in low visibility conditions). Due to the high cost of ASDE-3, only the busier airports can justify its installation. Those CAT II airports that can not justify the cost of ASDE-3 operate at lower traffic levels and in general, tend to experience relatively little delay in their runway operations. At these intermediate sized airports, the RMR has a safety benefit but not a delay benefit.

One major runway accident occurred during CAT II weather conditions in the United States from the time such operations started in 1969 through 1979, the last year for which statistics are available. That accident occurred at Chicago O'Hare International Airport on December 20, 1972, and involved: the total destruction of one air carrier aircraft, the substantial destruction of a second air carrier aircraft, ten fatalities,

TABLE 5-1. Dollar Estimate of Averted Damage and Injury Based on the Runway Accident Under Category II Weather Conditions that Occurred at Chicago O'Hare Airport on 12-2-72

Damage and Injury Involved in the 12-20-72 O'Hare Accident #1	1981 Dollar Estimate of Damage and Injury #2
1) Total destruction of one air carrier aircraft	$9.92 M
2) Substantial destruction of a second air carrier aircraft	$3.30 M
3) Ten fatalities	$4.95 M
4) Nine serious injuries	$0.65 M
	Total $18.8 M

Notes #1 Based on the accident report

#2 Estimates based on the reference: Benefit/cost analysis of airways planning standards, order No. 7031, FAA/Office of Aviation System Plans, March 1976 and nine serious injuries. Table 5-1 gives an itemized listing of the FAA/ASP dollar estimates of averted damage and injury that can be associated with this accident. The estimate total is $18.3 million (M) in 1981 dollars.

This accident occurred at the busiest airport in the world. However, the runway accident involving two Boeing 747 aircraft that took place at Tenerife in 1977 illustrates that costly low visibility runway accidents can occur at the smaller CAT II equipped airports that service air carrier aircraft.

Over the 11 years from 1969 through 1979, an estimated 24,500 air carrier arrivals and departures took place in the United States under Category II weather conditions. This estimate is based on:

1) 1979 traffic levels and the assumption that the annual number of CAT II air carrier operations (i.e., arrivals and departures) that take place at an airport is equal to twice the airport's annual number of CAT II air carrier instrument approaches).

2) The assumption that the growth in the annual number of CAT II air carrier operations was linear from 1969 through 1979.

Assuming that the one major runway accident over these 24,500 operations is typical for all CAT II operations, one can calculate the RMR net present benefit for each airport based on the airport's annual number of CAT II air carrier operations. Specifically:

NET PRESENT BENEFIT $= \frac{(\$18.8M)}{(24,500)}(8.37)$ (airport's ann. no. of CAT II air carrier ops.)

$= \frac{(\$6,410)}{operation}$ x (airport's annual no. of CAT II air carrier operations)

where $18.8M is the averted damage and injury for each major CAT II runway accident prevented

24,500 is the number of CAT II air carrier operations assumed to occur in the United States on average between each major CAT II runway accident

8.37 is the factor associated with the total benefits over a system lifetime of 15 years

Table 5-2 presents an estimate of each CAT II airport's annual number of CAT II air carrier operations based on 1979 traffic levels.

The assumption, that one major runway accident over 24,500 CAT II, air carrier operations is typical for all CAT II operations, also permits the probability of such an accident to be calculated on an airport by airport basis. Using the 1979 traffic levels presented in Table 5-2, the probability of a major CAT II runway accident at an airport like Greater Pittsburgh International which does not have ASDE-2 but will get ASDE-3 is .93% (i.e., 228 CAT II air carrier operations divided by 24,500 operations per major CAT II accident). Over the 15 year lifetime of either ASDE-3 or the RMR this probability becomes 14%. In a similar calculation presented in the ASDE-3 Establishment Criteria (Ref. 5), the probability of a major low visibility runway accident over 15 years at Pittsburgh is estimated to be 41%. The assumption on safety benefits used in this study is considerably more conservative than that made in the ASDE-3 Establishment Criteria.

TABLE 5-2. (a) Estimate of 1979 CAT II Aircarrier Runway Operations for ASDE-3, CAT II Airports

Airport	1979 Aircarrier Annual Instr. Appr. #1	Percent of Weather CAT II #1	1979 Cat II Aircarrier Ops Est #3
Andrews AFB (MD)	0	0.80	0
Atlanta International (GA)	55007	0.75	825
Boston Logan Intl.(MA)	23600	0.50	236
Chicago O'Hare Intl.(IL)	88710	0.35	621
Cleveland Hopkins Intl.(OH)	14619	0.25	73
Dallas Ft Worth Regional(TX)	20753	0.15	62
Denver Stapleton Intl.(CO)	13144	0.15	39
Detroit Wayne Co.(MI)	13051	0.45	117
Houston Intercontinental(TX)	17634	0.45	159
Kansas City Intl. (MO)	10656	0.15	32
Los Angeles Intl. (CA)	22277	0.45	200
Memphis Intl. (TN)	12733	0.15	38
Minneapolis St Paul Intl.(MN)	13716	0.20	55
Newark International (NJ)	8554	0.40	68
New York Kennedy Intl. (NY)	18098	0.60	217
Philadelphia Intl. (PA)	11114	0.35	78
Pittsburgh Greater Intl.(PA)	32507	0.35	228
Portland International (OR)	1214	0.40	10
San Francisco Intl.(CA)	20500	0.15	62
Seattle Tacoma Intl. (WA)	17935	0.55	197
Tampa International (FL)	4838	0.30	29
Washington Dulles Intl.(VA)	3624	0.55	40
Washington National (DC)	19004	0.25	95
New Orleans Moisant(LA)	8146	0.30	49
Oklahoma City, W.Rogers(OK)	4213	0.50	42
		Total	3572

Notes #1 Reference: FAA Air Traffic Activity-Fiscal Year 1979

#2 Reference: Ceiling-Visibility Climatological Study and System Enhancement Factors; Department of Transportations Report Number DOT-FA75WAI-547; June 1975

#3 Estimate Calculation = (2)(value in column 1) (value in column 2) / 100

TABLE 5-2. (b) Estimate of 1979 CAT II Aircarrier Runway Operations for Non-ASDE-3, CAT II Airports

Airport	1979 Aircarrier Annual Instr. Appr. #1	Percent of Weather CAT II #2	1979 CAT II Aircarrier Ops. Est. #3
Anchorage International (AK)	3004	0.60	310
Baltimore/Washington (MD)	5972	0.45	52
Birmingham Municipal (AL)	4870	0.05	5
Bristol Tri City (TN)	2932	0.40	23
Buffalo International (NY)	11121	0.40	89
Cincinnati Greater (KY)	9202	0.40	74
Columbia Metropolitan (SC)	1695	0.25	8
Dayton International (OH)	5192	0.45	47
Fairbanks International (AK)	408	0.50	4
Indianapolis Intl. (IN)	9223	0.35	65
Jackson Municipal (MS)	1770	0.25	9
Jacksonville Intl. (FL)	2033	0.40	16
Louisville Standifd Field (KY)	5976	0.15	18
Milwaukee Mitchell (WI)	8678	0.60	104
Nashville Metropolitan (TN)	7964	0.15	24
Oakland International (CA)	5225	0.15	16
Omaha Eppley (NB)	3857	0.20	15
Orlando Jetport Intl. (FL)	3014	0.25	15
Richmond Byrd Intl. (VA)	3445	0.30	21
Sacramento Metropolitan (CA)	3439	0.50	34
Salt Lake City Intl. (UT)	3625	0.20	15
San Antonio Intl. (TX)	8337	0.35	58
Shreveport Regional (LA)	2973	0.25	15
Spokane International (WA)	2487	0.75	37
Tulsa International (OK)	4435	0.20	18
W. Locks Bradley Intl. (CT)	8113	0.45	73
		Total	891

Notes #1 Reference: FAA Air Traffic Activity - Fiscal year 1979

#2 Reference: Ceiling-visibility Climatological Study and System Enhancement Factors; Department of Transportation Report Number DOT-FA75WAI-547; June 1975

#3 Estimate Calculation = (2)(value in column 1) $\frac{(\text{value in column 2})}{100}$

AD-A125 903 EVALUATION OF A MARINE RADAR FOR USE AS A LOW COST RUNWAY MONITORING RADA..(U) TRANSPORTATION SYSTEMS CENTER CAMBRIDGE MA P J PANTANO ET AL. JUN 81 2/2

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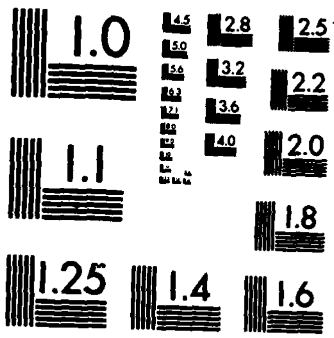
1.0
4.5
5.0
5.6
2.8
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3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

The probability of a major CAT II runway accident at the smaller non-ASDE-3 qualified, CAT II airports is low. Tulsa International, as an example of this group, has a 1% probability of having such an accident over a 15 year period. If the RMR is to be cost beneficial at an airport like Tulsa International, the unit will have to be inexpensive.

5.2 RMR DEPLOYMENT TO THE CURRENT NON-ASDE-3 QUALIFIED CAT II AIRPORTS

Based on the cost discussion presented in Section 4, the total initial RMR cost including installation is $74.2K and the unit's annual operations and maintenance cost is $.5K in 1981 dollars. The net present RMR cost is:

NET PRESENT COST= $74.2K + ($.5K) (8.37)

= $78.39K

Based on this net present cost and the net present benefit relationship developed in the previous subsection, the B/C ratios for the 26 non-ASDE-3 qualified, CAT II airports can be calculated. These ratios are presented in Table 5-3. It is seen that 22 of the 26 airports can justify the RMR with B/C ratios greater than one.

5.3 RMR INCLUSION INTO THE STANDARD CAT II ILS EQUIPMENT PACKAGE FOR FUTURE DEPLOYMENT TO NON-ASDE AIRPORTS

For those non-ASDE qualified airports that will get a CAT II Instrument Landing System in the future, it would be ideal if the RMR could be installed as part of the standard CAT II ILS equipment package and not considered as a possible add-on to that system after the fact. In this subsection, the possible inclusion of the RMR into the standard CAT II ILS equipment package for non-ASDE airports is considered from the viewpoint of

TABLE 5-3. RMR Benefit/Cost Estimate for Currently Projected Non-ASDE, CAT II Airports

	1979 CAT II AIRCARRIER OPS. EST. #1	RMR NET PRESENT BENEFIT #2	RMR B/C RATIO #3
ANCHORAGE INTERNATIONAL (AK)	36	$231K	2.95
BALTIMORE/WASHINGTON INTL. (MD)	52	333	4.25
BIRMINGHAM MUNICIPAL (AL)	5	32	.41
BRISTOL TRI CITY (TN)	23	147	1.83
BUFFALO INTERNATIONAL (NY)	89	570	7.27
CINCINNATI GREATER (KY)	74	474	6.05
COLUMBIA METROPOLITAN (SC)	8	51	.65
DAYTON INTERNATIONAL (OH)	47	301	3.84
FAIRBANKS INTERNATIONAL (AK)	4	26	.33
INDIANAPOLIS INTERNATIONAL (IN)	65	417	5.32
JACKSON MUNICIPAL (MS)	9	58	.74
JACKSONVILLE INTERNATIONAL (FL)	16	103	1.31
LOUSIVILLE STANDIFORD FIELD (KY)	18	115	1.47
MILWAUKEE MITCHELL (WI)	104	667	8.51
NASHVILLE METROPOLITAN (TN)	24	154	1.96
OAKLAND INTERNATIONAL (CA)	16	103	1.31
OMAHA EPPLEY (NB)	15	96	1.22
ORLANDO JETPORT INTL. (FL)	15	96	1.22
RICHMOND BYRD INTL. (VA)	21	135	1.72
SACRAMENTO METROPOLITAN (CA)	34	218	2.78
SALT LAKE CITY INTERNATIONAL (UT)	15	96	1.22
SAN ANTONIO INTERNATIONAL (TX)	58	372	4.75
SHREVEPORT REGIONAL (LA)	15	96	1.22
SPOKANE INTERNATIONAL (WA)	37	237	3.02
TULSA INTERNATIONAL (OK)	18	115	1.47
WINDSOR LOCKS BRADLEY INTL. (CT)	73	468	5.97

NOTES #1. FROM TABLE 5-2

#2. IN 1981 DOLLARS

#3. BASED ON NET PRESENT RMR COST OF $78.39K

TABLE 5-4. Impact of RMR Cost on the Benefit/Cost Estimation for Category II Instrument Landing Systems

	RMR B/C RATIO #1	CAT II ILS B/C RATIO #2	CAT II ILS WITH RMR B/C RATIO #3
ANCHORAGE INTERNATIONAL (AK)	2.95	5.05	4.90
BALITIMORE/WASHINGTON INTL. (MD)	4.25	4.79	4.65
BIRMINGHAM MUNICIPAL (AL)	.41	.66	.64
BRISTOL TRI CITY (TN)	1.88	2.53	2.45
BUFFALO INTERNATIONAL (NY)	7.27	6.44	6.25
CINCINNATI GREATER (KY)	6.05	5.12	4.97
COLUMBIA METROPOLITAN (SC)	.65	.90	.87
DAYTON INTERNATIONAL (OH)	3.84	3.10	3.01
FAIRBANKS INTERNATIONAL (AK)	.33	.56	.54
INDIANAPOLIS INTERNATIONAL (IN)	5.32	4.99	4.84
JACKSON MUNICIPAL (MS)	.74	.96	.93
JACKSONVILLE INTERNATIONAL (FL)	1.31	1.85	1.79
LOUISVILLE STANDIFORD FIELD (KY)	1.47	1.88	1.82
MILWAUKEE MITCHELL (WI)	8.51	7.60	7.37
NASHVILLE METROPOLITAN (TN)	1.96	2.84	2.75
OAKLAND INTERNATIONAL (CA)	1.31	1.42	1.38
OMAHA EPPLEY (NB)	1.22	1.62	1.57
ORLANDO JETPORT INTL. (FL)	1.22	2.63	2.55
RICHMOND BYRD INTL. (VA)	1.72	1.94	1.88
SACRAMENTO METROPOLITAN (CA)	2.78	4.56	4.42
SALT LAKE CITY INTERNATIONAL (UT)	1.22	2.82	2.74
SAN ANTONIO INTERNATIONAL (TX)	4.75	5.19	5.03
SHREVEPORT REGIONAL (LA)	1.22	1.54	1.49
SPOKANE INTERNATIONAL (WA)	3.02	3.09	3.00
TULSA INTERNATIONAL (OK)	1.47	2.20	2.13
WINDSOR LOCKS BRADLEY INTL. (CT)	5.97	5.44	5.28

NOTES #1. FROM TABLE 5-3

#2. USED B/C ESTIMATE PROCEDURES FROM REFERENCE (ESTABLISHMENT CRITERIA FOR CATEGORY II INSTRUMENT LANDING SYSTEMS; DOT REPORT FAA-ASP-76-1; JULY 1976) AND DATA FROM REFERENCE (FAA AIR TRAFFIC ACTIVITY-FISCAL YEAR 1979)

#3. BASED ON ESTIMATE THAT THE RMR WOULD ADD 3.1% TO COST OF CAT II ILS EQUIPMENT PACKAGE BUT IGNORES INCREMENTAL RMR SAFETY BENEFIT its probable impact on that system's B/C ratio calculation, and consequently, on the future deployment of the CAT II Instrument Landing System to these intermediate sized airports.

As a start, the B/C ratios of the RMR were compared with those of the CAT II ILS for the current set of non-ASDE, CAT II airports. This comparison is presented in columns 1 and 2 of Table 5-4. It is seen that the RMR ratios track those of the CAT II ILS quite well, specifically:

1) The smallest CAT II B/C ratio found is 0.56 for Fairbank International which is matched by 0.33, the smallest RMR B/C ratio found (Traffic levels, on which the CAT II B/C calculation is based, vary from year to year, which may explain why some of the CAT II ILS B/C ratios for these airports have values less than 1.0 based on 1979 traffic levels.),

2) Both the RMR and the CAT II ILS ratios show exactly the same four airports with B/C ratios of less than 1.0,

3) Both the RMR and the CAT II ILS have their largest B/C ratio for the same airport, Milwaukee Mitchell.

For this one example, based on 1979 traffic data, the inclusion of the RMR into the CAT II ILS equipment package would not have had any obvious impact on the deployment of the CAT II ILS to any of these 26 airports.

Going to the extreme, if one adds the incremental cost of the RMR to the cost of the CAT II ILS but ignores the incremental RMR safety benefit, the resulting decrease in the CAT II ILS B/C ratio would be slight and could be expected to have little adverse impact on the overall deployment of the CAT II Instrument Landing System. The discounted 15-year cost of the CAT II ILS in 1975 was $1435K (Ref. 5). Assuming a 10% compounded annual inflation rate, this cost becomes $2542K in 1981 dollars. Adding the corresponding RMR cost of $78.39K, would increase the CAT II ILS cost by 3.1% to $2620K. The impact of this incremental cost increase on the CAT II ILS B/C ratios for the 26 non-ASDE, CAT II airports is presented in column 3 of Table 5-4. For the 22 airports with CAT II ILS B/C ratios greater than 1.0, the added RMR cost to these ratios would have only reduced the average B/C ratio from 3.19 to 3.09 and would have reduced the smallest ratio found from 1.42 to 1.38. Consequently, even if one ignores the incremental safety benefit provided by the RMR, the RMR cost is so small when compared to the overall CAT II ILS cost that its inclusion into that system would have had little or no adverse impact on the CAT II ILS deployment to these 26 airports.

5.4 RESULTS OF THE COST/BENEFIT ANALYSIS

1) The probability of a major runway accident at a small Category II equipped airport is quite low (e.g., Tulsa International has a probability of 1% that a ground surveillance related accident will occur in the next 15 years) when compared with a large airport which is planning to receive ASDE-3 (e.g., Pittsburgh International has a probability for such an accident of 14%),

2) Due to the low cost of the RMR, 22 of the 26 non-ASDE-3 qualified, CAT II airports currently justify the cost of the RMR with a benefit/cost ratio greater than one (including Tulsa International),

3) On an airport by airport basis, the RMR B/C ratio closely tracks that of the CAT II ILS (e.g., of the 26 non-ASDE equipped, CAT II airports, the 4 airports that could not justify the cost of the RMR based on 1979 traffic data were also shown to have CAT II ILS B/C ratios of less than 1.0 when 1979 traffic data were used to compute these ratios),

4) Adding the RMR to the standard CAT II ILS equipment package for non-ASDE qualified airports would only add 3.1% to the total cost of the system, and would have little adverse impact on the overall deployment of the CAT II ILS to these intermediate sized airports, even if the incremental RMR safety benefit is ignored.

6. REFERENCES

1. Bloom, Bishop, Kuhn, "Detection Performance Evaluations of the ASDE-3 Using Fixed Frequency and Frequency - Agile Operation;" March 1981, RD-81-41.

2. Air Force Cambridge Research Laboratories, Handbook of Geophysics and Space Environments, New York NY, McGraw-Hill, 1965, P. 9-15.

3. M. Skolnik, Introduction to Radar Systems, 2nd Edition, McGraw-Hill, New York NY, P. 501.

4. Establishment Criteria for ASDE-3; Department of Transportation; December 1975, ASP-75-3

5. "Establishment Criteria for Category II Instrument Landing Systems; "U.S. Dept. of Transportation; July 1976, FAA-ASP-76-1.

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