FAA-RD-75-113

Project Report
ATC-54

Design Validation of the Network Management Function

P. Mann
H. Vandevenne

2 February 1976

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LEXINGTON, MASSACHUSETTS

Prepared for the Federal Aviation Administration,
Washington, D.C. 20591

Technical Report Documentation Page

1. Report No.
FAA-RD-75-113

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Design Validation of the Network Management Function

5. Report Date
2 February 1976

6. Performing Organization Code

7. Author(s)
P. Mann and H. Vandevenne

8. Performing Organization Report No.
ATC-54

9. Performing Organization Name and Address
Massachusetts Institute of Technology
Lincoln Laboratory
P.O. Box 73
Lexington, Massachusetts 02173

10. Work Unit No. (TRAIS) 45364
Proj. No. 034-241-012

11. Contract or Grant No.
DOT-FA72-WAI-261

12. Sponsoring Agency Name and Address
Department of Transportation
Federal Aviation Administration
Systems Research and Development Service
Washington, D.C. 20591

13. Type of Report and Period Covered
Project Report

14. Sponsoring Agency Code

15. Supplementary Notes
The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology under Air Force Contract F19628-76-C-0002.

16. Abstract

This document presents the results of a major design validation effort of the Network Management function described in the DABS Engineering Requirements document. The design validation is based on simulation of a DABS network of three sensors interacting with airborne traffic of approximately 800 aircraft.

17. Key Words
Network management
Simulation
Design validation
Environment model

18. Distribution Statement
Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151.

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
54

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (cont.)

TABLES

DESIGN VALIDATION OF THE NETWORK MANAGEMENT FUNCTION

I. OVERVIEW

The Network Management Function

The network management function of the Discrete Address Beacon System (DABS) sensor is to control the interaction between the individual sensor and the network of DABS sensors. It is responsible for providing surveillance control, determining sensor priority, controlling the interface, and regulating the exchange of messages.

The Engineering Requirement document [Ref. 1] defines in detail the procedure for separating the preceding set of control functions into tasks and determining when and how each task will be executed. The network management function performs tasks that are triggered by the occurrence of "events." An event may initiate a one-time task or start a sequence of tasks that will be repeated on subsequent scans until terminated by a new event. Reference 2 explains the network management function and provides motivation for certain options adopted in the design.

Simulation as a Design Validation Technique

A large-scale simulation program was developed on the SEL-86 computer in order to validate the network management design. Validation consisted of (1) providing a detailed evaluation of the performance of the system under a variety of circumstances, (2) establishing estimates of program size and use of computer time, and (3) providing assessments of the number and general mix of intersensor messages generated by network management.

Simulation Approach

The major goal of the simulation was to verify the consistency of the design. A secondary goal was to obtain a satisfactory estimate of program size, storage requirements, and computer time under various load conditions. Twenty special flights were generated to check out specific paths in the logic of the network management flow diagram. These were conceived to represent normal conditions as well as especially unusual combinations of events. After it was established that the logic was correct, the simulation was conducted with a high-density traffic model. The model selected was one developed by the Mitre Corporation to represent the potential traffic environment in the Los Angeles area in 1982. This produced an additional check of the logic as well as an evaluation of the system under load conditions.

The traffic environment was only a portion of the simulation model; the remaining portions were the network of DABS sensors and the characteristics imparted to the sensors and the transponders carried by the aircraft. The network consisted of three sensors (a minimal requirement) carefully located with respect to each other and with respect to the traffic environment of the Mitre model. The sites were Ontario, Burbank, and Long Beach, California; all are existing FAA radar sites. The corresponding coverage assignments and maps are based on this siting configuration. The model of the DABS sensors reflected the entire description of the Engineering Requirement document only insofar as the network management function was concerned. The other sensor functions were greatly simplified and were simulated only for their interaction with network management. The model did not have a DABS data link processing function; hence, no up - and downlink message traffic was considered in the simulation. A reply model was used to simulate all-call replies, discrete replies, and misses. A sequence of misses determines a fade which constitutes a major trigger for network management activity. Misses were generated based on a model of the DABS sensor antenna pattern, the target position, and a random number generator. The model for the DABS transponder included the lock-out feature.

With the constraints on the model for the traffic environment and the DABS sensor model, the principal output of the simulation program was the printout of all internal state-changes and messages generated and received by each sensor.

Structure of the Report

The general structure of the simulation program, DABSIM, is presented in Section 2. Section 3 provides details regarding the traffic model. Section 4 includes a description of the DABS network in terms of siting and coverage capability. The coverage map, which is the basic tool for network management decision making, is presented in detail. Section 5 summarizes the analysis of a few specially chosen flight trajectories. Section 6 summarizes operational characteristics that are important to network management such as computer load, and frequency of occurrence of events. Section 7 contains conclusions and recommendations.

II. THE SIMULATION PROGRAM (DABSIM)

General Description

Figure 1 illustrates the principal components of the simulation program. The environment section consists of traffic tapes for each site and a reply model. The single sensor section indicates the function of the individual sensor. The multisensor executive controls the switching to sensors A, B, and C and selects the correct environment tape.

The simulation program operates on the basis of 512 azimuth-wedges per 360 degrees. Azimuth wedges are counted clockwise from north. The multisensor executive initiates the program for a new wedge (loop 1); the single-sensor function is executed by sensors A, B, and C for all functions in loop 2 for this wedge. At each set of 16 wedges, loop 2 is extended to include loop 3, the processing of the intersensor message buffer.

The sensor executive controls loops 2 and 3. At the start of loop 2 for sensors A, B, or C, channel management schedules the appropriate interrogations; the environment tape for each sensor is searched for scheduled DABS targets and all-calls; the reply model then determines the nature of the reply, which is processed, and reports are formulated by the reply processor. The surveillance processor next integrates the reports into a track, initiates a new track or drops a discontinued track. Finally, network management processes all tracks in the azimuth wedge under consideration. Although the Engineering Requirement does not stipulate when network management will be processed, it has been found during simulation that performing this function directly after surveillance processing is a very effective procedure because network management decisions are thereby based upon the most up-to-date track information.

Network Management Function

The network management function is described in detail in reference 2. The principle tasks in the order of performance are:

1. Calculating the cell index
2. Accessing the coverage map if: (a) a cell change has occurred, or (b) a sensor failure/recovery has taken place, or (c) a target is in the sensor's zenith cone.
3. Processing boundary transitions, if any, when found in task 2
4. Adjusting the sensor priority status
5. Checking and processing any track status transitions

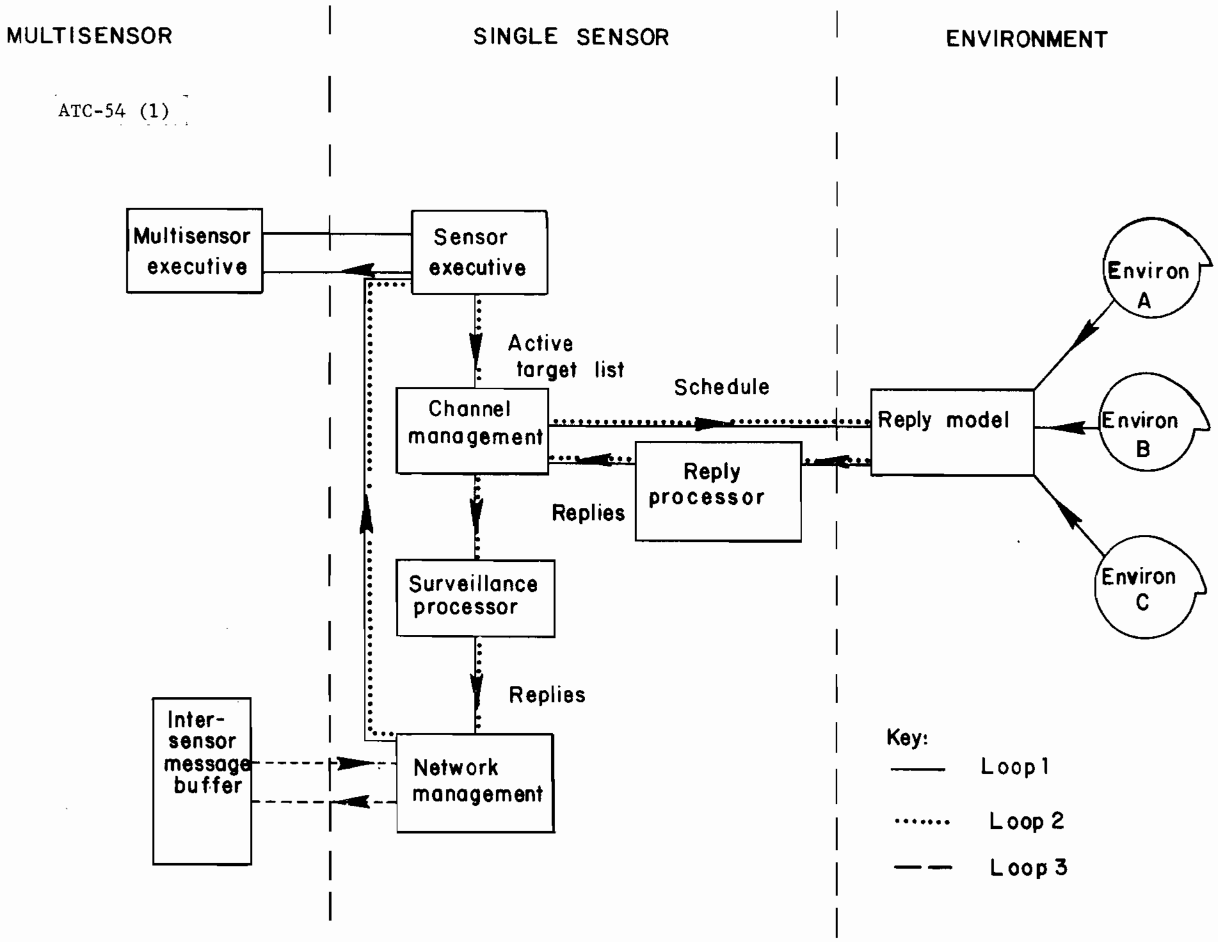

Fig. 1. Simulation program flow chart.

6. Servicing the out list by issuing appropriate track data messages

7. Processing the buffer of incoming messages if the time is appropriate.

The main purpose of the coverage map is to define the assignment of sensors that provide surveillance coverage and data link service for the volume of airspace containing the target. If changes in assignment occur, such as adding or deleting a sensor, then appropriate action must be taken. There is a set of rules for reading the assignments from the map, largely determined by the operational status of the network of sensors. In the simulation, a change of operational status was triggered by declaring a sensor down or up at predetermined instants of time. A change in assignment causes the issuance of network control messages and may cause a change in priority status of the local sensor.

A principal network management activity is to react to messages received from adjacent sensors. In the simulation process, an intersensor message buffer, capable of containing 90 messages, was accessed 32 times a scan. No overload condition was experienced even under extreme stress such as failure/recovery of an adjacent sensor.

The simulation of the network management function is incomplete in some respects that do not affect the assessment of its performance, e.g., no Intermittent Positive Control (IPC) interaction or interaction with air traffic centers was simulated and no ATCRBS targets were considered.

III. THE ENVIRONMENT MODEL

In order to test the network management function, the air traffic environment had to be simulated. Due to the fact that our primary interest was to test the system in the most difficult circumstances, the air traffic model had to reflect the maximum sensor target load with a high degree of target clustering and a realistic altitude distribution. The model chosen, which was developed by the Mitre Corporation [Ref. 3], is an extrapolation to the early 1980(s) of what is experienced today in the Los Angeles area. The model consists of a data tape that provides a report every four seconds on approximately 800 targets. Figure 2 illustrates the target distribution over the area at the start of the tape. For the simulation, only the first 100 scans of the tape were used. Each report consists of position, velocity, aircraft type, heading, turning rate, origin and destination of flight for each aircraft in the system.

The Mitre model was used to generate three new tapes representing the same air traffic but seen by the three selected sites (Long Beach, Ontario and Burbank). Each tape consists of an azimuth and time ordered list of reports as they would be acquired by a rotating radar (with a 4-second scan period) at each site viewing the traffic in the Mitre model. The reported positions represent intersections of the radar beam with the aircraft trajectory determined by the discrete (in time) positions of the aircraft in the model. The report consists of true azimuth, true range, altitude, and turn rate directly derived from the traffic model. In addition, a model for signal attenuation and measurement error generates a measured range, measured azimuth and down-link power.

The model for measurement error consists of white Gaussian noise with zero mean and a 100-ft standard deviation range, and 0.15° for azimuth. The signal attenuation model consists of a characterization of the down-linked power at boresight determined by a simplified model of aircraft transmitter power, path loss, and site antenna pattern. The tapes were edited to extract some 20 special flights to be used as the traffic environment for the first portion of the simulation concerned with checking detailed logic (Section 5). The full tapes were used while gathering operational characteristics (Section 6).

ATC-54 (2)

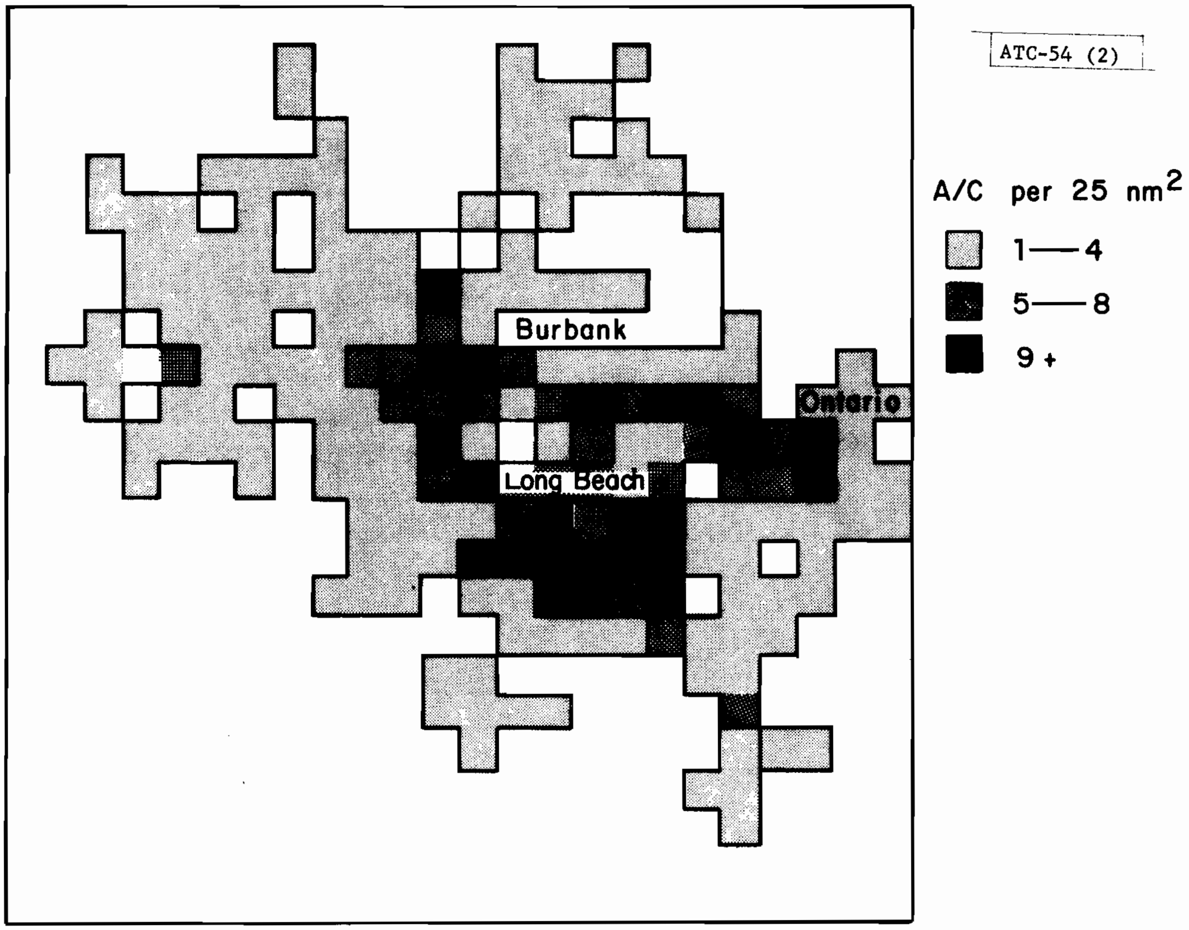

Fig. 2. Aircraft density in Los Angeles Basin (MITRE traffic model).

IV. COVERAGE MAP

The DABS sites used in the simulation model are Ontario, Long Beach, and Burbank. Their location relates to the traffic area as illustrated in Fig. 3, which also indicates the assumed maximum range of coverage for each sensor (≃ 60 nmi). No natural or man-made obstacles are considered. Flat earth and an antenna pedestal height of zero have been assumed.

The coverage and priority assignments under these assumptions (see Fig. 4) are based strictly on proximity. These two-dimensional assignments are completed in the vertical dimension by specification of the lower cutoff elevation angle of the coverage cone of each site. The elevation angle is clearly a function of the assumed antenna pattern. In the simulation process, a uniform cutoff angle of $1/2^{o}$ has been assumed. In order to translate the tri-dimensional assignments into a lookup table of tractable dimensions, the area is overlaid with the grid illustrated in Fig. 5. Vertical coverage is specified in terms of altitude ranges. In each cell the first sensor listed is assigned to ground level. An altitude (referred to as the altitude breakpoint) that approximates the vertical coverage capability in the cell is specified for the remaining sensor(s).

For a given target location (ρ, θ, H), the cell number can be identified readily with the simple algorithm of Table 1. By comparing the target altitude, H, against the altitude breakpoints and retaining the first NMAS (system parameter) of the sensors, whose breakpoints are lower than H, the "assigned" sensors can be identified for each target. The structure of the three maps is explained in Reference 2. First, the width of the altitude induced zone of overlap at the boundary of primary zone has to be determined. The overlap is the consequence of using slant range instead of ground range to locate the target on the coverage map. (The need for considering overlap in the construction of the map was explained in detail in Appendix A of Reference 2.) The overlap area of the three maps is implemented in each grid in terms of integral cells to form the "transition zone" of the coverage map. On an individual map, the transition zone then constitutes a portion of the primary area of the local sensor in which "primary assignment" must be negotiated with the adjacent sensor sharing the overlap area as explained in Reference 2. Figures 6 through 8 present the completed coverage maps for the three sites.

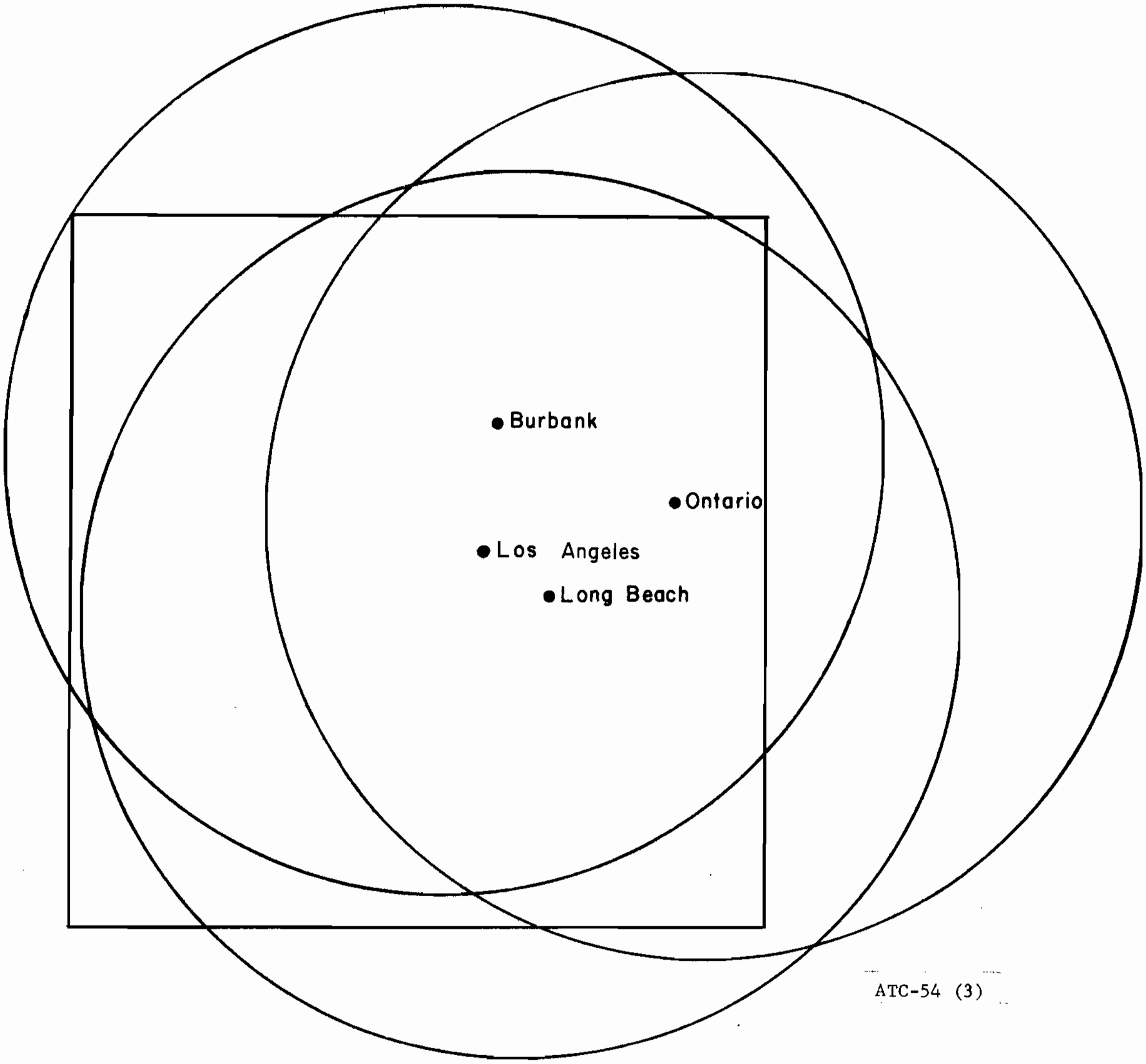

Fig. 3. DABS sites vs traffic area.

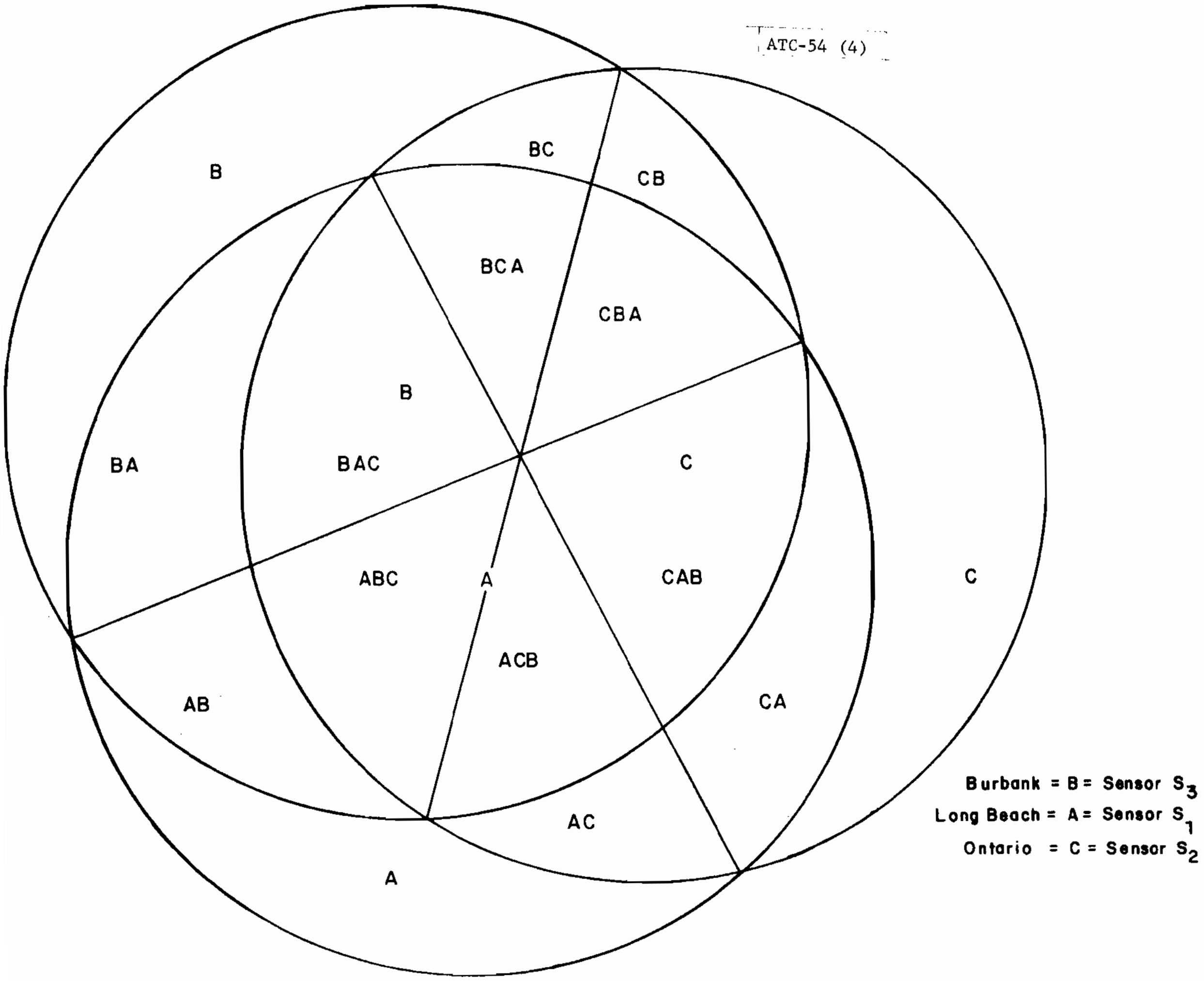

Fig. 4. Coverage assignments.

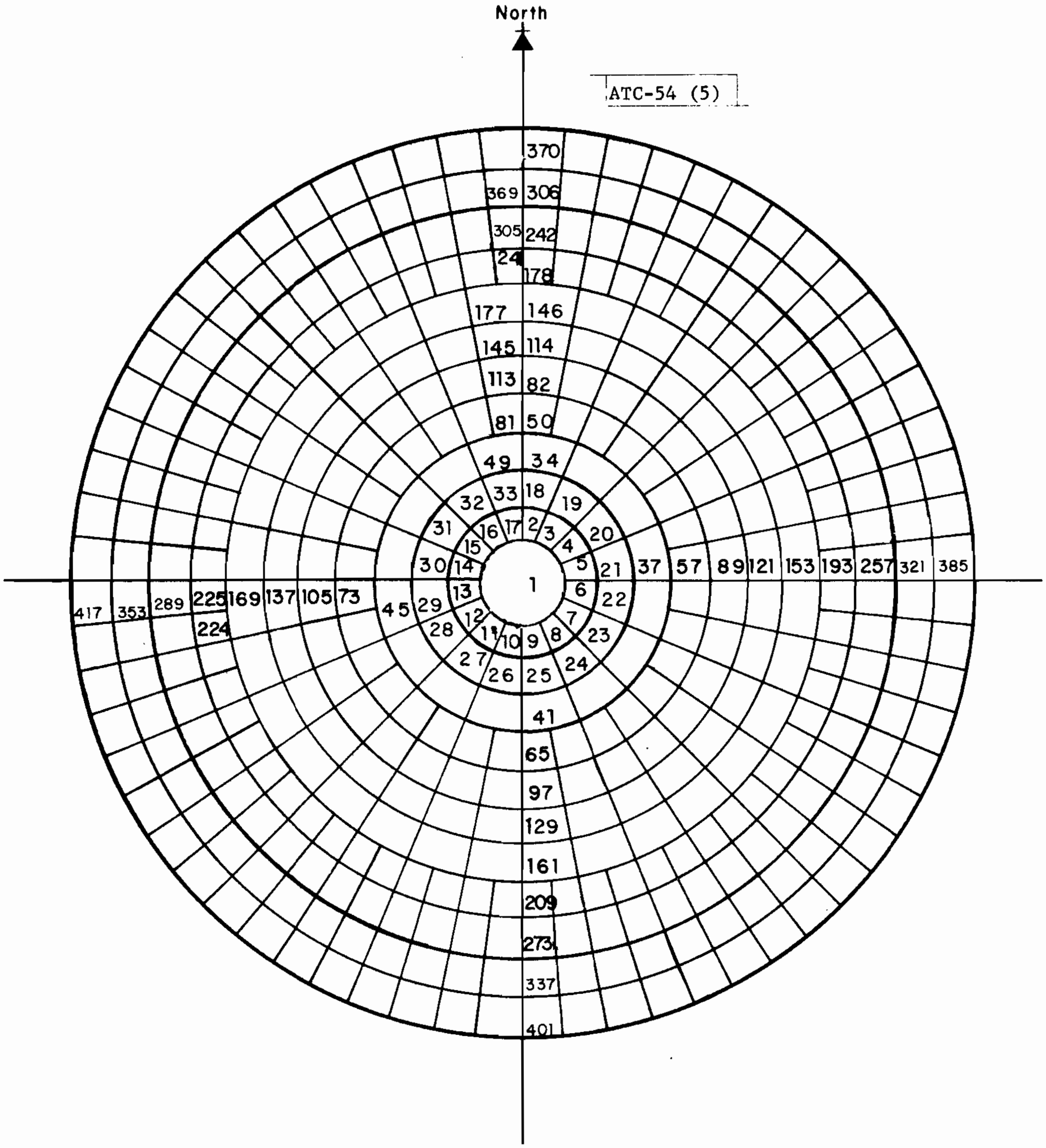

Fig. 5. Grid structure.

TABLE 1

ALGORITHM FOR CALCULATION OF CELL INDEX 1

Let ρ and θ represent the measured target position (16 bits for range in range units, and 14 bits for azimuth in azimuth units).*

Let θ_1, θ_2, and θ_3 represent the quantized azimuth fields comprised of the 6, 5, and 4 most significant bits of θ.

Let X_1 and X_2 represent the quantized range fields comprised of the 5 and 6 most significant bits of ρ.

Cell Index I can then be obtained via the algorithm:

If $(X_1 - 8 = Y) \geq 0$, $I = 64\,Y + 690 + \theta_1$

Otherwise

if $(X_2 - 8 = Z) \geq 0$, $I = 64\,Z + 178 + \theta_1$

Otherwise

if $(X_2 - 4 = R) \geq 0$, $I = 32\,R + 50\,\theta_1$

Otherwise

if $(X_2 - 1 = Q) \geq 0$, $I = 16\,Q + 2 + \theta_3$

Otherwise

$I = 1$

---

*One range unit equals approximately 30 ft, and one azimuth unit equals $\pi\, 2^{-13}$ radian.

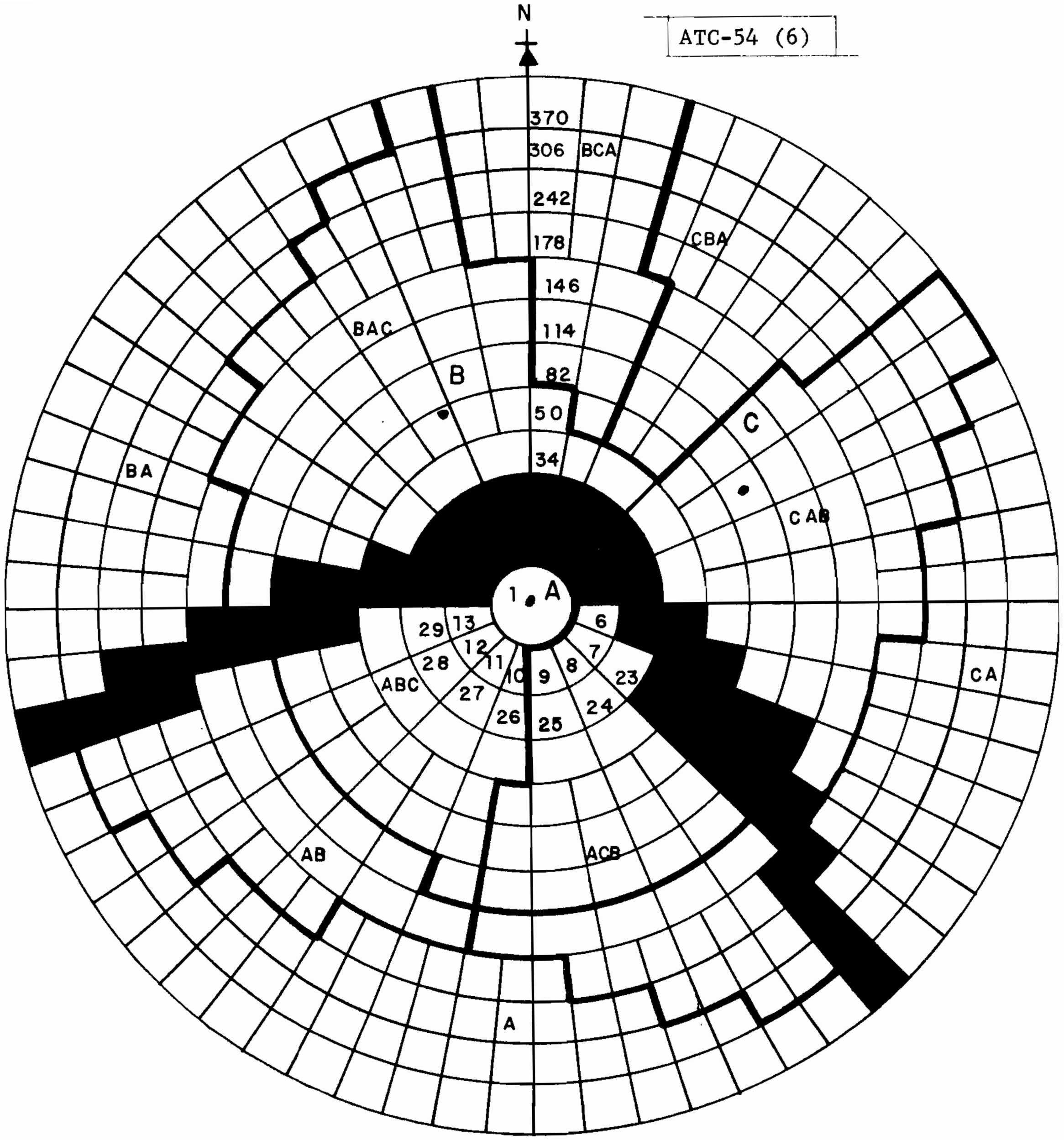

Fig. 6. Map for Long Beach (Sensor A).

ATC-54 (7)

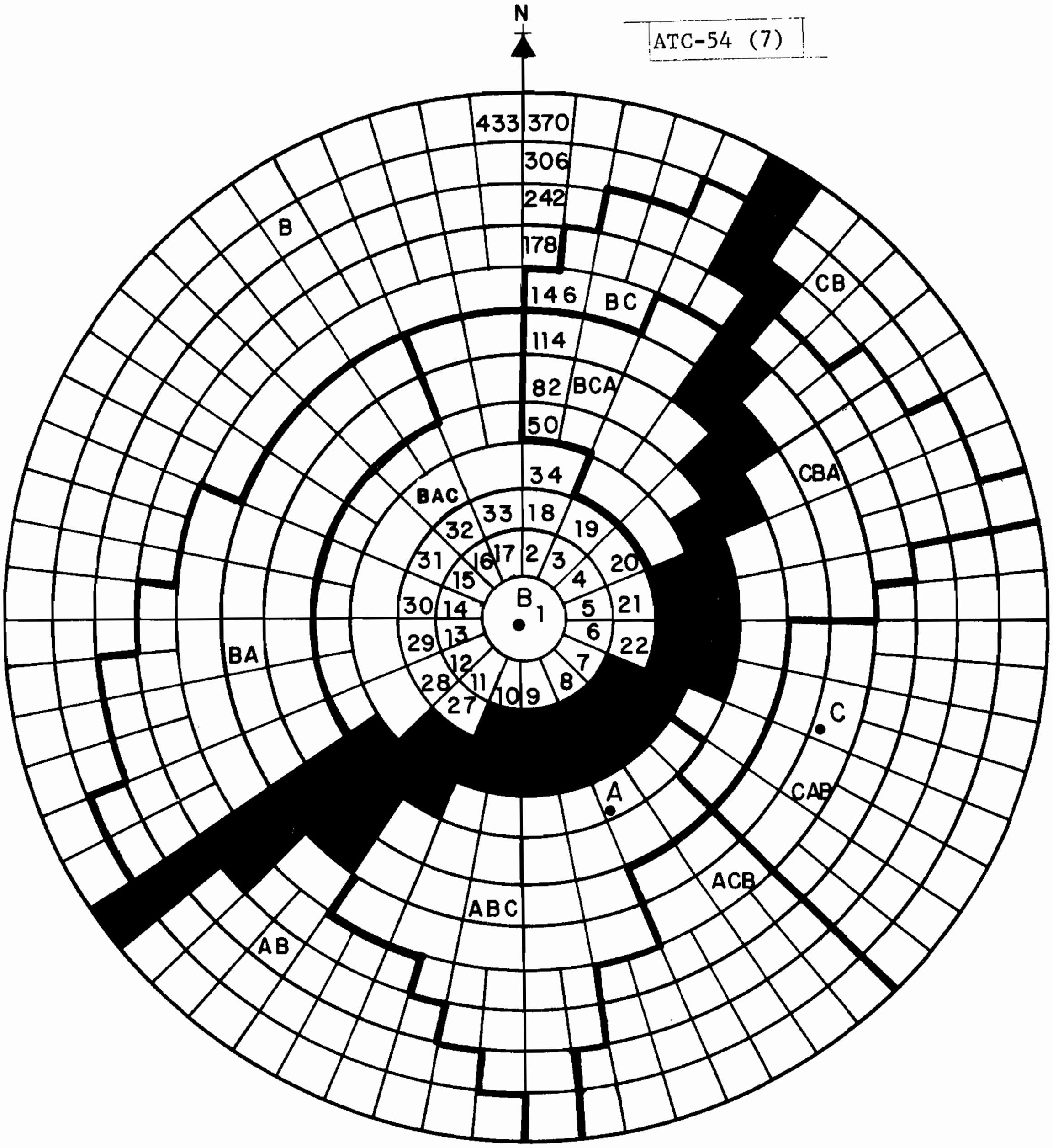

Fig. 7. Map for Burbank (Sensor B).

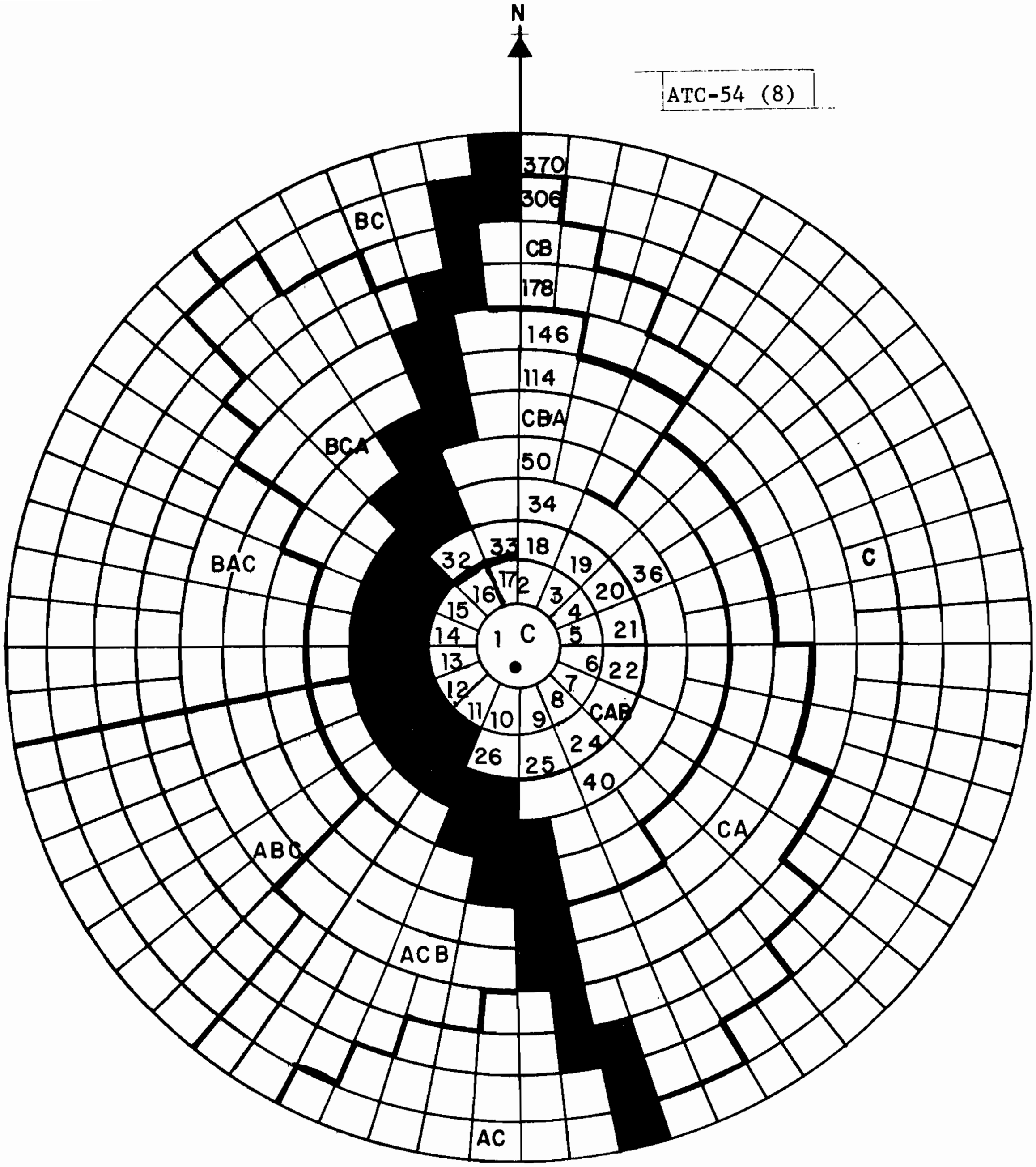

Fig. 8. Map for Ontario (Sensor C).

V. CASE STUDIES

A major reason for the relative complexity of the network management function is the need to cope with the "exceptional case," such as an aircraft going into a fade for which the local sensor has data link and IPC responsibility, or an aircraft "popping up" in a coverage volume where assignment of primary responsibility has to be negotiated among adjacent sensors. To test each detail of the logic of network management, some 20 flights were selected in which as many "exceptional cases" as possible occurred, thus subjecting the logic to maximum stress in terms of rapid sequence of events and complexity. All network management activity, in terms of message output and internal state changes, was recorded and analyzed in detail.

Figures 9 through 13 and Tables 2 through 6 illustrate five "exceptional case" flights, including a summary of the analysis. The figures present the flight trajectory superimposed on the relevant part of the coverage maps of the sites involved. Figures 6, 7, and 8 provide the cell indices of the sensor assignments. The letter T, preceded by a cell index, indicates that the cell is situated in the "transition area" of the coverage map. Each small square on the illustrated trajectory corresponds to a scan listed in the summary tables. The tables indicate several internal network management states:

1. RTN designates the type of return used for updating the track.

   A = all-call
   D = DABS rollcall
   E = external

2. PS is the priority status adopted.

   N = undetermined
   P = primary
   P_T = temporary primary
   S = secondary
   S_T = temporary secondary

3. S is the track status

   S_0 = undetermined
   S_1 = coast
   S_2 = tracking on all-call
   S_3 = tracking on external rollcall
   S_4 = tracking on local rollcall

An entry in a particular column for a particular scan is listed only if it is the result of a network management decision during that scan or if a significant change occurred.

Analysis of Case 1 (Figure 9 and Table 2)

At scan 1, both sensors acquire the aircraft on all-call. Since the target is in the zenith cone of sensor B (Burbank), that sensor requests external track data from the next assigned sensor, sensor A (Long Beach), during scan 2. Because the track became well established at sensor A, the request is promptly satisfied with a Data Start message, and the exchange of standby track data now continues uninterrupted during the following scans. At scan 8, sensor B experiences a miss that causes it to hand off primary status to sensor A on a temporary basis. Sensor B continues its track on external reports until scan 11 when it reacquires and rescinds the hand-off of its primary status to sensor A. At scan 17, the target leaves the zenith cone of sensor B, which notifies sensor A to discontinue sending track data. At scan 42, the target simultaneously enters the zenith cone of sensor A and its primary coverage area. It requests standby track data from sensor B and imposes permanent secondary status on sensor B while becoming primary itself.

Analysis of Case 2 (Figure 10 and Table 3)

Although the maximum number of assigned sensors is two, it is possible that three sensors are assigned in a particular volume of airspace; this is due to quantization of the coverage map. On the sensor A coverage map, sensors A and C are assigned. On the sensor C coverage map, sensors C and A (in that order of priority) are assigned. On the sensor B coverage map, sensors C and B are assigned. The aircraft also "pops up" in the transition zone between sensors A and C requiring some initial negotiation on priority assignment.

At scan 7, sensor C discovers that sensor B has been assigned instead of sensor A. Since sensor C is not aware of the fact that sensor B has the target already under surveillance, it attempts to introduce it to sensor B via a Data Start message. Sensor B promptly replies with a Cancel Request, which is simultaneously an acknowledgment and a request to discontinue the track data exchange. At scan 24, sensor A discovers that it is no longer assigned and drops the track. At sensor C, a fade occurs, and it requests assistance from the other assigned sensor, which is sensor B. Because it was primary, it hands off that status to sensor B, which is now primary on a temporary basis (PS = P_T). Sensor C is temporarily secondary (PS = S_T).

During scan after scan, sensor C receives track data from sensor B allowing it to re-acquire the target finally on scan 27. Sensor C cancels the request for data and (in the same message) cancels the priority handoff. On scan 43, the target enters the secondary zone of sensor C. It promptly hands the primary status (on a permanent basis) to sensor B, which accepts it.

ATC-54 (9)

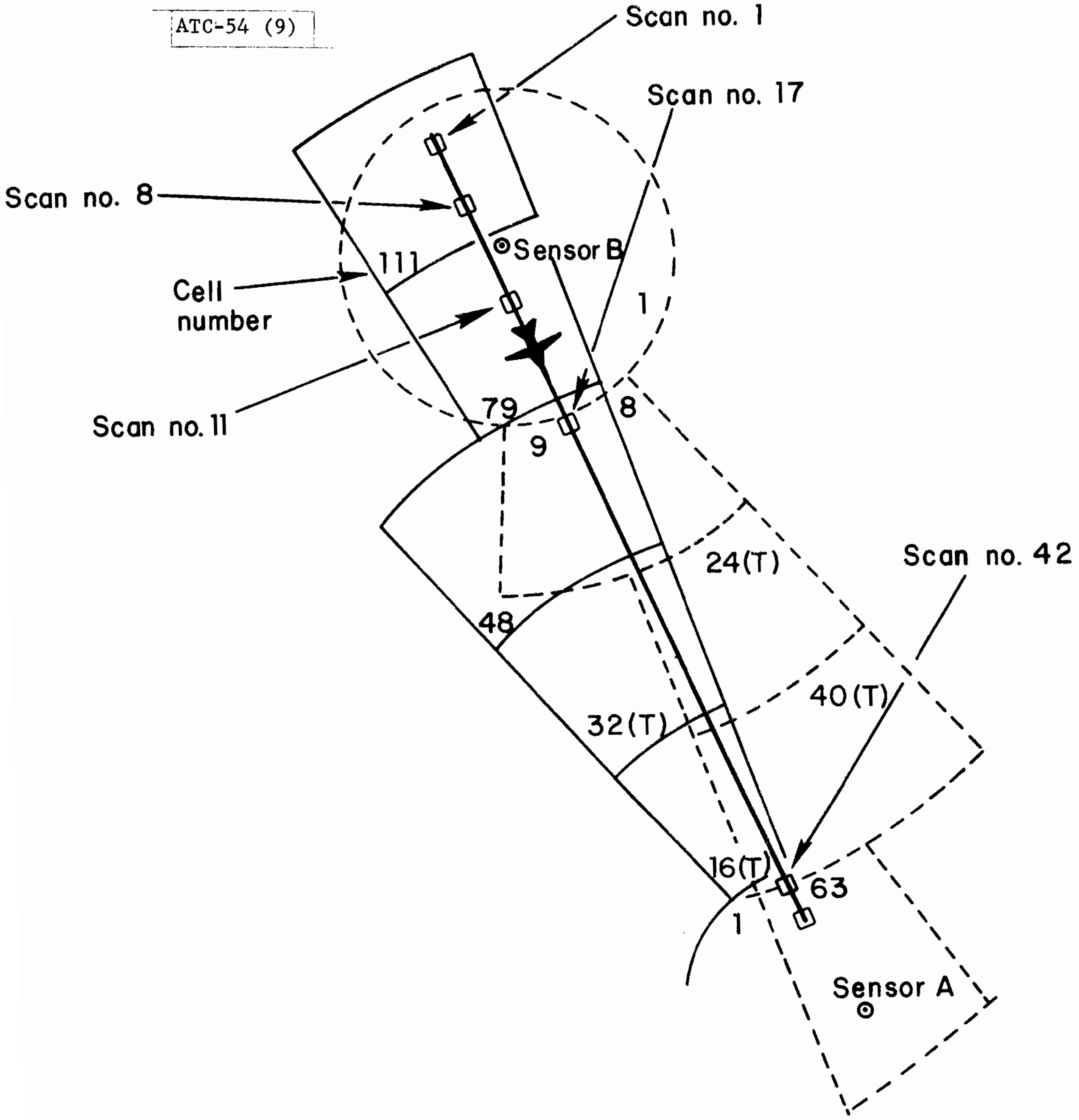

Fig. 9. Trajectory for Case 1.

TABLE 2

SUMMARY FOR CASE 1

	Sensor A					Sensor B					
Scan No.	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell	Activities
1	A	N	S_0 S_2			A	N	S_0, S_2 S_2			
2	D	S	S_4	B, A	111	D	P	S_4	B, A	1	B: Data request → A A: Data start → B
3	D					D					A: Track data → B
4	D					D					A: Track data → B
5	D					D					A: Track data → B
6	D					D					A: Track data → B
7	D					D					A: Track data → B
8	D	P_T		B, A	79	Miss E	S_T	S_1 S_3			B: Temp. handoff → A A: Track data → B
9	D					E					A: Track data → B

TABLE 2

SUMMARY FOR CASE 1 (cont.)

	Sensor A					Sensor B					
Scan No.	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell	Activities
10	D					E					A: Track data → B
11	D	S				D	P	S_4			B: Cancel temp. handoff → B A: Track data → B
16	D			B, A	48	D					A: Track data → B
17	D					D			B, A	9	B: Cancel request → A A: Data stop → B
35 36 37	D			B, A	16(T)	D			B, A	40(T)	
42	D	P		A, B	1	D		S			A: Data request → B Perm. sec. handoff → B B: Accept perm. sec. handoff A Data start → A
43	D					D			A, B	63	
44	D					D					B: Track data → A

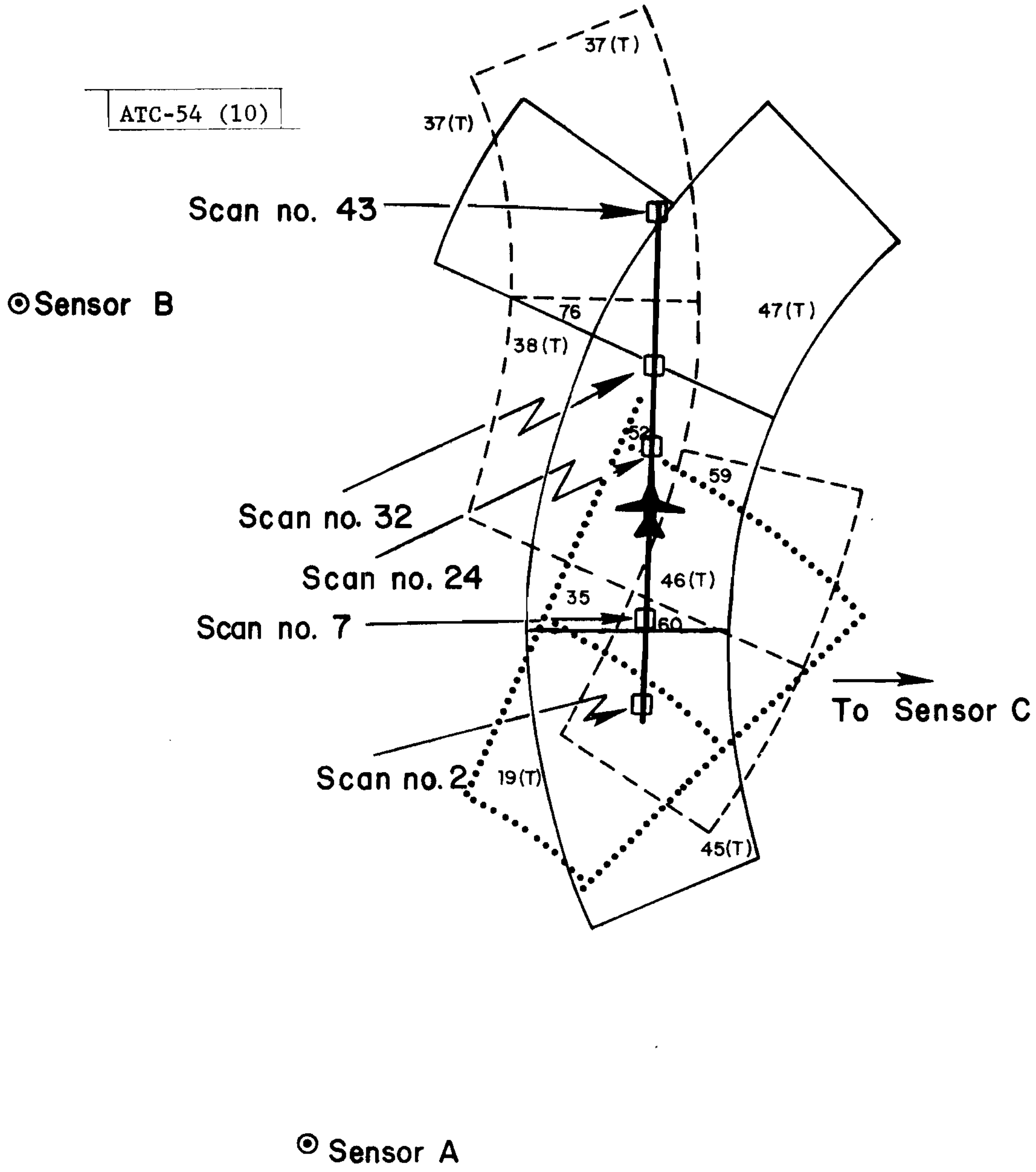

Fig. 10. Trajectory for Case 2.

TABLE 3

SUMMARY FOR CASE 2

	SENSOR A					SENSOR B					SENSOR C					
Scan No.	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell	Message Exchange
1											A	N	S_0 S_1			
2	A E	N S	S_0 S_2 S_3			A	N	S_0 S_2			D	P	S_4	C, A	45(T)	C: Request for primary → A Data start → A A: Primary approval → C
3	D		S_4	A, C	19(T)	D	S	S_4	C, B	60	D					A: Cancel request → C C: Data stop → A B: Data start → C C: Cancel request → B B: Data stop → C
5	D			A, C	35	D					D					
7	D					D					D			C, B	46(T)	C: Data start → B B: Cancel request → C C: Data stop → B

TABLE 3
SUMMARY FOR CASE 2 (cont.)

	SENSOR A					SENSOR B					SENSOR C					
Scan No.	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell	Activities
11	D					D			B, C	59(T)	D					
14	D					D			B, C	38(T)	D					
23	D					D					D					
24	D	Deletes		C, B	52	D	PT				Miss E	S_T	S_1 S_3			C: Data request and prim. handoff → B B: Data start → C
25						D					E					B: Track data → C
26	D					D					E					B: Track data → C
27						D	S				E D	P	S_4			B: Track data → C C: Cancel request and cancel handoff → B B: Data stop → C

TABLE 3
SUMMARY FOR CASE 2 (cont.)

	SENSOR A					SENSOR B					SENSOR C					
Scan No.	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell	Activities
28						D					D					
32						D					D			C, B	47(T)	
38						D			B, C	37(T)	D					
43						D	P				D	S		B, C	76	C: Perm. handoff of Prim. → B B: Accept handoff → C

Analysis of Case 3 (Figure 11 and Table 4)

In this case again, due to map quantization, three sensors are assigned simultaneously. At the start of the flight, sensor C is the first to receive the all-call reply. However, when checking the position against its coverage map, sensor C realizes it is not assigned and deletes the track record. This process will not repeat itself because the assigned sensors will soon place the aircraft transponder in lock-out status.

At scan 3, both sensors A and B have established a firm track. Sensor B commands highest priority, thereby imposing secondary status upon sensor A. At scan 18, sensor C receives a Data Start from Sensor B and starts a new track. During scans 18 through 39 the three sensors remain assigned simultaneously until sensor A deletes. At scan 45, sensor B relinquishes primary status to sensor C.

Analysis of Case 4 (Figure 12 and Table 5)

Case 4 illustrates the mechanism of anticipating the fade that is likely to occur when an aircraft overlies the sensor. At scan 2, the tracks are established and, based upon its coverage map, sensor A assumes primary status, thereby forcing sensor B in secondary status. At scan 13, the trajectory enters the zenith-cone of sensor A which requests external track data from sensor B. At scan 29, the expected fade occurs and sensor A hands off its primary status to sensor B on a temporary basis. At scan 32, the fade is over and sensor A rescinds the temporary primary assignment to sensor B.

Analysis of Case 5 (Figure 13 and Table 6)

Case 5 illustrates the failure of an assigned sensor. At scan 13, sensor C stops operations, however, without having been able to distribute the appropriate sensor status message signaling failure. Sensor A no longer receives messages from sensor C, and at scan 18 declares an "inferred" failure. It is determined from the coverage map that for the given target at a 200-ft altitude, sensor B can be assigned. Sensor A provides the necessary track data to initiate a track record at sensor B, simultaneously imposing secondary status.

At scan 25, sensor C resumes normal operations and issues an "OK-status" message (not shown) to all adjacent connected sensors. Sensor B re-instates the "normal" reading mode for its coverage map, discovers that it is no longer assigned, and erases the track record. Sensor A provides sensor C with the necessary track data to re-instate the track and, in addition, hands it the primary assignment.

ATC-54 (11)

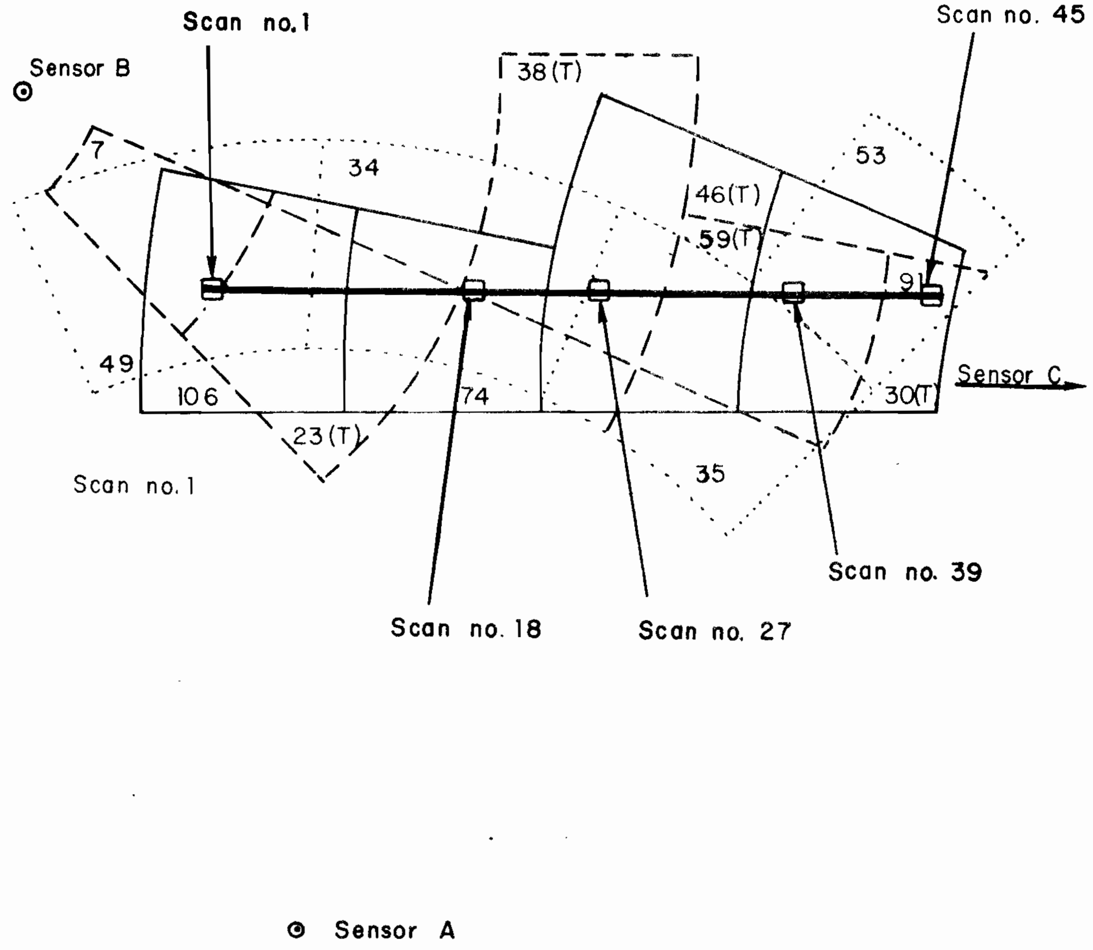

Fig. 11. Trajectory for Case 3.

TABLE 4
SUMMARY FOR CASE 3

SENSOR A						SENSOR B					SENSOR C					h	
Scan No.	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell		Activities
1											A	N	S_0				
2	A	N	S_0 S_2			A	N	S_0 S_2			A	Deletes		B, A	106	1010	
3	D	S	S_4	B, A	49	D	P		B, A	7						1020	A: **Data start → B** B: **Permanent handoff of sec. → A** B: **Cancel request → A**
4	D					D			B, A	23(T)						1030	A: **Data stop → B**
10	D			B, A	34	D										1093	
18	D					D			B, C	38(T)	E D	N S	S_0 S_3 S_4	B, C	74	1177	B: **Data start → C** C: **Cancel request → B** B: **Data stop → C**
19	D					D					D					1187	
24	D					D					D			C, B	46(T)	1240	
25	D					D					D					1250	

TABLE 4

SUMMARY FOR CASE 3 (cont.)

	SENSOR A					SENSOR B					SENSOR C					h	
Scan No.	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell		Activities
27	D			C, A	35	D					D					1270	A: Data start → C C: Cancel request → A A: Data stop → C
32	D					D			B, A	59(T)	D					1323	
37	D					D					D			C, A	30(T)	1375	C: Data start → A A: Cancel request → C C: Data stop → A
39	D	Deletes		C, B	53	D					D					1396	
40						D					D					1414	
45						D	S		C, B	91	D	P				1466	B: Permanent handoff of prim. → C C: Accept handoff → B
46						D					D					1476	

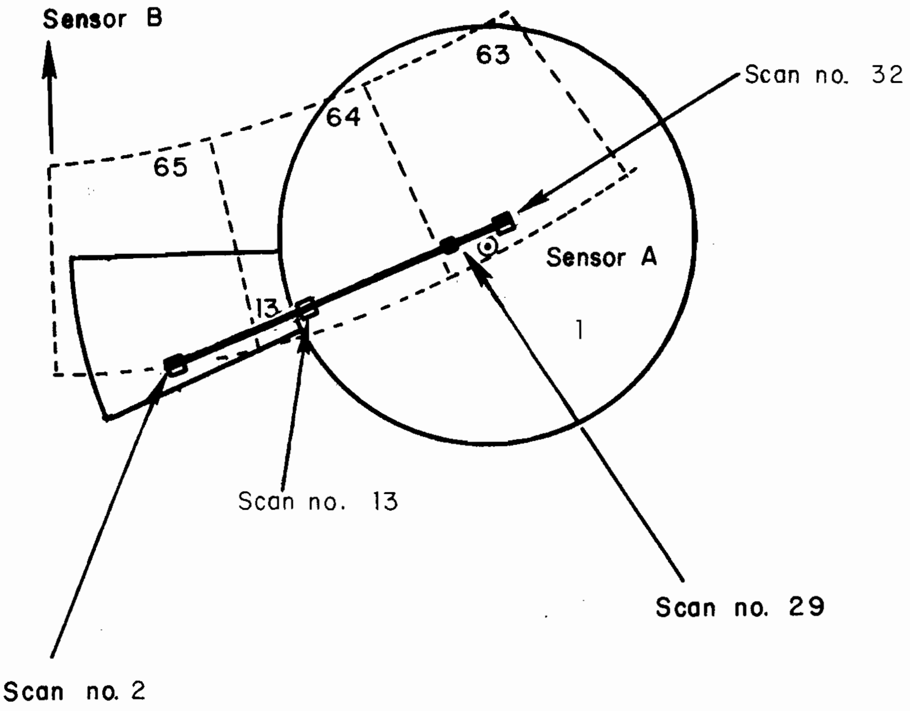

Fig. 12. Trajectory for Case 4.

TABLE 5
SUMMARY FOR TRAJECTORY CASE 4

SENSOR A						SENSOR B					SENSOR C					h	
Scan No.	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell		Activities
1	A	N	S_0 S_2			A	N	S_0 S_2								1000	
2	D	P	S_3 S_4	A, B	13	D	S	S_4	A, B	65							B: Data start → A A: Permanent handoff of signals → B : Cancel request → B B: Data stop → A
3	D					D											
13	D			A, B	1	D				64							A: Data request → B B: Data start → A
14	D					D											B: Track data → A
29	Miss E	S_T				D	P_T										B: Track data → A A: Temperature handoff → B
30	E					D											B: Track data → A
31	E					D											B: Track data → A
32	D	P				D	S										B: Track data → A A: Cancel handoff → B
33	D					D											B: Track data → A

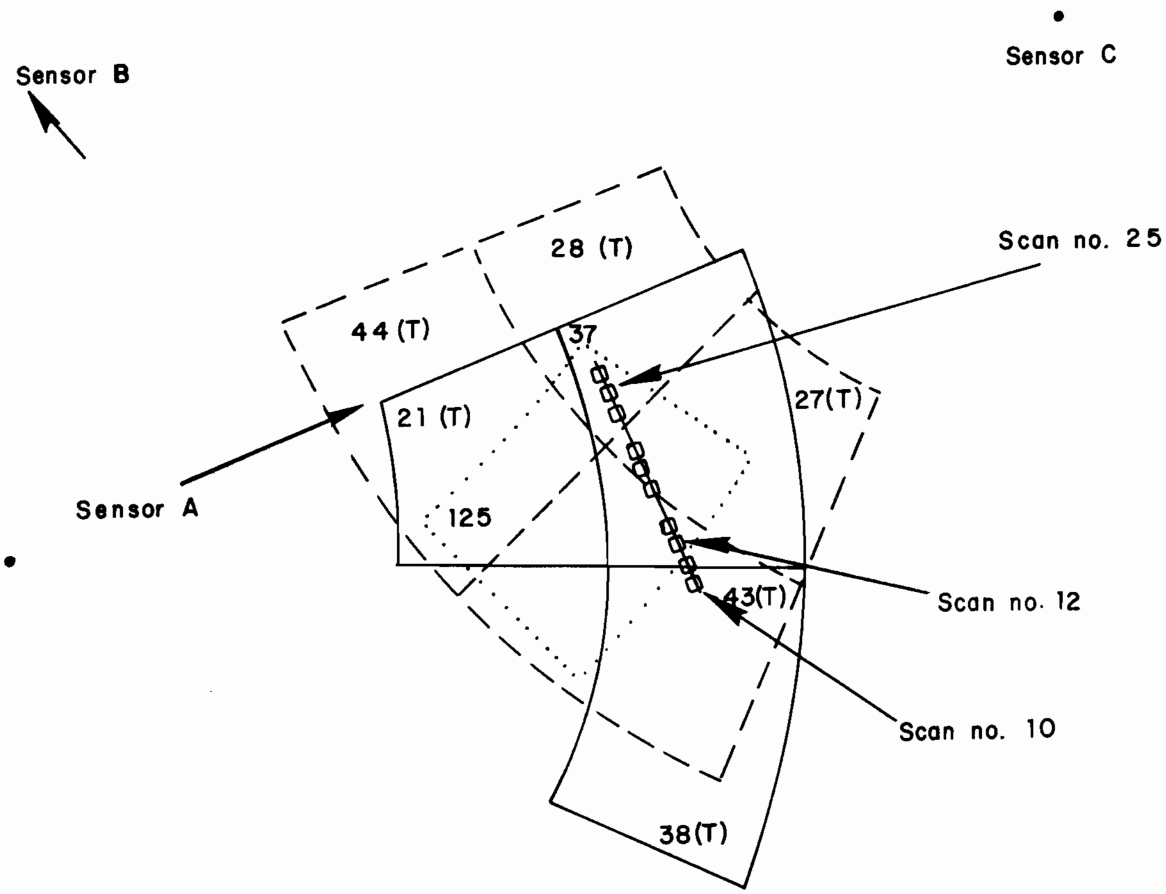

Fig. 13. Trajectory for Case 5.

TABLE 6
SUMMARY FOR CASE 5

	SENSOR A					SENSOR B					SENSOR C					h	
Scan No.	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell	RTN	PS	S	Assigned Sensors	Cell		Activities
10	D	P	S_4	A, C	38						D	S	S_4	A, C	43		
11	D										D						
12	D	S		C, A	37						Sensor down						A: Permanent primary handoff → C (PHP set)
13	D																
14	D																
18	D																
19	D	P				E D	N S	S_0 S_3 S_4	A, B	125							A: Perf. mon. function infers failure of Sensor C A: Data start → B Permanent handoff of sec. → B B: Cancel request → A A: Data stop → B
20	D					D											
24	D					D											
25	D	S		C, A	37	D	Deletes		C, A	125	Sensor up E D	P	S_0 S_3 S_4	C, A	28		A: Data start → C Permanent handoff of prim. → C C: Accept handoff → A C: Cancel request → A A: Data stop → C
26	D										D						

VI. OPERATIONAL CHARACTERISTICS

A summary of the results of the use of computer time and storage required by network management during normal operations and transients is presented in this section. Table 7 indicates the program size of the principal network management subtasks, the storage requirements for the coverage map, and principal network management lists. The size of the map is proportional to the maximum range of coverage of the radar. The lists are proportional to the number of targets under suveillance at a specific time. Table 8 is a summary of the program execution time for a load of 500 targets per sensor. The program execution time is an average of the CPU time for the three sensors over a total of 85,000 scan targets, or 500 targets over 170 scans.

The major portion of the network management logic is triggered by an event such as an aircraft crossing a surveillance boundary on the map or the start of a fade. Table 9 summarizes the average occurrence of particular events, e.g., on the average the coverage map is accessed for 8.31% of the aircraft, and all associated information transfer is performed. This could be the result of three events: (1) either the target is in the zenith cone, (2) its position places it in a different cell on the map as compared to the previous scan, or (3) the target was affected by major operational change in the network (a sensor failed or was restored). Similarly, 0.3% of the targets on an average scan was experiencing a fade, the occurrence of which is obviously strictly controlled by the choice of fade model.

Message Load During Normal Operations

The events summarized in Table 9 and the subsequent internal state changes cause message exchange with adjacent sensors. Figures 14 through 16 illustrate (over scans 18 to 38) the number and types of messages received by all three sensors. Sensors A, B, and C have a target load of 620, 280, and 440 targets, respectively. The sharp increase in the number of messages at scan 22 is a result of a sudden increase in the number of targets in the zenith cones of the three sensors.

Figure 1 illustrates sensor A at scan 22 receiving a large number of data requests on targets in the zenith cones of sensors B and C and simultaneously receiving data starts on targets in its own zenith cone.

The average number of messages exchanged per scan between sensors should be a key factor in determining the size of the transmission lines. Another factor is the number of messages caused by changing operational conditions in the network such as a failure/recovery of a sensor.

TABLE 7

PROGRAM SIZING

Program Size for Internal Network Management Tasks

		Bytes
Cell index calculation		350
Coverage map search		450
Boundary transition (adjacent sensor added or deleted)		500
Boundary transition (local sensor deleted)		250
Zenith cone		250
Sensor priority determination		800
Track status transitions		1300
Issuing track data messages		200
Formating of messages to be output		1150
Bit manipulation and miscellaneous		750
	Total	6000

Program Size for Processing Incoming Network Management Control Messages

		Bytes
Data start		1000
Data stop		100
Track data		1000
Data request		400
Cancel request		200
Permanent hand-off		100
Transition zone coordination		400
Bit manipulation and miscellaneous		800
	Total	4000

Storage Requirements

		Bytes
(a) Coverage map (60 nmi max range or 433 cells), 8 bytes per cell		3464
(b) Network management lists (for 400 targets), 12 bytes per target		4800
	Total	8264

TABLE 8

PROGRAM EXECUTION LINE PER 500 TARGETS

	msec/sec
Internal network management tasks	42.5
Time consumed interpreting coverage map (subset of the previous tasks)	2.5
Processing incoming network management control messages	11.0
Total	56.0

TABLE 9

PERCENTAGE OF TARGETS SUBJECTED TO SPECIAL NETWORK MANAGEMENT TASKS

	% Targets/Scan
Coverage map accessed	8.31
Boundary transition occurred (adjacent sensor added or deleted)	0.33
Boundary transition (local sensor deleted)	0.21
Fade occurred (track status enters S_1)	0.30
Track started or continued with external data (track status enters S_3)	0.30
Track enters stable condition (track status enters S_4)	0.46
Zenith cone logic used (subset of accessed coverage maps)	4.02

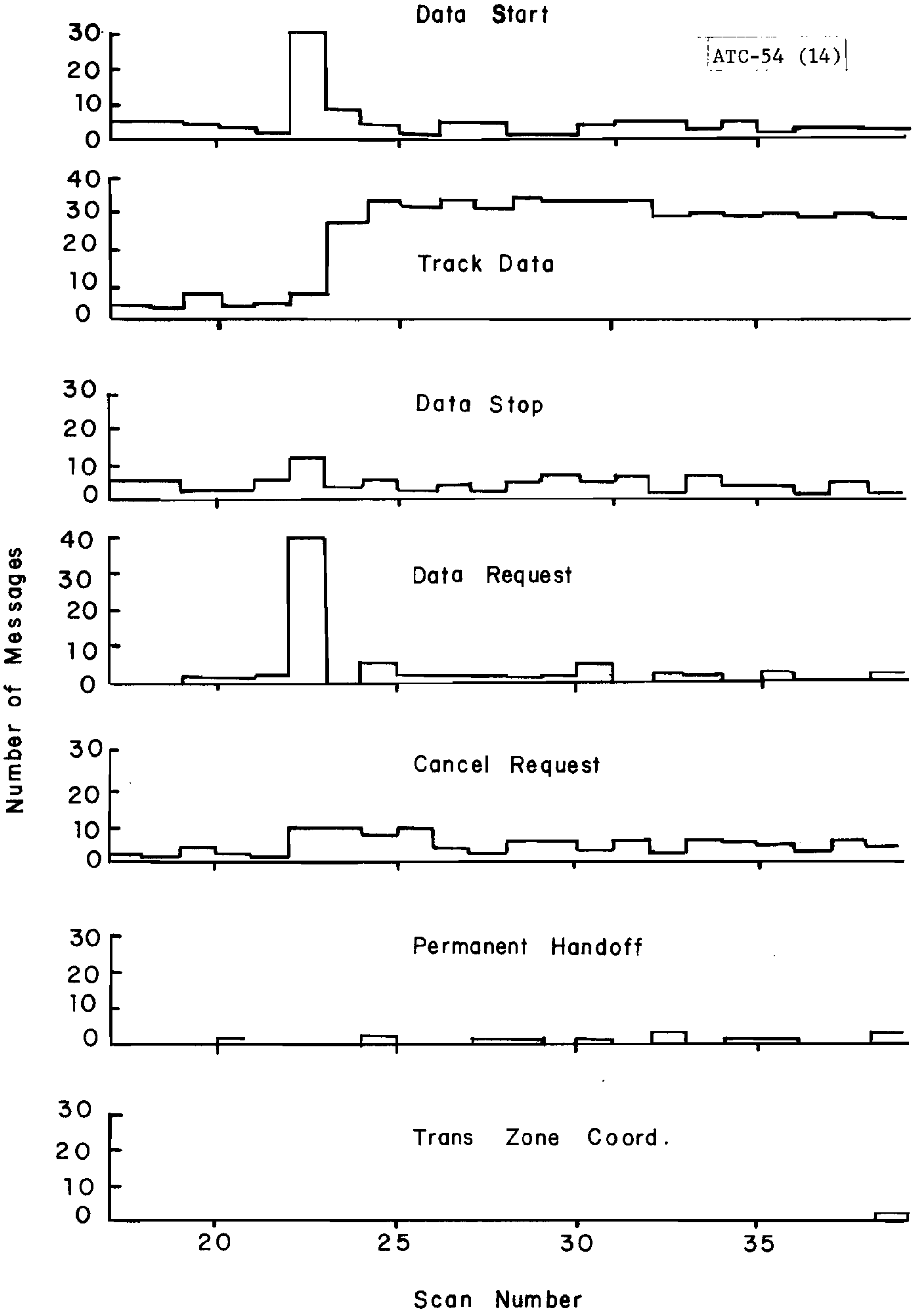

Fig. 14. Messages received per scan by Sensor A.

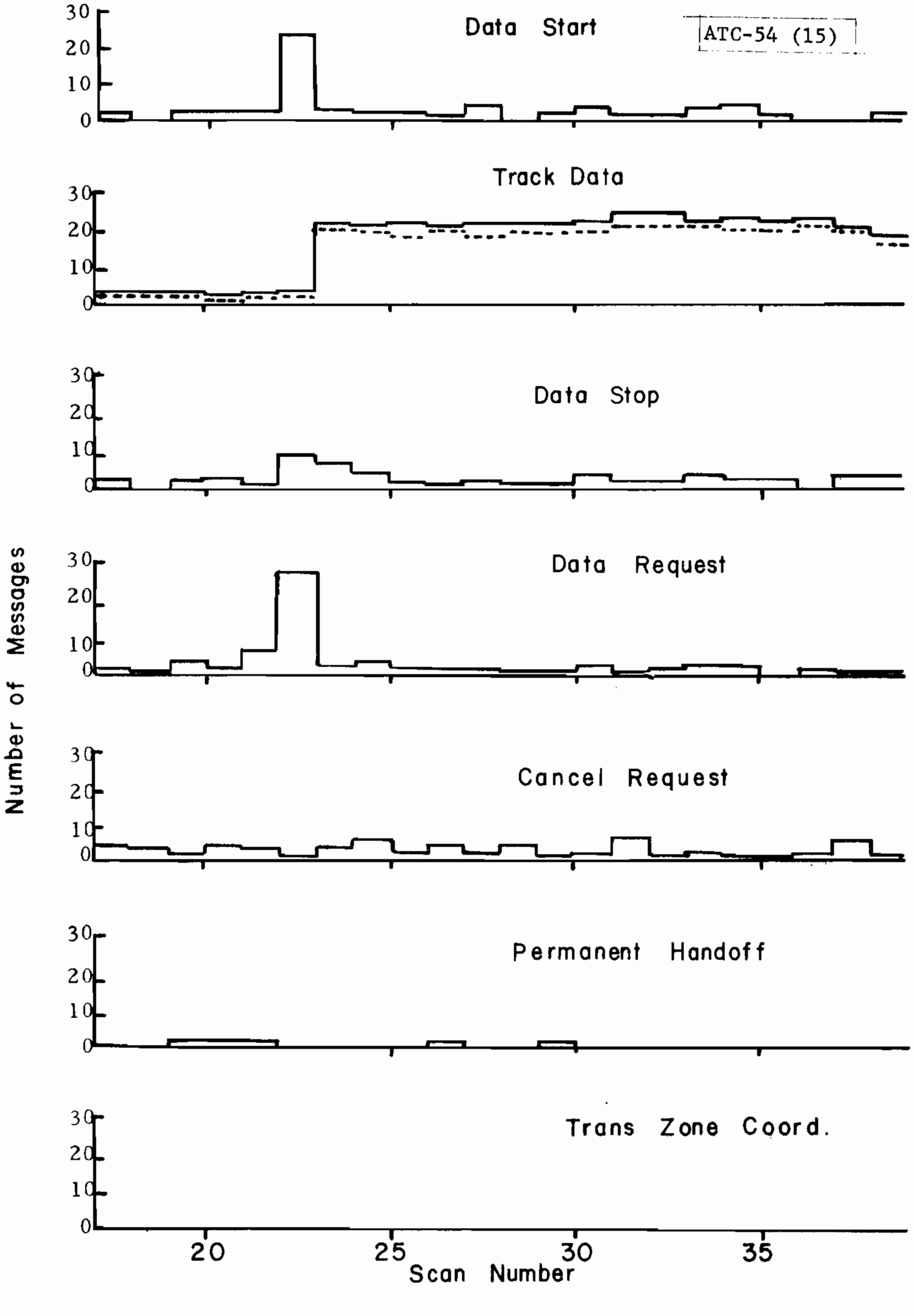

Fig. 15. Messages received per scan by Sensor B.

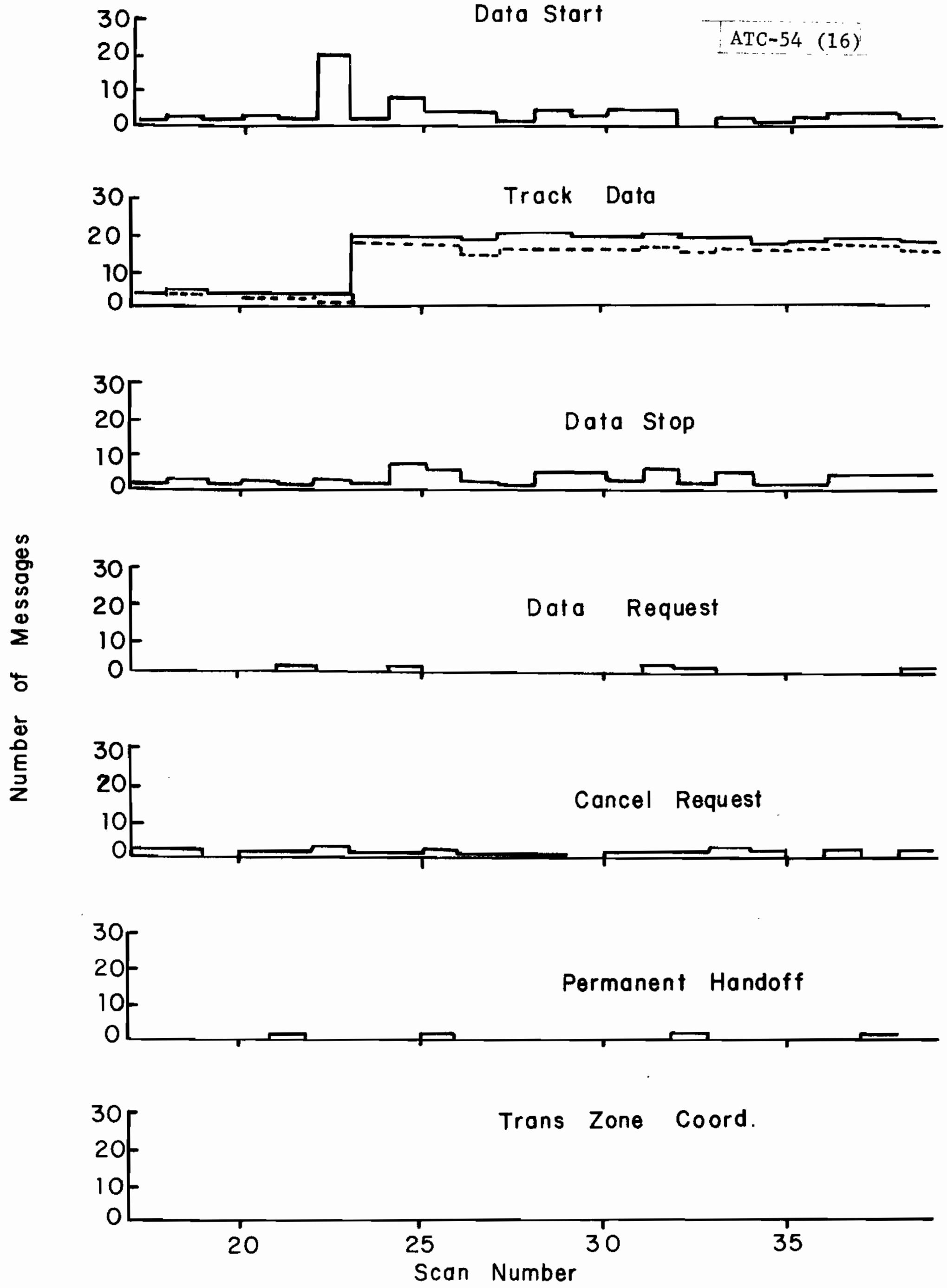

Fig. 16. Messages received per scan by Sensor C.

Message Load Caused by Failure/Recovery of a Sensor

In a network of several normally operating sensors, some types of failure may occur. The sensors routinely exchange status messages among themselves; consequently each sensor knows when its neighbors are operating satisfactorily. Two types of failure are identified. The first type of failure is when a particular sensor, monitoring its own performance, concludes that it is unable to perform satisfactorily and transmits a message indicating that it is in a state of failure. In that case, neighboring sensors know that the sensor has failed; this is called a positive failure. A second type of failure occurs when a given sensor is communicating with one of its neighbors and the communication suddenly stops. In this case, the local sensor does not know if the absence of messages is caused by a communications malfunction or failure of the adjacent sensor. This situation is known as an inferred failure. Inferred failure status is resolved by exchanging messages with other sensors that are connected to the presumed failed sensor by an alternate communications route. It is the responsibility of the sensor performance monitoring function to detect these failures. When failures occur, network management reconfigures the network to the extent possible to cover the area normally assigned to the faded sensor.

The configuration has been stored in the coverage maps as part of adaptation site. Two modes of reading the map are defined: (1) when all sensors are operating normally, and (2) when a failure of an adjacent sensor has been declared. If only an inferred failure has been determined, the presumption is that the sensor itself continues operating. In this case, it is necessary that the aircraft proceeding across the boundary toward the sensor, with which communication has been lost, be unlocked so that they can be acquired on that sensor's all-call interrogation. In this way, the aircraft will not come into the coverage of that sensor undetected. For either positive or inferred failure, the coverage boundary of the adjacent sensors automatically extends to attempt to cover the area where a failed sensor has been operating.

The simulation has sensor C (Ontario) fail at the beginning of scan 20. The failure-inference procedure, as described in reference 1, was not simulated. For simplicity, it is assumed that at scan 26 the failure is fully declared and all appropriate actions are taken by sensors 1 and 3. At scan 32, the recovery takes place and re-instatement of normal operations is started.

When a sensor fails, there is a sudden surge of messages among adjacent sensors to pick up the target load. At recovery of a sensor, a similar surge in communications occurs as a result of track information provided to the recovered sensor to initiate tracks on targets in its area of assignment. Sudden peak loads in message traffic may cause the communications buffers to be temporarily overloaded. A mechanism is provided in the network management design that artificially delays messages to be generated when such a "buffer-full" condition occurs. With a buffer size for 90 messages and the buffers emptied 32 times a scan, the simulation never caused such an overload condition to occur. Figure 17 illustrates how the traffic load from sensor C is divided between sensors A and B. Figures 18 through 21 illustrate the surge in the number of specific messages caused by the failure and recovery.

A failure/recovery situation causes an extra burden on the computers at all sites involved. The surge in messages received and issued causes the network management function to use more than its usual share of CPU time. Figure 22 illustrates the time in seconds per scan used by the network management for the failure/recovery of sensor B. At no time did the execution time exceed one second per scan. To study the total impact on the sensor caused by failure/recovery, it would be necessary to analyze the peak time requests of the other functions. This was beyond the scope of the present effort.

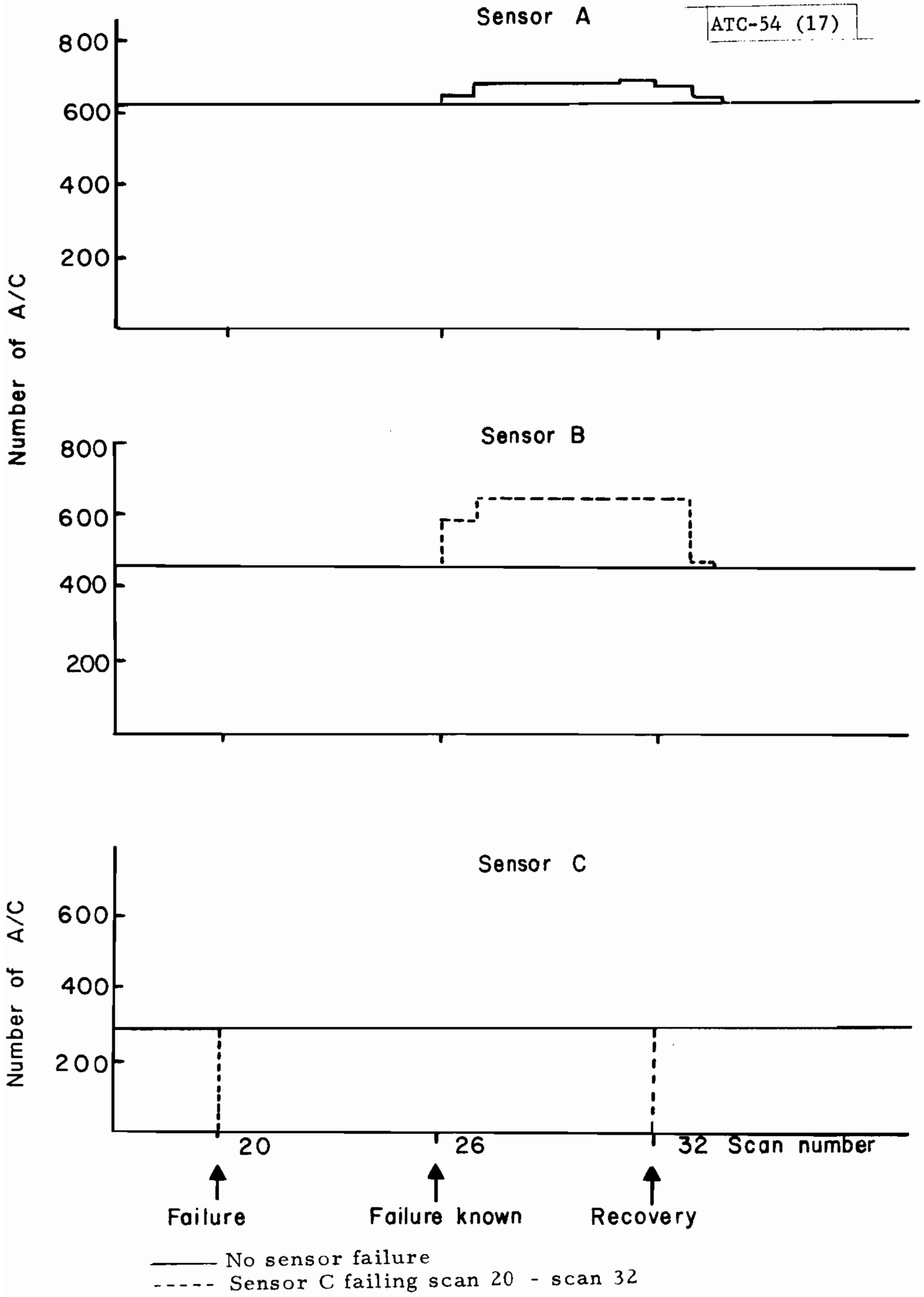

Fig. 17. Number of aircraft under surveillance.

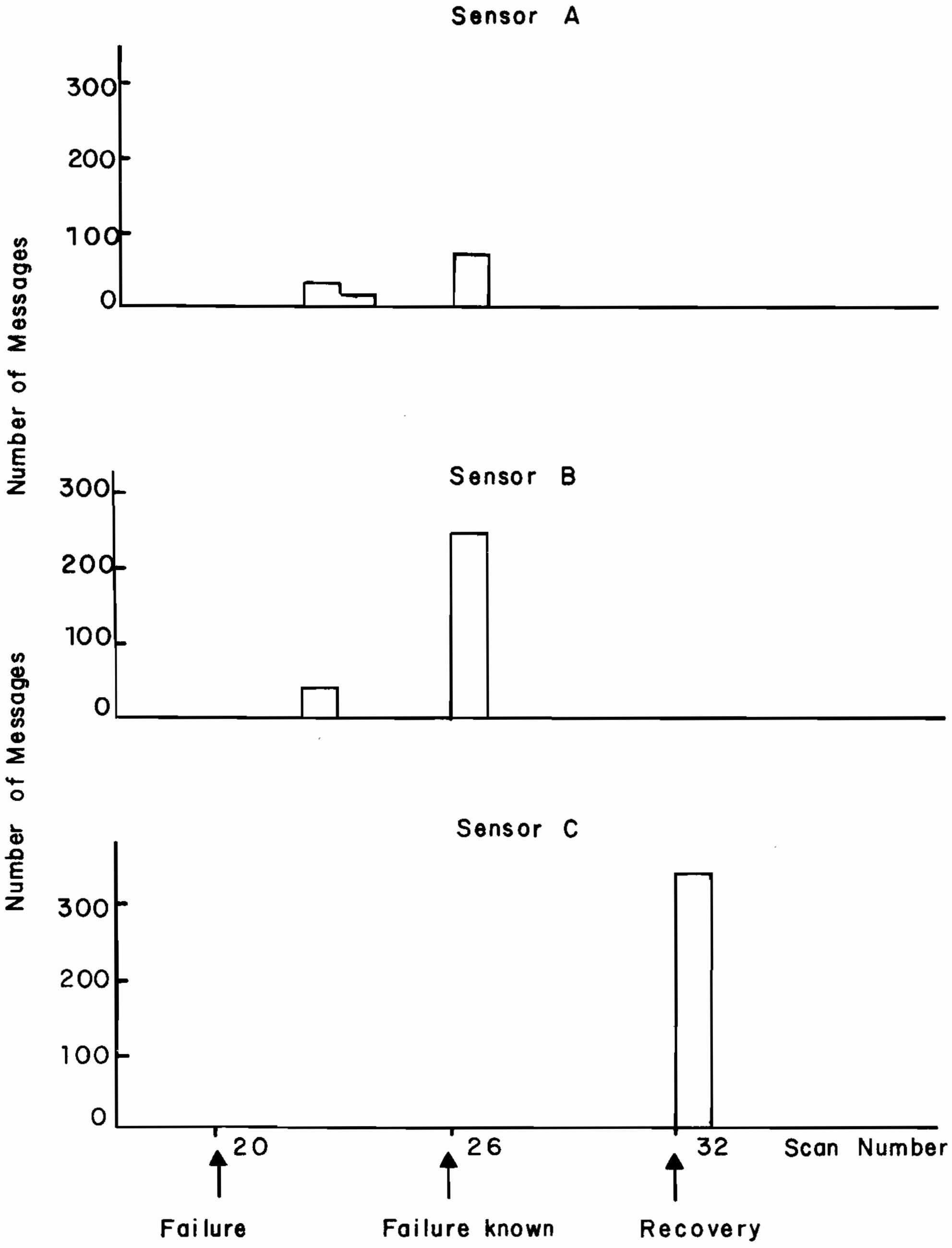

Fig. 18. Data start messages received per scan.

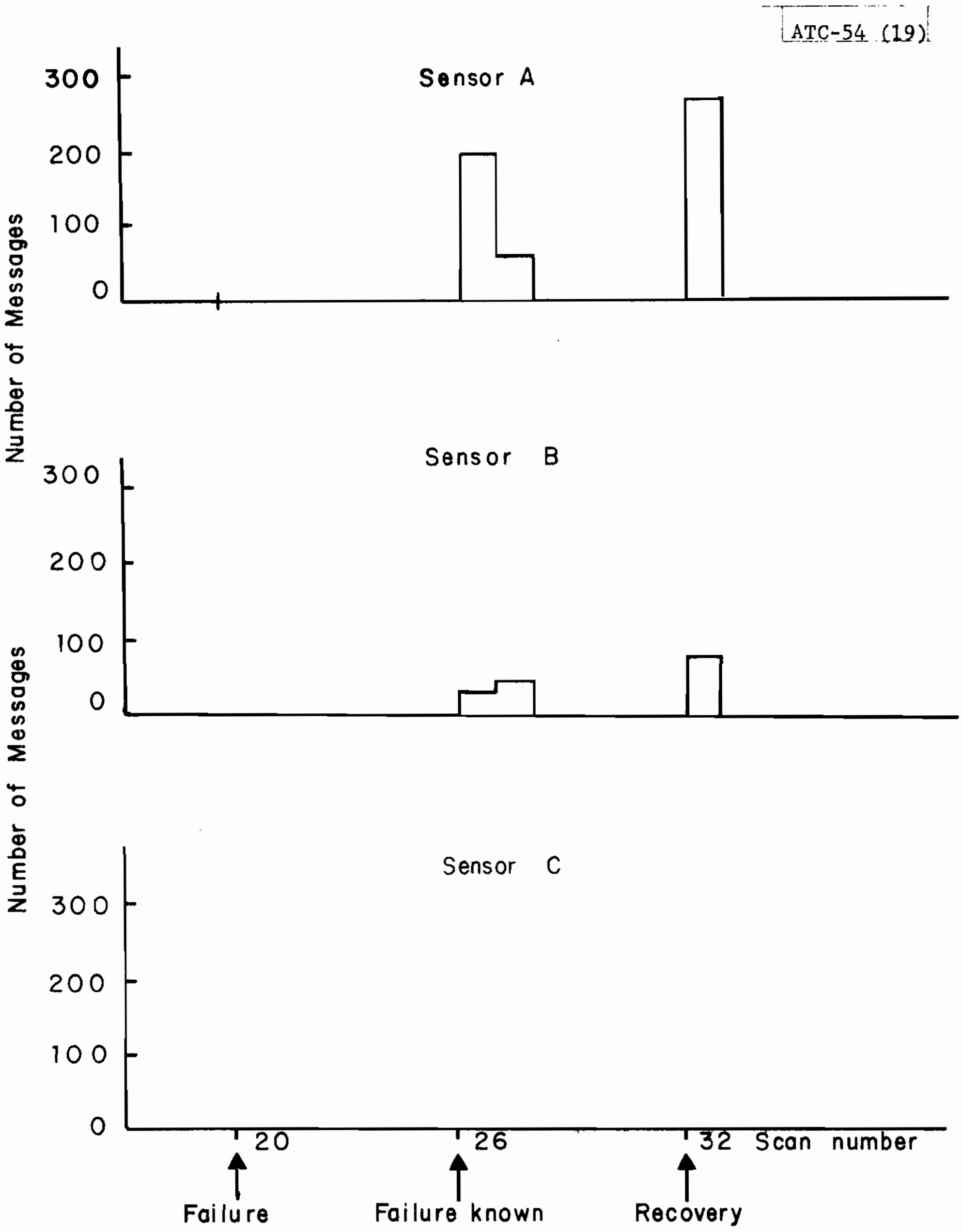

Fig. 19. Cancel requests received per scan.

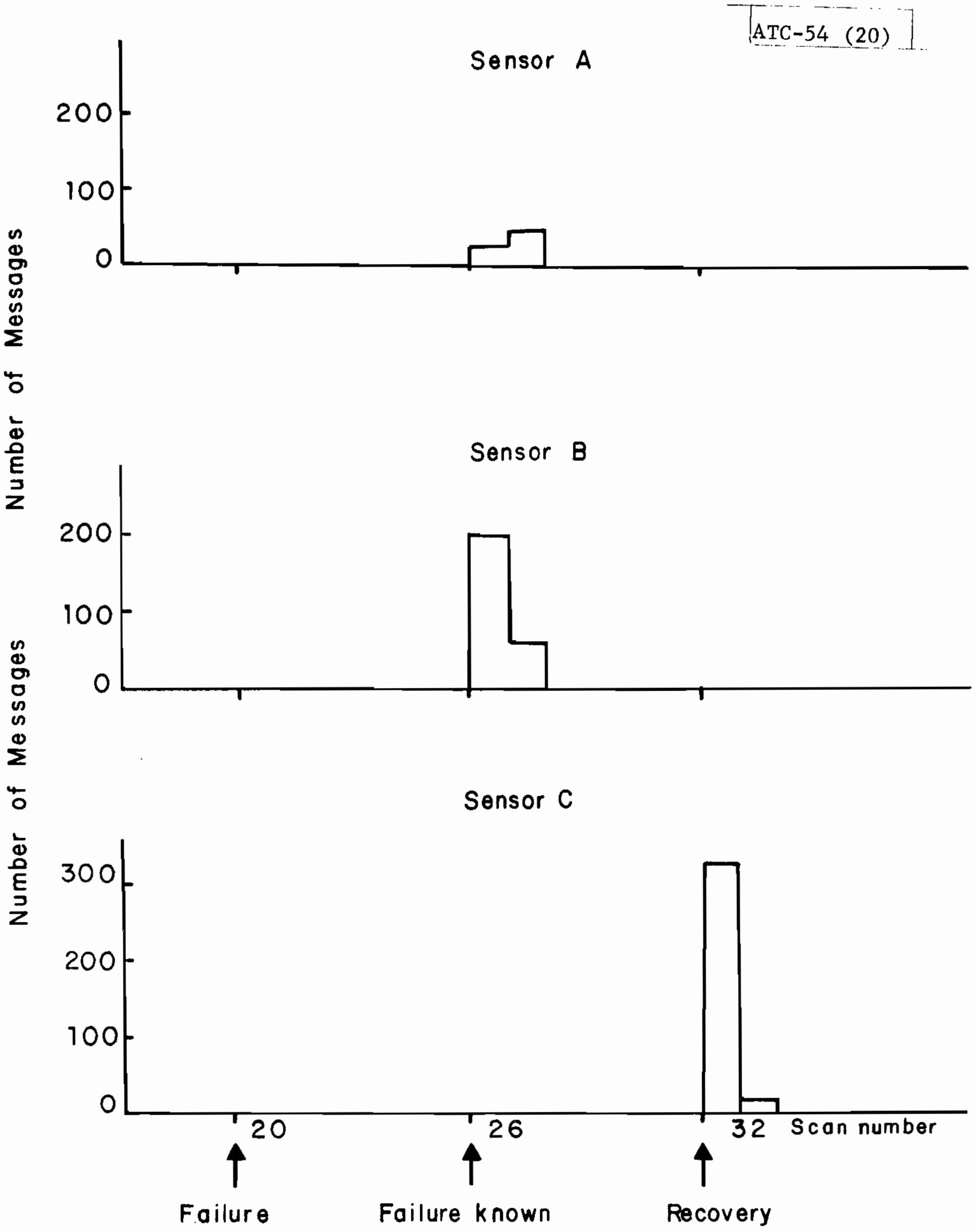

Fig. 20. Data stop messages received per scan.

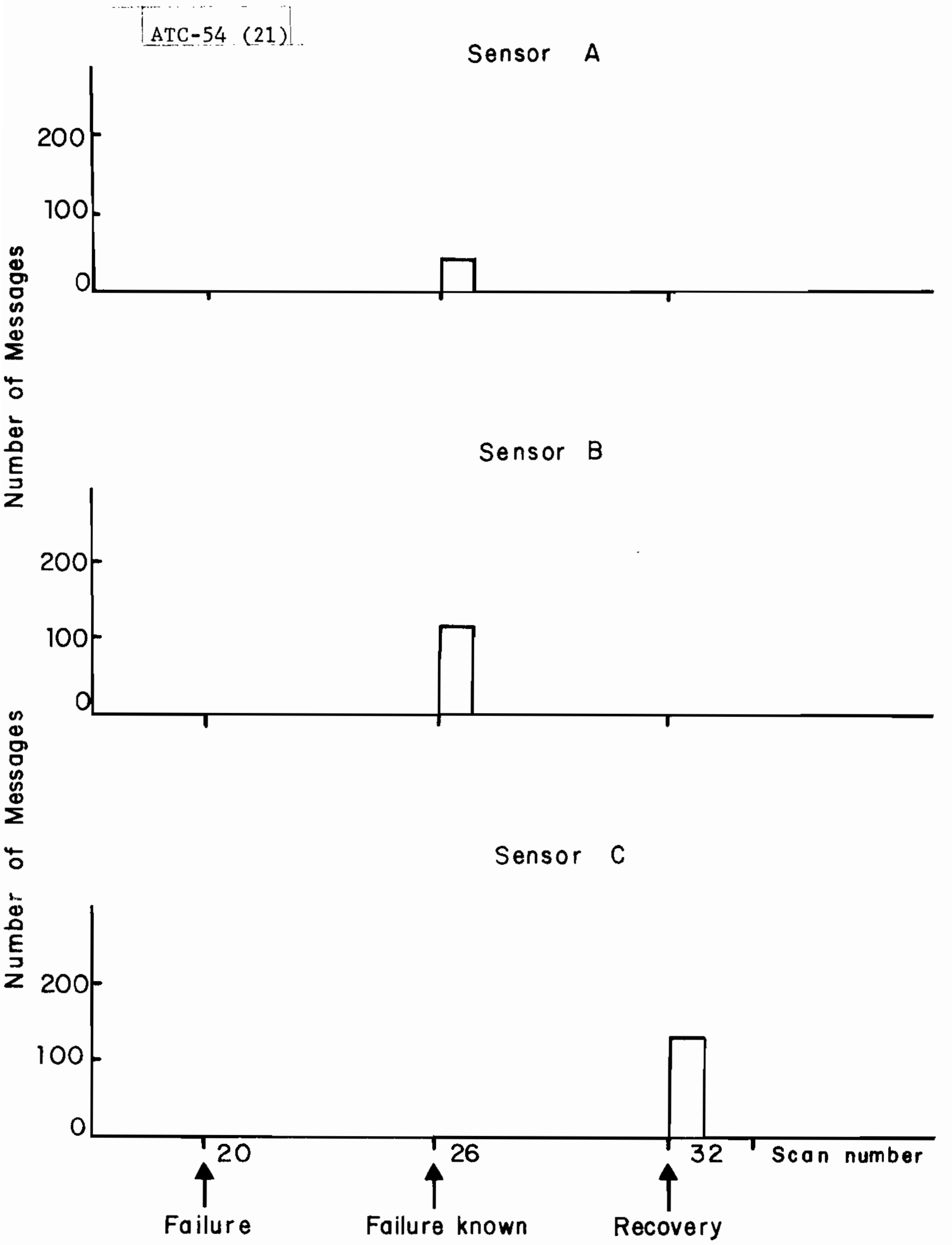

Fig. 21. Permanent hand-off messages received per scan.

ATC-54 (22)

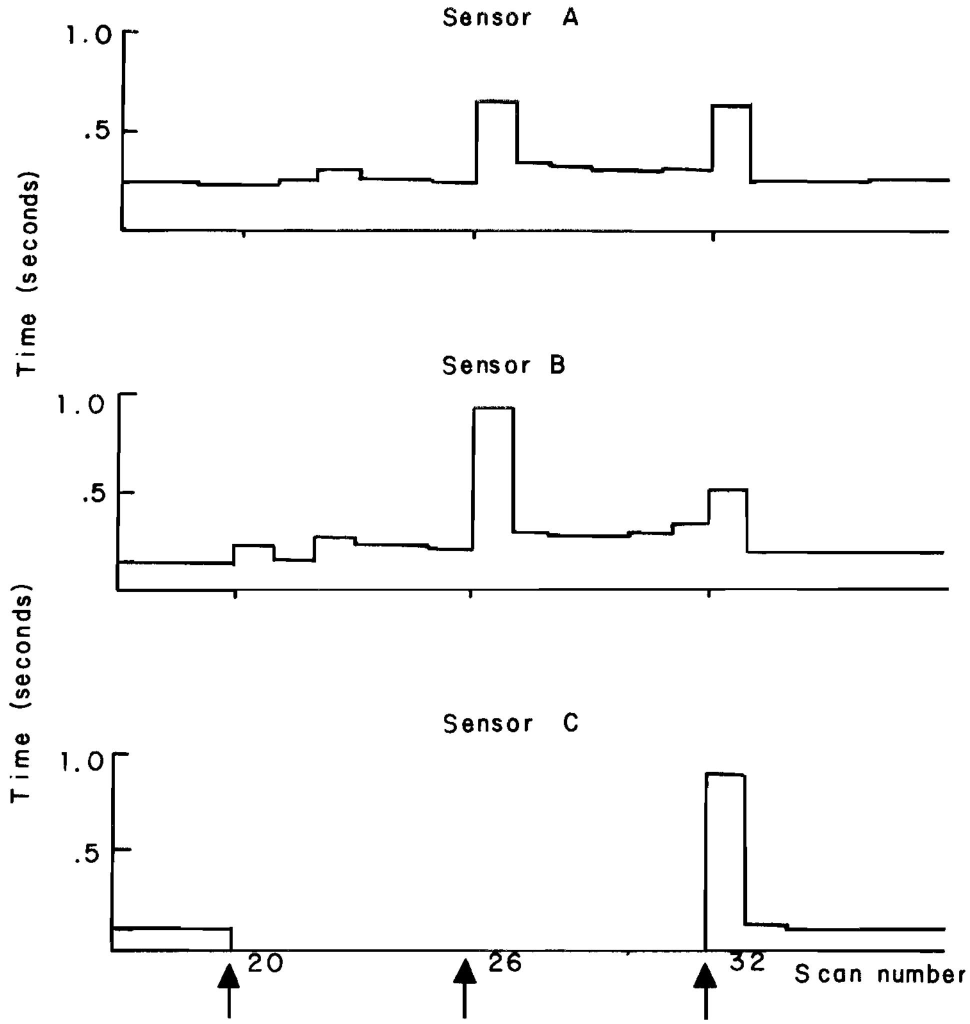

Fig. 22. Execution time per scan for network management.

VII. CONCLUSIONS AND RECOMMENDATIONS

The principal conclusion of the simulation procedure was that it did demonstrate the consistency of the design of the network management function. Some minor changes were made to the design based upon the simulation.

There had been some concern regarding the order in which the many tasks for network management were executed. In the simulation, the network management function was made to operate after each azimuth wedge of 0.7031 degree was processed by surveillance processing. Although this is not specified in the Engineering Requirements document, it is advisable that network management follow closely (in time) the surveillance function because in that way, no external triggers (messages) effect parameter changes for a given track before it is updated with local information. A different sequence of execution of tasks may cause problems.

The simulation provided some insight into the usefullness of the track data exchange, set up in anticipation of a fade in the zenith cone of the sensor. The zenith cone was defined in Reference 1 as the volume of airspace defined by a slant range of less than 5 miles. Using that definition, the simulation conclusively showed that the larger portion of the track data message (95%) was never used because the anticipated fade never materialized. Occurrence of a fade was obviously totally controlled by the adopted model for a fade. It was nevertheless thought to be necessary to redefine the zenith cone as the volume of airspace determined by a slant range of less than 5 miles and an elevation angle of more than 45^{o}. This additional constraint reduces the volume by 70%. However, in view of aircraft distribution in altitide that peaks at approximately 3,000 ft and drops off to a few percent of that peak at approximately 10,000 ft, it is clear that the number of aircraft in the new zenith cone is reduced by considerably more than 70%. Moreover, the new definition is closer to the original intent of the meaning of a "zenith cone."

Finally, an important conclusion, which could be drawn regarding the description of the network management function in Reference 1, was that it translates easily and directly into a software program.

REFERENCES

1. Engineering Requirement, Discrete Address Beacon System (DABS) Sensor Report FAA-ER-240-26 (1 November 1974).

2. H. Vandevenne, "Network Management," Project Report ATC-45, Lincoln Laboratory, M.I.T. (16 May 1975).

3. "Statistical Summary of the 1982 Los Angeles Basin Standard Traffic Model," Report FAA-RD-73-87 (April 1973).