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ANALYTICAL DETERMINATION OF TACAN/DME SYSTEM PERFORMANCE IN A D--ETC(U)
JUN 76 J L WINGARD, C W EHLER DOT-FA-70WAI-175

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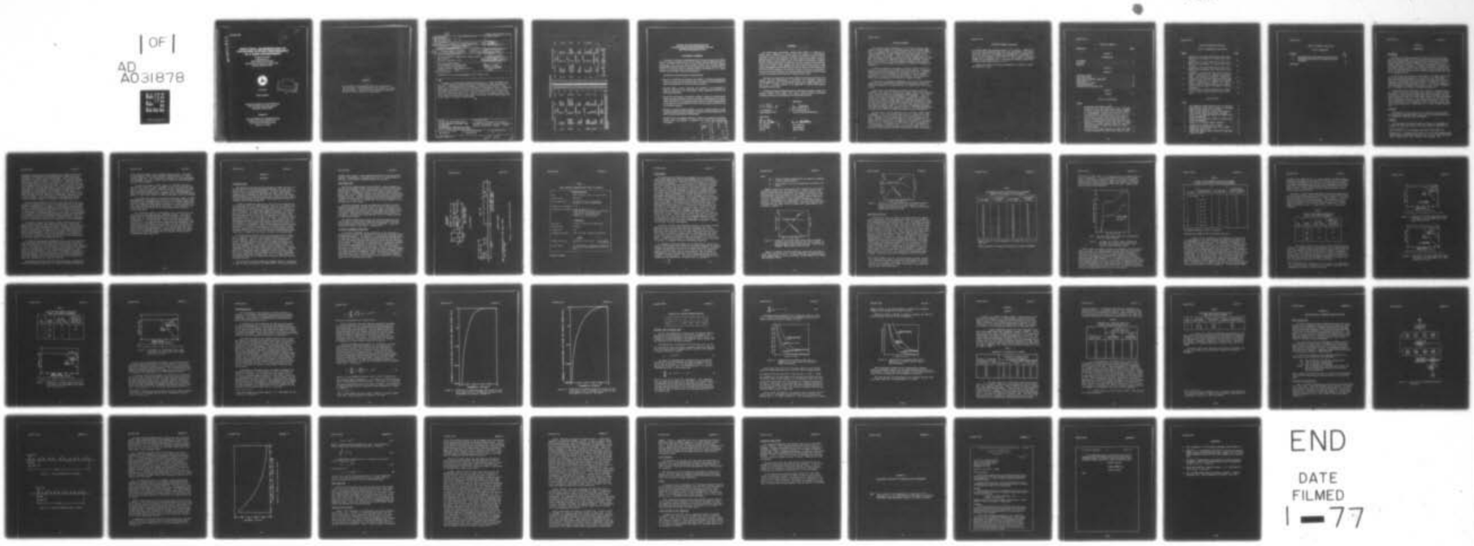

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FAA-RD-76-85

ANALYTICAL DETERMINATION OF TACAN/DME SYSTEM PERFORMANCE IN A DABS ENVIRONMENT

IIT Research Institute
Under Contract to
DEPARTMENT OF DEFENSE
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Annapolis, Maryland 21402

June 1976

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16. Abstract

A program is developed for simulating operation of a single TACAN/DME beacon with various numbers of TACAN/DME aircraft interrogators. Beacon performance is predicted. Interference from a deployment of airborne DABS aircraft is superimposed upon the TACAN/DME beacon to determine the interference effect. TACAN/DME interrogator performance as a function of beacon performance is also predicted. Simulation results are presented in terms of probability of beacon reply, probability of interrogator acquire lock, expected time for interrogator acquire lock, beacon dead time generated by DABS signals, and number of TACAN replies generated by the beacon in response to DABS signals.

17. Key Words

TACTICAL AIR NAVIGATION (TACAN)
DISTANCE MEASURING EQUIPMENT (DME)
INTERROGATOR
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DISCRETE ADDRESS BEACON SYSTEM (DABS)

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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

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

Approximate Conversions from Metric Measures

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

FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT STAFF

STATEMENT OF MISSION

The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource--the electromagnetic radio-frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio-frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.

- Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend the aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

- Developing automated frequency-selection computer programs/routines to provide frequency planning, frequency assignment, and spectrum analysis capabilities in the spectrum supporting the National Airspace System.

- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

PREFACE

The Electromagnetic Compatibility Analysis Center (ECAC) is a Department of Defense facility, established to provide advice and assistance on electromagnetic compatibility matters to the Secretary of Defense, the Joint Chiefs of Staff, the military department and other DoD components. The Center, located at North Severn, Annapolis, Maryland 21402, is under executive control of the Office of the Secretary of Defense, Director of Telecommunications and Command and Control Systems and the Chairman, Joints Chiefs of Staff, or their designees, who jointly provide policy guidance, assign projects, and establish priorities. ECAC functions under the direction of the Secretary of the Air Force and the management and technical direction of the Center are provided by military and civil service personnel. The technical operations function is provided through an Air Force sponsored contract with the IIT Research Institute (IITRI).

This report was prepared for the Systems Research and Development Service of the Federal Aviation Administration in accordance with Interagency Agreement DOT-FA70WAI-175, as part of AF Project 649E under Contract F-19628-76-C-0017, by the staff of the IIT Research Institute at the Department of Defense Electromagnetic Compatibility Analysis Center.

To the extent possible, all abbreviations and symbols used in this report are taken from American Standard Y10.19 (1967) "Units Used in Electrical Science and Electrical Engineering" issued by the United States of America Standards Institute.

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EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) has instituted a program for the development of a Discrete Address Beacon System (DABS) that will upgrade, and eventually replace, the existing Air Traffic Control Radar Beacon System (ATCRBS) as the primary means of air traffic control surveillance. Since the DABS will operate on the same interrogation and reply frequencies as the ATCRBS (1030 and 1090 MHz), the DABS must be compatible with existing TACAN/DME services. The FAA has engaged the DoD Electromagnetic Compatibility Analysis Center (ECAC) to investigate the impact of the DABS on TACAN/DME performance.

A computer program was developed to simulate TACAN beacon performance, using a time-event-store simulation technique. Parameters investigated through simulated beacon operation were the probability of beacon reply to interrogations, the amount of beacon deadtime generated as a result of receiving DABS signals, and the number of TACAN replies generated by the beacon as a result of DABS.

To represent interrogator performance, the criteria for acquiring range lock were obtained from equipment specifications and used to calculate probability of acquiring lock as a function of reply probability.

Calculations described above were made for several simulated situations, consisting in each case of a single TACAN beacon operating with a specific number of interrogating TACAN aircraft. This established a baseline of system performance for TACAN/DME, in terms of beacon reply probability and interrogator acquire-lock probability. To assess the impact of DABS signals on TACAN/DME performance, calculations similar to those described for baseline performance were made. In each case, however, simulation of DABS signals was included, and the resulting effects noted. In this manner, TACAN/DME performance with DABS interference was compared to baseline TACAN/DME performance, so that the net effects of DABS interference could be determined.

Typical results of the simulation are as follows: TACAN X-mode performance, with a 5:95 search-track ratio, is unaffected by DABS on all channels except 64 through 68, used exclusively by the military. Channel 66 is unaffected when 70 or less interrogators are being serviced; however, as the number of interrogators is increased from 70 to 110, the presence of DABS replies causes the probability of beacon reply to decrease from .77 to .50. Thus, the probability of an interrogator acquiring range lock decreases from .99 to .79, and the average expected time for an analog-type TACAN interrogator

EXECUTIVE SUMMARY (Continued)

to acquire range lock increases from 11 to 14 seconds. Channels 65 and 67 are each unaffected when 85 or less interrogators are being serviced; however, as the number of interrogators is increased from 85 to 120, the presence of DABS replies causes the probability of beacon reply to decrease from .77 to .70. This results in negligible changes in the probability of an interrogator acquiring range lock and the average expected time to do so.

Simulation results for Y-mode performance are similar to those described for X-mode.

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SECTION 1

INTRODUCTION

BACKGROUND

The Federal Aviation Administration (FAA) has instituted a program for the development of a Discrete Address Beacon System (DABS) which will upgrade, and eventually replace, the existing Air Traffic Control Radar Beacon System (ATCRBS) as the primary means of air traffic control surveillance. To support the eventual automation of air traffic control, the DABS will have the potential to improve the aircraft-tracking capacity, azimuth resolution, and ranging accuracy of the existing ATC system and will include a ground-to-air data link as an integral feature.

To facilitate the transition from ATCRBS to the DABS, DABS equipments will include the capability to operate in the ATCRBS mode. Since the DABS will operate on the same interrogation and reply frequencies as the ATCRBS (1030 and 1090 MHz), the DABS must also be compatible with existing TACAN/DME services. The FAA has engaged the DoD Electromagnetic Compatibility Analysis Center (ECAC) to investigate the impact of the DABS on TACAN/DME performance.[1]

A related analysis conducted by ECAC involved a determination of the impact of the provisional DABS signal formats on specific TACAN equipments.[2] Based on data extrapolated from an equipment test program, interference effects of DABS signal formats on TACAN performance were described in terms of 1) total DABS signal level received at a TACAN interrogator, relative to the maximum interference level that can be tolerated by the interrogator, and 2) the amount of dead time and loading generated at a TACAN beacon as a result of DABS interference.

OBJECTIVE

The objective of this analysis was to determine through simulation techniques the interference impact of the provisional DABS signal formats on TACAN/DME system performance.

APPROACH

An investigation of DABS interference effects on TACAN/DME performance was initiated by ECAC, based upon computer simulation of

[1]Task Assignment 16 of Interagency Agreement DOT-FA-70WAI-175.

[2]Wingard, J. L., *Interference Potential of the Discrete Address Beacon System (DABS) Provisional Signal Formats on X and Y mode TACAN Equipments*, FAA-RD-75-109, ECAC, Annapolis, MD, December 1975.

equipment operation, with and without external (DABS) interference. A baseline of TACAN/DME system performance was established in an environment free from external interference. For a single beacon replying to a variable number of interrogators, simulated TACAN/DME system performance was described in terms of 1) probability that a beacon would reply to a given interrogation, and 2) probability that an interrogator would acquire range lock. Using results of the previous analysis involving DABS impact on specific TACAN/DME equipments (Reference 2), the simulation was expanded to include the case of TACAN/DME system performance in the presence of DABS signals. A comparison was then made between the simulation of baseline (TACAN/DME) performance and the simulation of TACAN/DME performance in the presence of DABS. From this comparison, a determination was made of the interference impact of the DABS on TACAN/DME performance.

Only the range-determining portion of the TACAN system was investigated in this analysis, since the azimuth function in the TACAN beacon is independent of the number of interrogators being serviced. Further, a determination was made in an earlier analysis (Reference 2) that direct interference from DABS will not affect the ability of an interrogator to acquire azimuth lock. As a result, all references in this analysis to TACAN/DME system operation imply range measurement. To determine a baseline of TACAN/DME system performance, it was necessary to examine the degree of beacon loading and reply efficiency, as well as the process of range-lock acquisition in the interrogator.

The computer program developed to simulate TACAN beacon performance used a time-event-store simulation technique. The program generated start and stop times for bearing reference bursts, squitter pulses, and aircraft interrogation pulses. Precedence and time-of-arrival considerations were applied to determine whether each interrogation would generate a reply or be pre-empted. The probability of the beacon replying to an aircraft interrogation was defined as the ratio of the number of replies generated by valid interrogations to the total number of interrogations received.

To represent interrogator performance, the criteria for acquiring range lock were obtained from equipment specifications and used to calculate probability of acquiring lock as a function of reply probability. For the purposes of this analysis, the probability of acquiring range lock depended only upon the proper number of replies being received by the interrogator. Two specific interrogator types were chosen as representative of those likely to be found in a normal operating environment. Using the respective acquire-lock criteria for each type, probabilities of acquiring range lock were generated as a function of probability of reply for each case.

Calculations described above were made for several simulated situations, consisting in each case of a single TACAN beacon operating with a specific number of interrogating TACAN aircraft. The number of interrogators was an input variable, ranging from 10 to 120 aircraft in each case. This established a baseline of system performance for TACAN/DME, in terms of beacon reply probability and interrogator acquire-lock probability.

To assess the impact of DABS signals on TACAN/DME performance, calculations similar to those described for baseline performance were made. In each case, however, simulation of DABS signals was included, and the resulting effects noted. In this manner, TACAN/DME performance with DABS interference was compared to baseline TACAN/DME performance, so that the net effects of DABS interference could be determined.

As an additional measure of the DABS interference impact on TACAN/DME performance, calculations were made of 1) the amount of dead time produced by the TACAN/DME beacon as a result of receiving DABS signals, and 2) the number of TACAN replies generated as a result of DABS signals being received and decoded by the beacon. These parameters were investigated at the request of the system engineering contractor, Lincoln Laboratory.

The interference effects investigated in this analysis deal only with the results of DABS downlink (1090 MHz) formats. The case of interference to TACAN/DME performance from DABS uplink (1030 MHz) formats was not investigated here, based on results of the analysis in Reference 2. In that analysis, it was shown that DABS uplink signals, even at close range and with minimum frequency separation, were insufficient to interference with the ability of the interrogator to acquire azimuth lock (which was shown to be the function most sensitive to DABS uplink interference). It was further shown that interference to the TACAN/DME beacon from DABS uplink signals was minimal and could be controlled through the use of proper siting criteria (frequency/distance separation).

SECTION 2

ANALYSIS

TACAN/DME SYSTEM

The function of the Tactical Air Navigation (TACAN) System is to provide pilots of interrogator-equipped aircraft with slant range and bearing to a selected ground beacon. Distance information is obtained at the interrogator by measuring the time elapsed between transmitting an interrogation and receiving a reply from the beacon. Bearing information is derived through analog techniques that compare the phase relationship of the beacon signal modulation envelope to reference pulses being transmitted.

A TACAN interrogation consists of a pair of pulses [separated by 12 microseconds (μs) in X-mode operation, and 36 μs in Y-mode] which, when received and decoded by the beacon, cause the generation of a corresponding pair of reply pulses (separated by 12 μs in X-mode and 30 μs in Y-mode). In typical interrogator performance, the interrogator operates in the search mode when initially activated, transmitting interrogations at the rate of approximately 140 pulse pairs per second (pp/s). The actual PRF is "jittered," or purposely varied, between 130 and 150 pps at a random rate. This is done so that the interrogator receiver, using a gating pulse synchronized with the interrogations, can identify beacon replies that are in response to that particular interrogator. When a predetermined number of replies synchronous with these interrogations is received from the beacon, the interrogator switches to the track mode of approximately 26 pp/s (randomly jittered between 22 and 30 pps) which is maintained unless range lock is broken, at which time it reverts to the search mode.

The TACAN beacon operates with a constant output rate of 3600 pp/s. Included in this total are bearing reference pulses, replies to interrogations, squitter (filler) pulses, and identification pulses. Bearing reference pulses, which account for 900 pp/s, are used by the interrogator in the process of azimuth determination, and take precedence over other types of beacon output pulses. The remaining 2700 pp/s of beacon output consist of replies to aircraft interrogations, squitter pulses, and beacon identification. Squitter pulses are random pulse pairs, generated to keep the beacon output duty cycle at 3600 pp/s when the number of reply pulses being generated is not sufficient to produce this total. A signal keyed with international Morse code is transmitted at regular intervals for beacon identification.

The operation of Distance Measuring Equipment (DME) is essentially the same as that described for the TACAN system. The major difference between these systems is that bearing information is not provided by the DME. Consequently, the maximum duty cycle of the DME beacon is 2700 pp/s, since bearing reference pulses are not used.

DABS DESCRIPTION

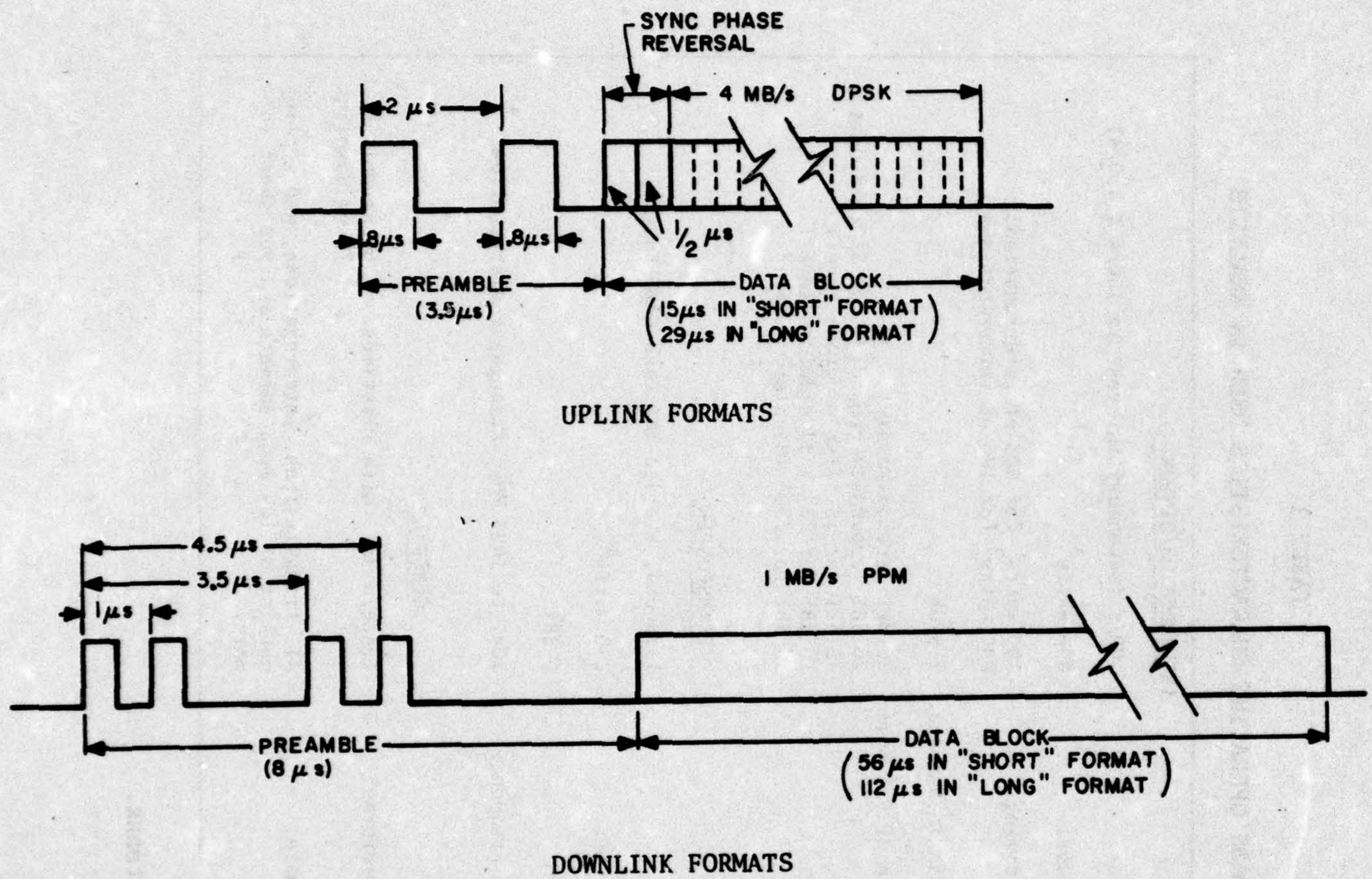
The Discrete Address Beacon System (DABS) is being developed to upgrade and eventually replace the existing Air Traffic Control Radar Beacon System (ATCRBS) as the primary means of air traffic control surveillance. The DABS will consist of a network of ground interrogators that, like the ATCRBS, measure range and bearing to transponder-equipped aircraft. Aircraft identity and altitude can be automatically obtained from their encoded transponder replies and displayed to the controller. In addition, a digital data link will be available as an integral part of the system.

The major difference between the DABS and the ATCRBS is in the method of interrogating aircraft within the area of responsibility. ATCRBS interrogates all aircraft within its range, eliciting a reply from each during every sweep of the antenna beam, while DABS will use a discretely coded address message to interrogate each aircraft individually, scheduling the interrogations so as to eliminate overlap and garbling of replies.

The specific DABS signal formats and operating characteristics used by ECAC in performing this analysis were provided by the DABS system engineering contractor, MIT Lincoln Laboratory. These are described in Figure 1 and TABLE 1, respectively.

TACAN/DME PERFORMANCE SIMULATION

To determine TACAN/DME system performance, it was necessary to mathematically simulate the operation of a TACAN beacon and both TACAN and DME interrogators. The operation of TACAN beacons and DME beacons is essentially the same, the major exception being that the DME beacon does not generate bearing reference bursts and envelope modulation of the signal. The operation of the TACAN beacon, therefore, includes DME operation, and simulation of TACAN operation represents the general case of TACAN/DME beacon performance. Since the operational mechanisms of interrogators vary from model to model, two interrogators were chosen as bases for simulation, with the understanding that these particular equipments [AN/ARN-21C (TACAN) and RCA AVQ-75 (DME)] were representative of their respective types. The interrogator feature chosen for simulation in this analysis was the function of acquiring range lock on a desired beacon signal.



NOTE: ALL TRANSMISSIONS CONSIST OF 90% "SHORT" FORMAT, 10% "LONG" FORMAT.

Figure 1. Provisional DABS signal formats.

TABLE 1

DABS OPERATING CHARACTERISTICS USED IN ANALYSIS

	INTERROGATOR/SENSOR:
PRF:	200/s (secondary interest in 100/s & 500/s)
Transmit Power:	800 watts[a]
Power Programming:	100 watts[a] for 90% of interrogations 800 watts[a] for 10% of interrogations
Coupling Loss to Antenna:	1.5 dB
Antenna Gain of Fan Beam:	26 dBi (ground-to-air) } for 3° main beam 20 dBi (ground-to-ground) } for 3° main beam -5 dBi for 15° (1st sidelobe level) -10 dBi for 72° (2nd sidelobe level) -16 dBi for 270° (backlobe level)
	TRANSPONDER:
Reply Rate:	1/second, average for each DABS target
Transmit Power:	250 watts[a]
Antenna Gain:	0 dBi
Transponder Frequency:	1087 to 1093 MHz, triangular distribution
	GENERAL:
Shape of waveforms:	Trapezoidal, with risetimes = 60 ns uplink 75 ns downlink
Mix of Formats:	All transmissions, interrogations, and replies consist of 10% long formats and 90% short formats.

[a]Input to antenna.

BEACON MODEL

The simulation of TACAN beacon performance used a time-event-store model based upon a Monte Carlo approach to event generation. A brief description of the simulation is given below, with a detailed description in APPENDIX A. The situation to be simulated consisted of a single TACAN beacon and various groups of interrogator-equipped aircraft. The start and stop times of the various events taking place in the beacon were generated by selection of random numbers. The simulation of beacon performance necessarily included simulation of signals received from aircraft equipped with TACAN/DME interrogators, since beacon performance is a direct function of the valid TACAN/DME interrogations received. Valid interrogations received at the beacon were generated randomly by the model, simulating, in effect, the receipt of all interrogations at or above the minimum discernible signal level (MDS). The position and transmitted signal level of each interrogator is not considered here, since the net effect of a deployment of interrogators (i.e., the number of interrogations received at the beacon and their respective signal levels) is of primary importance. Model inputs included a search-track ratio, which determines the percentage of TACAN/DME interrogators in both the search mode (140 interrogations per second) and in track (26 interrogations per second). Search-track ratios of 5:95 and 10:90 were used in this analysis. The total number of TACAN/DME-equipped aircraft interrogating the beacon was also a model input. For this analysis, calculations were made for groups of TACAN/DME interrogators, ranging in size from 10 to 120 interrogators.

Initially, aircraft interrogations received by the beacon, bearing reference bursts, and squitter pairs were assigned start times. When start times for all events had been determined, the earliest occurring event was found, and all other events interfering with this event would be handled in a proper manner, depending upon the nature of the event and its precedence level. Once an event had been completed or eliminated, a new event would be generated for a later start time. A count was maintained of eliminated events as well as successful events, to determine statistics for beacon operation.

To determine system performance of the TACAN beacon, several measures of effectiveness were considered, including the number of squitter (random noise-generated pulse pairs) produced, the number of TACAN/DME aircraft interrogations received at the TACAN beacon, the number of beacon replies to TACAN aircraft interrogations, and the number of TACAN/DME aircraft interrogations not eliciting replies due to overloading of the TACAN beacon. The primary measure of TACAN beacon performance was the probability of beacon reply, p, defined as

$$p = \frac{N_R}{N_I} \quad (1)$$

where

N_R = number of replies generated by the beacon in response to valid interrogations

N_I = total number of valid interrogations received by the beacon.

Figures 2 and 3 show the results of the simulation for baseline (no DABS) performance of the TACAN beacon. Figure 2 displays the number of squitter pulses generated, the number of replies to valid interrogations, and the probability that a beacon will reply to any TACAN aircraft interrogation for an interrogator search-track ratio of 5:95. The probability of reply remained constant at .77 for groups of interrogators up to approximately 110 TACAN/DME-equipped aircraft. As the number of interrogators increased beyond this point, the probability of reply started to drop, and at approximately 120 aircraft it reached .7.

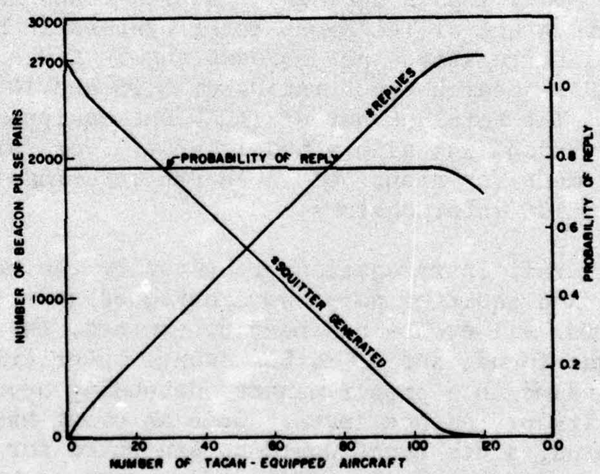


Figure 2. Probability of X-mode TACAN beacon reply and number of beacon replies and squitter for various numbers of TACAN-equipped aircraft being serviced. (Baseline performance, search-track ratio of 5:95).

Figure 3 represents the same situation, except that the search-track ratio was set at 10:90. In this situation, the probability of reply dropped below .7 for an environment of approximately 100 TACAN/DME-equipped aircraft.

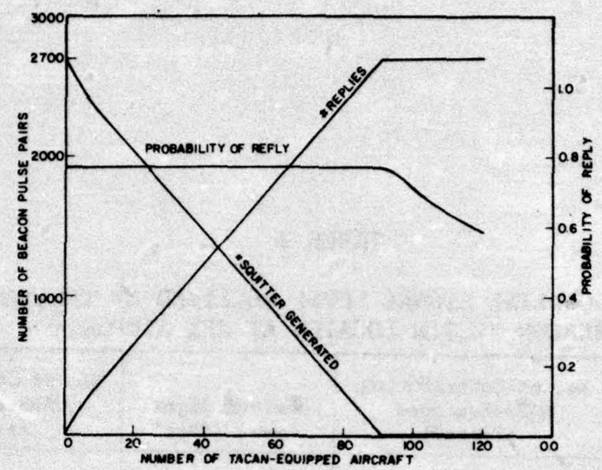


Figure 3. Probability of X-mode TACAN reply and number of beacon replies and squitter for various numbers of TACAN-equipped aircraft being serviced. (Baseline performance, search-track ratio of 10:90).

DABS IMPACT ON TACAN

To measure the impact of DABS on the TACAN beacon, the signals from an environment of DABS-equipped aircraft were superimposed on the TACAN/DME operation described above. This environment, provided by the system engineering contractor as being a conservatively large prediction of air traffic in 1980, consisted of 1121* DABS-equipped aircraft within 200 nautical miles (370.4 km) of JFK Airport. This traffic model has a density of 0.025 aircraft per nmi^2 within about 20 nmi (37 km) of New York City. TABLE 2 describes the DABS deployment in terms of the signal level of each DABS aircraft reply as measured at the TACAN beacon. Figure 4 (obtained from the test program described in Reference 2), displays the amount of beacon dead time generated as a result of receiving DABS replies. Dead time, defined as the period of beacon operation during which the beacon cannot process an incoming interrogation, can be caused by either of two mechanisms within the beacon. If the interference is interpreted by the beacon as being a valid interrogation and is decoded, a minimum of 60 μs of dead time is generated, as with any valid decode. If the interference is not decoded, an amount of desensitization that varies as a function of interference signal strength, resulting in an effective deadtime to desired signals

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*This figure differs from the 1152 DABS-equipped aircraft referred to in FAA-RD-75-109, which included the total number of aircraft seen by a victim TACAN interrogator at an altitude of 10,000 feet. Line-of-sight considerations reduce this total to 1121 aircraft seen by the victim TACAN beacon.

TABLE 2

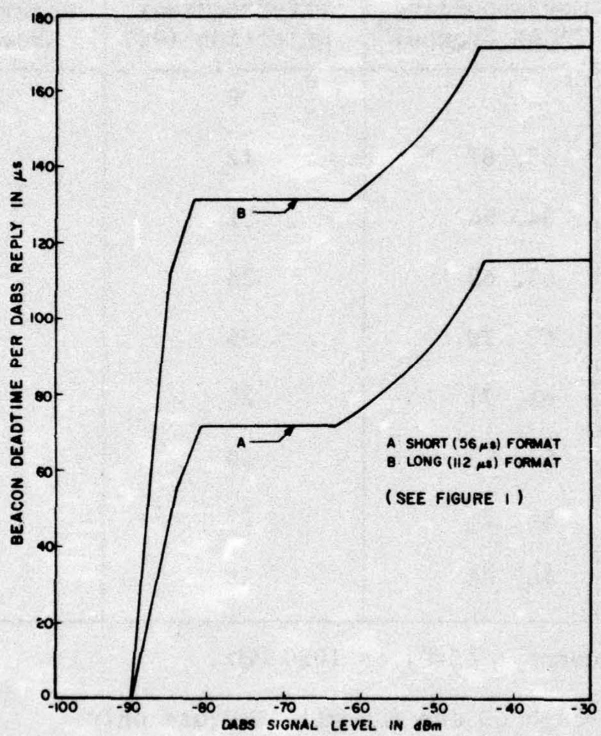
DABS DOWNLINK SIGNAL LEVEL RECEIVED AT TACAN/DME BEACON VICTIM LOCATED AT JFK AIRPORT[b]

Received Signal Level (dBm)[a]	No. of Contributing DABS-Equipped Aircraft	Received Signal Level (dBm)[a]	No. of Contributing DABS-Equipped Aircraft
-42	1	-73	53
-45	1	-74	47
-49	2	-75	55
-53	1	-76	54
-54	2	-77	58
-55	2	-78	80
-56	4	-79	68
-57	3	-80	46
-58	3	-81	53
-59	6	-82	42
-60	4	-83	36
-61	3	-84	44
-62	12	-85	31
-63	9	-86	19
-64	11	-87	23
-65	12	-88	26
-66	29	-89	23
-67	31	-90	7
-68	21	-91	12
-69	38	-92	20
-70	26	-93	5
-71	36	-94	8
-72	49	-95	5

[a]Signal level of -70 dBm represents the range from -69.5 to -70.5 dBm, etc.

[b]Beacon operating on Channel 66X (Receiver Frequency 1090 MHz).

received at the MDS level, will be generated by echo suppression circuits in the beacon. It was determined in testing that for these formats, DABS replies received at signal levels above -81 dBm were always decoded. Replies having a signal level between -81 dBm and -85 dBm were decoded approximately 50% of the time. Signal levels below -85 dBm were not decoded.



Note: This data based upon extension of experimental data for similar formats.

Figure 4. Deadtime to a desired signal at MDS level per DABS reply generated in X-mode TACAN beacon by DABS downlink formats.

TABLE 3 shows the effect of beacon off-frequency rejection on the number of replies from DABS-equipped aircraft received by the TACAN beacon from the 1121 aircraft in the DABS aircraft environment. (This data, obtained in the test program described in Reference 2, depicts the off-frequency rejection of the TACAN beacon for these particular DABS signal formats.) If the TACAN beacon were co-channel with the DABS replies, all 1121 replies would be received by the beacon. If the TACAN frequency were 1 MHz removed from the DABS frequency, off-frequency rejection of the beacon would cause a 12 dB drop in signal level of the DABS replies and only 653 of the 1121 DABS aircraft would be above the minimum sensitivity level of the beacon.

TABLE 3

EFFECT OF OFF-FREQUENCY REJECTION ON NUMBER OF DABS AIRCRAFT ABOVE TACAN BEACON THRESHOLD

Δf (MHz)[a]	Corresponding TACAN Channel[b]	Off-Frequency Rejection (dB)	DABS-Equipped Aircraft Responses Above Threshold
0 (on-tune)	66	0	1121
1	65, 67	12	653
2	64, 68	21	195
3	63, 69	24	105
4	62, 70	26	64
5	61, 71	27	53
9	57, 75	30	29
10	56, 76	32	19
20	46, 86	38	4

[a]Co-channel frequency (Δf=0) is 1090 MHz.

[b]Channels 60 through 69 are for military use only.

Figure 5 shows the effect on the probability of reply from the TACAN beacon if 1121 DABS-equipped aircraft are superimposed on the TACAN/DME-only operation, with the TACAN/DME interrogators comprising a 5:95 search-track ratio. The upper curve represents an environment with no DABS aircraft and is the baseline for TACAN performance, while the lower curve shows the result of 1121 DABS replies co-channel with the TACAN beacon receiver frequency. The intermediate curve represents 653 DABS-equipped aircraft above sensitivity, corresponding to the case of 1121 DABS-equipped aircraft tuned one TACAN channel away, or 1 MHz off-frequency. As the frequency difference is increased, the intermediate curve shifts toward the upper curve. All three curves are essentially the same until approximately 70 TACAN aircraft are present together with DABS. At this point the beacon is operating at its maximum reply rate of 2700 ± 90 pulse pairs per second with minimal squitter generation. The predominant effect of DABS on the TACAN beacon is to cause generation of TACAN replies. Receiving interrogations from more than 70 TACAN aircraft in addition to the DABS environment, the beacon is in an overloaded condition, resulting in desensitization and some TACAN interrogations not being serviced by the beacon, thereby reducing the probability of beacon reply. Figure 6 displays the case for a similar situation, with a search-track ratio of 10:90.

The effect of DABS signals upon X-mode TACAN beacon performance, in terms of percentage of beacon deadtime and number of DABS interrogations decoded by the TACAN beacon, is shown in TABLE 4. This data was derived from the simulation process. These parameters are included to indicate where the preliminary criterion[a] for tolerable beacon interference, as proposed by Lincoln Laboratory in a letter dated 30 May 1975, is met. A copy of this letter is included as APPENDIX B.

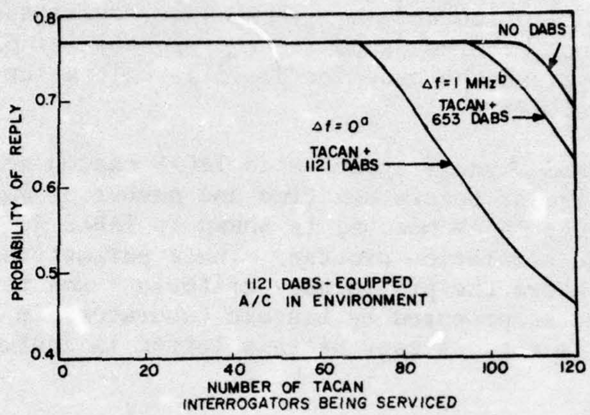
TABLE 4

EFFECT OF DABS DOWNLINK SIGNALS ON
X-MODE TACAN BEACON PERFORMANCE

Δf (MHz)	TACAN Channel	Per Cent Dead Time Caused by DABS	Number of DABS Replies Decoded by TACAN Beacon
0	66X	6.5	797
1	65X 67X	2.6	222
2	64X 68X	0.6	36

The results shown thus far are for X-mode TACAN beacon performance. A similar analysis was performed for the Y-mode TACAN beacon, using appropriate data gathered in the previous testing for the Y-mode case. These results are displayed in TABLE 5 and Figures 7 and 8. For both X-mode and Y-mode, at Δf = ±2 MHz, the percentage of deadtime is below 5% and the number of decodes per second is less than 150, thus meeting the preliminary criterion for tolerable beacon interference as proposed by Lincoln Laboratory.

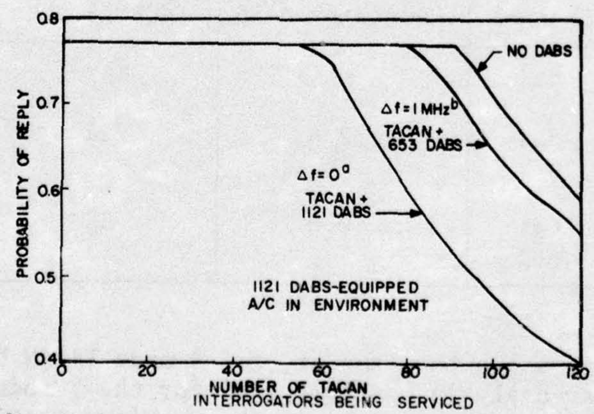
[a] This criterion is not intended to be, nor should it be construed to be, the establishment or definition of acceptable TACAN/DME system performance criteria in a DABS environment.



[a]TACAN Beacon Receiver Frequency on channel 66X (1090 MHz).

[b]TACAN Beacon Receiver Frequency on channel 65X or 67X (1089 or 1091 MHz).

Figure 5. Probability of X-mode TACAN beacon reply with DABS in the environment, for search-track ratio of 5:95.



[a]TACAN Beacon Receiver Frequency on channel 66X (1090 MHz).

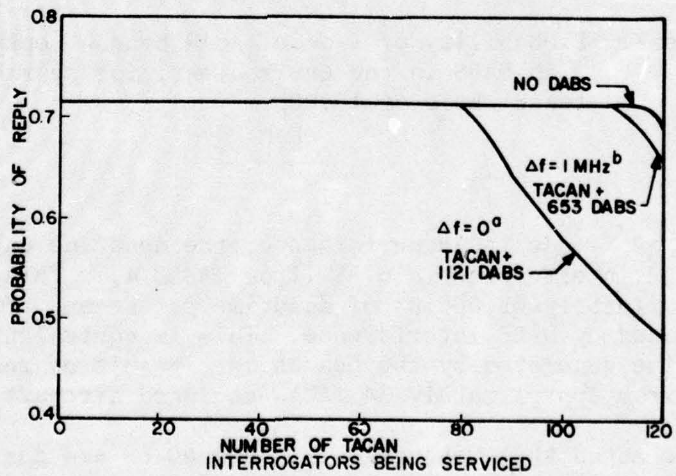
[b]TACAN Beacon Receiver Frequency on channel 65X or 67X (1089 or 1091 MHz).

Figure 6. Probability of X-mode TACAN beacon reply with DABS in the environment, for search-track ratio of 10:90.

TABLE 5

EFFECT OF DABS DOWNLINK SIGNALS ON
Y-MODE TACAN BEACON PERFORMANCE

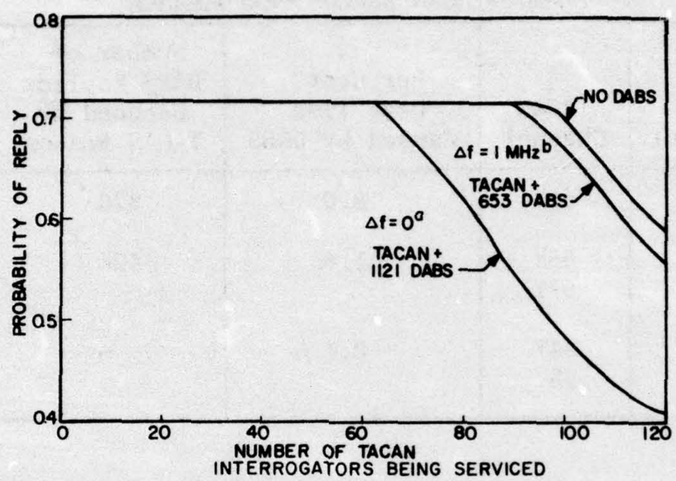
Δf (MHz)	TACAN Channel	Per Cent Dead Time Caused by DABS	Number of DABS Replies Decoded by TACAN Beacon
0	66Y	8.0	820
1	65Y 67Y	1.6	126
2	64Y 68Y	0.1	6



[a]TACAN Beacon Receiver Frequency on channel 66Y (1090 MHz).

[b]TACAN Beacon Receiver Frequency on channel 65Y or 67Y (1089 or 1091 MHz).

Figure 7. Probability of Y-mode TACAN beacon reply with DABS in the environment, for search-track ratio of 5:95.



[a]TACAN Beacon Receiver Frequency on channel 66Y (1090 MHz).

[b]TACAN Beacon Receiver Frequency on channel 65Y or 67Y (1089 or 1091 MHz).

Figure 8. Probability of Y-mode TACAN beacon reply with DABS in the environment, for search-track ratio of 10:90.

In the case of X-mode TACAN performance, the deadtime caused by on-frequency DABS interference is 6.5% (from TABLE 4). This indicates that approximately 65,000 μs of deadtime per second of beacon operation is caused by DABS interference. This is equivalent to the amount of deadtime generated by the beacon as a result of receiving interrogations from approximately 34 TACAN-equipped aircraft.

It should be noted that "channels 1-16 and 60-69 are designated for the military services for tactical uses and are not used in the National Airspace System."[3] Thus, the TACAN channels shown here to be affected by DABS interference (co-channel and first and second adjacent channel operation) are assigned in CONUS only to military users, who "shall coordinate in advance with the FAA relative to the use of TACAN channels 16, 60, and 69 for land-based facilities."[3]

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[3]*OTP Manual of Regulations and Procedures for Radio Frequency Management*, Office of Telecommunications Policy, Washington, DC, par. 4.3.5, p. 4-140, 141.

INTERROGATOR MODEL

For the purposes of this analysis, the only function of interest in an airborne interrogator was the ability to acquire range lock. This aspect of system performance was evaluated by determining analytically 1) the probability of acquiring lock, and 2) the time required to do so.

To determine the exact mechanism of range-lock acquisition in various interrogators, a study was made of equipment specifications and technical manuals. From this study, the characteristics of two specific interrogators (one TACAN and one DME) were chosen as examples representative of those likely to be found in a typical operating environment. These characteristics were represented mathematically and used to obtain the statistics of interest.

The TACAN interrogator investigated, AN/ARN-21C, has a maximum range of 200 nautical miles and a search cycle of 20 seconds. The requirement for obtaining range lock is that a minimum of six replies to interrogations be received coincident with the late gating pulse of the interrogator.[4] This gating pulse, whose position in time is directly proportional to the distance readout on the interrogator display, is synchronized with the transmitted interrogation pulses. The late gating pulse travels in a direction corresponding to increasing distance, reaches maximum, returns to zero, and travels through the entire range again. As a worst case, the gating pulse will have just passed through the correct range position when the search mode is initiated, thus requiring a complete cycle to again attain the correct position. For the AN/ARN-21C, the width of the late gating pulse is such that it is possible to receive 14 reply pulses coincident with its duration.

A mathematical representation of the TACAN interrogator was obtained as follows. If the receipt of a reply pulse from the beacon is considered to be an event that will either occur or not occur, a minimum number of events (6) must occur in order for the interrogator to acquire range lock. (It was assumed, for the purpose of this analysis, that each reply generated by the beacon was received by the interrogator.) The probability of this number of events occurring is a binominally distributed random variable. For the occurrence of 6 or more events out of a possible 14, the probability of acquiring range lock, w, is given by

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[4] *Radio Set AN/ARN-21C, Technical Manual*, T. O. 12R5-2ARN21-42, US Air Force, 1 June 1963.

$$w = \sum_{i=6}^{14} \binom{14}{i} (p)^i \, (1-p)^{(14-i)} \tag{2}$$

where p is the probability of beacon reply.

Strictly speaking, the above equation represents the probability that range lock will occur when the late gating pulse of the interrogator is in the position corresponding to precisely the correct range from the beacon. However, assuming that the late gating pulse will pass through that position at some point during one complete search cycle, regardless of where it starts, w may be defined as the probability of acquiring range lock during one complete search cycle. The above equation was used to generate the curve of acquire-lock probability as a function of probability of beacon reply, displayed in Figure 9.

The DME interrogator investigated, an RCA AVQ-75, also has a maximum range of 200 nautical miles, but the search cycle in this case is 5 seconds. The criterion for this equipment to acquire range lock is that 3 consecutive replies be received coincident with the late gating pulse.[5] In the AVQ-75, a maximum of 9 replies may possibly be coincident with the gating pulse. A binomial probability distribution was used to obtain the probability of receiving a sufficient number of replies, but it was modified to ensure that the replies were properly arranged (i.e., 3 consecutive replies). In this case, the probability of acquiring range lock, w, is given by

$$w = \sum_{i=3}^{9} N_i \binom{9}{i} p^i \, (1-p)^{9-i} \tag{3}$$

where N_i is the probability that at least 3 out of i replies received during range coincidence (i.e., 9 trials) will be consecutive, and p is the probability of beacon reply. The values of N_i, obtained through combinational analysis, are given in TABLE 6. The probability of acquiring range lock as a function of reply probability is shown in Figure 10.

[5] *AVQ - 75 DME System Instruction Manual*, IB96435-1, Aviation Equipment Dept., Radio Corporation of America, July 1967.

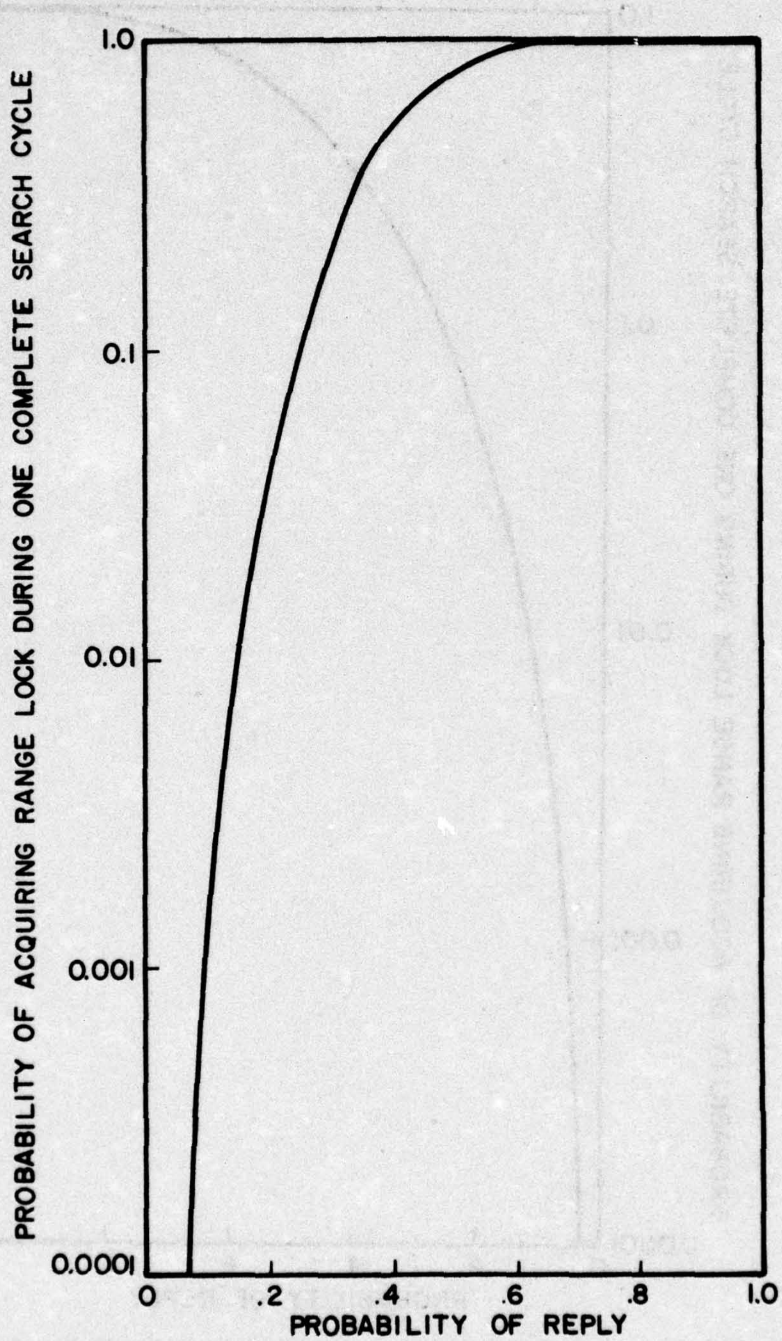

Figure 9. Probability of acquiring range lock during one complete search cycle vs. probability of beacon reply. Interrogator of interest: AN/ARN-21C.

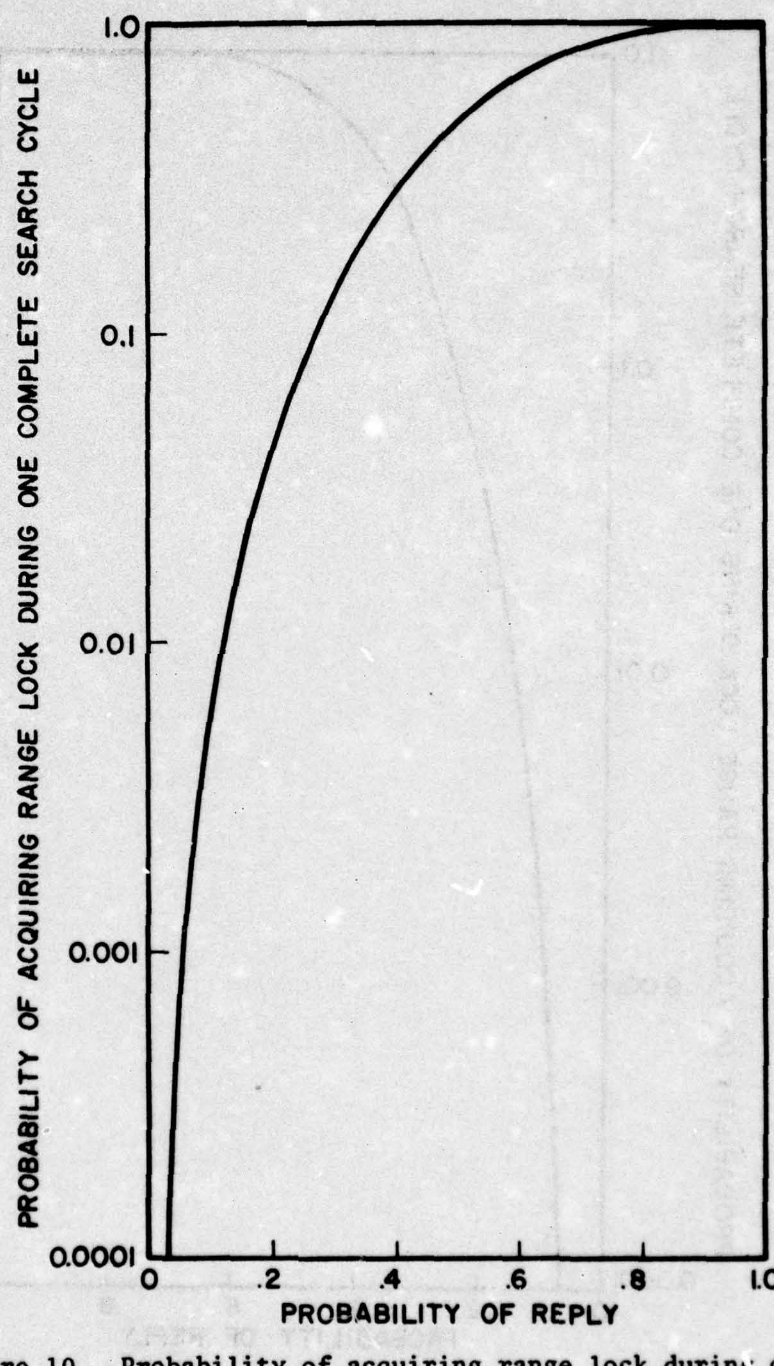

Figure 10. Probability of acquiring range lock during one complete search cycle vs. probability of beacon reply. Interrogator of interest: RCA AVQ-75.

TABLE 6

VALUES OF N_i OBTAINED THROUGH ANALYSIS

i	9	8	7	6	5	4	3
N_i	1	1	1	0.88	0.60	0.29	0.08

EXPECTED TIME TO ACQUIRE LOCK

Once p, the probability of beacon reply to aircraft interrogations, had been determined, it was used to determine w, the probability of acquiring range lock during one search cycle. As a measure of system performance, the expected time to acquire lock was evaluated by the following technique.

The probability of acquiring lock on the nth cycle, P_n, may be calculated by using the negative binomial probability function, since the probability of acquiring lock on the nth cycle requires n-1 misses and one hit so that

$$P_n = w(1-w)^{n-1} \quad (4)$$

To obtain the expected time to acquire lock, calculations were made for the most-favorable and least-favorable positions of the late gating pulse in the interrogator receiver. The expected time to acquire lock, if the gating pulse is in the most-favorable position, is calculated using

$$\sum_{n=1}^{\infty} P_n \cdot (n-1) \cdot \tau = \frac{\tau}{w} - \tau, \quad (5)$$

where τ is the cycle time of the interrogator. This represents the case when the late gate is at the point in the search cycle corresponding exactly the correct range from the beacon. If the late gate has just passed this correct range position and must continue through the entire cycle to attain the correct position, the expected time to acquire lock (least-favorable position) is calculated using

$$\sum_{n=1}^{\infty} P_n \cdot n \cdot \tau = \frac{\tau}{w} \quad (5a)$$

Evaluating these expressions over a range of values for probability of beacon reply produces the corresponding expected time to acquire range lock shown in Figures 11 and 12.

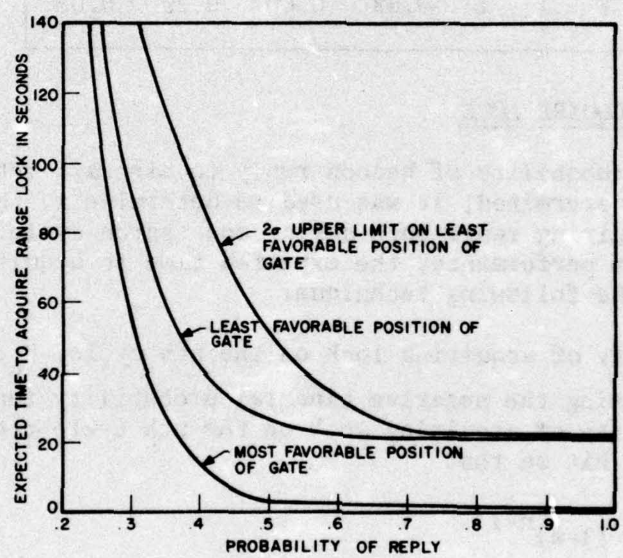

Figure 11. Expected time to acquire range lock vs. probability of beacon reply for AN/ARN-21C TACAN interrogator.

Since these values for time to acquire range lock are average times, the standard deviation of these times can be calculated from the negative binominal probability function and $\sigma_\tau = \frac{1-w}{w}\tau$. Using this information, an upper bound can be placed on the expected time to acquire range lock by adding $2\sigma_\tau$ to the expected value, since most of the time range lock will occur within two standard deviations of the mean. These values of the mean time plus 2 standard deviations are plotted in Figures 11 and 12 for the least favorable position of the starting gate. This curve then serves as an upper bound for the expected time to acquire range lock.

For the TACAN interrogator, the expected time to acquire lock remains relatively unchanged when probabilities of beacon reply are greater than .5, as shown in Figure 11. When the probability of beacon reply is below .5, the time necessary to acquire lock increases rapidly as the probability of reply decreases.

Figure 12, which is similar to Figure 11, displays the expected time to acquire lock for the DME interrogator.

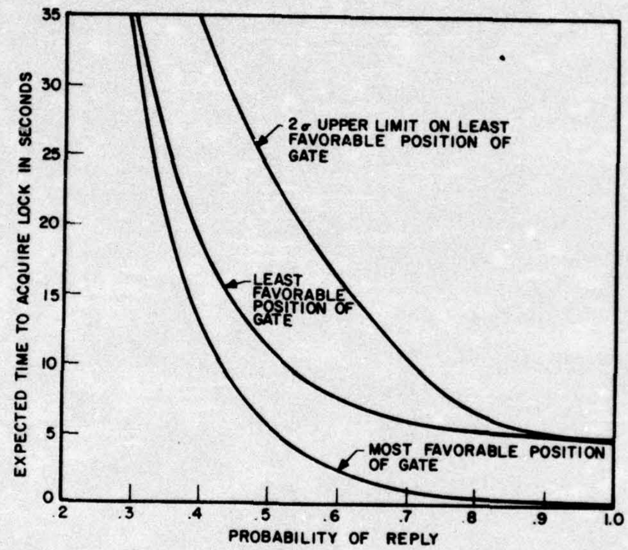

Figure 12. Expected time to acquire range lock vs. probability of beacon reply for AVQ-75 DME interrogator.

These performance predictions are representative figures. Specific performance figures can be readily generated for other interrogators, using the same reply probabilities and modifying acquire-lock criteria to represent the interrogator of interest.

The newer digital type interrogators have average expected times to acquire range lock of approximately 0.1 second.

SECTION 3

RESULTS

To analyze the impact of DABS on TACAN, a conservatively large predicted environment of 1121 DABS-equipped aircraft within 200 nautical miles (370.4 kilometers) of the TACAN beacon was utilized. TACAN performance on all channels other than 64 through 68, used exclusively by the military, was unaffected by DABS. For channels 64 through 68, the interference effects were as indicated below.

1. Typical simulation results of X-mode TACAN/DME performance when experiencing DABS interference appear in TABLE 7. As can be seen from this table, the probability of reply is not affected by DABS whenever the number of TACAN interrogators is 70 or less. For on-tune DABS, the probability of reply drops from .77 to .46 as the number of TACAN interrogators introduced into the environment was increased from 70 to 120. With a frequency separation of 1 MHz, there are fewer interfering DABS signals and the probability of reply does not drop as rapidly as the on-tune case but does fall from .77 to .63, as shown in TABLE 7.

TABLE 7

PROBABILITY OF BEACON REPLY (X-MODE)

Number of TACAN/DME Interrogators (Track/ Search Ratio = 95:5)	Probability of Beacon Reply to Valid Interrogation		
	TACAN Only	TACAN & DABS ($\Delta f=0$)	TACAN & DABS ($\Delta f=1$ MHz)
≤70	.77	.77	.77
80	.77	.70	.77
90	.77	.63	.77
100	.77	.56	.75
110	.76	.50	.70
120	.69	.46	.63

2. The major effect of a reduction in beacon reply probability is to produce a reduction in the probability that an interrogator will acquire range lock. Typical results are shown in TABLE 8 for X-mode TACAN/DME performance. Similar results were obtained for Y-mode operation. Figures 11 and 12 display the expected time to acquire lock for representative analog-type TACAN and DME interrogators as a function of probability of beacon reply. The DME interrogator analysis was included for comparison purposes only and is not involved with any consideration of performance on the military

tactical channels. It should be noted that the probability of acquiring range lock is dependent upon the type of equipment being used as well as the probability of reply. Some equipment may perform satisfactorily with lower levels of probability of reply than indicated; others may not perform satisfactorily at the same level.

TABLE 8

PROBABILITY OF ACQUIRING RANGE LOCK
(X-MODE) DURING ONE SEARCH CYCLE

Probability of Beacon Reply	Probability of Acquiring Range Lock	
	DME Interrogator (RCA AVQ-75)	TACAN Interrogator (AN/ARN-21C)
.77	.90	.99
.76	.89	.99
.75	.88	.99
.70	.83	.98
.69	.81	.98
.63	.71	.97
.56	.58	.89
.50	.47	.79
.46	.39	.70

3. Since probability of beacon reply is only one possible measure of effectiveness for beacon performance, it was desirable to determine and evaluate other measures, independent of the probability of reply. Deadtime generated in a TACAN beacon by DABS signals, and the number of TACAN replies generated by the beacon in response to DABS signals were also measured. Simulation results for calculation of these parameters are given in TABLE 9. For the on-tune case, deadtime attributable to DABS was 65,000 microseconds per second and the number of DABS-induced TACAN replies was 797. These two measures would be comparable to introducing approximately 34 additional TACAN interrogators into the environment. While the effect of over-interrogation reduces the probability of reply in the on-tune case, DABS-induced deadtime is, for all practical purposes, insignificant. The loss of beacon replies caused by overloading is more prominent than that caused by deadtime.

4. Results similar to those shown in TABLE 9 were obtained for Y-mode performance.

TABLE 9

TACAN DEAD TIME AND REPLIES RESULTING FROM DABS SIGNALS (X-MODE)

Δf (MHz)	Military TACAN Channel	DABS Induced Dead Time	Number of TACAN Replies Generated by DABS Signals
0	66	6.5%	797
1	65, 67	2.6%	222
2	64, 68	0.6%	36

5. When a $\Delta f \geq 2$ MHz is maintained, both parameters (dead time produced by DABS interrogations and DABS-produced decodes) were reduced to a level below the interference criterion[a] (see APPENDIX B) established by Lincoln Laboratory (5% dead time and 150 decodes per second). Similarly, probability of beacon reply is unaffected by DABS when the frequency separation is greater than 2 MHz ($\Delta f \geq$ 2 MHz).

The above results were obtained from simulation techniques, and as such, are subject to the simulation limitations outlined in APPENDIX A.

[a]This criterion is not intended to be, nor should it be construed to be, the establishment or definition of acceptable TACAN/DME system performance criteria in a DABS environment.

APPENDIX A

TACAN/DME BEACON PERFORMANCE PREDICTION MODEL

MODEL DESCRIPTION

To obtain statistical data concerning the operation and performance of the TACAN/DME beacon in both interference and interference-free environments, a computer simulation was developed, using the modeling technique of the time-event-store simulation. A flow chart of the simulation is displayed in Figure A-1. The operation of the beacon is classified into various events. Each event is assigned a time of occurrence in accordance with beacon operating characteristics, and the interplay between events is checked to determine beacon performance.

The search-track ratio and the number of TACAN aircraft in an environment are model inputs. The model was exercised for TACAN aircraft environments of up to 120 aircraft, and search-track ratios of both 5:95 and 10:90. The description below is of X-mode beacon operation. Appropriate modifications were made in the program to simulate Y-mode operation.

To establish the events for the simulated operation of a TACAN beacon, four subroutines were developed.

- TDB: Time of direction or bearing reference burst
- TS: Time of squitter transmissions
- TA: Time of aircraft interrogation
- TRNOIS: Time of random noise, including DABS signals that may act as TACAN interrogations or mask valid TACAN interrogations.

These subroutines, which initially set up the time of occurrence for the events taking place in beacon operation, are described below.

Description of Subroutines

TDB. The bearing reference bursts produced by the TACAN beacon are of two types. The north reference burst consists of 12 pulse pairs spaced 30 μs apart, with intra-pair spacing of 12 μs for a total of 345 μs per burst, as shown in Figure A-2. The auxiliary reference burst consists of 6 pulse pairs spaced 24 μs apart with intra-pair spacing of 12 μs, for a total of 135 μs per burst (Figure A-3).

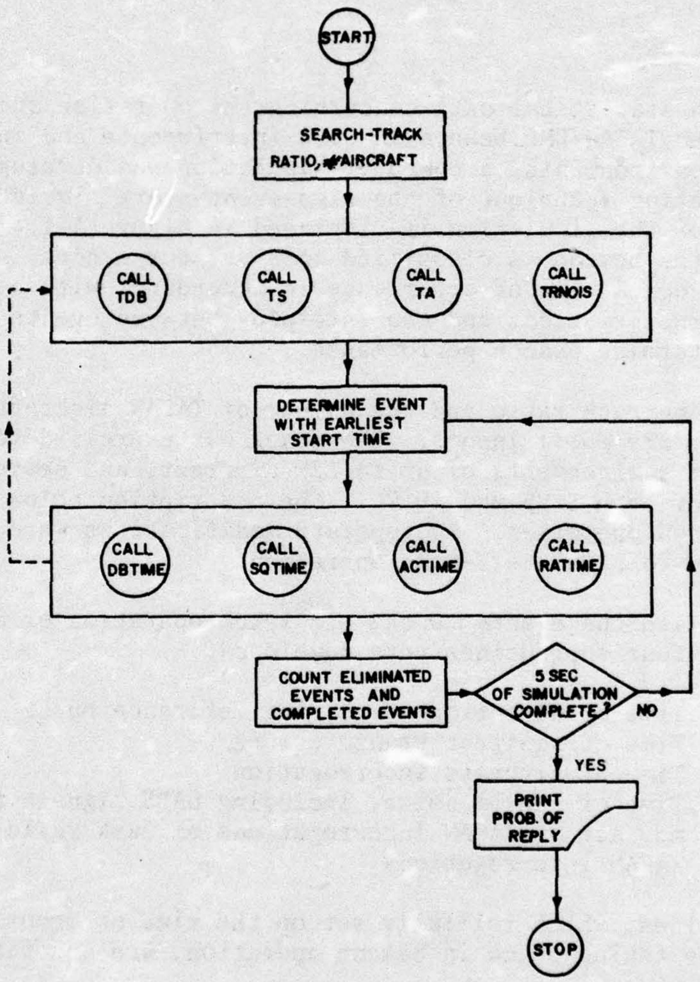

Figure A-1. Flow chart of TACAN/DME performance simulation.

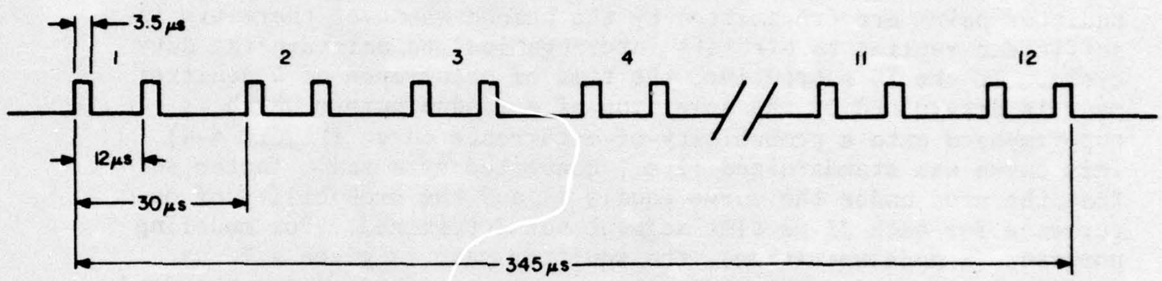

Figure A-2. North reference burst (X-mode).

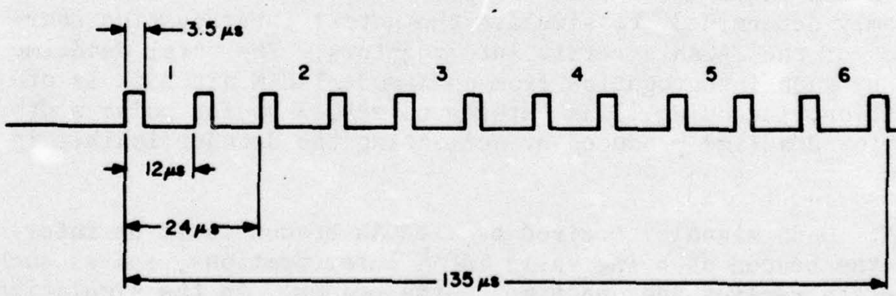

Figure A-3. Auxiliary reference burst (X-mode).

Auxiliary bearing reference bursts occur at the rate of 135 per second. North reference bursts occur synchronously at the rate of 15 per second and have precedence over the auxiliary bursts. The model generates the first bearing reference burst (a north reference burst) at time zero. The next and all subsequent bearing reference bursts occur at intervals of 7407.4 μs after this, with every ninth burst being a north reference burst.

TS. To maintain the duty cycle of 2700 replies per second, squitter pairs are transmitted by the beacon whenever there are insufficient replies to aircraft interrogations to maintain the duty cycle. In the TS subroutine, the time of occurrence of a squitter pair is determined by the selection of a random number, which is superimposed onto a probability-of-occurrence curve (Figure A-4). This curve was standardized (i.e., converted by a scale factor so that the area under the curve equals 1), and the probability of occurrence for each 25-μs time segment was determined. For modeling purposes (X-mode operation), the squitter pair is given a 72 μs duration: 12 μs for the time between pulses and 60 μs for the deadtime produced by activating the decoder inhibit in the beacon. During this 72 μs period, no other request from aircraft for service may be replied to by the beacon.

TA. The time of occurrence of a TACAN aircraft interrogation arriving at the TACAN beacon is individually determined for every aircraft interrogating the beacon and depends upon whether the aircraft is in search or track mode of operation. The event start times were randomly determined, to simulate the actual interrogation characteristics of the TACAN aircraft interrogators. The total deadtime generated by each interrogation from an X-mode TACAN aircraft is of 75 μs duration, including 12 μs between pulses, 3 μs for pulse width, and 60 μs for deadtime produced by activating the decoder inhibit in the beacon.

TRNOIS. DABS signals received by a TACAN beacon could be interpreted by the beacon as being valid TACAN interrogations, and as such, could generate replies and deadtime in the beacon. In the simulation of beacon operation, the time of occurrence of each DABS event is determined from an exponential probability function, with the number of DABS aircraft in the envrionment as an input. The number of DABS replies appearing at the TACAN beacon is specified to be one reply per second per DABS aircraft, from an aircraft deployment provided by the system engineering contractor.

To determine the time of occurrence of each DABS event, the number of DABS events is assumed to be a Poisson-distributed random variable. The time between events will then be exponentially distributed with

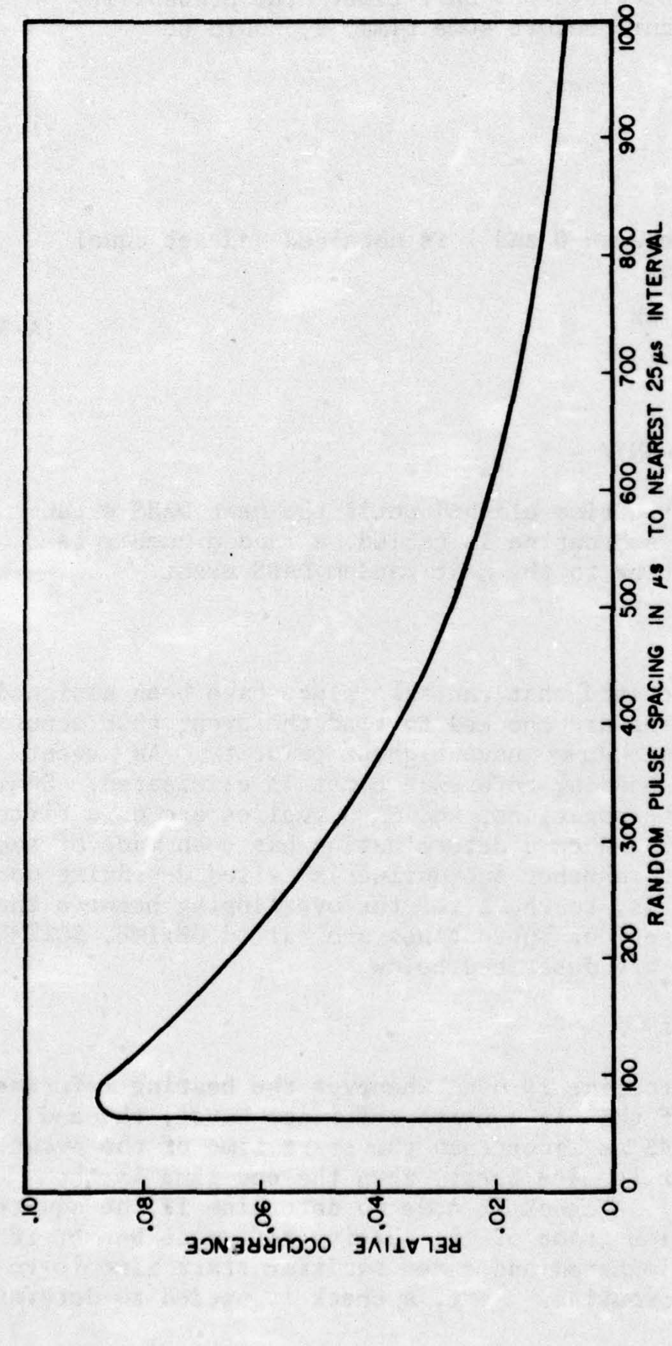

Figure A-4. Random pulse distribution limits.

$$f(t) = \lambda e^{-\lambda t} \tag{A-1}$$

where λ is the occurrence rate per unit time. The probability that the DABS event occurs before some time, k, would be

$$\int_0^k \lambda e^{-\lambda t}\, dt \tag{A-2}$$

A random number between 0 and 1 is obtained and set equal to this integral so that

$$RN = 1 - e^{-\lambda k} \tag{A-3}$$

and solving for k,

$$k = \ln (1-RN)/ - \lambda$$

The time k is used as the time elapsed until the next DABS event occurs. Each time the subroutine is called, a random number is used to determine the time to the next random DABS event.

MODEL OPERATION

After all of the events that can take place have been assigned a start time, these times are checked to find the event that occurs first. Bearing reference bursts have highest priority. Any event that would overlap the bearing reference burst is eliminated. Squitter, TACAN aircraft interrogations, and DABS replies are on a first-come, first-served basis. When a determination has been made of the event that occurs first, another subroutine is called, depending upon which type of event it is, to check for the overlapping between the different events. These four subroutines are called DBTIME, SQTIME, ACTIME, and RATIME, and are described below.

Subroutine Descriptions

DBTIME. This subroutine is used whenever the bearing reference burst occurs first. If this is a north reference burst, the end time of the event is 345 μs later than the start time of the event. If it is an auxiliary reference burst, then the end time is the start time plus 135 μs. A check is made to determine if the squitter event falls into the time frame of the bearing reference burst; if so, the squitter is eliminated and a new squitter start time is requested from the TS subroutine. Next, a check is needed to determine if any of the TACAN aircraft in the environment have interrogation start times that fall within the bearing reference burst. If so, the overlapped interrogations are eliminated and new interrogation start times are requested from the TA subroutine. After all TACAN interrogations have been checked against the bearing reference burst, the DABS event start time is checked to determine if the DABS reply occurs during a bearing reference burst. If it does, the DABS event is eliminated and a new start time for the DABS event is requested from the TRNOIS subroutine.

When all of these checks have been made with appropriate events counted and eliminated, the TDB subroutine is called to generate the start time for the next bearing reference burst. Once this has been accomplished, control is returned to the main program and a check of all event start times is again made to determine which event occurs first.

SQTIME. When the squitter pair event occurs first, the SQTIME subroutine is used. A check is made to determine if the beacon duty cycle of 2700 pulse pairs per second is exceeded. This is done by dividing the number of squitter pairs plus TACAN replies plus decoded DABS replies, by the elapsed time of the simulation. If this ratio is greater than .0027 pulse pairs per microsecond, the duty cycle is being maintained and no squitter pair is needed. The TS subroutine is called to generate the next squitter pair start time. The program then reverts back to checking for the earliest occurring start time. If the duty cycle has not been exceeded, a check is made to determine if the squitter pair will end before the next bearing reference burst begins. If there is overlapping (i.e., the squitter pair falls into the direction burst) the squitter pair is eliminated and a new squitter start time is requested from TS. Again the event start times are searched to determine the earliest occurring event. If, however, the squitter pair does not overlap the direction burst, then a valid squitter pair is generated. Once a valid squitter pair has been established, all TACAN interrogation start times are checked to determine if they fall within the squitter pair. If so, they are considered as being eliminated and new event start times for the TACAN interrogations so eliminated are requested from TA. The last check made is to determine if a DABS reply will overlap the squitter pair. If so, the DABS reply would be eliminated, causing a request for a new DABS event start time for TRNOIS. Finally, after all events have been checked and compared, a new squitter pair start time is requested from TS for the next occurring squitter pair, and a return to the main program is made to determine the next earliest occurring event.

ACTIME. Whenever the earliest occurring event is a TACAN interrogation, the subroutine ACTIME is called. A check is made to determine if the beacon duty cycle of 2700 pp/s has been exceeded. If so, the TACAN interrogation event is classified as not generating a reply, due to a beacon overload condition, and is so recorded. Then a new TACAN interrogation start time is generated, and control reverts to the main program. If the duty cycle has not been exceeded, a check is made to determine if the TACAN interrogation event ends before the next scheduled bearing reference burst. If not, the TACAN interrogation event is again classified as not generating a reply from the beacon and is so recorded. A new start time is generated for the TACAN aircraft whose interrogation has been eliminated. If the TACAN interrogation does not overlap the bearing reference burst, then another check on the TACAN interrogation event is made to determine if any squitter start times fall within the time duration of the aircraft interrogation event. If so, the squitter is eliminated and a new squitter start time is generated. For a fourth check, all other TACAN interrogation events are compared to the present aircraft interrogation event to determine if any overlap occurs. If so, the overlapping interrogation is eliminated and a new one is generated for the TACAN interrogation event that was overlapped. The last check is to determine if the DABS event falls within the aircraft interrogation event. If so, the DABS event is eliminated and so recorded. If, after all of these checks have been made and the aircraft interrogation event is not eliminated, it generates a reply, this is recorded, and a new TACAN interrogation event start time is generated.

RATIME. Whenever the event simulating the DABS reply has the earliest start time, the subroutine RATIME is called. A random number determines whether a long- or short- format DABS reply was received, with 90% of the replies being short format and 10% being long format. The deadtime associated with the DABS event is calculated according to the power level of the DABS reply, provided the duty cycle of 2700 replies per second has not been exceeded. A separate random number determines the power level of the incoming DABS reply, which, in turn, specifies the amount of deadtime generated. The information contained in TABLE 2 (page 12) and Figure 4 (page 13) was utilized in this determination of deadtime.

Having established the length of the DABS event, a check is made to determine if a squitter pair falls within the DABS event. If so, the squitter is eliminated and a new squitter start time is generated. A check is then made to determine if any TACAN interrogation events fall within the DABS event. Those that do are eliminated and new start times for these TACAN interrogations are regenerated, using the TA subroutine. In addition, a check is made to determine if the power level of the DABS reply is high enough to be decoded, and a count is maintained of the number of TACAN replies generated by decoded DABS signals. Finally, a new DABS start time is generated for the next DABS event from the TRNOIS subroutine. No check is made to determine if the DABS event ends before the bearing reference burst starts. Should this occur, the DABS event will not be eliminated, but will be ignored and the bearing reference burst will be transmitted. The DABS event, however, which starts before the direction reference burst occurs, may eliminate the squitter event or other TACAN interrogation events.

End of Program

The generation of starting event times and the regeneration of new event times is continued until 5 seconds of simulated time has elapsed. The computer running time for the 5-second simulation, which evaluates 12 groups of TACAN interrogators (10 to 120 aircraft), is 6 minutes.

The simulation can be continued for any length of time desired. However, accuracy level and degree of confidence of the statistics generated by the simulation, together with consideration of running time, do not warrant a longer simulation.

Output

To determine beacon performance, the simulation generates the number of TACAN aircraft interrogations that were made, and the number of TACAN aircraft interrogations that successfully elicited a reply, and divides the number of successful interrogations by the total number of interrogations made, to obtain probability of reply by the beacon to any interrogation by a TACAN aircraft. This is the primary measure used to determine TACAN beacon performance.

Other parameters generated during the simulation include the number of squitter pulses produced by the beacon, the number of TACAN interrogations deleted because of an overload condition on the beacon, the number of DABS replies decoded by the beacon, and the amount of beacon deadtime associated with DABS replies.

OTHER FEATURES OF THE SIMULATION

A subroutine called TAI and its companion AITIME are available to generate event start time and overlap checks for an aircraft of interest, if the user desires to follow a particular aircraft through the 5-second simulation. These subroutines produce the time at which an aircraft of interest would shift from search to track mode, as well as the number of interrogations and number of associated replies for the aircraft of interest.

SIMULATION LIMITATIONS

The simulation maintains the 2700 pp/s duty cycle of the TACAN beacon. However, it does not desensitize when the duty cycle is exceeded. Instead, the probability of reply is still determined by dividing the number of replies generated by the number of interrogations made. This is somewhat unrealistic, in that the beacon would normally densensitize and maintain a standard probability of reply. However, a count is made of the number of interrogations made when the duty cycle was exceeded so that, in effect, desensitization can be measured.

At the present time, the TACAN aircraft interrogators are all assumed to be above the beacon sensitivity threshold. No effect of distance to the aircraft is taken into account, since it was the purpose of the simulation to determine the beacon effectiveness as a function of the number of TACAN aircraft in the environment.

In the simulation of the DABS replies received by the TACAN beacon, a particular deployment of DABS aircraft at various power levels was provided as input. The results of the simulation are a function of the DABS environment and should be so interpreted. The model could be exercised for any given DABS environment, but results must be interpreted as being dependent upon this specific environment.

APPENDIX B

PRELIMINARY CRITERION OF TACAN/DME BEACON INTERFERENCE

NOTE: This criterion is not intended to be, nor should it be construed to be, the establishment or definition of acceptable TACAN/DME system performance criteria in a DABS environment.

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30 May 1975

Area Code 617
862-5500

Mr. William B. Hawthorne (ARD-620)
Chief, Spectrum Analysis Branch
Federal Aviation Administration
2100 Second Avenue, SW
Washington, DC 20591

Attention: Mr. Isadore D. Goldman

Dear Mr. Hawthorne:

The following statements refer to the interference analysis tasks being carried out by ECAC under Interagency Agreement DOT-FA70 WAI-175, Task Assignment No. 16. Points documented here have been previously discussed with ECAC.

For the sake of concreteness in the ECAC investigation of DABS-to-TACAN/DME EMC, the following preliminary criterion of beacon interference is established for purposes of this investigation.

Criterion

Electromagnetic signals from non-TACAN/DME sources entering a TACAN/DME beacon transponder are said to be tolerable if they satisfy both of the following conditions:

deadtime (at receiver sensitivity) < 0.05
loading < 150 decodes/sec

regardless of whether the beacon is TACAN or DME, regardless of whether X-mode or Y-mode, and regardless of channel number.

Discussion

It should be emphasized that this criterion is preliminary and intended for use only in this preliminary investigation. Establishment of a final criterion would be more appropriate at a later time, after DABS has been more fully demonstrated and its use in an operational environment better understood.

This criterion corresponds approximately to the conditions that would result from five additional TACAN/DME aircraft. The criterion was arrived at as a judgement, by Lincoln Laboratory, based on TACAN/DME Standards (the National Standard, Military Standard, and ICAO Standard), and the results of ECAC investigations as to the types of effects which DABS would cause. While the choice of this criterion was largely arbitrary, the result does not appear to be in conflict with any available information of relevance. We are aware that it is possible for DABS interference to exceed this criterion in certain worse cases involving non-FAA-use channels.

Mr. William B. Hawthorne -2- 27 May 1975

It is requested that ECAC, in using this criterion, provide at some place in the final documentation, the data for other values of deadtime and loading. In this way, a reader who may want to apply a different criterion will be able to obtain the appropriate results.

Respectfully yours,

William H. Harman

William H. Harman

WH/dc

REFERENCES

1. Task Assignment 16 of Interagency Agreement DOT-FA-70WAI-175.

2. Wingard, J. L., *Interference Potential of the Discrete Address Beacon System (DABS) Provisional Signal Formats on X and Y mode TACAN Equipments*, FAA-RD-75-109, ECAC, Annapolis, MD, December 1975.

3. *OTP Manual of Regulations and Procedures for Radio Frequency Management*, Office of Telecommunications Policy, Washington, DC, par. 4.3.5, p. 4-140, 141.

4. *Radio Set AN/ARN-21C, Technical Manual*, T. O. 12R5-2ARN21-42, US Air Force, 1 June 1975.

5. *AVQ - 75 DME System Instruction Manual*, IB96435-1, Aviation Equipment Dept., Radio Corporation of America, July 1967.