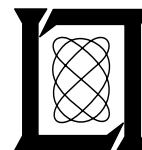


Simulation of Surveillance and Processing Algorithms Proposed for the DABS Mode of BCAS

P. H. Mann

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Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LEXINGTON, MASSACHUSETTS



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1. INTRODUCTION

Lincoln Laboratory is assisting the FAA in the development of an active air-to-air ranging technique using DABS interrogation and reply waveforms to provide surveillance of DABS-equipped aircraft. In this beacon-based collision avoidance system (BCAS), DABS equipped aircraft will be acquired by listening for squitter transmissions from the DABS transponders. Aircraft within a defined threat zone will be discretely interrogated and their replies processed to obtain range, range rate, relative altitude, and altitude rate. These targets will then be tracked to determine whether or not they represent a collision threat.

This mode of BCAS has two principal surveillance advantages over other proposed BCAS modes: (1) it is relatively simple since code correlation and synchronous garble problems are eliminated by the DABS addressing capability; and (2) the DABS waveforms also include parity protection and special modulation formats which make them relatively immune to interference from the ATCRBS environment.

A key element in this system is the surveillance processor, which acquires DABS targets, interrogates and tracks targets which are potential collision threats, and provides periodic track updates to the collision avoidance logic. This report describes the work which has been accomplished at Lincoln Laboratory to date in developing the algorithms for this airborne DABS surveillance processor.

Several approaches are being taken for refining the design of this system and determining its performance in typical airborne beacon environments. Preparatory to building and evaluating a full engineering model of the DABS mode of the BCAS system, a pair of complementary experimental facilities have been implemented for preliminary evaluation of the surveillance processor design and for extending the evaluation to future high density traffic environments. The facility addressed principally in this report is a software simulation of the surveillance processor algorithms. The other facility is a recent modification to the Lincoln Laboratory Airborne Measurement Facility (AMF) with capability of transmitting DABS airborne interrogations at a high repetition rate and recording the replies to these interrogations for subsequent processing in software.

The surveillance simulation is capable of operating on either a simulated surveillance data base or on the recorded data base obtained from the AMF airborne interrogations. This report describes the results of a number of runs of simulated encounter data extended to predicted high traffic densities which would currently be unattainable by measurement. The collection of recorded AMF data has just recently begun. The performance of the surveillance simulation with recorded AMF data will be reported at a later date.

2. DABS MODE SURVEILLANCE OVERVIEW

A summary overview of the DABS Mode BCAS surveillance algorithms is given in this section. The algorithms are defined in detail in Appendix A.

2.1 DABS Target Acquisition

All DABS transponders transmit a parity-protected squitter waveform at random intervals averaging about one second except when operating in a region where squitters are locked out by ground control. This squitter transmission contains a 6-bit subset of the digitized altitude code. When a BCAS-equipped aircraft receives a squitter, it checks the (truncated) altitude of the target against its own altitude to determine whether the target should be ignored, immediately acquired in range, or tracked in altitude to determine if the altitude difference is decreasing at a fast enough rate to warrant range acquisition. Since it is assumed that the BCAS unit will have to operate in a relatively high-density traffic environment, the surveillance processor attempts to minimize the number of active DABS interrogations to prevent unnecessary electrical interference with the ground-based surveillance system.

When the squitter processing routine determines that a target should be acquired in range, the target ID is placed in an acquisition queue. Four times per second, as a normal part of the DABS surveillance process, the acquisition queue is examined to determine if one or more targets are designed for acquisition. from new targets. If so, discrete interrogations are transmitted to determine the range of these targets. The antenna used (top or bottom) for the transmission of the first of these interrogations to each target is the antenna which last received a valid squitter from that target. All acquisition interrogations are transmitted at full power. After each interrogation, the reply processor reports the status of the reply. If a valid reply is not received in the listening window

an additional interrogation is transmitted immediately from the same antenna. If this also fails, the antenna is switched and the interrogations are repeated 1/4 second later. Reinterrogations are scheduled every 1/4 second until 2 ungarbled replies are received which correlate in range, or 6 seconds have elapsed with no correlation.

After reception of the discrete reply, the altitude is checked to verify that the target is still within the altitude threat zone. The reply correlation process assures that the reply is not a multipath reply, or a reply to some other discrete interrogation. After two or more acquisition replies have satisfactorily correlated, the range of the target is tested to determine if it is in the range threat zone. If so, the target is added to the active track file. If the target is not within the range zone, a calculation is made of the minimum time required for it to penetrate this zone, and it is placed in a dormant file until that time has elapsed. While dormant, subsequent acquisition attempts are inhibited.

2.2 DABS Roll-Call Surveillance

When a target is initially acquired, its ID, range, and altitude are entered into the active track file along with track firmness and history parameters; these are used for track update and track drop and for the calculation of predicted range uncertainty. In addition, the acquisition routine sets a flag indicating which antenna was used when the target was acquired. Once each second (or "scan"), the surveillance executive updates all active targets in the track file. As in acquisition, 1/4-second interrogation "frames" are scheduled until either the maximum number of tries is reached or a valid reply is received from the target. Power programming is used to automatically determine the minimum transmitter power required to successfully track the target.

If four successive interrogations are successful, the transmit power is reduced to the next available discrete power level. If four interrogation attempts fail to elicit a reply, the transmit power is increased by one step. As in acquisition processing, automatic antenna switching and interrogation rate control is employed to minimize the number of interrogation attempts.

If a reply is not elicited from a target during a 1-second scan, the track is coasted until the next scan and the track history and firmness parameters are appropriately updated. If a valid reply is received and altitude and range tests are passed, the target track file is updated with new predicted values of range and range rate.

3. NON-REAL TIME SURVEILLANCE PROCESSING

3.1 Objectives

The algorithms described in Appendix A have been implemented in software using FORTRAN IV. The software is presently written to handle one DABS target but may be easily modified to process files of targets should the area of interest be expanded to the study of multiple targets.

The non-real time processor was developed in order to evaluate and refine the surveillance algorithms. The processor will ultimately use a data base of airborne interrogations and replies at a high repetition rate relative to the BCAS interrogation rate. This data base will provide a real airborne reply and interference environment for the surveillance processor. The processor will select a subset of the available prerecorded interrogations and replies in accordance with the decisions of the surveillance algorithms.

This surveillance processor can also be operated in a mode wherein the interrogation and reply data base is simulated. In this way the scope of the investigation may be expanded to the study of effects of variations in parameters beyond the limits of current measurable environments. Both modes assist in the selection of parameters in the algorithms themselves as well as in validating the overall design. Each mode has its particular advantages. The recorded data mode includes effects such as multipath, whereas the simulated data mode can handle the dense fruit environments expected in the future.

3.2 Input Modes

3.2.1 AMF Recorded Data

The AMF transmits BCAS DABS interrogations every 16.32 msec alternating between top and bottom antennas. The target transponder transmits a 56-bit DABS message in reply to the discrete interrogation. The DABS transponder also transmits squitters at an approximate rate of one per second. This squitter is a modified All/Call reply which differs from a normal All/Call reply in that a squitter identification bit is set. The discrete reply does not presently carry maximum airspeed information*. This information is provided to the surveillance processing program by input parameters.

The AMF receives the transponder replies and performs DABS preamble detection and raw bit decoding for each real or apparent DABS message received. The reply data are recorded on magnetic tape. These reply data are subsequently processed and reformatted for input to the non-real time surveillance processor. This software processing performs the remaining functions of the DABS reply processor: parity message decoding, error detection, and error correction. An important byproduct of this data processing is the development of statistics of the link performance.

The reformatted data input to the surveillance processor includes the time of arrival, message type, signal strength, receiving antenna, error detection status, and correction flag for every DABS preamble detected by the AMF. The data are scanned until a squitter is found. If a determination is made to enter acquisition processing, an interrogation is scheduled.

* The DABS transponder used in these tests is an early experimental version without full BCAS capability.

The program selects from the recorded interrogation sequence the first transmission after the scheduled interrogation time which used the desired antenna (top or bottom). The reply received in response to this interrogation is processed by the acquisition processing subroutine. The reply may be valid, garbled or missing entirely.

In summary, the AMF will create a large data base by interrogating at a relatively high fixed repetition frequency. The non-real time processor will select a subset of these interrogations according to the BCAS scheduling algorithms and will exercise the surveillance algorithms as if they were actually controlling the interrogations.

3.2.2 Simulated Link Data

The simulation mode differs from the recorded data mode described in Section 3.2.1 only in that the interrogation and reply data base is generated by simulation techniques using probabilistic propagation models to characterize link performance. Surveillance processing of simulated link data is identical to processing of the recorded data.

A simulated straight-line encounter is generated from a specific starting range and a specified constant closing rate. A uniform density of ATCRBS transponder-equipped aircraft and a constant aircraft antenna fade are also specified.

The data generation subroutine assumes the same interrogation interval of 16.32 milliseconds used by the AMF. Squitters are jittered about a one second interval. The nominal received power is calculated for each discrete or squitter transmission as a function of range and antenna loss as follows:

$$P = -44.5 - 20 \log (\text{Range}_{\text{nmi}}) + \text{ANTLOS}$$

where

P = receiver power at antenna assuming a 500 watt signal at the transponder RF ports.

ANTLOS = constant target antenna fade.

The DABS reply reliability is provided as a probabilistic function of received power and aircraft density from table lookups based on a series of previous simulations of the DABS reply processor performance in ATCRBS fruit*. Figure 1 presents plots of this reply reliability at two fruit levels resulting from aircraft densities of 0 and .06 aircraft per square mile.

The probability of detection P_x at received power P for aircraft density x is obtained as follows:

$$P_x = P_0(P) \cdot P_{.06}(P - 10 \log \frac{x}{.06})$$

where

P_x = probability of reply detection

P = received power at antenna

P_0 = probability at 0 density

$P_{.06}$ = probability at .06 density

x = aircraft density (aircraft/sq. nmi).

If we assume a constant interrogation reliability of 0.9, the round reliability, P_R becomes $P_R = 0.9 P_x$.

A random number R_n is generated ($0 \leq R_n \leq 1.0$) and compared to P_R for discretes, or to P_x for squitters, in order to determine whether a given reply is to appear in the simulated reply sequence.

* Ref., DABS QTS, 1 October 1976, FAA-RD-76-174, p. 29-32.

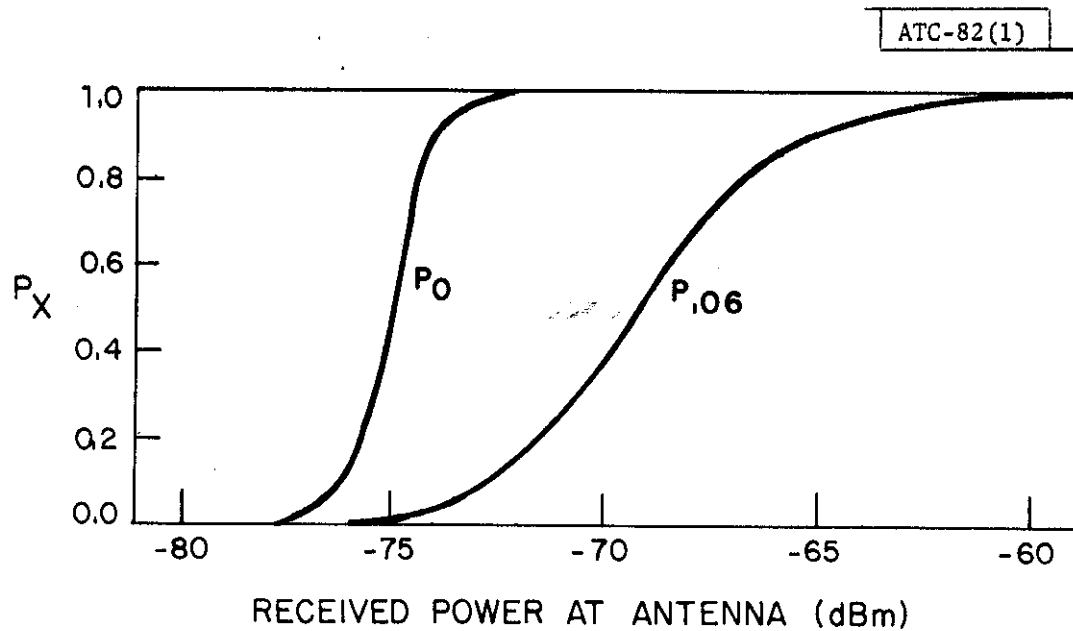


Fig. 1. Assumed probability for correctly receiving a reply (P_X) as a function of received power for aircraft densities of 0 (P_0) and 0.06 ($P_{0.06}$) aircraft/sq. nmi.

Using this simulated data set, the processing of the surveillance algorithms proceeds as previously described for recorded data.

3.3 Simulation Results

A large number of simulation trials have been conducted both to investigate the processor performance under a variety of antenna fade conditions and aircraft densities and to validate the surveillance algorithms. Simulation results presented illustrate how the simulation mode is being used in system analysis. It is important to understand the impact of increased aircraft densities on surveillance processor performance. The effect of increased traffic densities was introduced into the simulation by varying the assumed ATCRBS fruit rate. As indicated earlier, higher fruit rates cause reduced link reliability i.e., reply processing degradation. High speed collision encounters were generated in increasing levels of aircraft density in order to assess the overall DABS mode of BCAS performance, and in particular to determine the densest traffic environment consistent with acceptable system performance. In each case the link performance was modeled as described in Section 3.2.2.

Simulated high speed collision encounters were set up with an initial aircraft separation of 20 nmi. (at time $t = 0$ sec) and at a closing rate of 1000 kts. While the simulation has the capability for modeling top and bottom antenna links independently, no distinction was made between the links on the simulation trials under consideration. A constant 3 dB antenna fade was assumed for the link. For this scenario, the range threat boundary* occurs 38.4

* By definition, the range threat boundary is crossed 30 secs prior to the time of 1-nmi separation based on measured closing speed.

seconds into the simulation. The projected aircraft collision time is $t = 72$ sec.

Figure 2 presents calculated round link reliability vs time into the simulation with aircraft density as a parameter. A plot of aircraft separation vs time is included for reference, and the threat boundary is shown. It can be seen that the round link reliability at the threat boundary fell from 0.9 at $\rho = 0.02$ aircraft/sq. nmi to 0.35 at $\rho = 0.12$ aircraft/sq. nmi.

In the following 3 figures, five simulation trials are presented for each fruit level (aircraft density) using different input seeds to a random number generator. The algorithm used in these trials was a preliminary version, and will be seen to exhibit unnecessarily poor performance. The maximum aircraft density used was 0.12 aircraft/sq. nmi. It was assumed that this would be sufficiently high to cause the system to fail to establish track before the threat boundary time. Track establishment is defined as the time when the first valid discrete is received in the Roll-Call mode. The first Roll-Call range measurement is used in conjunction with the range measured in acquisition to calculate the closing rate and the predicted threat boundary crossing time.

Aircraft Density = 0.02

The five simulations performed at $\rho = 0.02$ (Fig. 3 top) display almost identical behavior. A squitter was received early in the simulation causing a state transition into the acquisition mode. Acquisition was unable to obtain a pair of correlating replies and placed the target in dormancy for 12 seconds since squitters had been received during the acquisition attempt period. Upon release from dormancy, a squitter again triggered a transition into the acquisition mode which quickly acquired the target. The target was placed in

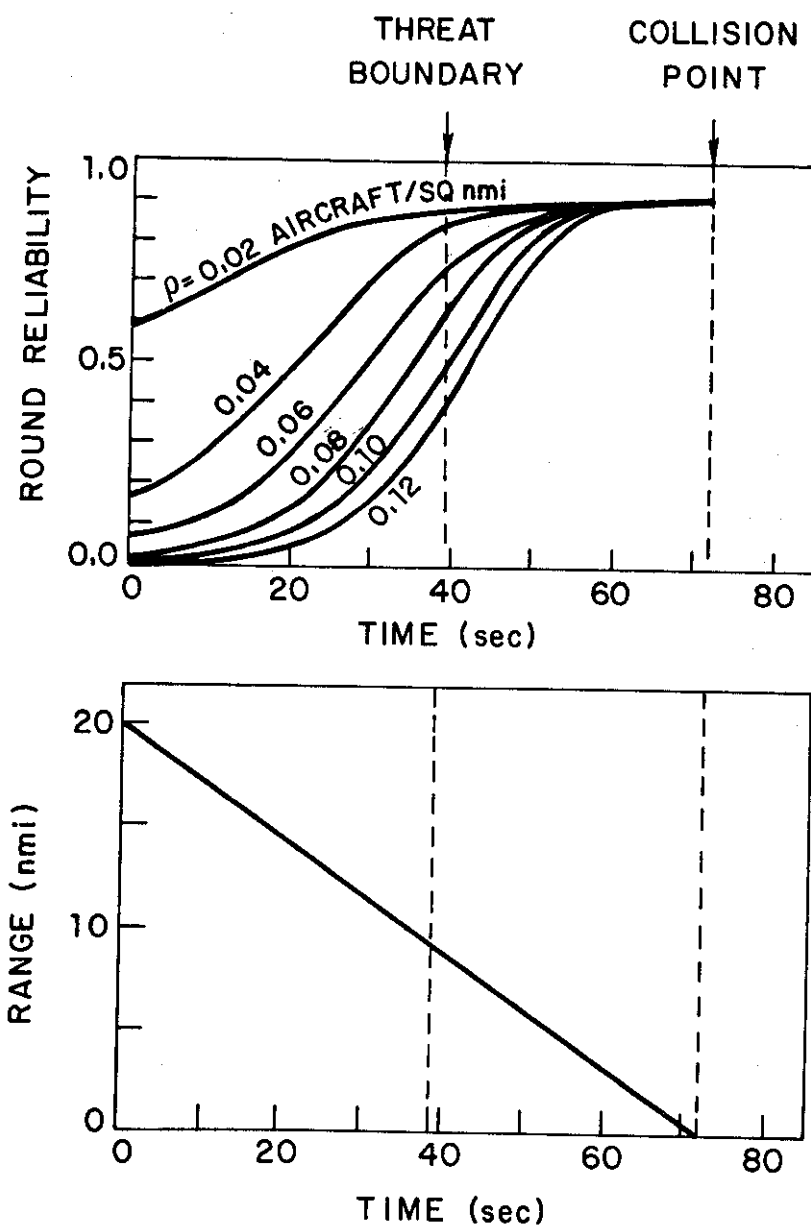


Fig. 2. Simulation input conditions.

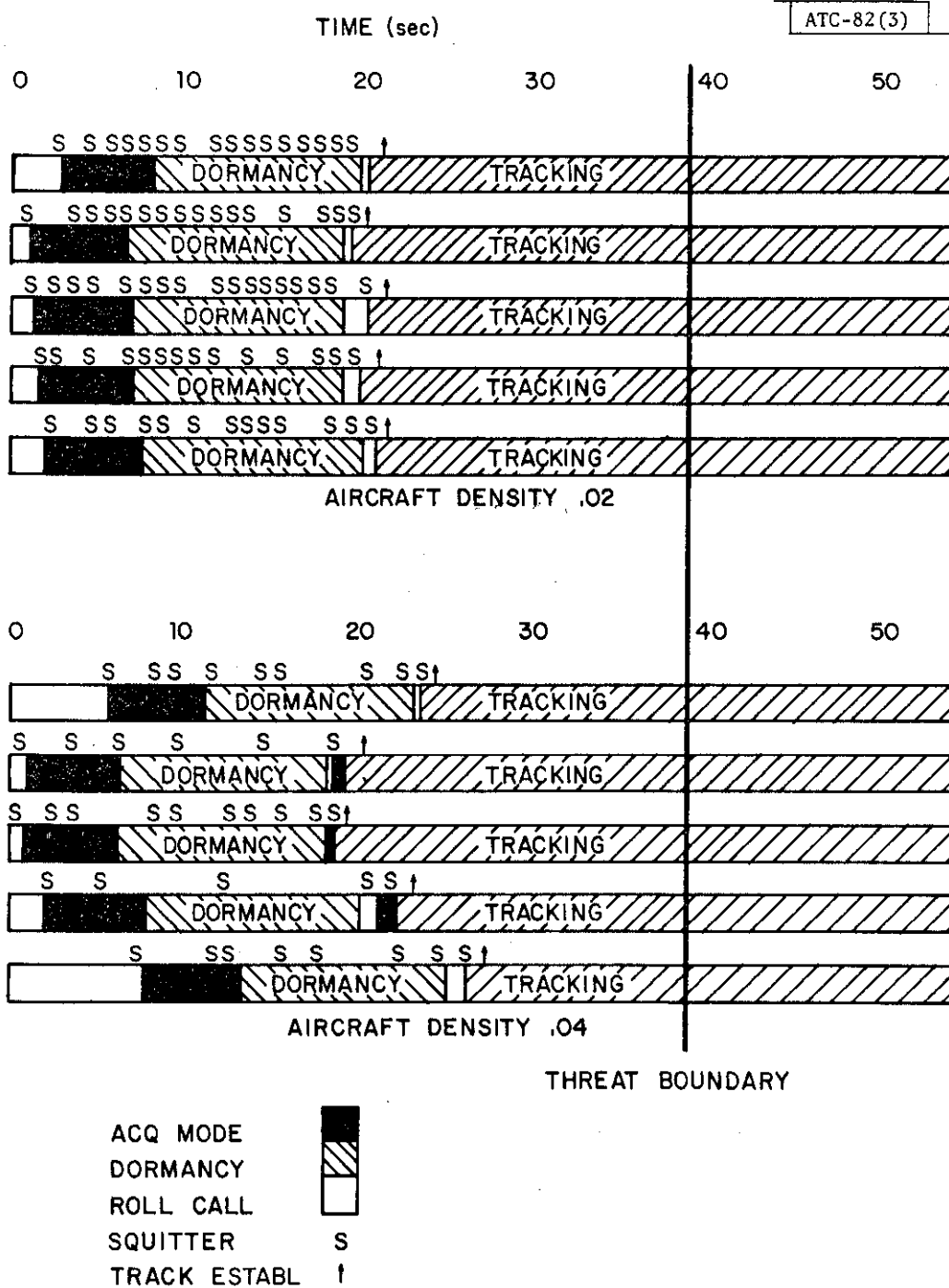


Fig. 3. State transitions for simulations $\rho = 0.02, 0.06$.

Roll-Call which successfully interrogated it. This reply in conjunction with the one received in the acquisition mode is used to calculate the closing rate and to determine the threat boundary time. In all cases track establishment occurred at approximately 21 seconds into the simulation.

The acquisition range listening window is open only to 17 nmi. Because of this, the target cannot possibly be acquired prior to 11 seconds into the simulation. In these trials dormancy is thus used to inhibit further interrogations of targets that give evidence of being beyond the range window. If acquisition is unsuccessful after 6 scans and if squitters were received during the acquisition period then the target is placed in dormancy for 12 seconds. At this low aircraft density the failure to acquire early in the simulation is indeed due to the range window limitation rather than to failure of the link, and the use of dormancy is warranted.

Aircraft Density = 0.04

The simulations performed at $\rho = 0.04$ aircraft/sq. nmi (Fig. 3, bottom) show state transition similar to those at the lower density. First acquisition attempts failed both because of the range window limitation and because of reduced link performance.

The second attempt at acquisition was successful in all cases upon release from dormancy. Average track establishment time was somewhat later than that at $\rho = 0.02$, but still well in advance of the threat boundary crossing.

Aircraft Density = 0.06

At this aircraft density, (Fig. 4, top) unsuccessful acquisition attempts appeared in all 5 trials. However, in the second trial the second attempt at acquisition also failed. In the fourth trial the second attempt at acquisition was successful but the target was placed in dormancy for 7 seconds because the measured range and maximum capable speeds indicated (correctly) that the target was of no immediate threat.

The second trial is of interest. The first attempt at acquisition failed and the target was placed in dormancy for 12 seconds. This was the proper action since the target was outside the range window at this time. The second attempt also failed and the algorithm again placed the target in dormancy for 12 seconds. However, this failure to acquire was the result of poor link performance due to the higher fruit level. The target was not released from dormancy until after the threat boundary time was exceeded. A change in the algorithm for the purpose of improving performance in such cases is discussed later in this section.

Aircraft Density = 0.08

As the fruit level is increased, fewer squitters are received (Fig. 4, bottom). The fourth trial shows two unsuccessful acquisition attempts. The second and fifth trials show transitions into dormancy for 12 seconds (again due to failure of the link). However, despite these problem, track establishment is achieved prior to the threat boundary in all cases except the last.

Aircraft Density = 0.10

The performance is further degraded (see Fig. 5, top). In only three cases out of five is track establishment achieved prior to the threat boundary time.

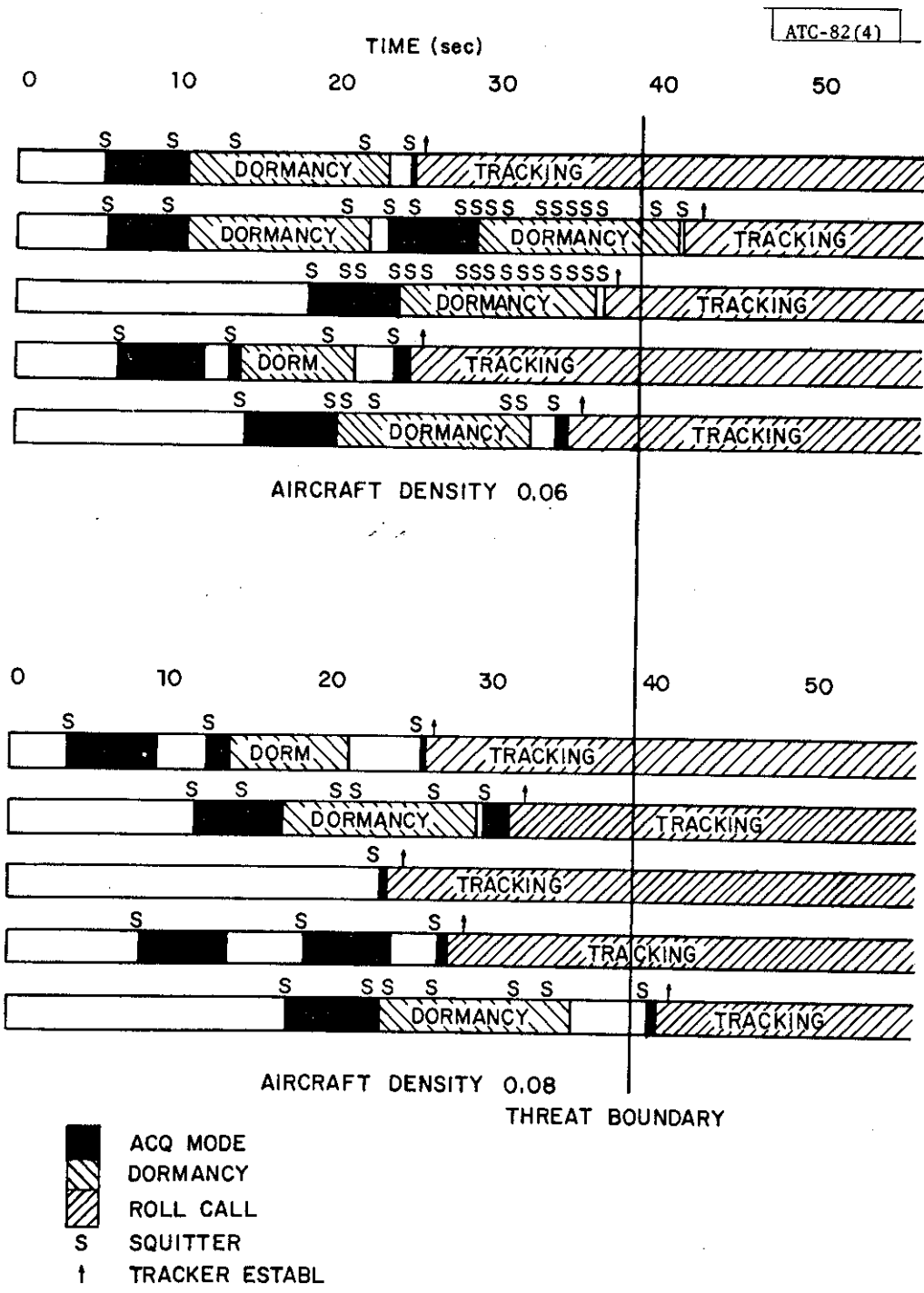


Fig. 4. State transitions for simulations $\rho = 0.06, 0.08$.

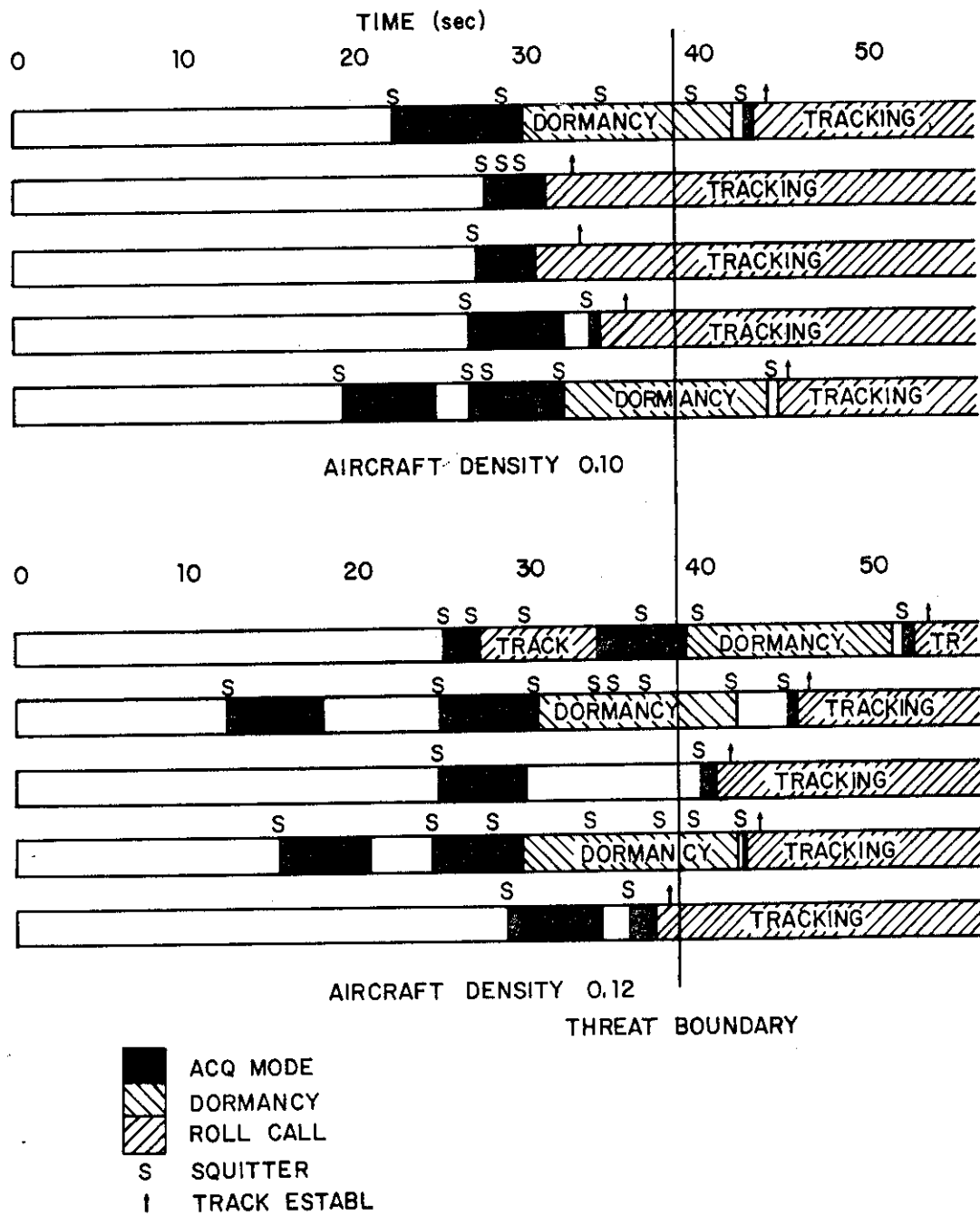


Fig. 5. State transitions for simulations $\rho = 0.10, 0.12$.

Aircraft Density = 0.12

At this aircraft density, track establishment was achieved prior to threat boundary in only one instance. An interesting sequence of state transitions occurred in the first trial. Acquisition was successful but Roll-Call Processing was unable to elicit a reply and therefore after 6 scans placed the target back into the acquisition queue (because squitters were received during the unsuccessful Roll-Call period). The acquisition attempt was also unsuccessful, resulting in the target being placed in dormancy for 12 seconds. Track was finally established at $t = 53.04$ seconds at a range of approximately 6 nmi.

It was expected that the performance of the surveillance processor would deteriorate as the fruit levels were increased. However, these preliminary trials indicate that performance might be improved by minor changes to the algorithms concerning dormancy

The dormant state is intended for two situations. It is used to prevent interrogations to targets whose ranges and maximum speeds are known and are determined to be of no immediate threat. The results show that the dormancy function operates very well in these situations and causes no problems.

The second function of the dormant state is to inhibit interrogations to targets whose ranges exceed the acquisition range listening window and cannot possibly be acquired. It was found in these early runs that dormancy can degrade performance when it is applied to targets within the range window that have not been acquired because of link failure. This problem arises only when both the fruit levels and the closing rates are very high. Such conditions were purposely established for these simulations.

For successful acquisition the algorithms require that a pair of replies correlating in range be received in a single frame. This correlation

requirement is intended to prevent fruit or multipath replies from being introduced into the track file. This constraint makes acquisition extremely difficult at low round reliability.

In order to improve acquisition probability the number of interrogations in the interrogation count table (Fig. A-9) was increased over the preliminary values assigned. (The new values are shown in parentheses in Fig. A-9). The same simulation trials were repeated for the higher fruit levels with the new table in force. The resulting state transitions are shown in Figs. 6 and 7. As expected the acquisition success was markedly improved, although the total number of interrogations preceding track establishment increased slightly (see Table I). Further efforts will be made to optimize this table.

Comparison of Figs. 4 and 6 shows a clear improvement in track establishment times for $\rho = .06$. Successful acquisition in trials 2, 3, and 5 prevented placement of the target in dormancy for the 12 second period. Track establishment occurred well in advance of the threat boundary in all cases. Track establishment times remained essentially the same for $\rho = .08$ except in the last case where successful acquisition improved track establishment time by 17 seconds.

Comparison of Figs. 5 and 7 shows improvement also. Successful acquisition in the first trial at $\rho = .10$ improved the track establishment time by 15 seconds. The last trial remained the same with track establishment

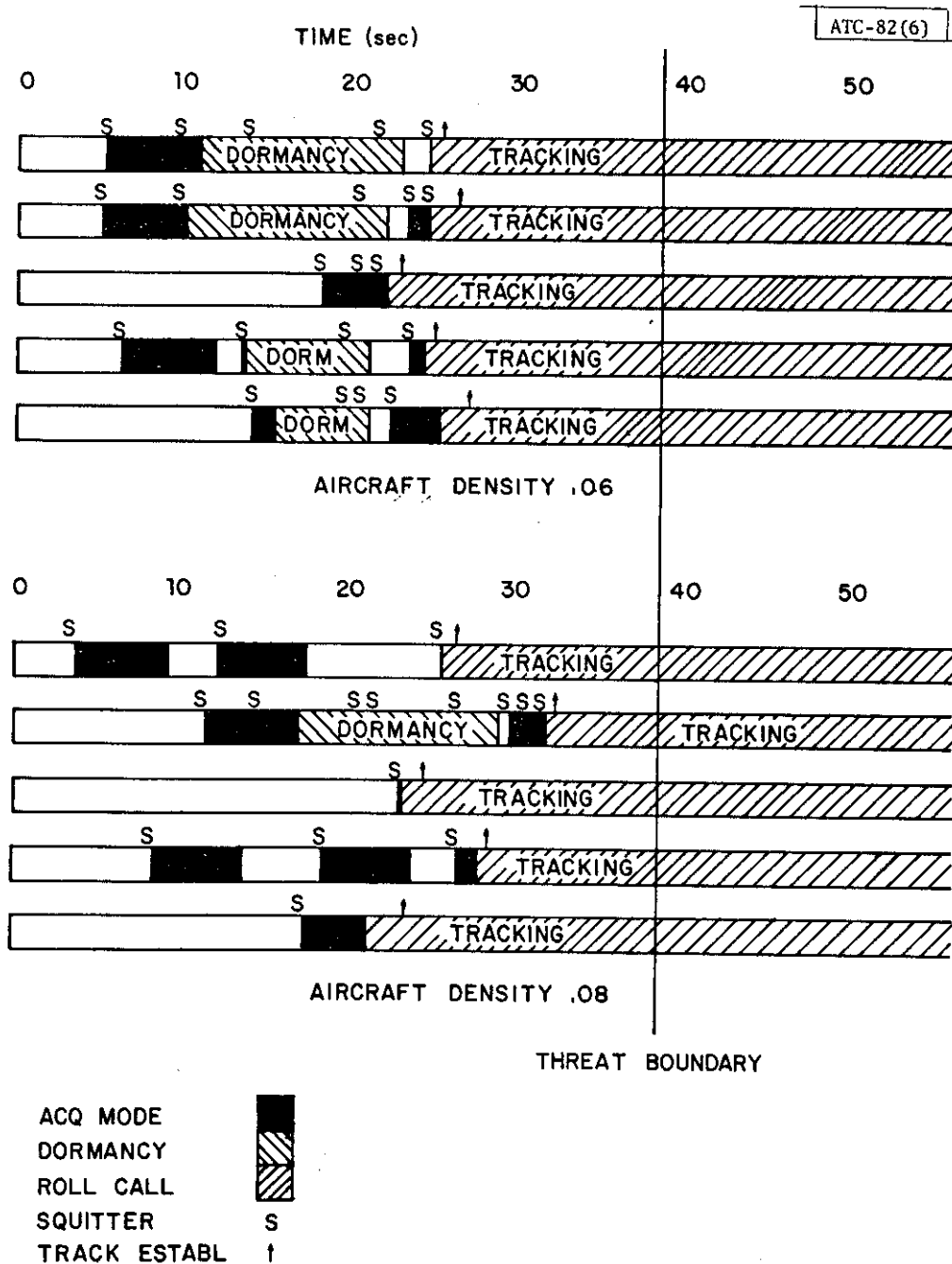


Fig. 6. State transitions for simulations with modified table, $\rho = 0.06, 0.08$.

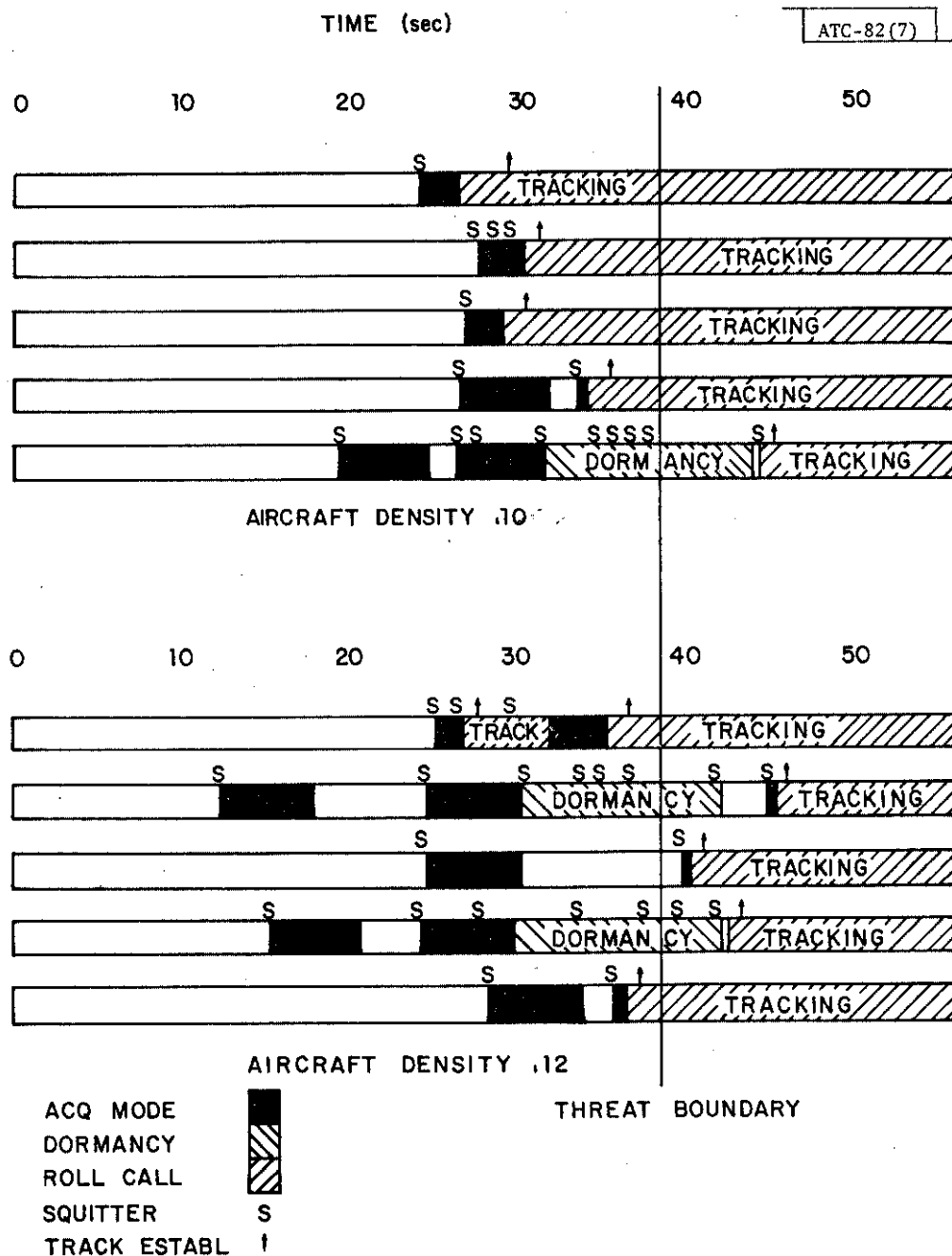


Fig. 7. State transitions for simulations with modified table, $\rho = 0.10, 0.12$.

TABLE I
PERFORMANCE COMPARISON BETWEEN NEW
AND OLD INTERROGATION COUNT TABLES

AIRCRAFT DENSITY	OLD TABLE		NEW TABLE	
	TRACK EST TIME (SEC)	NUMBER INTERROGATIONS	TRACK EST TIME (SEC)	NUMBER INTERROGATIONS
.06	25.04	18	25.04	26
	42.32	45	26.29	43
	37.08	22	23.32	25
	25.06	28	25.06	38
	35.05	22	27.04	24
.08	26.29	29	26.29	51
	32.08	31	32.08	39
	24.52	7	24.52	7
	28.34	42	28.34	58
	41.04	19	23.54	27
.10	44.09	23	29.55	28
	32.79	23	31.05	18
	33.05	24	30.55	17
	35.54	26	35.33	32
	45.05	36	45.05	50
.12	53.04	50	36.52	42
	46.08	38	46.08	51
	41.09	24	41.09	53
	43.10	37	43.10	51
	38.08	30	37.06	34
TOTAL		574		704

occurring at 45 seconds. With aircraft density at 0.12 aircraft/sq. nmi an improvement was achieved in the first and last trial. A successful Roll-Call interrogation occurred at $t = 27.04$ seconds permitting a calculation of the threat boundary time. However, no more replies were received in the Roll-Call mode and the target was placed back in the acquisition queue. Track was finally reestablished at $t = 36.52$ seconds. The link is very weak at this high fruit level and track establishment cannot be expected to always be achieved prior to the threat boundary time.

Figure 8 presents a summary of track establishment time as a function of aircraft density from the simulations performed with the modified interrogation count table.

The effects on performance caused by an increase in interference are clearly evident in this plot. For interference levels up to $\rho = 0.08$ aircraft/sq. nmi, performance deterioration is minor, with target track being established before the threat boundary in all simulation trials. As interference is increased further, an appreciable number of trials fail to establish track prior to the threat boundary. A simplified insight into this behavior is provided by the curve marked "link continuity point" in Fig. 8. This indicates the time at which it becomes 50% probable to obtain correct reception of a BCAS reply or squitter.

In terms of this curve, the simulation results may be summarized as follows: reliable target acquisition is achieved either prior to the threat boundary or within about 5 to 10 seconds of the link continuity point. It is anticipated that this statement of the results will be found to hold true under more general conditions involving other closing speeds, other values of antenna fade, and other threat boundary criteria. Further simulation work will explore this generalization.

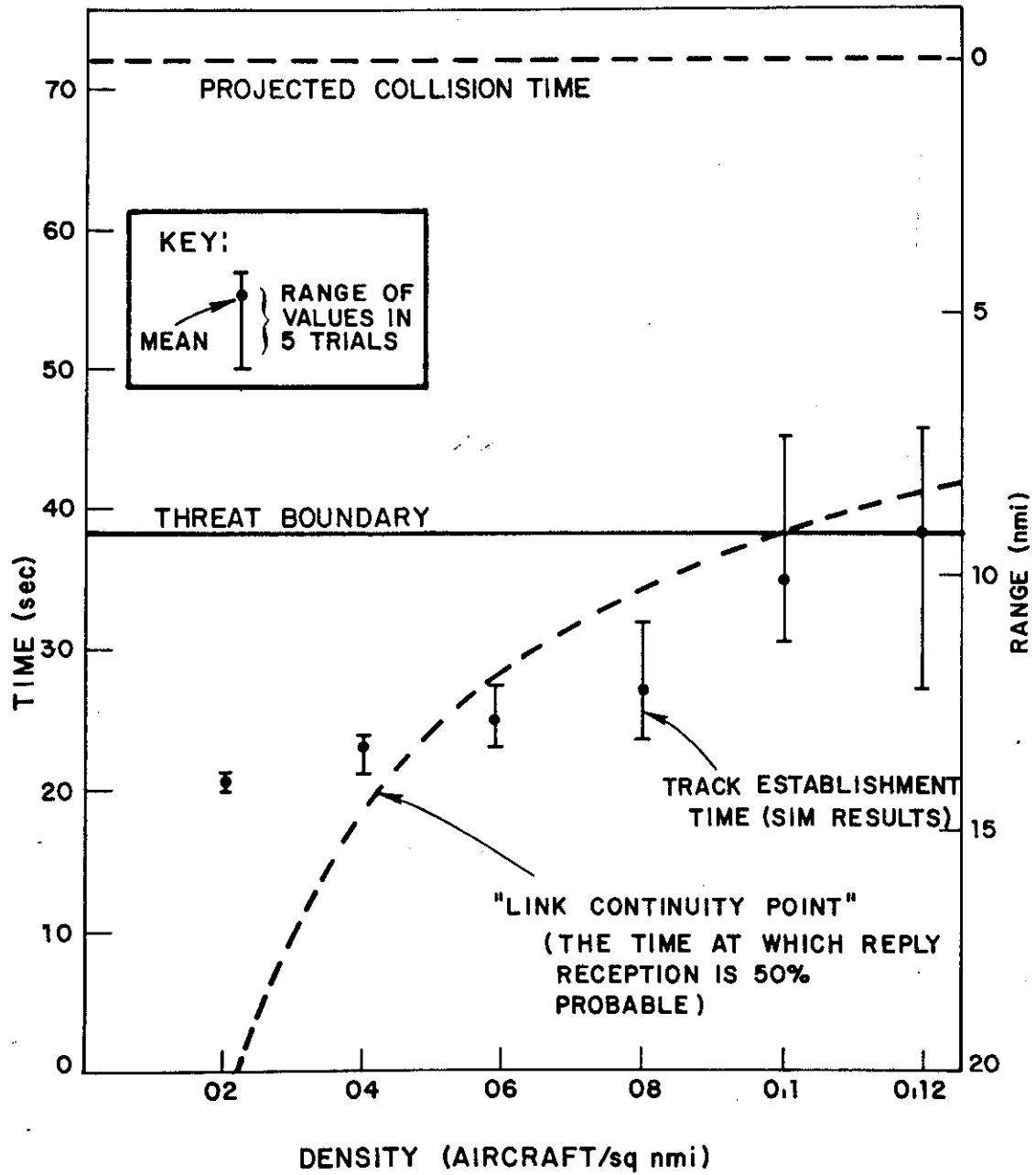


Fig. 8. Summary of simulation results as a function of interference environment.

4. Summary

The non-real time surveillance processor has been shown to be an effective tool for investigating the acquisition and track performance of the surveillance algorithms. Processing of simulated link data has been useful for several reasons. It uncovered several shortcomings in the original algorithms and allowed parameter refinement to proceed to the point where the separate subroutines have been integrated into a consistent and relatively efficient surveillance data processing system. As link parameters were varied, the simulation results clearly indicated several critical system parameters and algorithms, and also provided insight into system calibration algorithm development, and interpretation of recorded data. For example, the algorithms and timing associated with the dormancy mode proved to be unnecessary in some cases, harmful in some cases, and useful in others. Another important product of the simulation is a validation of the adequacy of the algorithms in supporting the CAS function in all but the most severe traffic environments.

Further simulations are being conducted to identify other critical system parameters. Timing tradeoffs between algorithms are emerging and design insight is continually being provided by surveillance performance, parameter sensitivity, and processing efficiency considerations. Thus as parameter variation studies progress, system limitations can be more clearly defined and the algorithms can become more adaptive in nature.

Future non-real time processing of real data will provide a chance to investigate a number of effects not considered in the simulated data. Real

fruit and multipath environments will adversely affect the link either by garbling replies and reducing round reliability or by causing processing time to be wasted in false DABS preambles. Realistic flight profiles will cause a wide variety of fade conditions on all antennas used.

APPENDIX A
DABS SURVEILLANCE ALGORITHMS

APPENDIX A

DABS SURVEILLANCE ALGORITHMS

The DABS surveillance algorithms consist of routines which support DABS acquisition and roll-call surveillance and result in estimates of range and range rate for DABS targets. The collision avoidance logic for DABS targets is not included in this description.

Fig. A-1 is a block diagram of the DABS surveillance processing software functions and files. The active track file contains targets that are under discrete surveillance and the acquisition file contains targets undergoing acquisition. Squitter processing is described in Section A.1, acquisition reply processing and scheduling in Section A.2 through A.7; and track update and scheduling in A.8 through A.11.

A.1 Surveillance Management and Timing

The surveillance update cycle is designated a "scan" and is of one-second duration. The scan is subdivided into four frames plus an interval for ATCRBS interrogations and replies. Fig. A-2 presents a breakdown of this cycle showing the timing relationships between the various tasks. An executive calls ATCRBS scheduling and reply processing, it performs housekeeping tasks on the various DABS acquisition and surveillance files and then calls the DABS frame processor (see Fig. A-3) once for each of the 4 frames. During each frame the DABS frame processor calls Acquisition Processing and Roll Call processing which schedule interrogations and process replies for acquisition and surveillance targets. The processing continues until all targets have been processed or an interrupt has been received from the frame

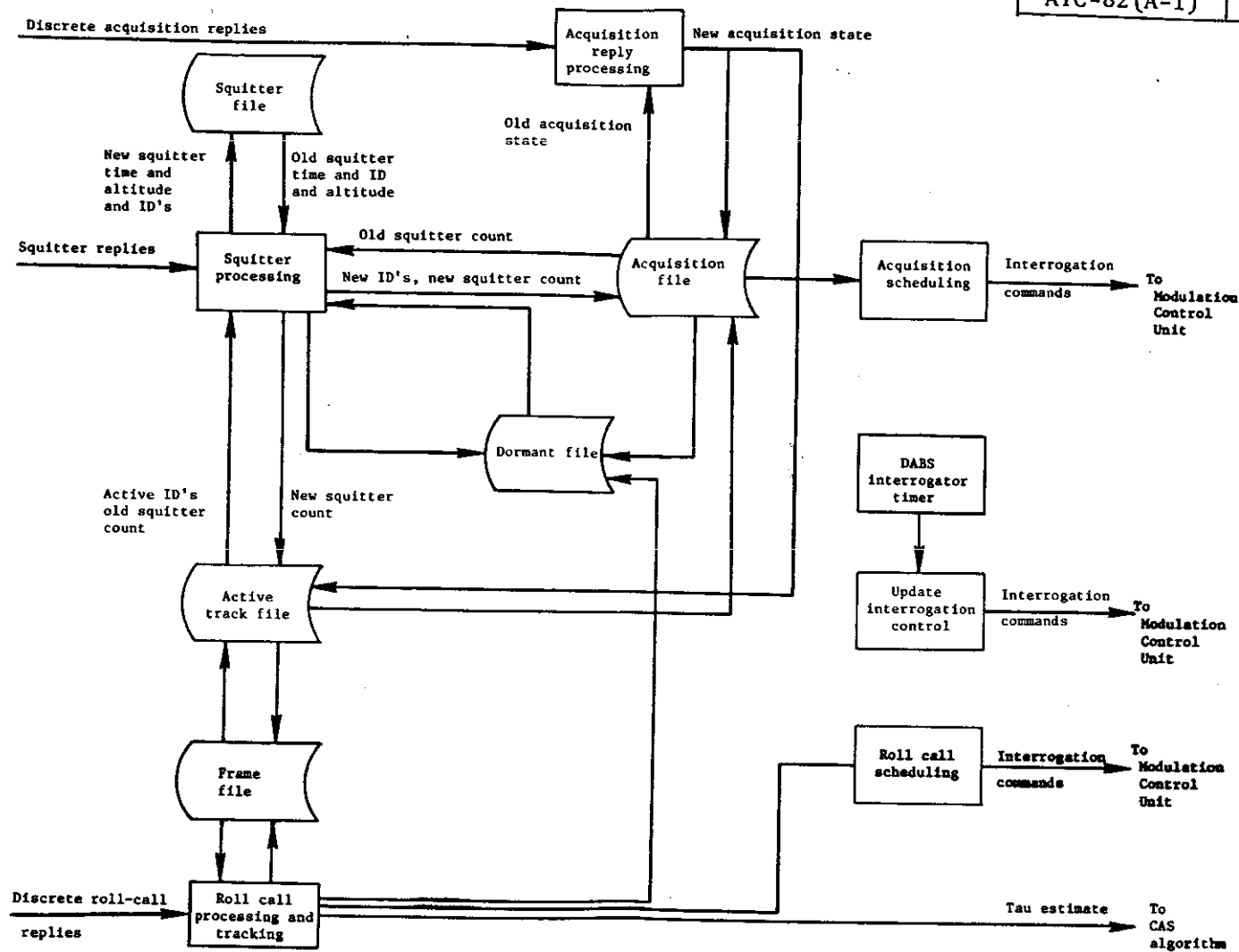


Fig. A-1. DABS surveillance processing software.

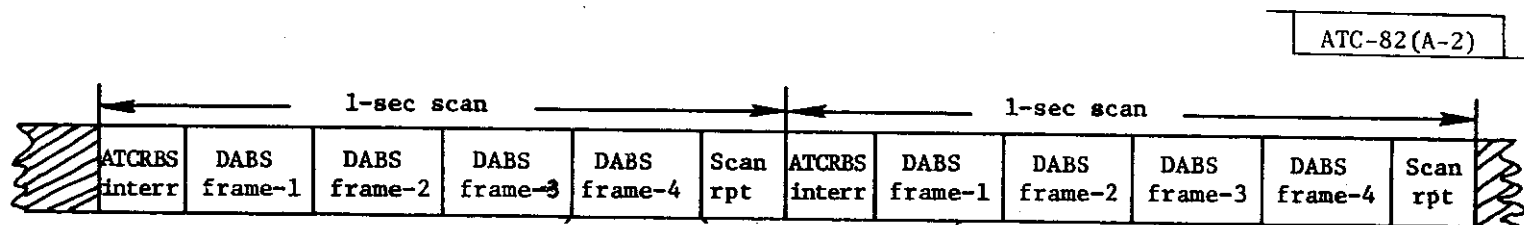


Fig. A-2. Surveillance scheduling.

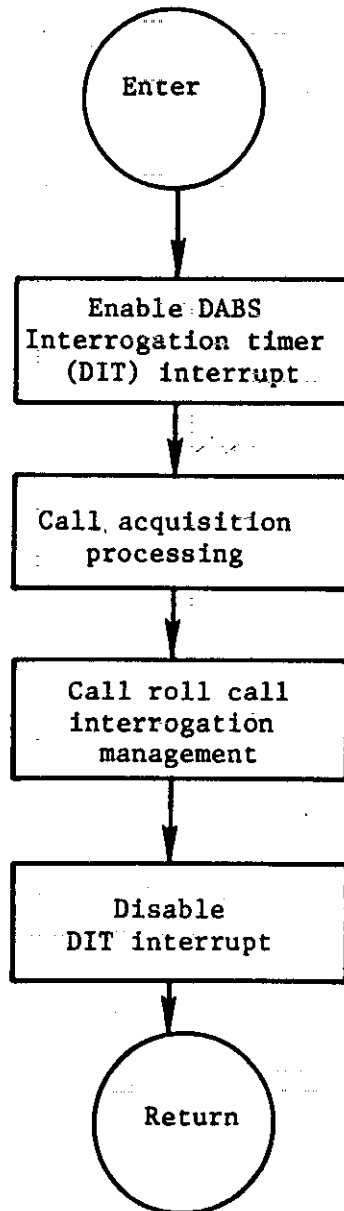


Fig. A-3. DABS frame processor.

timer. The time between the scheduling of each interrogation and receipt of an interrupt from the reply processor is devoted to the performance of background tasks. Squitters are serviced on an interrupt basis as described in Section A.3. Upon completion of the 4th frame, the updated target reports for the scan are handed over to the CAS logic.

Surveillance processing involves the use of a number of flags and counters which are listed in Fig. A-4. A block diagram detailing the functions of the surveillance executive is given in Fig. A-5 and will be described in detail as follows:

The squitter drop counter (c) is decremented by 1 for each target in the track file, the acquisition queue, and the squitter file. Squitters are dropped from the squitter file if $c=0$. The squitter counter indicates the number of scans elapsed since receipt of the last squitter from that DABS target. The DABS Range Sort and Valid Track Processing routine is called to write the frame file and make additions to the acquisition queue. This routine is described in Section A.2.

The antenna switch counter (w) is initialized at 2 for all targets in the frame file and acquisition queue. This counter will be decremented by 1 each time an interrogation is unsuccessful. The antenna flag (AN) will be switched after 2 unsuccessful interrogations and the counter reinitialized.

The time for release (TR) is decremented by 1 for all targets in the dormant file. Dormancy serves to inhibit interrogation of targets which do not constitute a range threat. Targets were added to the dormant file by either Acquisition Processing or Roll Call Processing. Targets are deleted from the dormant file when TR is decremented to 0.

NAME	PURPOSE	SYMBOL *	COUNTER INT. VAL.	FLAG CODE		WHERE SET (AND/OR CLEARED)	WHERE DECREMENTED (AND/OR TESTED)
				0	1		
GARBLE COUNTER	POWER PROGRAMMING (UP)	p	2	-	-	EXEC/R.C. PROC-III	R.C. PROC-III
FAILURE COUNTER	ANTENNA SWITCHING	w	2	-	-	EXEC/ACQUISITION PROC-II	ACQ PROC-II
FRAME COUNTER	ROLL CALL SCHEDULING	x	4	-	-	EXEC	ACQ PROC-I
SQUITTER DROP COUNTER	DROPPING OLD SQUITTERS	c	6	-	-	SQUITTER PROC-I	ACQ PROC-I/R.C. PROC-I
REACQUISITION COUNTER	TRACK VALIDATION SCHEDULING	r	12	-	-	ACQ PROC-III	VALID TRACK PROC (R.C. PROC-I)
VALID TRACK FLAG	LABELS VALIDATED TRACKS	VT	-	NOT VALIDATED	VALIDATED	ACQ PROC-III/DABS R.S.	VALID TRACK PROC
ACQUISITION COUNTER	LIMITS NUMBER OF ACQUISITION SCANS	i	6	-	-	SQUITTER PROC	ACQ PROC-I
TARGET FRAME COUNTER	ACQUISITION SCHEDULING	xt	4	-	-	ACQ PROC-I/SQUI. PROC-II	ACQ PROC-I
MAX NO. INTERROG/ FRAME	LIMITS INTERROGATION RATE	n	N TABLE	-	-	ACQ PROC-I / R.C. PROC-I	ACQ PROC-I / R.C. PROC-I
VALIDATION COUNTER	COUNTS VALIDATION ATTEMPTS	v	4	-	-	R.C. PROC-I (SQ. PROC-II, DABS R.S.)	ACQ PROC-I&-II&-III & INTERROG SUB
CORRELATION PENDING FLAG	SHORT-RANGE FRUIT TARGET RECEIVED	CP	-	CORREL NOT PENDING	CORREL PENDING	ACQ PROC-III (ACQ PROC-I)	ACQ PROC-III
NEW TRACK FLAG	INDICATES SPECIAL RANGE UNCERTAINTY	NT	-	OLD	NEW	ACQ PROC-III (R.C. INTERROG)	R.C. INTERROG PROC
POWER DOWN COUNTER	POWER REDUCTION ON SUCCESS	d	2 or 4	-	-	R.C. PROC-II, -III	R.C. PROC-II
TRACK FIRMNESS	COUNTS TRACK COASTS	f	(6)	-	-	R.C. PROC-II	R.C. PROC-I
TRACK HISTORY FIRMNESS	COUNTS PREVIOUS TRACK COASTS	g	(6)	-	-	R.C. PROC-II	R.C. INTERROG SUB
REPLY COUNTER	COUNTS RECEIVED REPLIES	l	4	-	-	ACQ PROC-I	ACQ PROC-II

* COUNTERS ARE DESIGNATED BY LOWER CASE LETTERS-THEIR INITIAL VALUES ARE UPPER CASE, (E.G. r IS CURRENT VALUE, R IS UNDEFINED INITIAL VALUE).
 FLAGS ARE DESIGNATED BY DOUBLE UPPER CASE LETTERS.

Fig. A-4. List of counters and flags - surveillance processing.

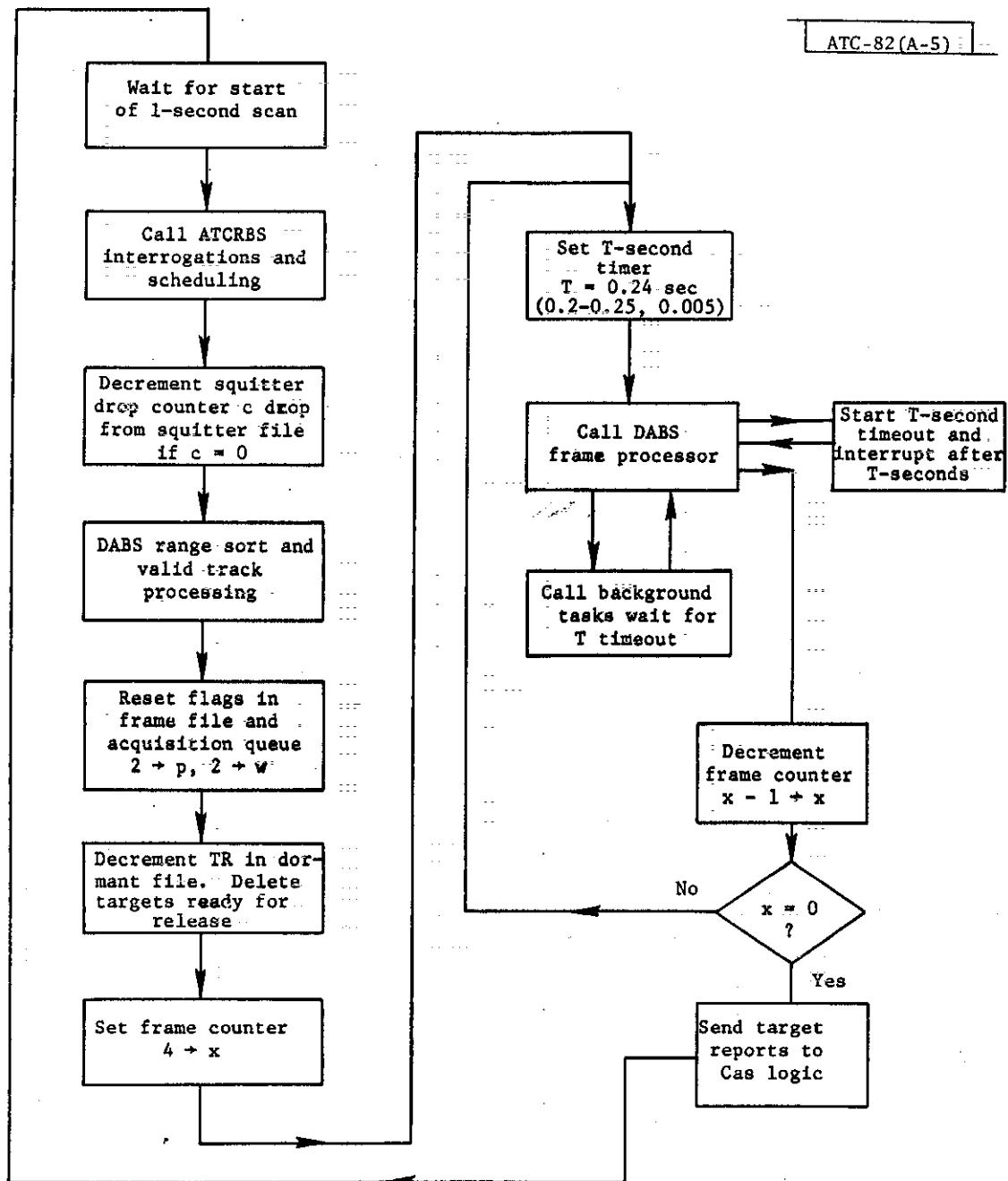


Fig. A-5. Surveillance Executive-DABS mode.

The frame counter (XT) is initialized to 4. The DABS frame processor is then called after resetting the frame timer (see Fig. A-5). The DABS Frame Processor calls Acquisition Processing which sets up interrogations for the targets in the acquisition queue and operates on replies received from the Reply Processor. Upon completion of Acquisition Processing the DABS frame processor calls Roll Call Processing which operates on the frame file in a similar fashion, and updates the track file. Background tasks are performed on an interrupt basis. Upon completion of Roll Call Processing, or receipt of an interrupt from the timer the DABS frame processor returns to the exec.

The DABS frame processor is called each frame until all 4 frames are processed. Upon completion of the last frame, the target reports in the track file are sent to the CAS logic.

A.2 DABS Range Sort and Valid Track Processing

This routine range sorts the track file which contains all targets that are currently being tracked. It writes the frame file and adds (to the acquisition queue) targets from the file that are scheduled for validation (see Fig. A-6).

The frame file is a queue of targets from the track file which will be scheduled for interrogation during the scan. Normally all targets in the track file are placed in the frame file. An exception is made for targets that are slated for validation. Each target will be deleted from the frame file sometime during the scan.

A target from the track file is always placed in the frame file once it has been validated. Validation indicates that there is no possibility that

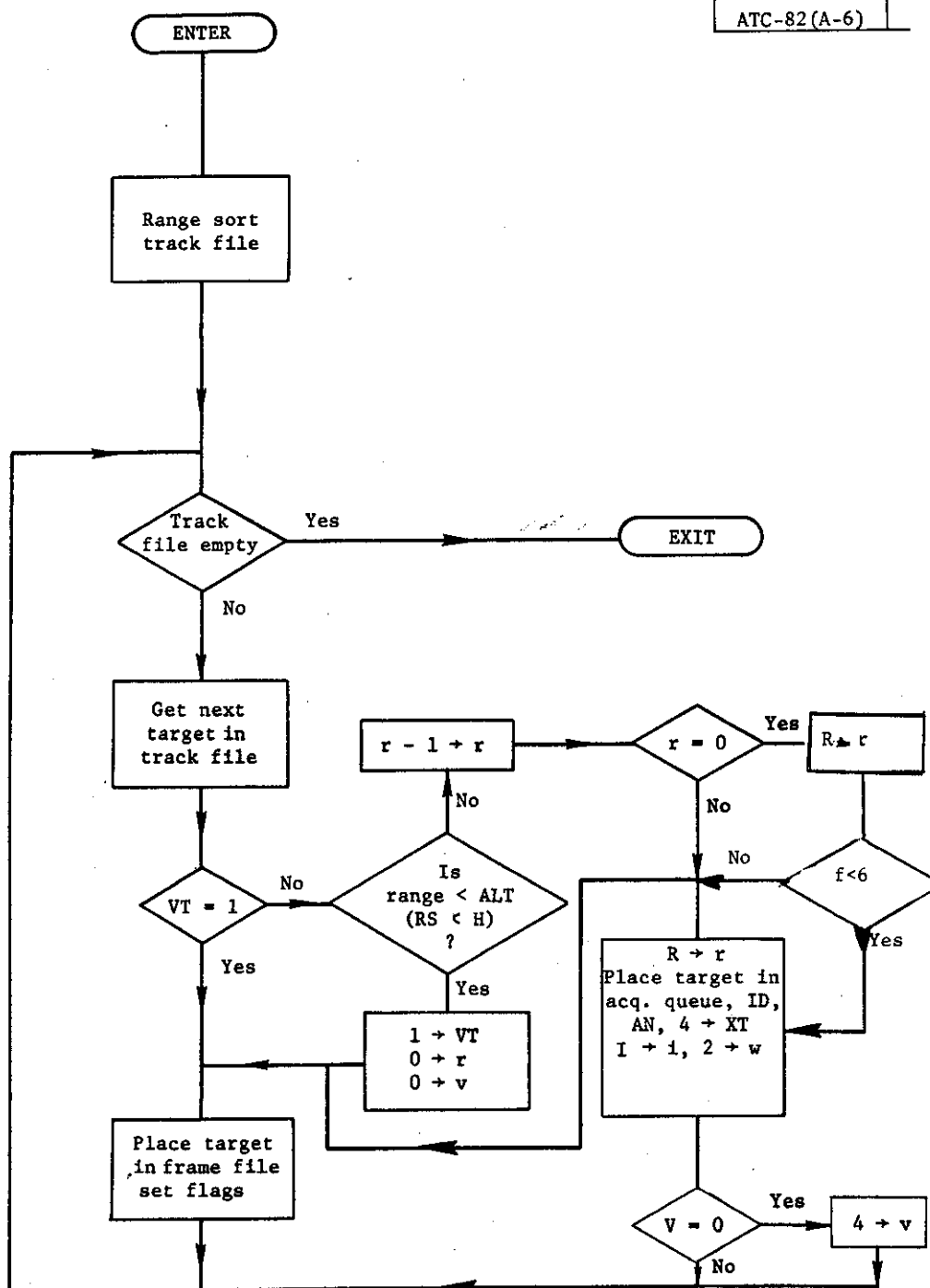


Fig. A-6. DABS range sort and valid track processing.

the track has been erroneously established on a multipath reflection. The validation flag (VT) is set immediately if the measured range is less than the target altitude since it would be physically impossible for such a track to be based on multipath reflections.

Another method of validation is used for targets which never satisfy the range/altitude test. Periodic attempts are made to reacquire the target at a closer range. If no shorter range target with the same ID is detected after nominally four reacquisition cycles, the track is declared valid. This process is accomplished as follows. The reacquisition counter (r) is decremented once per scan. After it has been decremented R times, the target is placed in the acquisition queue rather than in the frame file. The validation counter (v) is set to 4. If a successful interrogation is accomplished in Acquisition Processing and the predicted range does not exceed the measured range by more than the early range uncertainty, U_{RE} , the validation counter v is decremented by 1. This process is repeated every R scans until the v counter is decremented to 0. If this occurs without ever detecting a shorter range target, VT is set to 1 and the target is considered permanently validated.

A.3 Squitter Processing

Unlike discrete processing, which is scheduled four times per second, the squitter processing routine (Figs. A-7, A-8) is called by interrupt whenever a squitter reply is received. Squitter Processing services the interrupt immediately and either a) ignores the squitter because it is outside of an

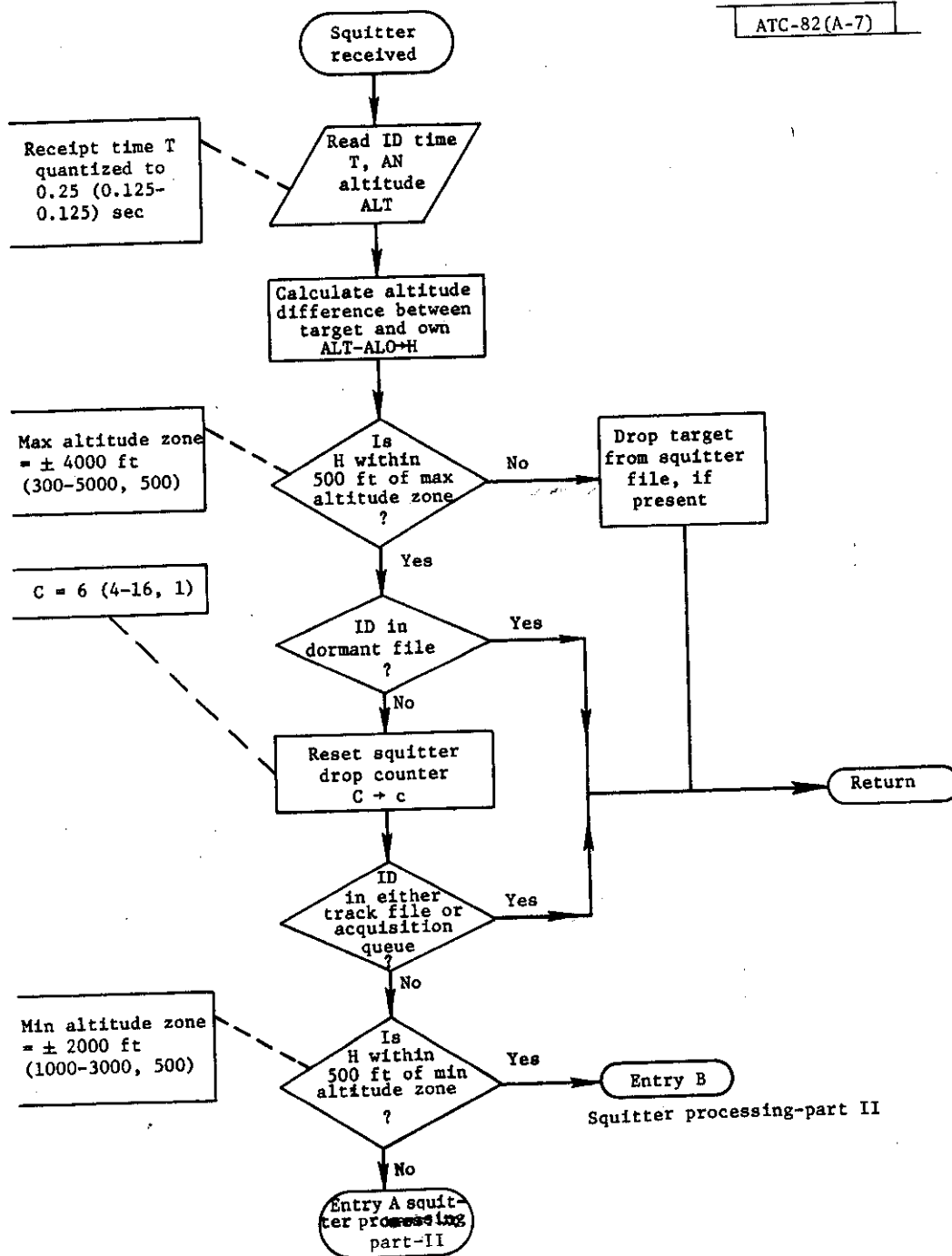


Fig. A-7. Squitter processing - Part I.

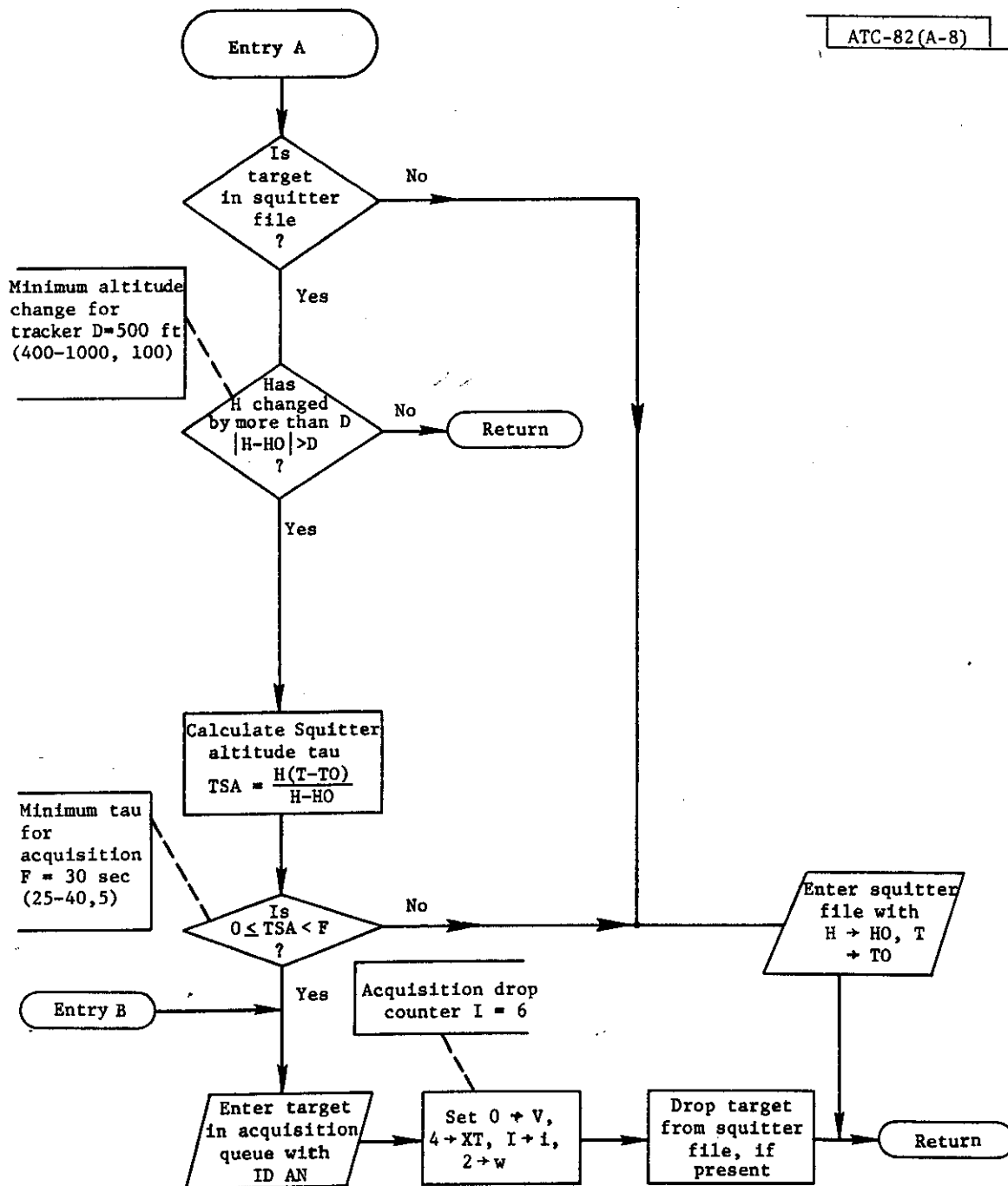


Fig. A-8. Squitter Processing - Part II.

altitude filter zone, b) places it in the acquisition queue because it has now become coaltitude, or c) tracks it in altitude in anticipation of a possible need to acquire it in the near future.

The altitude of squitter transmissions is quantized to 1000 ft. increments because only six bits of the pressure altitude code are available in the DABS format used for squitter transmissions. (Two bits are used for format control. The remaining data bits of the squitter reply are reserved for the target ID. The ID is needed for interrogating the target and decoding its discrete replies, i.e., discrete replies have their parity field overlapped with the 24-bit ID. The squitter is decoded in the BCAS receiver by assuming the parity field is overlapped with an all zero ID).

The relatively coarse quantization of altitude in squitter replies requires that altitude tracking of squitter replies be accomplished over a long time period by measuring the time between changes in the altitude code and assuming that the altitude rate is constant between observed changes. Altitude rates are sufficiently slow so that tens of seconds are typically required for each thousand foot change in the relative altitude between two aircraft. Thus, by measuring the time between thousand-foot changes, the altitude rate may be approximated with sufficient accuracy to permit a rudimentary sort of altitude tracking.

The first step in Squitter Processing is an input transfer from the DABS reply processor of the squitter address, altitude, and time of arrival. If the squitter altitude is not within 4500 feet of own aircraft, the target is dropped from the squitter file (if present) and control is returned to the exec. This is done to prevent targets that do not represent an altitude threat from being interrogated unnecessarily.

If the target altitude is within 4500 feet of own aircraft, the dormant file is searched for the target address. If the target is in the dormant file, control is returned to the exec. Targets in the dormant file are those which Acquisition Processing or Roll Call Processing determined were not of immediate threat. Dormancy inhibits acquisition of such a target for time TR.

If the target is not dormant, the squitter drop counter (c) is reset to its initial value C. This counter indicates the number of scans elapsed since receipt of a squitter. If the address is in the track file or acquisition queue, no further action is taken on the squitter reply.

If the squitter address is not in any of the files tested so far, the altitude difference is now compared to the minimum altitude zone. If it is within 500 feet of this zone, the squitter target will be entered immediately into the acquisition queue and dropped from the squitter file. (see Fig. A-8 ENTRY B Squitter Processing - Part 2).

If the target is not within 500 feet of the minimum altitude zone, further tests are necessary to determine whether the target should be placed in the squitter file or the acquisition queue.

If the target is not within 500 feet of the minimum altitude but the altitude difference has changed by more than 500 feet, the altitude tau (TSA) will be calculated. If the target is not in the squitter file, the new squitter (along with the altitude difference and time) is added to the squitter file. If the target is already in the file but the altitude difference has not changed by at least 500 feet since the last entry, no further action is taken.

The altitude tau (TSA) is the time at which the target will become coal-titude based on the present squitter and previous entry in the file. If TSA is less than 30 seconds the target is placed in the acquisition queue to be interrogated by acquisition processing. If the tau is greater than 30 seconds the squitter file is simply updated.

A.4 Acquisition Processing - Part I

Acquisition Processing is called every frame by the DABS Frame Processor. Block diagrams are given in Figs. A-9, A-10 and A-11. This routine cycles through all the targets in the acquisition queue. Each of these targets has an acquisition frame counter (XT) associated with it. This counter initialized at 4 upon entry into the queue and is not necessarily in phase with the Roll-Call frame counter X.

The Interrogation Count Table shown in Fig. A-12 is entered with XT and the acquisition counter i to obtain N. The counter i indicates the number of scans that have elapsed since the target was introduced into the acquisition queue. The value of N obtained from the table designates typically the minimum number of acquisition tries allowed in the frame. The scheduling of acquisition interrogations depends on both N and the results of interrogations made within the frame. The process is summarized in the following acquisition scheduling rules.

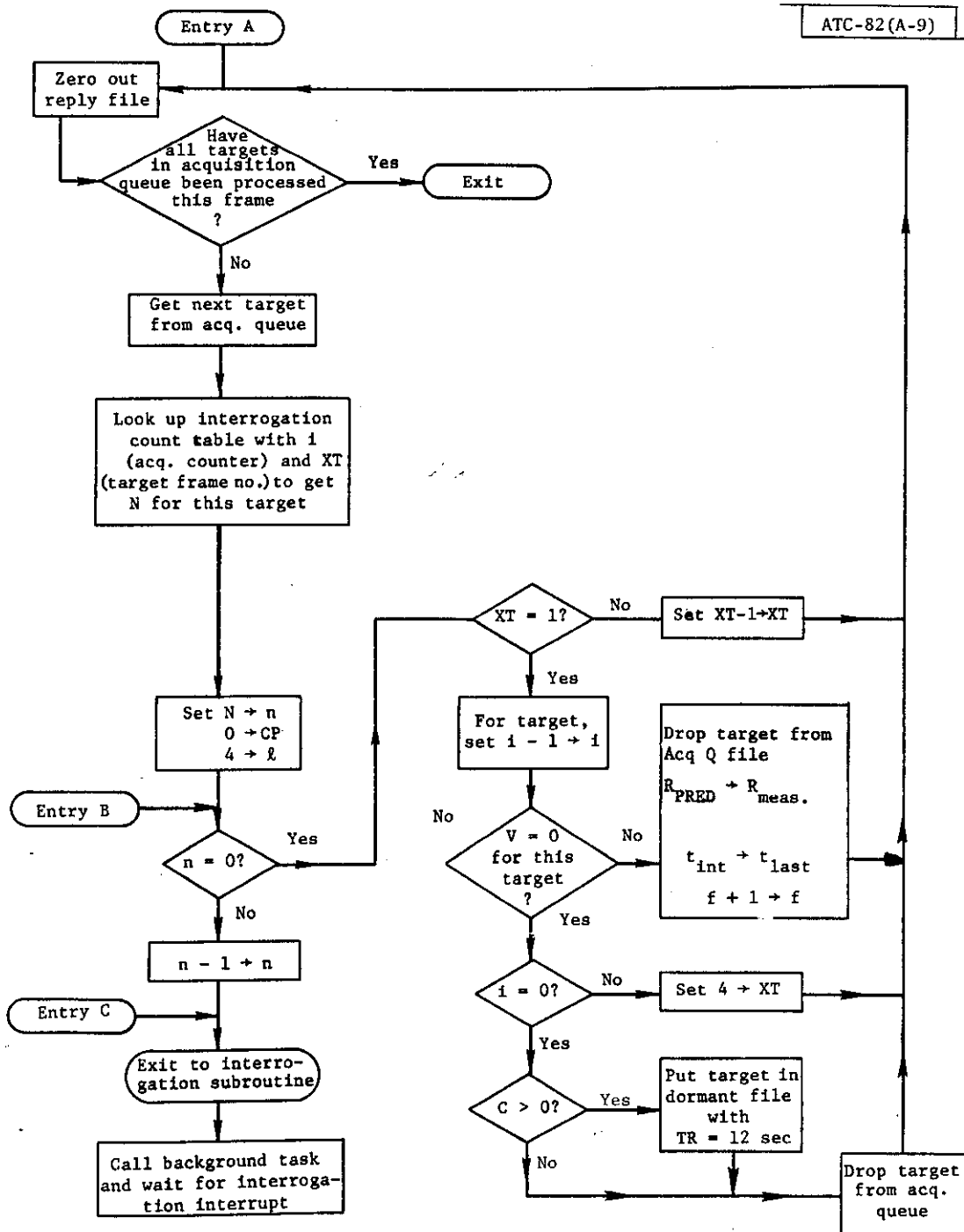


Fig. A-9. Acquisition processing - I.

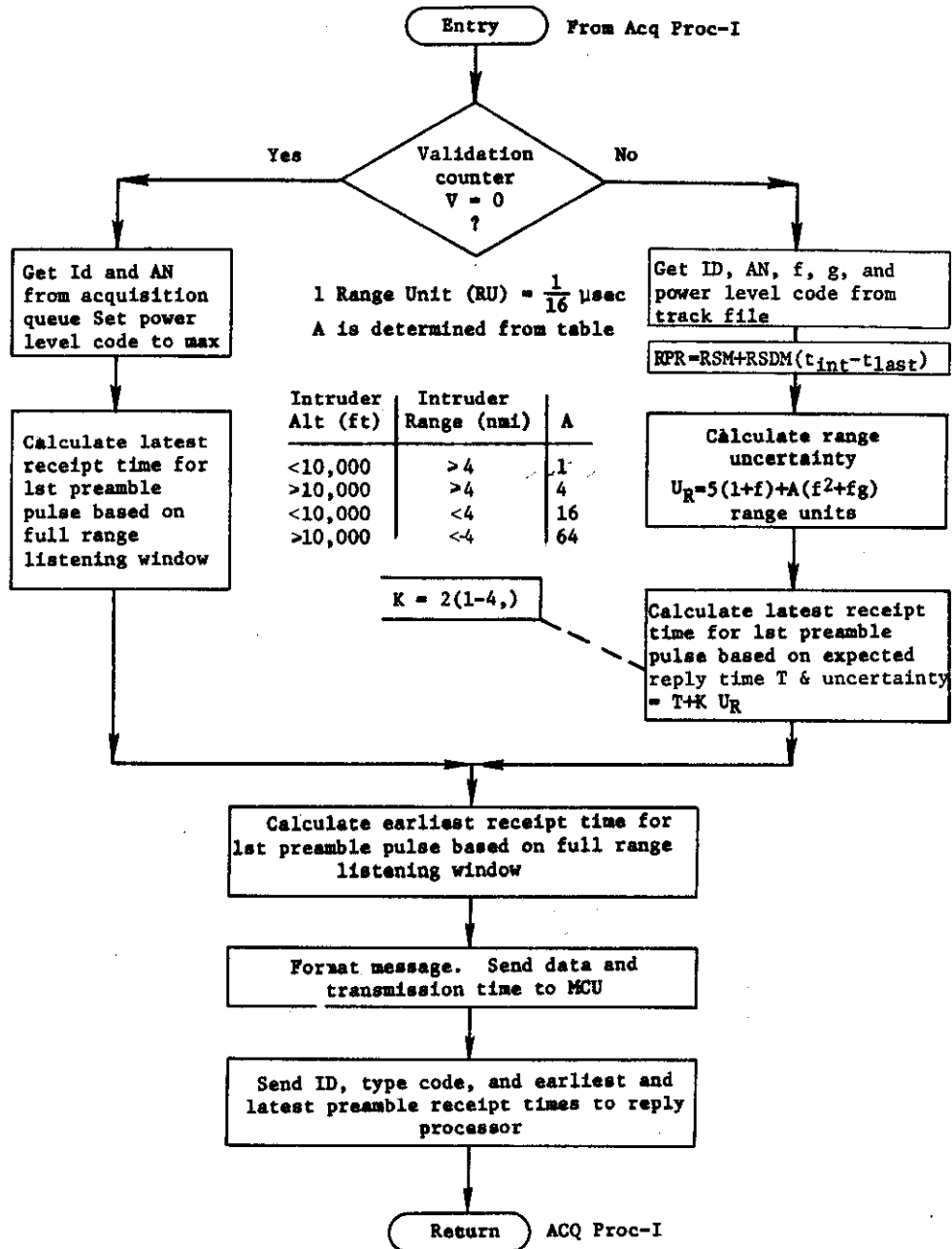


Fig. A-10. Interrogation subroutine - acquisition processing.

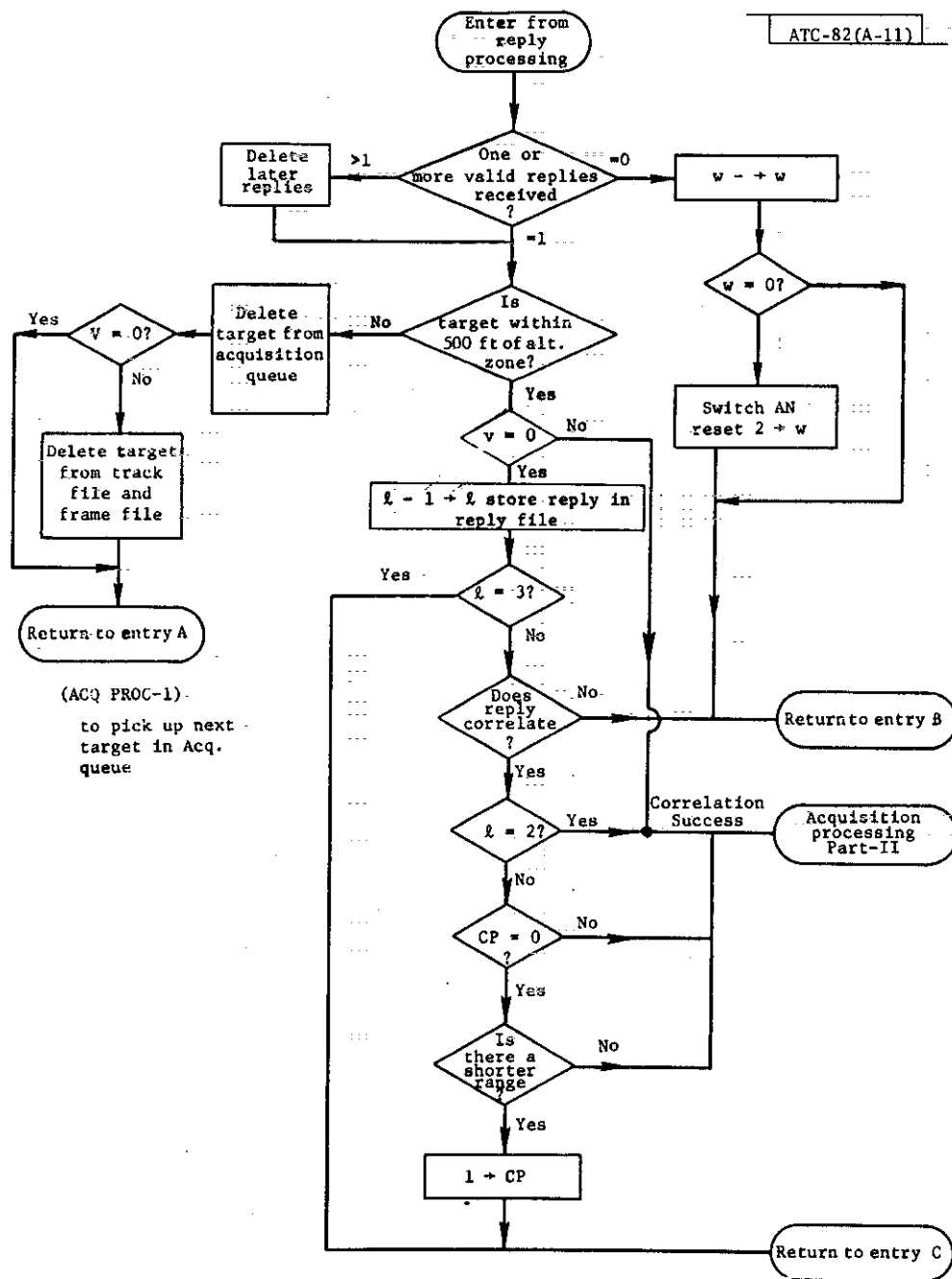


Fig. A-11. Acquisition processing - Part II.

Giving N = maximum number of interrogations per frame as a function of:

- 1) Track firmness f and frame count x (for Roll-Call targets)
- or 2) Acquisition count i and target frame count XT (for acquisition targets)

Acquisition Counter i	Track Firmness f	Frame Count x	Count X	or XT	
		4	3	2	1
6	1	2	2	1	0
5	2	1(2)	1(2)	1	1
4	3	1(2)	0	1(2)	0
3	4	1	0(1)	1	0
2	5	1	0	0	0(1)
1	6	1	0	0	0

Values in parentheses indicate changes in the table discussed in Section 3.3.

Fig. A-12. Interrogation count table.

Acquisition Scheduling Rules

Case 1 (N=1)

If 1st try fails, quit and wait for next frame

If 1st try succeeds, reinterrogate immediately

If 2nd try fails or does not correlate, quit and wait for next frame

If 2nd reply correlates put reply in track file.

Case 2 (N=1)

If 1st try succeeds or fails, reinterrogate immediately

If 2nd try fails and 1st try failed, quit and wait for next frame

If 2nd try fails or does not correlate and 1st try succeeded,
reinterrogate immediately

If 2nd try correlates, put reply in track file

If 3rd try fails, quit and wait for next frame

If 3rd try correlates with the longer range of 2 previous uncorrelating
replies, reinterrogate immediately (correlation pending case)

If 3rd try correlates and there is no previous reply with shorter range,
put reply in track file

If 4th reply correlates put reply in track file

If 4th reply fails or does not correlate, quit and wait for next
allowed frame.

If the counter n is non-zero, it is decremented by 1 and an interrogation is scheduled for the target by the interrogation subroutine which sends a format message to the Modulation Control Unit (MCU) and ID and gating information to the reply processor. The output from the reply processor returns to acquisition processing (see Fig. A-11), where correlation tests are made to prevent fruit or multipath returns from becoming accepted. If the interrogation fails or does not correlate, the program returns to ENTRY B where n is again

decremented by 1 if it is non-zero and another interrogation is sent out. If the reply succeeded but further correlation is necessary the interrogation subroutine is called immediately without decrementing n (ENTRY C).

Interrogations are scheduled for the target until either a satisfactory correlation is found or the counter n is decremented to 0. If the interrogations scheduled for the frame were unsuccessful and it is the last frame for the target, certain housekeeping tasks are performed before accessing the next target. The acquisition drop counter which indicates the number of scans elapsed without acquisition is decremented by 1. The target is dropped from the acquisition queue once i reaches 0, but will be placed in the dormant file if recent squitters have been received. The track file will be updated for targets that are in the acquisition queue for validation.

A.5 Interrogation Subroutine - Acquisition Processing

This subroutine is called by acquisition Processing Part 1 to set up the next interrogation (see Fig. A-10).

If $v \neq 0$ the target is in the acquisition queue for validation purposes. The late range uncertainty U_{RL} is calculated from the track firmness f, track history firmness g, and a constant A which accounts for large accelerations due to target passings. The latest receipt time for the first preamble pulse is calculated from the expected reply time and the late range uncertainty multiplied by a constant k.

The earliest receipt time is that for a zero-range target listening window. If the target to be acquired is a new target, $v=0$, the range window is opened from zero-range out to a maximum range of 17 nmi.

The interrogation is formatted and sent to the Modulation Control Unit (MCU). The expected reply time T along with earliest and latest receipt times are sent to the reply processor. The subroutine then returns to Acquisition Processing-Part I, which returns to background tasks until the DABS Interrogation Timer signals that an interrogation may be transmitted.

A.6 Acquisition Processing - Part II

This section of Acquisition Processing is entered when the reply processor has completed its tasks (see Fig. A-11).

If no reply was received from the interrogation, the failure counter, w, is decremented by 1. This counter is initialized at 2 at the beginning of the scan by the surveillance exec and also each time the antenna is switched. If w=0, the antenna flag AN is switched. The program returns to ENTRY B of Acquisition Processing Part I for a possible reinterrogation (Fig. A-9).

If more than one valid reply from the interrogation were received, the later replies are deleted since the delay time and dead time in a DABS transponder are such that it cannot reply more than once during the acquisition range window. The later replies are assumed to be multipath associated either with a reply to own interrogation or with a fruit reply.

If the target altitude is not within 4500 feet of own altitude, the target is deleted from the acquisition queue. If the validation counter v is non-zero, the target is undergoing reacquisition and therefore must also be deleted from the track file.

If the target is in the altitude threat zone, the reply is stored in the reply file, and the reply counter, l, is decremented by 1. If l=3, this

is the first reply received this frame. Processing returns to Acquisition Processing ENTRY C for a reinterrogation. If the reply is not the first, the range is compared to ranges of previous replies in the reply file. If it does not correlate, another interrogation may be made (ENTRY B).

If the reply correlates and it is the 2nd reply ($\ell=2$), the correlation is considered successful and the reply is processed in Acquisition Processing Part III (see Fig. A-13). If the correlating reply is the 3rd reply ($\ell>2$, $CP=0$) and the previous uncorrelating reply has a shorter range, the correlation pending flag CP is set to 1 and a 4th interrogation is scheduled. If there is no shorter range reply, the reply is accepted. If the correlating reply is the 4th reply ($\ell<2$, $CP=1$), the reply is accepted regardless of whether it correlates with the previous short range reply or the longer range pair.

A.7 Acquisition Processing - Part III

This section of Acquisition Processing operates on the successfully correlated reply (see Fig. A-13).

If the target altitude is below 10,000 feet and the maximum capable speed, SMT, is greater than 300 knots, SMT is set to 300 knots. If own altitude is below 10,000 feet and own maximum capable speed, SMO, is greater than 300 knots, SMO is set to 300 knots. The program now calculates TE, the time of earliest encounter. If $TE = 46$ sec the target is not considered an immediate threat and is therefore placed in the dormant file. The time to release from dormancy is set at $TR = TE - 40$ sec.

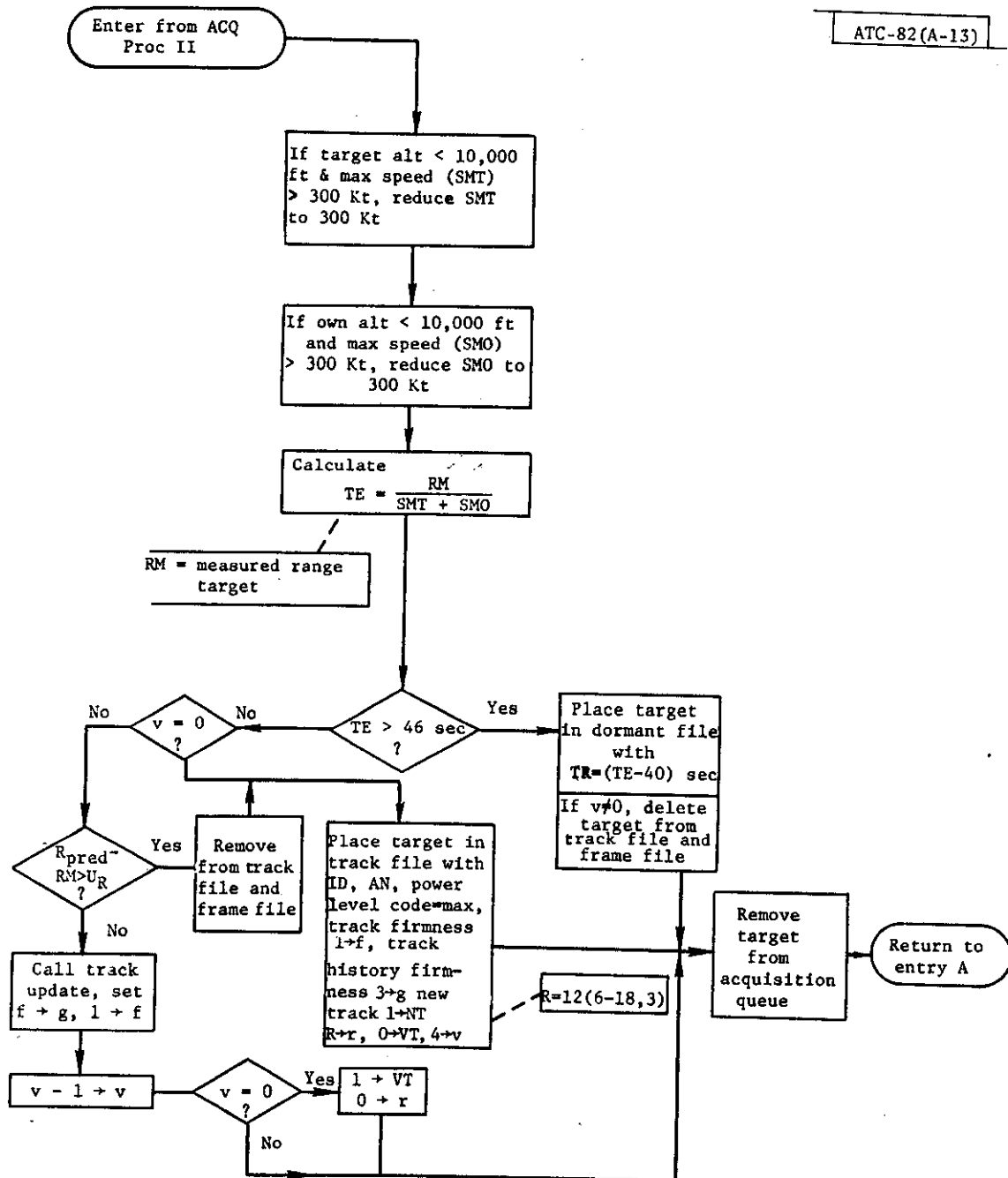


Fig. A-13. Acquisition processing - Part III.

If TE is less than 46 seconds and the target is not being validated, it is entered into the track file as a new target. It will be placed in the frame file by the Surveillance Processor at the beginning of the next scan. If the target is being validated ($v \neq 0$), a check is made to determine whether the predicted range exceeds the measured range by more than U_{RE} , the early range uncertainty. If it does, it is assumed that the old track was based on multipath returns. In this case the target is removed from the track file and reentered as a new target. If the measured range is within U_{RE} of the predicted range, the track file is updated and the validation counter decremented by 1. If v has now been decremented to 0, the validation process is complete and the validation flag VT is set to 1.

The target in all cases is removed from the acquisition queue before the program returns to ENTRY A Acquisition Processing Part I for the next target in the acquisition queue.

A.8 Roll-Call Processing - Part I

The frame file is accessed by Roll Call Processing 4 times per scan (see Fig. A-14). For each target in the frame file the interrogation count table is entered to obtain N, the maximum number of interrogations permitted during the current frame. The counter n is initialized at N and will be decremented each time an interrogation fails to achieve a valid reply.

If $n=0$ and it is the last frame of the scan, a valid reply has not been found during the entire scan. A decision must be made whether to coast the target or delete it from the track file. In the latter case the target may

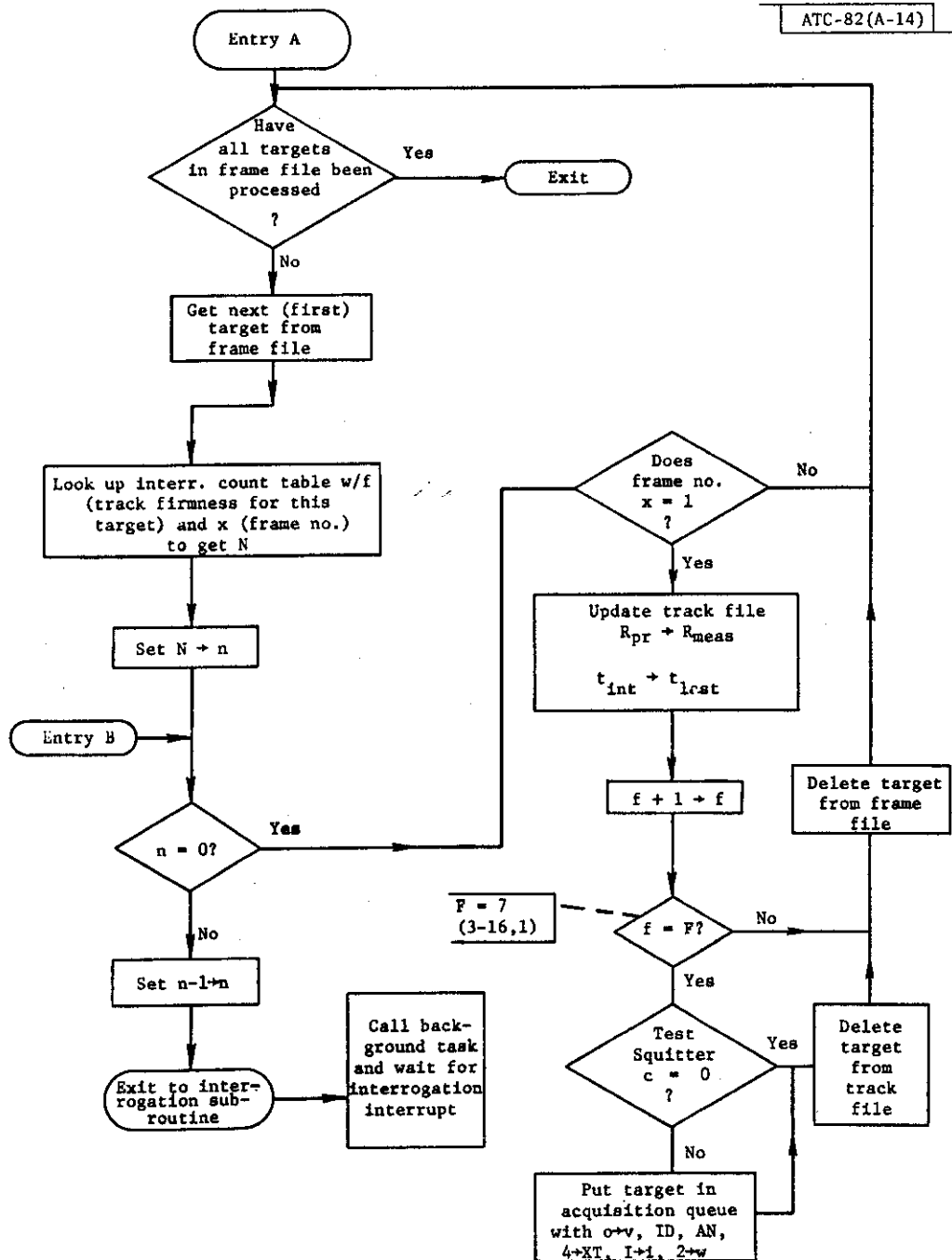


Fig. A-14. Roll-call processing - Part I.

be put back in the acquisition queue. If the track firmness $f < F$, the target will be coasted. If $f = F$, the target has failed to reply for nominally 6 seconds and will be deleted from the track file. This target will be put in the acquisition queue if squitters have been received during the last C scans; otherwise it will simply be dropped.

If $n \neq 0$, n will be decremented by 1 and the interrogation subroutine is called to set up an interrogation. The program will perform background tasks until an interrupt is received from the reply processor, at which time processing will continue to Part II or Part III depending upon the result of the interrogation. Part II processes valid replies and returns to ENTRY A. Part III processes garbled and missing replies and returns to ENTRY B. The above procedure continues until all targets in the frame file have been processed.

A.9 Interrogation Subroutine - Roll-Call Processing

This subroutine is called by Roll Call Processing and sets up the next interrogation for a target (see Fig. A-15).

First, it accesses the predicted range R_{pr} , antenna AN, track firmness f , track history g , and power level from the track file. If this is not a new target ($VT=0$), it calculates early as well as late uncertainties (U_{RE} and U_{RL}). If it is a new target ($VT=1$), U_{RE} and U_{RL} are both set to 80 range units. The interrogation is then formatted and sent to the MCU. The expected reply time T along with earliest and latest receipt times are then sent to the reply processor.

A.10 Roll-Call Processing - Part II

This section of Roll Call Processing operates on valid replies received from the Reply Processor (see Fig. A-16). It determines whether the target is

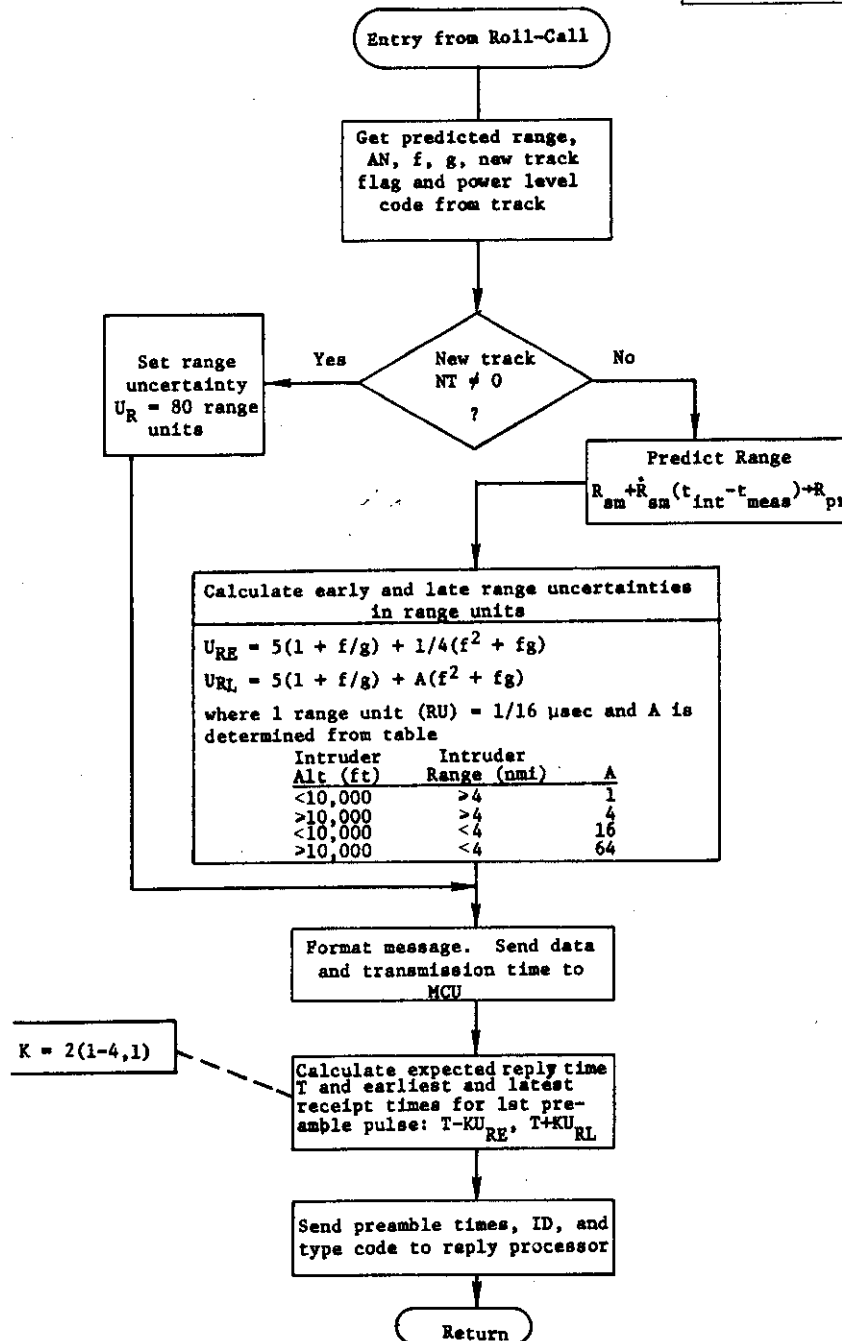


Fig. A-15. Interrogation subroutine roll-call processing.

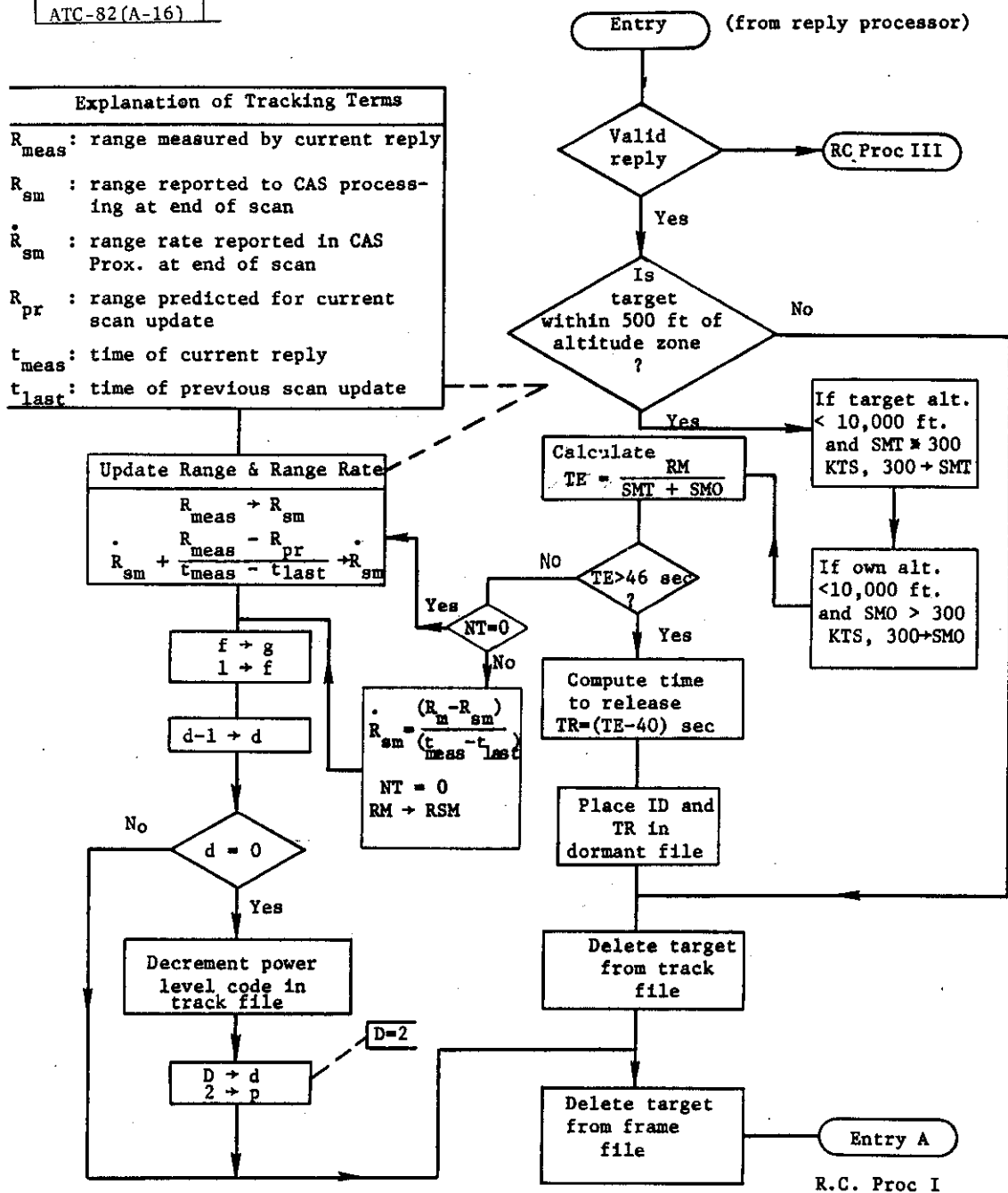


Fig. A-16. Roll-call processing - Part II.

still of interest and, if so, whether the power level can be reduced. Processing then returns to ENTRY A of Roll-Call Processing, Part I for the next target in the frame file.

If the target altitude is not within 4500 feet of own aircraft, the target is deleted from both the target file and the frame file. If it is within the altitude zone, the SMT (Maximum Speed of Target) is limited to 300 kts if the target altitude is below 10,000 feet. The SMO of own aircraft is treated in the same fashion. The program then calculates TE, the time of earliest encounter. If TE is greater than 46 seconds, the target is placed in the dormant file and deleted from both the track file and the frame file.

If however, $TE \leq 46$ seconds, the new reply is used to update the track file. The track history g is replaced by the track firmness f, and f is set to 1. The power level counter d is decremented by 1. If $d=0$, indicating that D' or D scans have elapsed with successful replies, the power level flag in the track file is set to reduced power. The garble counter p is then reinitialized at 2 and the power level counter d at D. Finally, the target is removed from the frame file since no more interrogations are necessary in this scan.

A.11 Roll-Call Processing - Part III

This section of Roll Call Processing operates on reply failures (see Fig. A-17). If the track firmness $f=1$ and it is the first frame, processing immediately returns to ENTRY B of Roll Call Processing - I for reinterrogation.

Otherwise, decisions are made whether to switch the antenna and increase the power level before returning to ENTRY B. First, the antenna switch counter is decremented by 1. If a garbled reply was received, the garble counter p

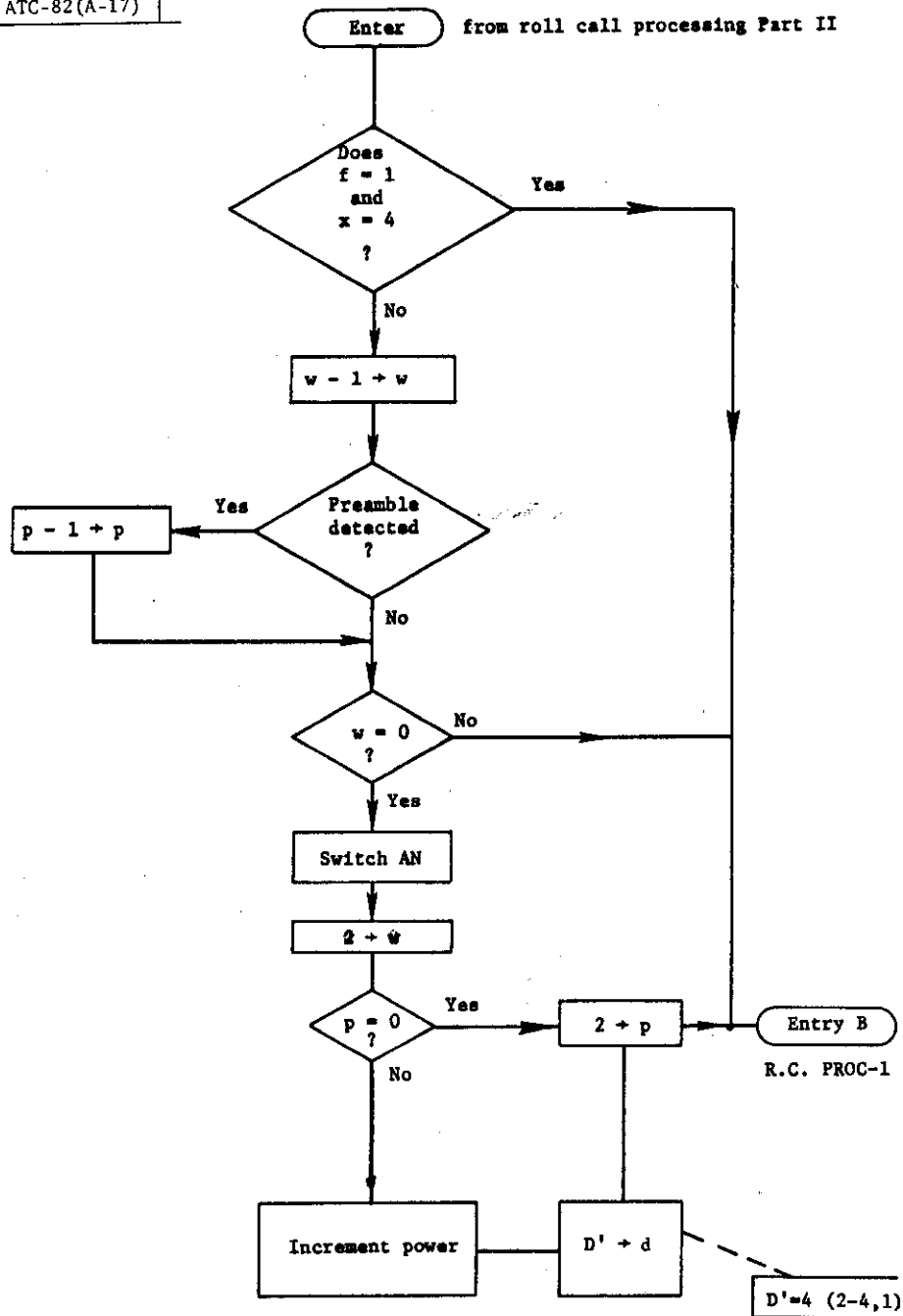


Fig. A-17. Roll-call processing - Part III.

is also decremented by 1. If the antenna switch counter w has been decremented to 0 it indicates that 2 invalid replies have been received with the current antenna selection. The antenna is switched and w reinitialized at 2. If the garble counter p is 0 it means that the last 2 replies were garbled and the problem is probably caused by multipath. In this case increasing transmitted power will not help. The counter p is reinitialized at P. These rules are summarized in Fig. A-18.

If the garble counter p is nonzero, the power level is increased and the counter d is reinitialized at D'. The counter d is decremented every time a valid reply is received. It is initialized at D' if the power is increased and at D if the power is decreased.

After each interrogation, DABS Reply Processor reports whether it received:

- A Valid Reply
- A DABS preamble followed by an uncorrectable data block
- No reply

Parameters are changed if:

- 2 consecutive failures follow a previous parameter change
- 4 consecutive failures follow a previous successful update

Result of two Consec Failures	Probable Cause	Power Change	Antenna Change
2 missing replies	fade	up	switch
1 preamble, 1 miss	?	up	switch
2 preambles	M'path	hold	switch

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Fig. A-18. Antenna and power programming (on failure).