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Further Studies of ATCRBS Based on ARTS-III Derived Data

A. G. Cameron

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Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LEXINGTON, MASSACHUSETTS

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16. Abstract

Lincoln Laboratory has been examining digital data extracted from operational ARTS-III radar beacon processing systems for the past eighteen months, in an attempt to determine the capabilities of today's civil Air Traffic Control Radar Beacon System. Our original report on the subject, "Empirical Assessment of ATCRBS," (Ref. [1]), covered data gathered during the first six months of the study from the Andrews AFB (ADW), Boston (BOS), and Las Vegas (LAS) ARTS-III equipment. This report discusses analysis of data received since the completion of that initial report, which was gathered at the Ontario, California (ONT), Albuquerque (ABQ), Minneapolis-St. Paul (MSP), Milwaukee (MKE), and Boston (BOS) ARTS-III sites, and also the Suitland, Md. en route radar site. The major topics considered here are false targets caused by multipath reflections, and asynchronous interference (fruit). Four different mechanisms resulting in false targets were observed in the data and are discussed in detail in the report. In addition, levels of asynchronous interference as measured and analyzed, and two procedures are discussed by which the characteristics of the interrogators responsible for the fruit (including location) can be determined. One of these is described in detail, and shown to yield results that agree closely with known parameters. Several other topics, including improper reply decoding, are also discussed.

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SECTION 1

INTRODUCTION

During Spring, 1973, Dr. Dennis H. Pruslin and this author performed a study of ATCRBS performance based on analysis of data derived from the ARTS-III digital processing system. The study addressed many problem areas, including false targets, weak targets, interference, synchronous garble, and several others. Because of time considerations, the report [1] on that study was limited to discussion of data from only three sites (Boston, Andrews AFB, and Las Vegas). Since the Spring when that report was completed, many more data tapes have been received from many other sites as well as several more from Boston.

Although the contract task under which [1] was performed had been completed by the time this new data was received, it was felt that analysis of the new data would provide useful background for the Transponder Performance Analyzer Support Program, which had superseded that task. This turned out to be the case.

The new data tapes were, for the most part, sent to us by sites with problems which were felt to be amenable to the type of analysis we had performed; thus, the performance levels revealed by their analysis are undoubtedly not representative of the entire FAA ATCRBS system. On the other hand, the fact that most of the problems revealed by the data tapes appeared analyzable and solvable* seems to confirm the conclusions arrived at during our initial study that overall ATCRBS system performance is presently quite good, and those instances in which it degrades can be generally corrected, using fairly simple techniques. Since both conclusions are fairly important, and since many new and interesting phenomena were revealed in the more recent data, it appears worthwhile to present the new data and analytical work in a sequel to the original study. That is the purpose of this report.

To date, ATCRBS data has been received and analyzed from five additional ARTS-III sites (for a total of eight), and an en route site. This data is in good general agreement with that of Ref. [1] and certainly does not infer that any of its conclusions should be modified. It does show, quite dramatically, that local circumstances, relating to both physical environment and traffic density and distribution, vary widely, contain many idiosyncracies and peculiarities, and do not allow much leeway for generalization. Simple models (say, for predicting received fruit rates), when calibrated with data from one site, do not yield results applicable to another site. In many ways, no two sites appear the same. Upon examination, the reasons for this become apparent, and common threads of performance begin to emerge.

The study of this additional data reinforces also the original conclusion [1] that the proper determination of the performance of the entire FAA Secondary Radar system could profit significantly from the analysis of digital data; tapes from the various installations should be analyzed one at a time in order to appreciate how each installation differs from the norm. This process is far less difficult than it appears. The work reported here required only four

*Correction of one fairly serious problem required little more than a potentiometer adjustment!

man-months, largely due to prior experience in rapid analysis of printout data gained during our initial study. Semiautomated display and analysis of tape data could further improve efficiency.

SECTION 2

ORGANIZATION

The work reported here was performed serially; tapes arrived essentially randomly, were analyzed manually, and were reported on informally, in internal MIT/Lincoln Laboratory memoranda, or occasionally more formal reports. Quite often, follow-up work was done on each site involving discussion of particular problems and possible solutions, or searching for additional data, such as that found on topographic charts, panoramic photographs, and so forth. Few direct comparisons were possible, since sites generally had unrelated problems. Thus, discussion of data in this report tends to be organized more around individual sites than individual problem areas. (In our previous report, all discussion on, say, false targets, was contained in a chapter on that subject.) As an aid to the reader who is more concerned with a particular class of problem than with a particular site, the problem addressed in this report and [1] have been tabulated and related to the various sites in Fig. 1.

Fortunately, the particular problems predominating at the sites generally fell into a few well-defined areas and therefore it has been possible to group the discussions logically. Section 3 of the report consists of discussions of the data analyses performed on the Milwaukee, Suitland (en route), Albuquerque, and Ontario, Calif. (March AFB RAPCON) sites, all of which suffered

18-4-16488

SITE ▶	ANDREWS AFB	LOGAN INT. APT.	McCARRAN INT. APT.	MITCHELL FIELD	ONTARIO, CALIF.	WOLD-CHAMBERLAIN	ALBUQUERQUE	SUITLAND
CODE ▶	ADW	BOS	LAS	MKE	ONT	MSP	ABQ	—
TYPE ▶	ASR(R)	ASR	ASR	ASR	ASR(R)	ASR	ASR	ARSR(R)
DISCUSSED ▶	ATC-16	BOTH	ATC-16	HERE	HERE	HERE	HERE	HERE
CHAPTER ▶	THROUGHOUT	THROUGHOUT	III B-6	III A	III D	IV B	III C	III B
PROBLEM/PHENOMENON								
FALSE TARGETS[1]								
CONVENTIONAL	SEVERE	MODERATE	LOW	SEVERE	MODERATE	LOW	SEVERE	SEVERE
SIDELOBE	NONE SEEN	SEVERE	NONE SEEN	NONE SEEN	NONE SEEN	NONE SEEN	SEVERE	NONE SEEN
MAINBEAM	NONE SEEN	NONE SEEN	SEVERE	NONE SEEN	NONE SEEN	NONE SEEN	MODERATE	NONE SEEN
OTHER[2]	—	—	—	—	SEVERE	—	—	—
DOUBLE REPLIES	OCCASIONAL	RARE	FREQUENT[3]	NONE SEEN	NONE SEEN	NONE SEEN	FREQUENT[3]	N. A.
FRUIT LEVELS	INDIRECT	DIRECT/INDIR	—	—	—	DIRECT	—	—
FRUIT SOURCE LOC'N	—	PER SWP	—	—	—	LONG TERM	—	—
WEAK/LOST TARGETS	MODERATE	MODERATE	NOT STUDIED	NOT STUDIED	NOT STUDIED	NOT STUDIED	NOT STUDIED	MODERATE
IMPROPER DEFRUITING	OCCASIONAL	NOT SEEN	NOT SEEN	NOT SEEN	NOT SEEN	NOT SEEN	NOT SEEN	N. A.
IMPROPER DECODING	NOT SEEN	SEVERE & CORRECTED	NOT SEEN	NOT SEEN	NOT SEEN	NOT SEEN	NOT SEEN	N. A.
INSUFFICIENT ANG. RES.	OCCASIONAL	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.
ANGULAR ACCURACY	MEASURED	NOT STUDIED	NOT STUDIED	NOT STUDIED	NOT STUDIED	UNDEFRUITED[4]	NOT STUDIED	NOT STUDIED
SPLITS	NONE	NONE	NONE	NONE	NONE	NONE	NONE	FREQUENT
SECOND TIME AROUND RPLYS	—	—	—	—	—	ONE SEEN	—	—
SYNCHRONOUS GARBLE	MEASURED	SEEN	RARE	NOT SEEN	RARE	NOT SEEN	NOT SEEN	VERY RARE

1. FOR DEFINITION OF TYPES, SEE FIG.
2. OUT-OF-PLANE GROUND REFLECTIONS
3. BELIEVED DUE TO MULTIPATH AT LAS, DUE TO MISALIGNMENT AT ABQ.
4. COMPARISON MADE BETWEEN DEFRUITED AND UNDEFRUITED DATA.

Fig. 1. Relationship between problems and sites.

various types of false target problems due to reflections. Section 4 considers fruit and interference, and is based on new undefruited data from Boston, and an undefruited data tape from Minneapolis/St. Paul. Section 5 is concerned with a reply decoding anomaly which caused difficulty at Boston, and could quite possibly exist at other sites. Section 6 presents conclusions.

SECTION 3

REFLECTION PROBLEMS

Problems caused by reflection of Secondary Radar signals from buildings, terrain, and so forth, have been noted since radar beaconry was first implemented. These problems generally fall into two categories, false targets (that is, apparent targets where in fact there are none), and lobing (that is, signal strength reduction due to phase cancellation between a direct and reflected signal). Lobing occurs within the antenna mainbeam, and necessarily involves reflecting paths that are only slightly longer* than the direct path, and therefore involve reflecting surfaces quite close to the interrogator. False targets can occur from reflecting paths that are either in or out of the mainbeam; reflecting surfaces causing them can be vertical, horizontal, or at arbitrary angles. What distinguishes them from lobing is the time delay relative to the direct path associated with the reflecting path. As this delay increases to the point where it becomes comparable to a pulse width (450 nsec), the effect is to create a separate (false) reply, different from the legitimate one, rather than to cause phase interference to the legitimate reply. No severe fading attributable to vertical lobing was cited as a problem at any of the sites, and therefore, it was not examined in great detail. False targets due to several types of reflection mechanisms were noted extensively. The three mechanisms noted in Ref. [1] (see Fig. 5) were observed, as well as a new, apparently quite rare, mechanism.

*That is, excess path length is short compared to a pulse width.

3.1 MILWAUKEE (MKE)

3.1.1 Introduction

The false target situation here is similar to that seen at Andrews AFB [1], and, in fact, appears to be typical of what is seen throughout the ATCRBS system. We received two ARTS-III extractor tapes taken from the ATC Beacon Interrogator at General Mitchell Field, Milwaukee, Wisconsin; it was understood that the site has a serious problem with false targets.

3.1.2 The Data

The first 100 scans of the MKE tape dated 5 June 1973 were examined. Aircraft present are listed in Table 1. (Positions given in that table are those noted on scan 46.) Only target report data was used; the tape contains individual reply data, but printout of this was suppressed for this examination.

Based on this data, by far the most noticeable problem at MKE is a high level of false target generation, primarily due to two close-in reflecting surfaces. Figure 2 shows the measured reflector locations and orientations; the number alongside each indicates the number of false target declarations associated with it during the period of observation.

3.1.3 Discussion

It should be noted that the actual ranges of the aircraft which caused the false targets varied between 8 and 48 nmi; in addition, one false target resulted from an aircraft less than 2 nmi away. In all cases, the time delay associated with each reflector was such that, Improved Interrogation Siedlobe Suppression (I^2SLS) should have suppressed the transponders during the instants

Table 1. Aircraft present at Milwaukee during analysis.

(Scan 46)

Code	Range (nmi)	Azimuth (degrees)	Altitude	Situation
1100	49	60	-	Opening
1104	8	76	047	Arriving; descending
1100	43.5	90	-	Opening
1100	37.6	106	-	Opening
2707	46.5	139	113	Holding; descending
0740	14.7	165	-	Arriving
2710	49	172	054	Opening; descending
1631	37.6	172	-	Departing
1100/1705*	41.8	181	-	Closing
2632	47.1	194	-	Opening
2625	44.0	201	042	Opening descending
1644	18.7	206	060	Circling
2667	41.6	207	-	Opening
2664	31.2	221	105	Opening; descending
1100	47.7	239	-	Closing
1100	34.1	260	-	Closing
2600	3.6	279	-	On final
1753	16.6	283	-	Approaching
1100	34.1	289	-	Opening
2606	15.1	314	068	Arriving; descending
1100/2622*	38.7	326	-	Closing

*Code changed during examination.

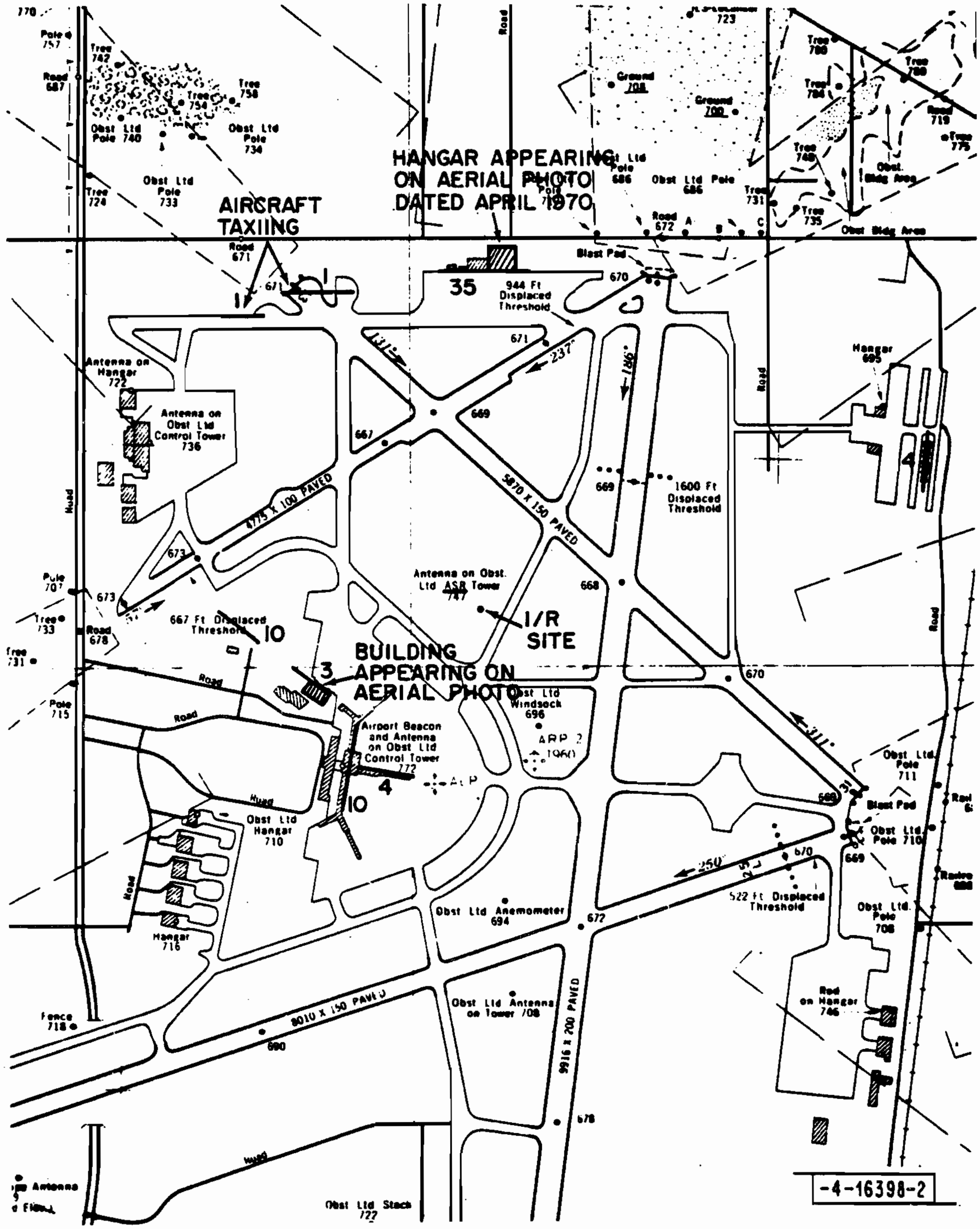

Fig. 2. Location of Reflectors at MKE.

(Numerals refer to quantities of false target declarations caused by each reflector during observation interval) when the reflected interrogations were received. According to MKE personnel, Improved ISLS was in operation, and the output power level in use at the time was 330 W; this corresponds to an effective Improved ISLS range (Table 2) of approximately 25 nmi. Thus, a major fraction of the false targets should not have occurred. Similar behavior was observed at Andrews, where Improved ISLS should have eliminated many false targets, but did not. It appears from this data that I^2SLS is not functioning properly at either site; the only data analyzed that indicates conclusively that it is functioning somewhere is from Albuquerque (Section 3.3 following). In all of our data from sites other than ABQ, numerous false targets occur at all places where they would be expected, based on examination of obstruction charts. ARTS-III extractor data does not provide sufficient information to allow any inference as to why I^2SLS is not functioning properly. In order to get more information in this area, MKE personnel agreed that they might try increasing the omni (I^2SLS) power for both P_1 and P_2 by a few hundred watts, while holding the directional power constant, and observe whether this affects the incidence of false targets. This would also result in the narrowing of legitimate targets (due to conventional ISLS action), and so should be done only in small increments. Regarding a more complete long-term solution, it appears that the software false target elimination procedure discussed in Sections 3.3-6 and 3.3-7 below would successfully eliminate all the false targets observed.

3.1.4 Conclusions

The severe false target situation at MKE could have been anticipated by a cursory study of the MKE obstruction chart. The bulk of the reflections

Table 2. Improved effective range.

Output power 330 W	=	55 dBm
Cable, etc., losses	-	2 dB
Power splitter loss (P_1 pulse)	-	3 dB
Omni antenna gain		6 dB
ERP		56 dBm
Typical MTL	-	72 dBm
Aircraft cable losses	-	2 dB
Maximum acceptable pathloss (no margin allowance for fading)	-	126 dB

This equates to a range of 25 nmi.

are due to large building surfaces in close proximity to the I/R, which subtend relatively large azimuthal segments. The surface responsible for most false targets was oriented broadside to the I/R. This has been the case at Andrews Chicago [2], Trevose [3], and Newark [4], and is undoubtedly the cause of most false targets in the FAA's system. It appears that the FAA ASR siting processes which have been used in the past leave something to be desired, and that guidance to siting parties (such as Spingler's, "Experimentation and Analysis of [ATCRBS] Siting Criteria" [5]) came about too late.

Why Improved ISLS, which was conceived as a fix to this problem, is not effective remains a mystery that should be investigated. As discussed in Section 3.3, there is a reasonable software approach for eliminating most false targets of this sort.

3.2 SUITLAND (Md) ARSR

3.2.1 Introduction

This en route radar site had severe false target problems, which, according to Washington ARTCC personnel, were deleterious to the NAS Stage A acceptance testing program currently being carried out there. As a result of a telephone conversation with Washington ARTCC personnel, we received a quantity of ATCRBS data printout from the ARSR site.

3.2.2 The Data

The NAS Stage A "COMDIG" routine was utilized by Washington ARTCC personnel to extract, format, and print out beacon target reports generated by the Production Common Digitizer at Suitland; this process is incapable of gathering individual reply data. Figure 3 shows a sample of the printout; about a half-hour of data was sent to us. System parameters are given in Table 3.

Table 3. Suitland ATCRBS/PCD parameters.

Output power	800 W
Omni (P_2) power	800 W
Sensitivity (MDL).	-87.5 dBm
PRF.	355 ips
Scan rate	6 rpm
Interlace	AAC
PCD thresholds:	
T_L. . . . 6	
T_T. . . . 4	
T_V. . . . 4	

(Thus, a minimum of six hits on mode A are sufficient to declare a target.)

CD SITE - SUITLAND

DATA REF - TRUE NORTH   SITE DECLINA - NONE   DATA TYPE - BEACON

TIME	IDENTIFICATION		USER	RANGE N.M.	1/8	AZIMUTH DEGREES	ACPS	MODE 3/A	BEACON ALTITUDE
21/53/05.2	B		FA	34	4	35.595	405	0000	
21/53/05.2	B 3	DR	FA	34	2	34.189	389	3467	
21/53/05.2	BC3	DR	FA	23	5	35.683	406	7217	- 1200.
21/53/05.2	BC	R	FA	35	6	35.947	409	4637	- 1200.
21/53/05.2	BC3	R	FA	165	7	36.914	420	2100	24000.
21/53/05.4	BC3	R	FA	159	5	39.814	453	2400	25900.
21/53/05.5	B 3		FA	175	7	42.978	489	2400	20700.
21/53/05.5	BC3	D	FA	125	2	43.242	492	1126	16500.
21/53/05.5	B 3	DR	FA	34	6	43.593	496	2741	
21/53/05.7	BC3	R	FA	87	7	46.933	534	1100	14400.
21/53/05.6	B 3	RI	FA	130	2	47.636	542	2000	
21/53/05.6	BC3	D	FA	92	5	47.988	546	1333	6400.
21/53/05.8	BC3	R	FA	85	7	50.537	575	1100	17100.
21/53/05.7	BC3	DR	FA	133	7	52.822	601	1111	14600.
21/53/05.8	BC3	D I	FA	156	4	54.755	623	2276	14300.
21/53/05.9	BC3	R	FA	105	3	55.371	630	1100	14000.
21/53/05.8	BC3	DR	FA	79	1	56.865	647	2004	5900.
21/53/06.0	BC3	DR	FA	127	5	60.205	685	2404	30500.
21/53/06.0	B 3		FA	162	4	63.369	721	2000	10800.
21/53/06.0	BC3	R	FA	176	5	62.050	706	2100	33000.
21/53/06.0	BC3	R	FA	71	3	62.490	711	2000	15500.
21/53/06.1	BC3	DR	FA	25	2	64.160	730	3446	7900.
21/53/06.1	BC3	R	FA	167	1	65.566	746	2000	18000.
21/53/06.3	BC3	R	FA	130	5	68.642	781	2000	19000.
21/53/06.3	BC3		FA	31	6	69.609	792	1100	14500.
21/53/06.3	B 3	R	FA	26	5	71.191	810	1200	
21/53/06.2	B 3	R	FA	69	3	70.400	801	1100	
21/53/06.3	BC3	R	FA	69	7	71.015	808	2100	30100.
21/53/06.3	B 3		FA	97	0	73.564	837	1100	
21/53/06.4	B 3	R	FA	51	5	74.619	849	1100	
21/53/06.3	B 3	R	FA	96	7	75.585	860	1100	
21/53/06.4	BC3	R	FA	50	3	74.794	851	1300	20000.
21/53/06.4	B		FA	97	1	76.992	876	1100	
21/53/06.4	B 3	R	FA	48	5	75.585	860	1100	
21/53/06.5	B	R	FA	32	3	79.541	905	0000	31000.
21/53/06.6	B 3	R	FA	35	0	79.716	907	1100	
21/53/06.7	BC3	R	FA	38	0	85.341	971	1100	- 1200.
21/53/06.9	BC3	R	FA	82	5	89.912	1023	2000	30900.
21/53/06.9	BC3	D	FA	27	4	91.406	1040	3425	7400.
21/53/07.0	BC3	R	FA	78	7	97.822	1113	2000	32600.
21/53/07.0	B 3		FA	64	0	98.876	1125	1100	
21/53/07.1	BC3		FA	79	0	101.689	1157	2100	35100.
21/53/07.4	B 3	R	FA	83	2	107.929	1228	1100	

Fig. 3. Sample CD message printout, as printed out by the "COMDIG" routine.

Notes: B = Beacon-equipped target (all were)
C = Mode C-equipped
3 = Radar reinforced
R = Radar reinforced
D = Discrete

I = Identing (SPI)
Altitudes uncorrected
-1200 implies empty bracket replies to Mode C

Thirty-two scans were examined in detail; these scans were recorded from 2126Z to 2131Z (around 4:30 p.m. local time) on 28 November 1973. An average of two hundred targets were declared on each scan. Roughly, sixty mode 3/A codes were discrete; of the remainder, the majority were 1100's, 2100's, 1200's, and 0X00's.* A list of the discrete codes (along with positions) is given in Table 4. Only the discrete codes were examined for evidence of false targets; whenever a particular code appeared twice on a scan, at positions consistent with a reflection process, the appropriate data was tabulated for subsequent analysis. This process was complicated by the fact that one code was assigned to two different aircraft (apparently by different TRACONs). These double occurrences of the same code were segregated on the basis of altitude and range.

Roughly, 70% of the aircraft detected were squawking altitude; of the remainder, about half replied to mode C interrogations with empty brackets. Traffic from Washington National Airport was regularly acquired at 400-500-ft altitudes (not corrected); altitudes as great as 38, 000 ft were noted. The majority of the mode-C reporting traffic was in the PCA (above 18, 000 ft).

3.2.3 General Observations

In the course of examining discrete target declarations, several characteristics of the system were noted which differ from the general behavior of ARTS-III, as noted in other work. The most prominent was the high incidence of target splits (perhaps four or five per scan on discretes). Two types were noted: in one, a single aircraft was declared twice, separated by perhaps 2 or 3^{o}, in adjacent range cells; the other type of split produced two

*X signifies any number between 1 and 7.

Table 4. Discrete code aircraft at Suitland.

Code/Altitude	Range (nmi)	Azimuth (degrees)	Code/Altitude	Range (nmi)	Azimuth (degrees)
0142/	80	29.2	2145/189	130	37
0144/	91	31	2161/239	97	252
0420/	42	170.2	2262/172	150	58.5
0702/	5	275.7	2302/189	150	16.8
0720/	22	290*	2361/102	153	49.6
1001/	42	26	2365/101	124	48*
1010/005	4	270*	2402/330	81	230.2
1101/00	35	91.8	2403/330	67	222
1102/00	46	160.8*	2404/330	36	196.4
1114/010	70	71.3	2422/350	89	327.5
1120/	43	179	2436/350	117	1.2
1121/00	106	30.6	2444/	19	98.6
1123/	10	272.6*	2465/278	182	27.7
1263/	15	322.8	2543/143	153	54.7
1266/042	11	303	2556/140	105	35
1335/219	131	48.9	2566/069	98	47.2
1360/280	105	32.6	2601/	55	284
1521/075	68	39	2615/	124	167.8
1564/140	78	75.7	2624/	29	286.3*
1570/	112	47.5	2626/00	29	329.3*
1740/00	16	303.9	2631/	27	90*
1741/00	14	3.4	2662/112	56	297
1744/	26	147*	2665/	31	143.4
2002/064	14	294.1	2677/	84	165
2007/121	28	0	2703/	54	283.4
2017/170	141	42.8	2706/	6	290.3
2017/034	7	296.3*	2710/094	56	239.2*
2130/264	111	0	2714/	81	181.8

Table 4. Continued.

Code/Altitude	Range (nmi)	Azimuth (degrees)	Code/Altitude	Range (nmi)	Azimuth (degrees)
2724/	37	283.1	3404/065	72	164.7
2742/020	6	224.6	3406/	127	206.1
2743/	30	64*	3423/115	43	286.2
2646/	22	98.8	3425/104	22	97*
2747/024	8	209.10	3430/105	52	270.7
2752/050	4	170.4	3431/026	38	27.8
2753/085	33	293.4	3444/	20	101.2
2763/00	36	196.6	3447/050	25	72.3
2765/00	25	50.6	3453/135	77	384.5
2770/151	58	188.9	3474/034	6	182.2*
2774/130	47	35.7	3510/075	41	220.5
2777/150	57	35.2*	3513/	38	356.3
3224/	8	277.7	3514/105	37	283.7
3232/008	5	132.5	3541/	27	66.5
3247/015	25	287*	3545/	24	60.9
2363/	15	322.9*	7217/00	58	68.2*
3266/007	13	287	7220/	24	38.9
3273/023	6	288.7	7221/00	56	358.2

*Note: position on scan three except where asterisk denotes target first appeared later. Altitudes in hundreds of feet, uncorrected. 00 denotes empty bracket replies to Mode C interrogations.

declarations in the same cell, perhaps 6 or 7° apart. While individual reply data would provide more conclusive insight into why these splits occur, it appears that the first type is a result of an aircraft being on the edge between two adjacent range cells, such that some of its replies fall into one, and some into the other. Since the PCD is incapable of correlating replies in adjacent range cells, whenever each cell contains sufficient replies for declaration a declaration will occur for both. This behavior has been apparent for some time in the PCD; the different correlation algorithms employed in ARTS-III preclude its occurrence in that system when it is properly aligned. The cause of the second type of split cannot be conclusively determined without reply data, but appears most likely due to partial ring around, or mainbeam reflections from tilted foreground.

The process of tracking discrete targets from scan-to-scan in order to acquire false target data revealed that the overall probability of detecting a target (i.e., the ATCRBS "blip/scan ratio") was somewhat low. While many discrete code tracks included reports from all thirty-two scans, several had quite low (50-60%) declaration rates. These low rates did not appear to correlate strongly with range or altitude (i.e., the missed declarations were not strongly attributable to marginal reception because of extreme range or low elevation angle). Whether they showed correlation in elevation angle or azimuth (and could thus be attributed to vertical lobing or shadowing) was not determined; proper determination of which phenomena were responsible for the low detection probabilities appears to require extensive analysis employing amplitude (or at least individual reply) information.

3.2.4 False Target Analysis

As noted, approximately 60 discrete-code aircraft were within the coverage area over the 32 scans examined. The target code listing was examined for instances in which any discrete code appeared at azimuths other than that of the actual aircraft. Of course, splits and dual occurrences of the same codes apparently assigned to two different aircraft were not counted. Fifty-nine instances attributable to reflections were noted in the 32 scans; all were consistent with reasonable reflection geometries.* That is, the false declarations were always at ranges between 0 and 2 miles greater than the instantaneous (interpolated) positions of the actual aircraft, and at azimuths removed by many degrees from those of the aircraft. The 59 false declarations were grouped in azimuth and found to fall entirely with 4 distinct narrow azimuthal sectors; all data pertaining to any one of these sectors agreed quite closely with regard to reflector orientation and range (well within a degree in orientation, and 1/8 nmi in range difference). The locations and orientations of the reflecting surfaces responsible for the false targets are shown in Fig. 4. As can be seen from that figure, two surfaces appear "bent." In each case, the calculated orientation angle appeared different at one extreme of the reflector azimuth segment than at the other. Differences are larger than can be explained from measurement inaccuracies, and are due either to edge diffraction, to the presence of two separate reflecting surfaces close to one another, or to some combination of these effects. In the case of one of the reflectors, half of the data samples fell to one side of an azimuth near the center of the reflector, and resulted in orientation angle data tightly

*Reflection geometry is discussed in detail in Section 3.3, which follows.

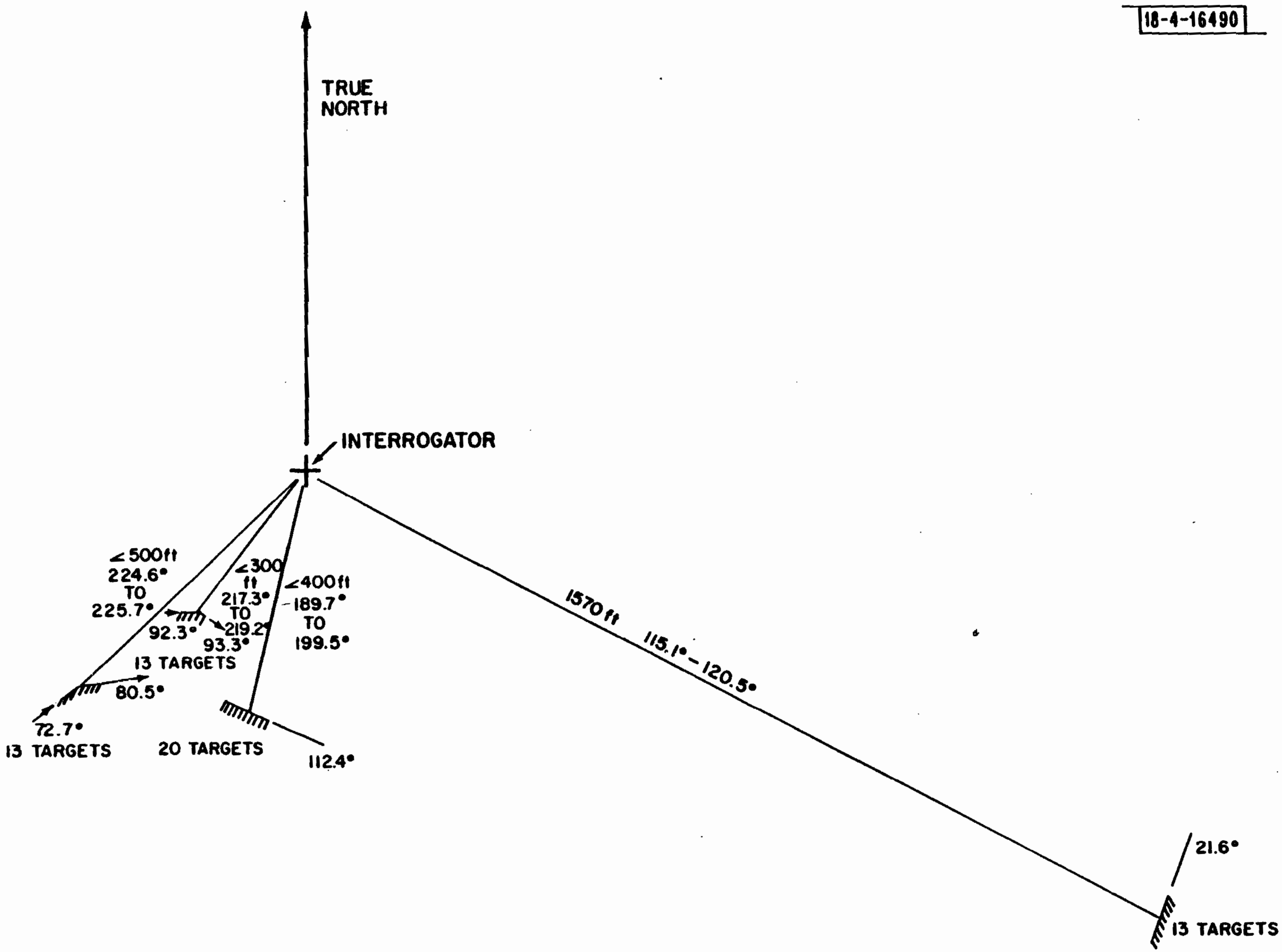

Fig. 4. Reflectors noted at Suitland

bunched around one value; the other half, which fell to the other side, all yielded orientation angle data tightly bunched around another value, which differed by one degree from the first.

The lengths of the false target tracks resulting from these reflectors varied widely: several only occurred once. A few occurred on 4 or 5 scans in sequence. One false target track, due to the reflector at 190°, continued over 11 scans within the 32 scans which were examined. That particular track was followed past the 32nd scan, and found to persist for a total of 51 scans* (slightly more than 8 minutes!). During that occurrence, the actual aircraft range decreased from 57 nmi to 20 nmi, and azimuth varied by about 8° (the aircraft was apparently inbound to DCA). Of course, false target position varied in a similar fashion.

Examination of the positions of discrete targets at the beginning and ending of the 32 scans showed that while most azimuths were transversed by one or more discrete-code aircraft during the period examined, there were a few azimuthal wedges which were not occupied at any time during that period. Any reflector illuminating airspace in those azimuths would therefore not have been apparent in the data. Thus, Fig. 4 does not necessarily show all reflectors which contribute to the false target problem at Suitland; there could perhaps be more.

Upon completion of the false target analysis, discussions were held with Washington ARTCC and ECAC personnel about the surroundings of the radar. They noted, and a subsequent panoramic photo confirmed, that there is indeed a building at close range to the south, whose shape fits the pattern

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*Only the 11 false declarations which occurred in the 32 scans examined in detail, were included in the statistical data discussed in this report.

of the three reflectors at 190°, 217°, and 224° closely. The building (Fig. 5) subtends roughly 40° of arc, and is in two sections with a connecting corridor. It was described by ECAC (and appears from the photograph) as an incinerator building serving the nearby Federal Documents Repository. It is significant to note that although the building (with the exception of its smoke-stack) is completely below the horizon, its walls all slope inward (in a "mansard roof" fashion): accordingly, they reflect all incident energy (from the higher ATCRBS antenna) upwards into the airspace rather than into the ground. The incinerator smokestack also has flat surfaces which also appear to tilt inwards. Orientation angles of the building were obtained from a 7.5 min - series topographic chart, and were found to agree within 2°; most of this error is attributable to imprecision in reading the chart. Past data has almost always agreed to within a degree.

A large building having a long flat wall appears to the southeast on the panoramic photo, consistent in location and orientation with the target at 115 to 120°. Whether the reflecting surface is perfectly vertical could not be determined from the photo, but it appears sufficiently close to the horizon to support reflections.

The incinerator building looks to be about 150 ft long; it would certainly be possible to modify its surface to cure the reflection problem it causes. Modifications of this sort would undoubtedly alter the lines of the building substantially. The other building, on the other hand, appears quite long, and probably prohibitively expensive to modify.

Installation of the NAFEC Dipole Fix (NADIF) should improve the situation somewhat, but probably not greatly, since that antenna has gain that

-4-16491

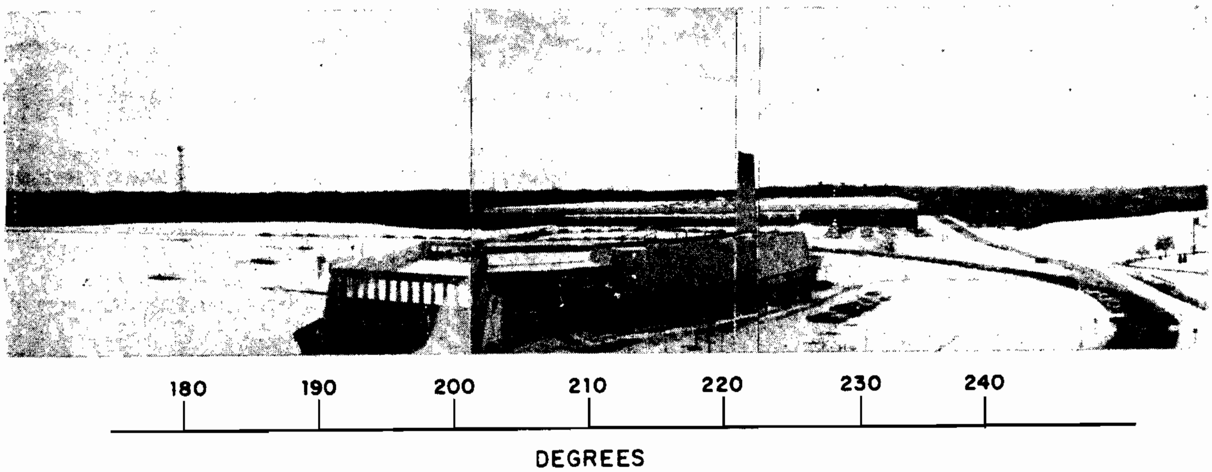


Fig. 5. Southerly sector of panoramic photograph taken from Suitland, MD. ARSR.

(photo courtesy of Mr. Garrett Huskins, Washington, ARTCC) diminishes relatively slowly with elevation angle, such that it does not achieve complete cutoff at the elevation angles of the buildings. Since both buildings are well within the first Fresnel zone, only small losses could be expected as a result of the reflection process; reflected signal levels would be reduced relative to direct signal level only by the differences in gain achieved by NADIF at the different elevation angles (i. e., that of the aircraft itself and that of the reflector). Since this is somewhat less than 5 dB, it appears that some false targets would persist even when NADIF has been installed. If this turns out to be so, the most promising means of eliminating false target problems from the Suitland SSR is software processing of the type to be discussed in Section 3.3.

3.2.5 I^2SLS Performance

The Improved ISLS technique should be successful whenever the reflector location and orientation are such that reflected interrogations arrive at the aircraft more than 2 μsec (and less than 30) after the omnidirectional suppression signals and aircraft are sufficiently close to receive the omni signals. The reflectors between 189 and 226° were all too close for proper I^2SLS operation. The reflector at 120° results in an excess pathlength of about 3,000 ft, corresponding to about a 6-μsec delay. Thus, its effects should have been suppressed by I^2SLS. Four aircraft, at ranges of 14, 35, 45, and 60 nmi, were involved with this reflector in producing false targets. From Table 5 we see that the omnidirectional signals should have covered that region if no losses occur due to lobing at either end of the link. Consequently, we would expect that I^2SLS should have prevented or at least reduced the severity of all of the false targets caused by this reflector. That it did not, is again consistent with what has been seen in previous data. In addition, it should be noted that even when working properly, I^2SLS is incapable of preventing reflections due to long-range aircraft; almost half of the false targets noted were due to aircraft at more than 60 nmi.

3.2.6 Conclusions

The Suitland situation seems suited for the type of software fix proposed in Ref. [1], and described in detail in Section 3.3. This conclusion has been presented to Washington ARTCC personnel for their consideration.

Table 5. Improved ISLS effective range.

P_{out}	800W	
P_1 power into omni	500W	27 dBW
Line losses		- 3 dB
Omni antenna gain		6 dB
ERP		30 dBW
Typical transponder MTL		-76 dBm
Aircraft cable losses		(3 dB)
Aircraft antenna gain		0 dB
Minimum needed received power		-73 dBm
Maximum acceptable pathloss:		133 dB
Corresponds to a range of 60 nmi		

3.3 ALBUQUERQUE (ABQ)

3.3.1 Introduction

The false target situation at Albuquerque was brought to Lincoln Laboratory's attention by U.S. Air Force personnel stationed at the Air Force Weapons Laboratory, Kirtland AFB, which shares the facility with the civilian terminal. AFWL is presently involved in the construction of a building to be known as the Armament Research Test (ART) facility, which will be located approximately 2 nmi from the FAA Airport Surveillance Radar. FAA regional personnel became concerned over the likelihood that the building might cause reflection problems, and suggested that the Air Force take preventive steps. AFWL requested that Lincoln Laboratory investigate the situation; this section discusses our results to date.

The approach to the problem that was decided upon involved as a first step the gathering and analysis of data taken before above-ground construction of the ART facility begins. During construction, appropriate procedures for eliminating any problems the ART might cause are to be developed. Upon completion, another analysis, similar to the first, will be performed to determine what, if any, changes result from the presence of the ART facility. The first step and portions of the second have been completed and are reported here; construction of the ART Facility will be completed in late 1974.

3.3.2 The Data

Two tapes were furnished to Lincoln Laboratory by ABQ FAA personnel. These tapes were reduced and printed in the format shown in Fig. 6. The first

```
-4-16492

REPLY MODE  REPLY CODE OR ALTITUDE  RANGE  AZIMUTH (ACP'S) (4096 ACP = 360°)  GARBLE FLAG  REPLY PULSE TRAIN
                                                    C1 C2 C4 X D1 D2 D4
                                                    F1 A1 A2 A4 B1 B2 B4 F2      SPI
A  0000      59.06 2062      1-------------1    -
   16  13  43.02     12.81   178.42         0  1200        1     0     3

A  0000      59.06 2065      1-------------1    -
C     0.00   59.06 2068      1-------------1    -
A  0000      59.06 2070      1-------------1    -
A  0000      59.06 2073      1-------------1    -
C     0.00   59.06 2076      1-------------1    -
A  0000      59.06 2079      1-------------1    -
A  0000      59.06 2082      1-------------1    -
C     0.00   59.06 2085      1-------------1    -
A  0000      59.06 2088      1-------------1    -
A  0000      59.06 2091      1-------------1    -
ARTS SIM CODE*960R=  23.87A= 177.49                                SWP= 32 HIT= 13 MS= 19 SUMH=   91

C     0.00   59.06 2094      1-------------1    -
A  0000      59.06 2097      1-------------1    -
A  0000      59.06 2100      1-------------1    -
C     0.00   59.06 2103      1-------------1    -
A  0000      59.06 2106      1-------------1    -
A  0000      59.06 2109      1-------------1    -
   16  13  43.02     59.06   182.81         0  0000        1     0     3

ARTS SIM CODE*029R=  59.06A= 183.03                                SWP= 34 HIT= 21 MS= 13 SUMH=  231  2

A  1200      56.62 2714      1-1-------1---1    -
A  1200      56.69 2720      1-1-------1---1    -
A  1200      56.69 2723      1-1-------1---1    -
C     0.00   56.69 2726      1-------------1    -
A  1200      56.69 2729      1-1-------1---1    -   ARTS III TARGET DECLARATION
A  1200      56.62 2732      1-1-------1---1    -
   16  13  43.66     56.62   239.24         0  1200        0     0     3
 HRS MINS SECS-TIME RANGE   AZIMUTH   ALTITUDE CODE   STRONG/  VALT  VCODE
A  1200      34.81 2897      1-1-------1---1    -         WEAK      VALIDITY
A  1200      34.81 2900      1-1-------1---1    -
A  1200      34.87 2906      1-1-------1---1    -
A  1200      34.87 2909      1-1-------1---1    -    THIS TARGET DECLARATION IS A RESULT OF ARTS III
A  1200      34.81 2915      1-1-------1---1    -    CORRELATION AND SUCCESSFUL DECODING OF
A  1200      34.81 2919      1-1-------1---1    -    THESE REPLIES.
A  1200      34.87 2925      1-1-------1---1    -
A  1200      34.87 2928      1-1-------1---1    -
   16  13  43.91     34.87   255.94         0  1200        1     0     3

A  0700      48.06 3860      1-------1-1-1-1    -
A  0700      48.06 3866      1-------1-1-1-1    -      RANGE QUANTIZATION = 1/16 NMI
A  0700      48.06 3869      1-------1-1-1-1    -
A  0700      48.06 3875   G  1-------1-1-1-1    -
A  0700      48.12 3875   G  1-------1-1-1-1    -
A  0700      48.06 3878      1-------1-1-1-1    -
A  0700      48.06 3884      1-------1-1-1-1    -
A  1216      13.62 3887      111-------11-11    -      NOTE TWO SIMULTANEOUS REPLY SEQUENCES
A  0700      48.06 3887      1-------1-1-1-1    -      (TARGETS AT DIFFERENT RANGES OVERLAPPED IN AZIMUTH)
C     0.00   13.62 3890      1-------------1    -
A  1216      13.62 3893      111-------11-11    -
A  0700      48.06 3893      1-------1-1-1-1    -
A  1216      13.62 3896      111-------11-11    -
C     0.00   13.62 3899      1-------------1    -
A  1216      13.62 3902   G  111-------11-11    -
```

Fig. 6. Sample printout - ABQ data

tape, made on 16 November 1973, contains 5.1 minutes of individual reply data (60 scans); 9 aircraft were present during the recording, and are listed in Table 6. Due to the limited azimuthal extent covered by those targets, another tape was requested and made on 3 December 1973. This second tape comprised 40 minutes of individual reply data, of which 8 minutes (120 scans) were examined in detail.* An average of 16 targets (also listed in Table 6) were present during the second recording.

3.3.3 False Target Analysis

During the 180 scans analyzed, 61 erroneous reply sequences due to reflections were noted. Of these, 15 resulted in erroneous false target declarations; the majority were comprised of only 1 to 3 replies. Three different sorts of reflection geometries were noted; all have been noted in data previously examined from other sites, but have never all been observed before at a single site. The three are:

"Conventional" false targets, the result of interrogations and replies reflected over a single path (Fig. 7(a)). In this geometry, the false target occurs at the azimuth of the reflector, and at a range greater than that of the actual aircraft, usually by one to two times the distance to the reflector.

"Sidelobe" false targets, the result of reflected interrogations to an aircraft so close to the interrogator that his replies are received directly via the interrogator antenna sidelobes (Fig. 7(b)). Occasionally, received simultaneously with "conventional" replies, these occur at the azimuth of the reflector,

*An additional 90 scans at the other end of the tape from the above were examined in connection with the spurious reply problem discussed later.

Table 6. Aircraft at ABQ.

TIME: 1612:02 GMT DATE: 16 November 1973

Code	Altitude* (ft)	Range (nmi)	Azimuth (degrees)
0207	8,800	5.31	25.3
0201	25,900	54.15	81.6
1540	13,900	22.56	142.6
0223	00	8.75	177.5
1200	00	29.75	178.4
1200	--	16.25	179.3
0700	--	35.56	339.1
2000	21,500	50.81	346.6
1216	--	10.44	349.5

NOTE: Positions at scan 20.

TIME: 1635.21 GMT DATE: 3 December 1973

Code/Altitude	Range (nmi)	Azimuth (degrees)	Remarks
1200/00	1.62	28.3	on airport surface
1577/053	1.88	46.4	taking off rwy 26
0202/190	34.25	91.0	approaching
2400/349	56.12	126.9	en route, closing
2400/350	40.18	152.2	en route, closing
1215/00	11.62	177.9	closing
1576/00	7.62	178.6	opening
1503/00	8.18	188.8	opening

*Altitudes relative to MSL; those below 18000 are corrected for local barometric pressure. 00 signifies empty bracket replies to Mode C. Blank signifies not replying to Mode C. (Airport altitude 5300 ft.)

Table 6. Continued.

Code/Altitude	Range (nmi)	Azimuth (degrees)	Remarks
1200/--	14.06	230.1	opening
2400/409	51.06	254.5	opening
2100/309	44.30	258.9	opening
1214/--	13.43	261.4	opening
0235/057	2.75	272.4	initial departure
1504/00	30.81	301.0	closing
1200/--	15.56	355.1	closing
1200/00	1.78	358.1	closing

and have an apparent range equal to the average of the direct range to the aircraft, and the range to it via the reflecting path.

"Mainbeam" false targets, or range splits (Fig. 7(c)). These have been observed only rarely, and are problematic to our knowledge only at the Las Vegas, Nevada ASR. They result from reflection of legitimate replies (during the time the aircraft is in the mainbeam) off of properly-oriented patches of planar ground, also in the mainbeam.

It is noteworthy that more than half of all the "sidelobe" false reply sequences were actually declared as targets by ARTS-III, most of which were accompanied by one or two replies received via the conventional (reflecting) path. That these were often of sufficient width to cause declaration while the

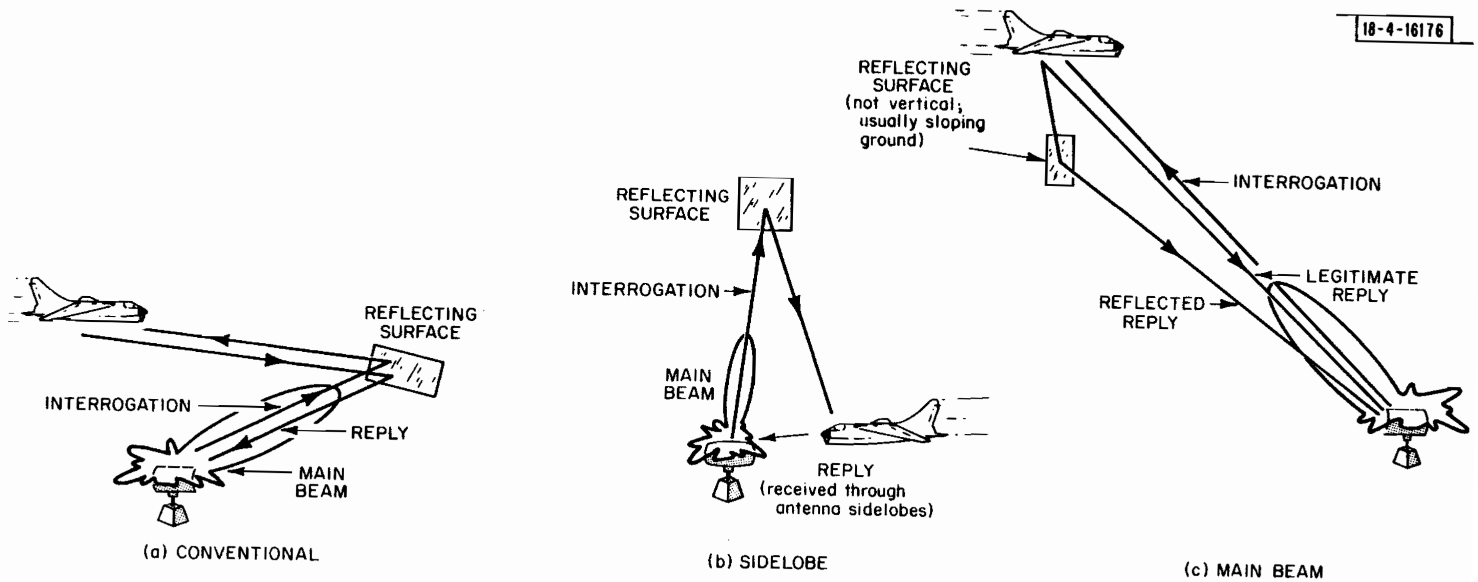


Fig. 7. Types of false targets

"conventional" reply sequences were far too short to be declared, suggests that the uplink is overpowered relative to the downlink. That is, the uplink is capable of eliciting transponder replies over a (reflecting) path which is too weak to successfully carry these replies back to the interrogator. The presence of synchronous sidelobe replies confirms that uplink interrogations are being successfully sustained over the reflecting path; the absence of reflected replies on the same sweeps confirms that the reply path is too weak. From Table 7 we see that the interrogator peak power is some 2 dB above the 175 W level that has been found satisfactory at many sites in the Western Region.

Table 7. ABQ ATCRBS parameters.

Peak power	
At ATCBI output	250 W
Less 2.8 dB line losses .	150 W into antenna
Sensitivity time control . . .	45 dB desensitization at t=15 μsec
Sensitivity (MDS)	-87 dBm
PRF.	343 ips
SLS type	Improved

The geometries of the 61 false reply sequences were analyzed, and found to be due to 11 different reflecting surfaces. The locations and orientations of these surfaces are as shown in Fig. 8 (a), (b), and (c). (Three separate figures were used for clarity; the reflectors were at quite disparate

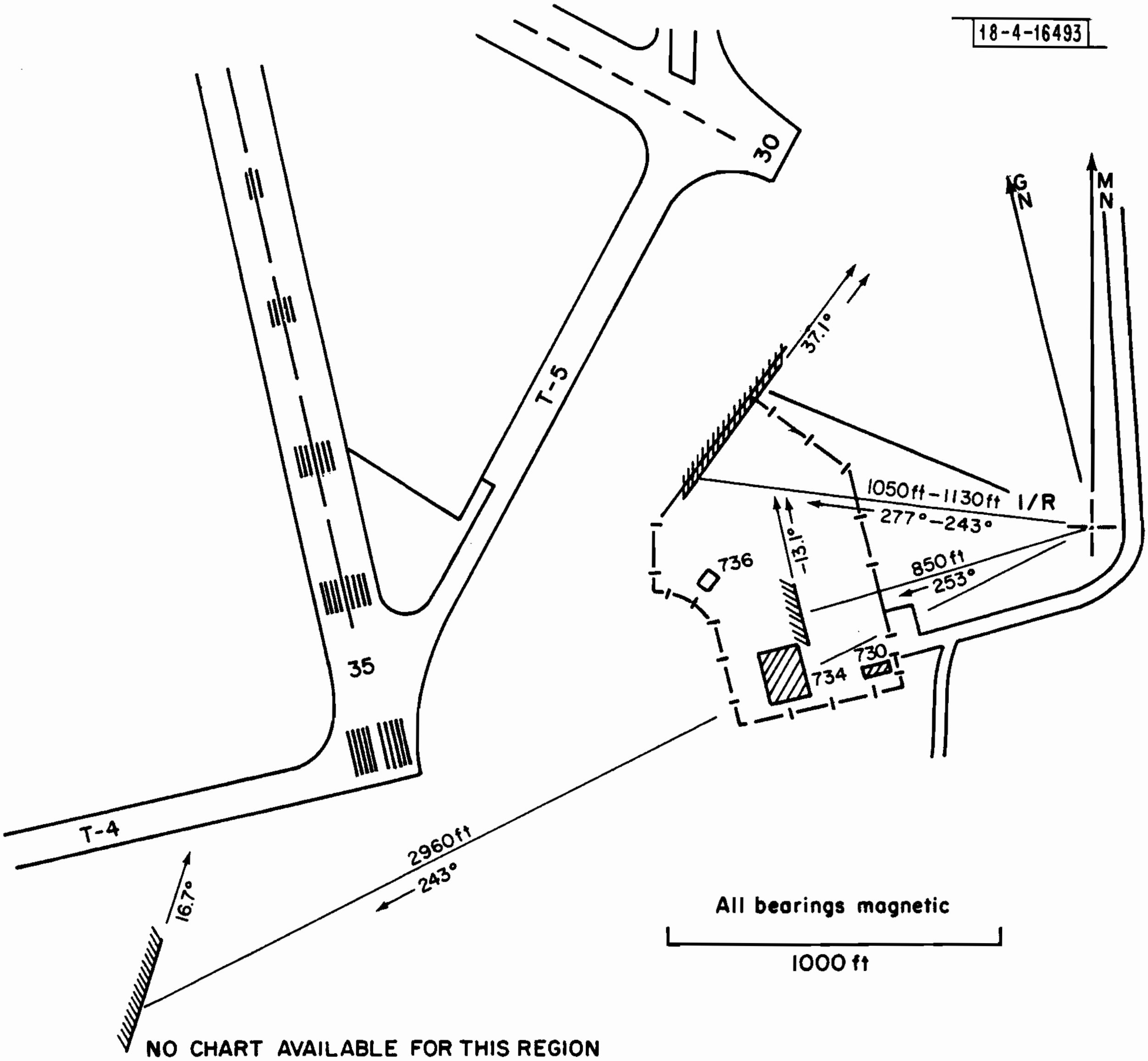
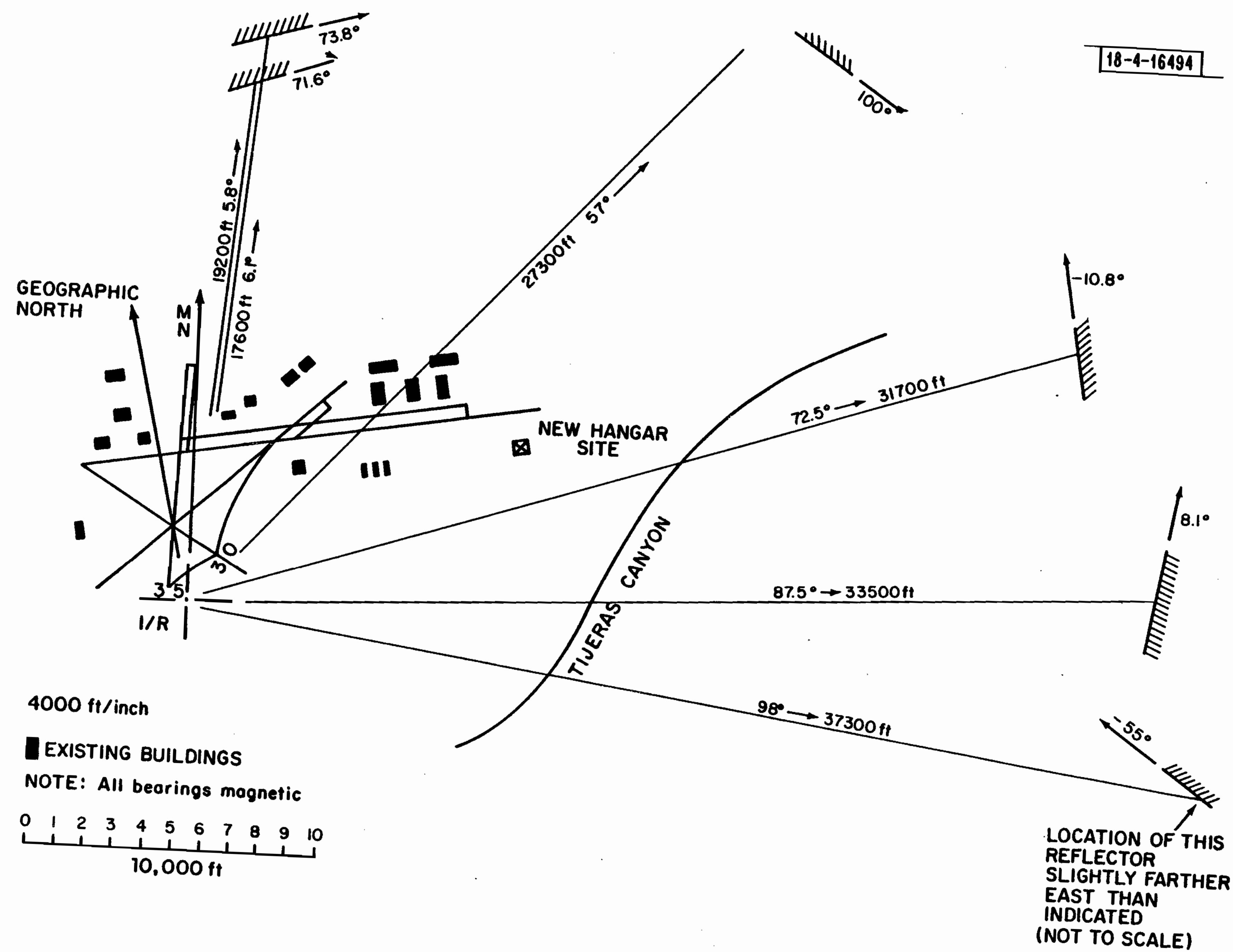
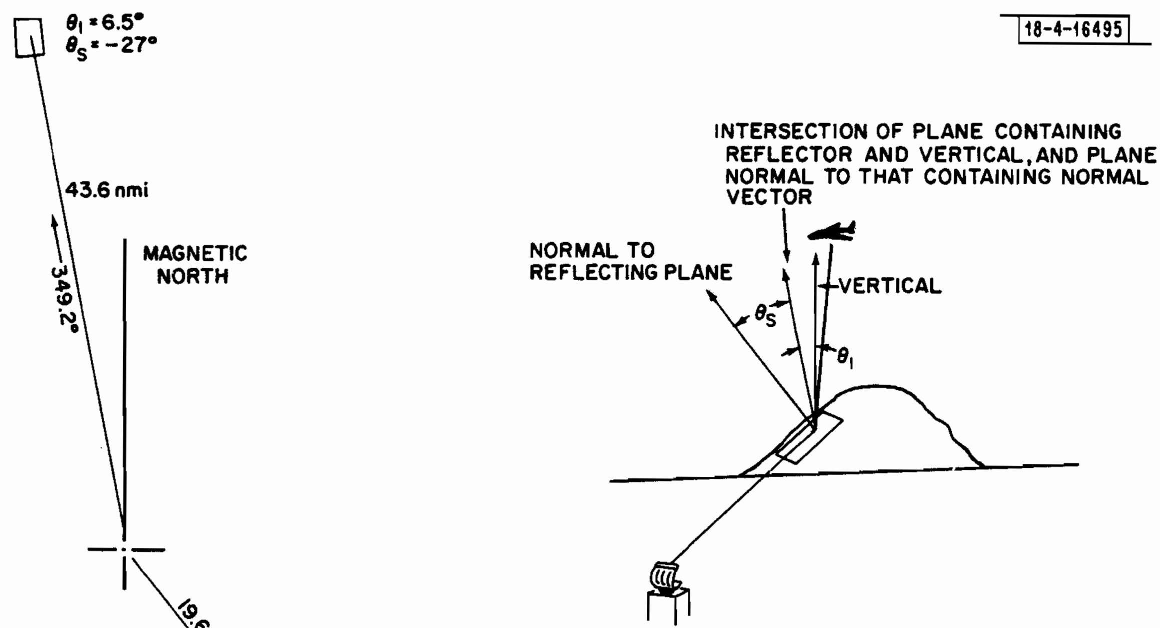


Fig. 8(a). Nearby reflectors - ABQ


18-4-16494
73.8°
71.6°
100°
19200 ft 5.8°
17600 ft 6.1°
27300 ft 57°
GEOGRAPHIC
NORTH
M
N
-10.8°
72.5° → 31700 ft
NEW HANGAR
SITE
8.1°
30
35
87.5° → 33500 ft
I/R
TIJERAS CANYON
98° → 37300 ft
-55°
4000 ft/inch
EXISTING BUILDINGS
NOTE: All bearings magnetic
0 1 2 3 4 5 6 7 8 9 10
10,000 ft
LOCATION OF THIS
REFLECTOR
SLIGHTLY FARTHER
EAST THAN
INDICATED
(NOT TO SCALE)



DEFINITION OF ANGLES

θ_I MEASURED IN VERTICAL PLANE CONTAINING INTERROGATOR AND REFLECTOR

θ_S MEASURED IN PLANE PERPENDICULAR TO THAT CONTAINING NORMAL TO REFLECTOR

θ_S NEGATIVE ⇨ PLANE TILTS DOWN TO THE LEFT

Fig. 8(c). Mainbeam reflectors - ABQ

ranges.) The quantities of false replies caused by these reflectors, compared with those caused by other reflectors at comparable ranges observed in past data from other sites (with appropriate corrections made for differences in system parameters), suggests that several of these reflectors are quite large, and long in extent, notably the two to the East at 72.5° and 87.5°. The reflectors and pertinent parameters are listed in Table 8.

When compared with obstruction charts, photographs, and other maps of the area, the data is of particular significance. Obstruction charts and panoramic photos reveal numerous fairly substantial reflecting surfaces associated with airport buildings that might be expected to produce many false targets, given the distribution of aircraft at Albuquerque. That they did not suggests that Improved Sidelobe Suppression is quite effective there; indeed, only 3 of the 61 false reply sequences involved geometries where Improved SLS might have inhibited replies.* The remainder were either so close that reflected interrogations would be received before suppression occurred, or so far that interrogations would not be received until after suppression was complete. (A pathlength difference greater than about 5 nmi results in arrival of the reflected interrogation 30 μsec after suppression; this is typical of the suppression times of commercial and general aviation transponders.)

Discussion with Airways Facilities personnel at ABQ revealed that most of the reflectors found corresponded to known buildings or fences. An apparent discrepancy between the data on close-in reflectors and engineering drawings of the airfield suggested that the ASR position shown on the drawings

*Of these, 2 were very close to the maximum reflector range at which I^2SLS is effective (i.e., the aircraft could have completed its suppression when the reflected interrogations arrived), and the third resulted from an aircraft 54 nmi away, beyond the range of the I^2SLS omnidirectional suppression transmission.

Table 8. False-target-generating reflectors seen at ABQ.

Reflector Name	Reflection Parameters			False Target Incidence	
	Range (ft)	Azimuth (degrees)	Orientation (degrees)	16 Nov. Data	3 Dec. Data
Manzano Mt. fence	33, 500	85-90	8.1	7 (2D)*	16 (7D)
Building #734	850	240-250	-13.1	3	12 (5D)
Fence north of Building #734	1, 000 to 1, 150	270-295	37.1	3	9 (1D)
South Manzano Mt. fence	37, 300	98-101	-55.0	2	1
Unknown	27, 350	58	118.0	0	2
Bank of New Mexico (Central and San Mateo)	18, 400	6	72.0	2	0
Unknown (probably an approaching aircraft)	2, 960	243	16.7	1	0
Unknown	31, 700	72.0	-10.8	1	0
Unknown (mainbeam)	19.6 nmi	141	$\theta_I=12$ $\theta_S=0$	1	0
Borrego Dome (?) (mainbeam)	43.6 nmi	349.2	$\theta_I=6.5$ $\theta_S=-27$	1	0

*"D" denotes declarations. The entry "7(2D)" should be interpreted as "7 false reply sequences observed, of which 2 resulted in erroneous target declarations."

was erroneous. Further discussion confirmed that this was the case. When the radar was placed in its proper location on the site chart, the data agreed well with reflecting surfaces shown on the chart (Fig. 8(a)). Subsequent detailed examination of an aerial photograph of the region further confirmed the proper location.

The Air Force building in question is to be built 10, 300 ft ENE of the ASR site; the side facing the radar will be 200 ft long and 75 ft high. Due to ground elevation differences, the top of the building will be 110 ft above the secondary radar antenna. Building orientation is such that incident energy from the radar will impinge at an angle of 18° from the normal to the building face (southerly), and will thus illuminate a region of airspace slightly north of magnetic west. The building subtends slightly more than 1° in azimuth. Assuming that it is highly reflective, losses over the reflecting path to aircraft centered in the reflecting beam at long range would only be at the most some 5 dB greater than direct pathloss. Thus, it appears that the building would be capable of sustaining reflections, albeit over a narrow angle. The noted successful operation of Improved Sidelobe Suppression at ABQ, however, greatly reduces the likelihood that false targets would be produced by the hanger.

3.3.4 Potentially More Severe Problem

A phenomenon which has been noted occasionally in data from other sites, occurred so frequently in the 3 December 1973 Alburquerque data as to result in frequent severe performance degradation. The fact that this phenomenon was not seen at all in the 16 November 1973 data suggests its source, and also the proper course of corrective action; these will be discussed below. Numerous spurious replies were seen throughout the data, in range cells adjacent to legitimate replies, with the same reply codes, and with garbling indicated. Since traffic was light, this normally occurred with aircraft which were quite distant from other aircraft, and was clearly due to a mechanism other than conventional synchronous garbling. Both the legitimate and the spurious replies were flagged as garbled by ARTS-III, although no erroneous decodes were noted. A few legitimate synchronous garble situations (involving two or more aircraft in close proximity) were also noted; ARTS-III appeared to perform properly in these situations. However, the number of garbled replies due to these situations (where garble-flag setting is appropriate, indeed, necessary) was quite small compared to the number of replies erroneously flagged as garbled.

The effects of these erroneous replies and the associated erroneous garble-flag settings on system performance were noticeable and severe. Dual declarations (target "splits") occurred at a rate of about one per scan, at comparable azimuths and ranges that differed by 1/16 nmi. Occasionally, two target declarations at the same range were noted. Perhaps more severe were repeated rejections of altitude data that appeared to ARTS-III to be of low quality, since garble flags were set, but was in fact correct. (This reduction in altitude decoding capability was further aggravated in some cases by an additional related problem, so-called "C_2-SPI phantom generation," which will be discussed in detail later on.) In addition, aircraft identity codes, although invariably declared correctly, were declared with low confidence (code validity levels of 0, 1, or 2). As a result of all this, mean track lifetimes, which were not measured directly, must have been quite short.

This behaviour is entirely consistent with the appearance of individual reply pulses of excessive width at the ATCBI/ARTS-III interface. Indeed, the ARTS-III Beacon Data Acquisition System (BDAS) is designed intentionally to interpret all pulses more than 600 nsec wide (the nominal width is 450 nsec) as two overlapped pulses. Pulses of widths between 550 and 600 nsec are interpreted as overlapped on a probabilistic basis, depending on how their arrival times relate to the ARTS-III sampling instants. The BDAS even automatically inserts leading edges into the data stream at locations consistent with the trailing edges of the wide pulses received (Fig. 9). This is done to improve performance in actual synchronous garble situations, and allows effective separation of closely aligned garbling replies in those situations.

There are two mechanisms by which ATCRBS reply pulses could be widened excessively: short time delay multipath and ATCBI receiver/ARTS-III front-end misalignment. Instances of both have been seen in past data. Indeed, two instances of multipath were noted in the 16 November 1973 Albuquerque data (the two "mainbeam" reflectors shown in Fig. 8(c)). However, in both these cases, the replies were separated by two or more range cells (rather than one). This amount of separation is inconsistent with excess pulse-width, and can only result from a channel in which a single input pulse results in a distinct pair of output pulses, separated by a microsecond or more.

The secondary surveillance radar at the Las Vegas, Nevada (LAS) airport surveillance radar (ASR) site [1] exhibits severe multipath of this sort, due to the dry, sandy nature and the topography of the nearby terrain. There, multipath "echoes" separated by one, two, or three or more range cells are

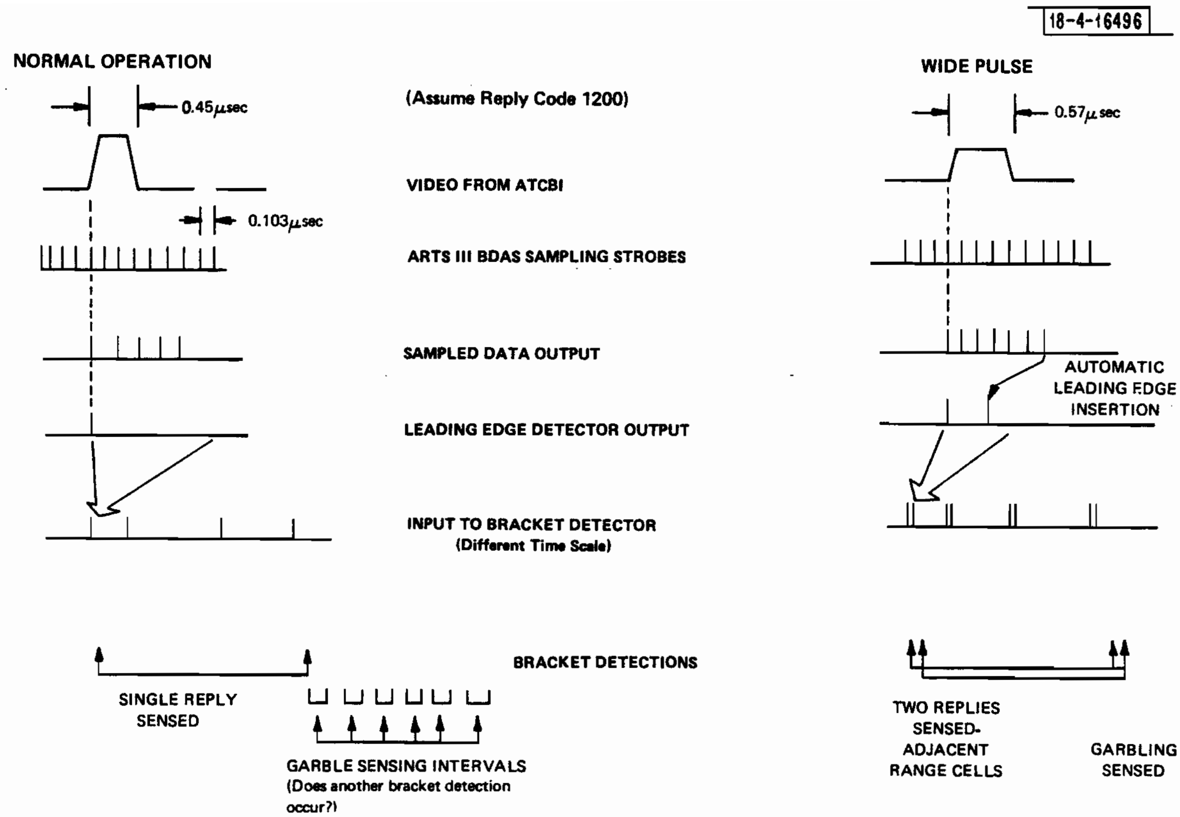


Fig. 9. Effect of excess pulsewidth on reply generation

frequent. Some of the echoes delayed by two or more range cells were analyzed by Lincoln Laboratory [1], and correlate fairly well with the topography (as did the two seen at Albuquerque). The one-range-cell echoes appeared to be due to pulse stretching, occurring somewhere in the RF or video sections of the ATCBI, or to improper level adjustment at the ATCBI/ARTS-III interface; however, extensive tests conducted by Las Vegas, NAFEC, and MITRE personnel appear to have ruled out all these causes. Pulse stretching appears to be due to a multipath environment at Las Vegas.

In a recent study conducted for FAA/SRDS [6], Sperry/UNIVAC noted that spurious replies of this sort could result from an excessively low BDAS threshold setting. Discussion with site personnel revealed that this was not the case at Albuquerque. On the other hand, since the phenomenon was noted frequently in the 3 December 1973 tape, and not observed at all in the 16 November 1973 tape, it appears unlikely to be due to environmental factors, but rather to differences in equipment parameters.

The beacon interrogator system at Albuquerque, as at most operational sites, is fully dual redundant. During the course of recording the 3 December 1973 data, the system was switched from channel 1 to channel 2. In order to test the hypothesis that pulse stretching caused by improper beacon interrogator receiver operation might be the source of the problem, some additional data were printed out from the end of the 3 December 1973 tape, after the switchover had occurred. The gross garbling statistics of this data were compared with those of the data from the beginning of the tape, and the differences were significant. Typically, out of about 200 replies per scan, the beginning data would contain about 50 garbled replies, usually due entirely to the wide pulse and C_2-SPI phantom problems. The wide pulse problem generally caused an additional reply to be generated, and flagged both this spurious reply and the adjacent legitimate reply as garbled. Occasionally, however, pulse stretching would be sufficient to cause the garble sensing mechanism to react, but not to generate the spurious reply. Thus, slightly more than half of the garbled replies were legitimate; for the typical values noted above, this would lead to the conclusion that out of 180 legitimate replies per scan, roughly 30 (16%) were disturbed by the pulse-stretching and C_2-SPI phantom phenomena, during that portion of the data derived from channel 1. The channel 2 data produced a far lower rate, typically 4 or fewer garbles out of 120 replies. These garbles were usually due to legitimate instances of synchronous garbling, and in the few cases seen where they could be attributed to excessive pulsewidth, they were generated entirely by a single aircraft. In the channel 1 data, virtually every aircraft in the coverage area exhibited the problem. On the basis of these data, it would appear that the problems of erroneous garble flagging and spurious reply generation are due to pulse stretching which occurs within the channel 1 beacon receiver.* Since the incidence of this behavior is fairly low even in the channel 1 data (about one chance in six per legitimate reply), the pulse stretching appears slight; ATCBI video output pulses of width only slightly in excess of 550 nsec could cause this incidence. Discussion with site personnel confirms that these pulsewidths are being measured. It should be noted that the national standards for ATCRBS transponders allow pulsewidths up to 550 nsec. It therefore appears essential to hold any pulse stretching in the receiver down to a very minimal value, since only very slight increases in pulsewidth above that allowed will cause severe system performance degradation.

*A telephone conversation with M. Holtz of NAFEC confirmed that this was indeed the case; the receiver has been repaired and is now operating properly.

3.3.5 The C_2-SPI Phantom Problem

ARTS-III interprets any pair of pulses received with 20.3 μsec spacing as a bracket pair, and decodes the intervening pulses accordingly. Since no two pulses within a single ordinary reply other than the F_1 and F_2 pulses satisfy this condition, no erroneous bracket detections usually occur. However, when the ident (SPI) pulse (which occurs three pulse positions, or 4.35 μsec, after F_2) is set, it and the C_2 pulse (the third in from F_1) can be mistakenly sensed as brackets, thus producing an erroneous reply, or "phantom." Circuitry within the ARTS-III BDAS is designed to sense whenever the SPI pulse is set, and automatically suppress any erroneously-generated replies resulting from it. Data from other sites reveal that this circuitry operates properly at those sites. It did not function properly in the channel 1 Albuquerque data. On about half the occasions when the C_2 and SPI bits were set at Albuquerque, a phantom reply was sensed in addition to the legitimate one, at a range in excess of the legitimate one by 3/8 nmi, with a code which was consistent with that of the legitimate one (Fig. 10).

This phenomenon was noted on Mode A in connection with SPI operation, which occurred only rarely. It was far more prevalent on Mode C; early specifications for altitude encoding transponders (cf. Ref. 7) required that the SPI pulse be set in a Mode C reply whenever the D_4 pulse was set. Many airline transponders today encode altitude in this fashion; the D_4 pulse only becomes set above pressure altitude 30,800 ft. Three of the aircraft in the ABQ coverage area replied in this manner, and whenever they were at altitudes such that the C_2 pulse was set as well (this occurs about 60% of the time in Mode C replies), their reply sequences contained multiple C_2-SPI phantoms.

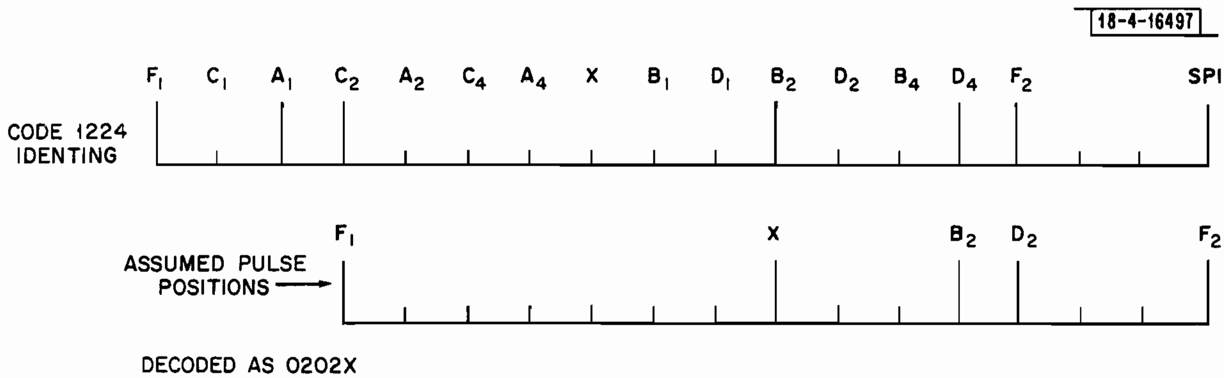


Fig. 10. Generation of a C_2 - SPI Phantom.

Approximately one time in four, these were of sufficient quantity to result in low validity or defaulted altitude decoding.

Again, since this phenomenon shares many common characteristics with Mode A reply garbling (in particular, a complete absence from the channel 2 data), it is likely that correction of the pulse stretching problem will eliminate the C_2-SPI phantom generation problem as well.

3.3.6 A Simple Procedure for False Target Elimination by means of ARTS-III Software.*

This section describes the software processing algorithm that has been proposed for use at Albuquerque. Since it will probably be ready for implementation and testing before the ART facility is completed, it has been tailored toward elimination of false targets due to the two reflectors nearby the interrogator (Bldg. 734 and the fence to the north of it in Fig. 8(a)). Should false targets arise due to the ART, it can easily be tailored to handle them as well.

Two basic assumptions were made for simplicity:

a) The assumption that interrogator-to-reflector range is small compared to aircraft range was made (Fig. 11). This results in a substantial simplification in the relationships between false and real target positions, and is almost always appropriate in practice.

b) It was assumed important to be able to identify a target as potentially false as soon as it is displayed; this requires slightly more processing time than a procedure which could afford to wait until subsequent declaration of the actual target before deciding.

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*The techniques described in this paragraph and paragraph 3.3.7 were developed under U.S. Air Force Contract F19628-73-C-0002, and are described more completely in MIT/Lincoln Laboratory Technical Note TN 1974-12. They are included here for completeness.

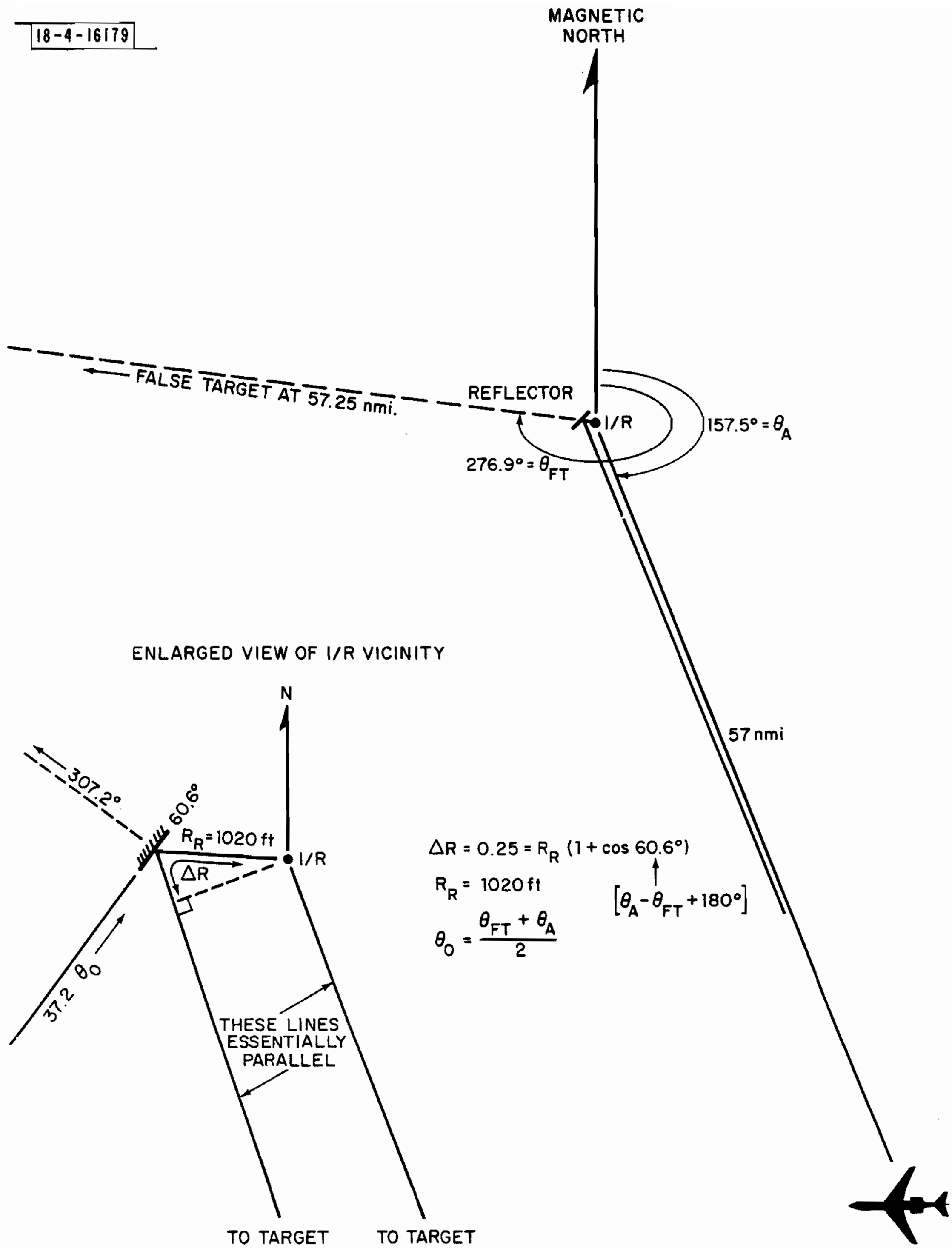

Fig. 11. Simplified geometry $R_A \gg R_R$.

These assumptions appear quite appropriate for the particular situation at Albuquerque. Should they prove undesirable in other applications, it is fairly straightforward to remove their effects from the algorithm. The basic false target elimination algorithm is first described in general terms, and then specifically tailored to the Albuquerque situation. The process involves recognition of aircraft in regions where they can cause false targets, calcuation on where those targets would be, search of those areas to see if correlated targets are present, and identification of those targets as false.

The first step in the process is to identify all aircraft which are in the regions illuminated by the reflectors, and which could thereby produce false targets.

The illuminated regions are simply defined as azimuthal wedges (Fig. 12), each corresponding to a particular known reflector. Whenever a target declaration azimuth falls within one of these wedges, its range, azimuth, identification, and altitude are stored for further processing (Fig. 13), along with the parameters of the particular reflector, θ_o and ΔR.

These parameters are defined in Fig. 11 and allow calculation of the position at which a false target would occur from the positions of the actual aircraft causing it. In particular:

$$R_{FT} = R_A + \Delta R$$

$$\theta_{FT} = 2\theta_o - \theta_A \quad .$$

Here, A denotes the actual target and FT denotes the false one.

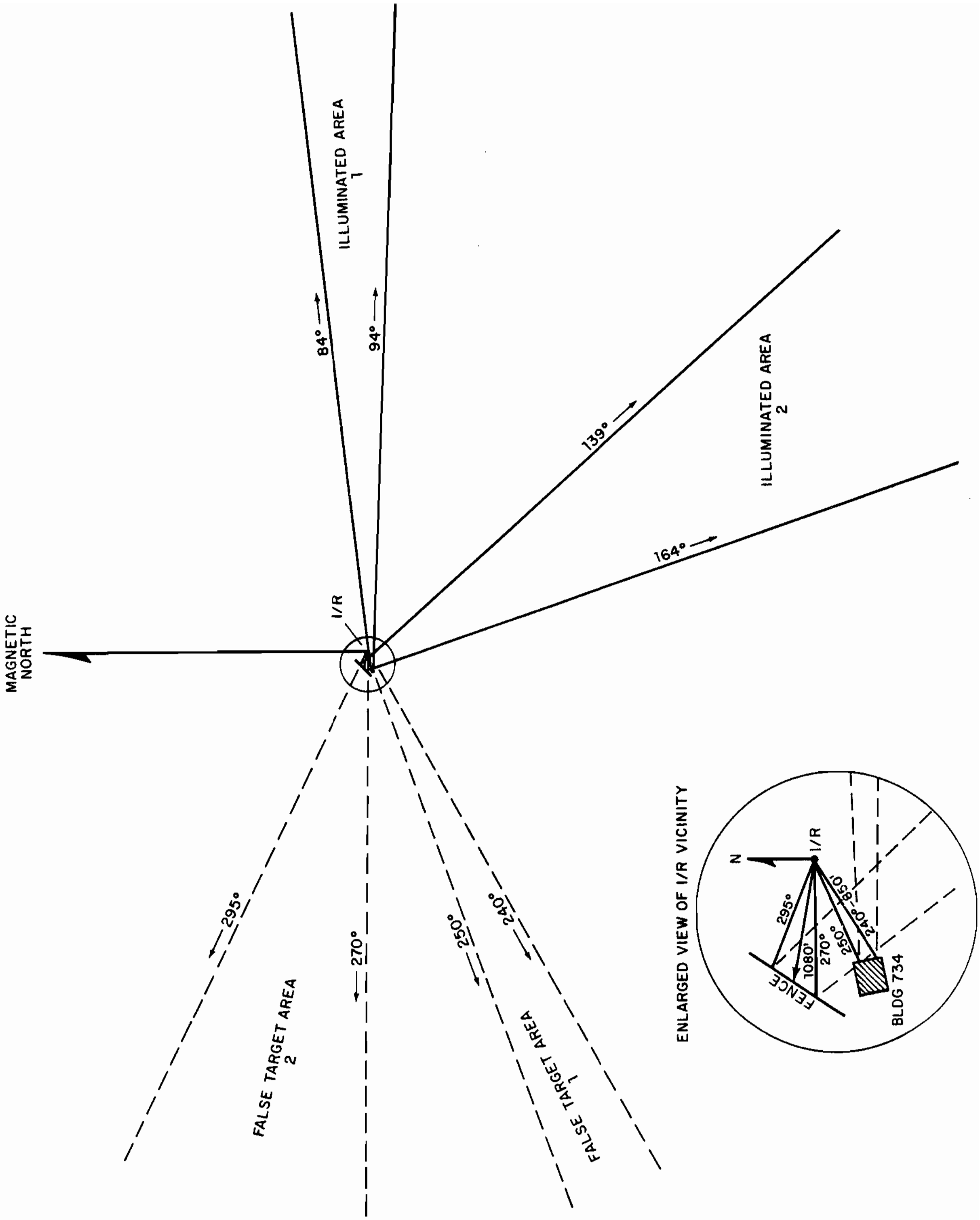

Fig. 12. Typical close-in reflection geometry.
(observed at Alburquerque)

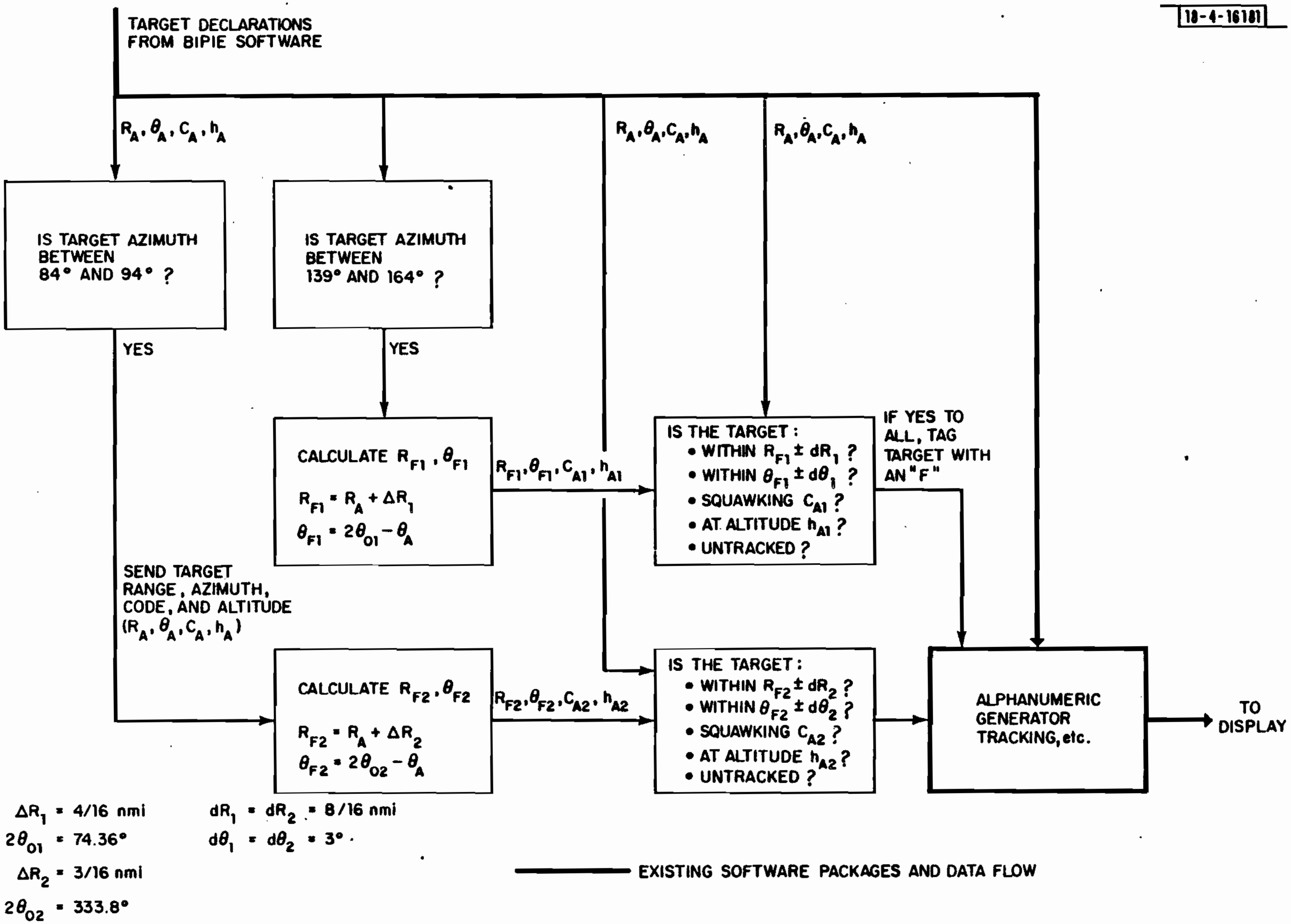

Fig. 13. Simple false target identification algorithm.
(tailored to parameters shown in Fig. 9)

The process next creates a window of size 2 dθ by 2 dR around the expected false target location, and examines the subsequent target declarations occurring in the next scan to determine if they, a) fall within the window, b) agree in code and altitude with the actual target, and c) are not updated positions of tracked aircraft which were at one time outside the illuminated area. If all of these conditions are satisfied for a particular target declaration, it is concluded to be false, and tagged with a special symbol (e.g., an "F").

Window size is determined by the precision with which the false target position can be calculated, and by the distance over which the target can move between the times when it and the false target occur (typically, 1 to 3 sec apart). Manual solutions, in which aircraft position has been interpolated between the two target reports adjoining the false target to the instant at which the false target appears, regularly yield errors less than $\pm$ 1/16 nmi (one range cell) and $\pm$ 0.5°. Additional error results from the fact that high-speed aircraft could change position by as much as 1/2 nmi and 3° during the interval between their legitimate declaration and the time at which they next cause a false target. Thus, window size depends primarily on uncertainty in instantaneous position due to aircraft motion; basing window position solely on aircraft position as of the last declaration leads to a window of moderate size; basing it on instantaneous (interpolated or extrapolated) position allows the use of an extremely small window.

This technique could conceivably flag a legitimate target as false, if that target was in the right place at the right time, squawking the right code and altitude. It is evident that the probability of that event - albeit very small-is proportional to window size. What is of interest here is whether the window size that results from basing window location solely on previous declared position is small enough to ensure that the probability of declaring a real target as false is maintained at an acceptably low level. Also, do the further reductions in that level that result from using the smaller window based on interpolated data warrant the complexity of the interpolation software? In a low-density environment, it would appear that the likelihood of a legitimate aircraft appearing in a window of moderate size (say, 1 mile by 6^{o}), and agreeing in code and altitude* with the aircraft whose presence has caused the window to be generated is exceedingly small. In addition, given that unlikely event, it would be highly unlikely that the relationships between the velocities and headings of the two aircraft would be such that the situation would persist over many scans. In short, it seems appropriate to develop the initial version of false-target-elimination software around the assumption that a window based solely on previous position is sufficiently small; this eliminates the need for interpolation, and the tracking/correlating process that would be necessary in that situation.

The ultimate output of the process described above and diagrammed in Fig. 13 would thus be a flagging of all targets determined to be false. The determination process would occur independently from scan-to-scan, and the way in which controllers treated flagged targets would, to some extent, be influenced by the number of scans over which they were flagged as false.

*For aircraft not equipped with altimeters, presence or absence of empty brackets could be checked. Since these aircraft are the most likely users of nondiscrete codes (e.g., 1200), perhaps consideration should be given to a more widespread discrete code assignment procedure.

Automated processes taking past history into account in determining the certainty with which targets are declared false are possible, perhaps, desirable; these all require that tracking logic be employed, and are all, therefore, somewhat more complicated to implement. The degree of added complexity must be weighed against the additional benefits derived in order to determine whether a process involving tracking is more desirable than the simple one described here. That determination is beyond the scope of this memo; much detailed information about the operation of the ARTS-III tracker is needed before it can be properly made. However, the following section discusses briefly a possible approach to false target elimination making use of ARTS-III tracking.

3.3.7 A More Complex Approach*

ARTS-III tracking involves both correlation and smoothing, and is intended in its present version primarily to keep data blocks properly positioned on the display, and to "coast" target symbols through short periods where aircraft replies are lost. It appears necessary to employ some elements of the ARTS-III tracking process, particularly the scan-to-scan correlation of target reports, in any false-target-elimination process which is more complex than the one discussed above.

This section presents a possible false-target-elimination procedure (see Fig. 14) which uses tracking to associate target declarations of a particular aircraft with one another. Many variations of this basic procedure are possible; it should be viewed as typical rather than preferred.

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*The techniques described here and in paragraph 3.3.6 were developed under Air Force Contract F19628-73-C-0002, and are described in more detail in MIT/Lincoln Laboratory Technical Note 1974-12.

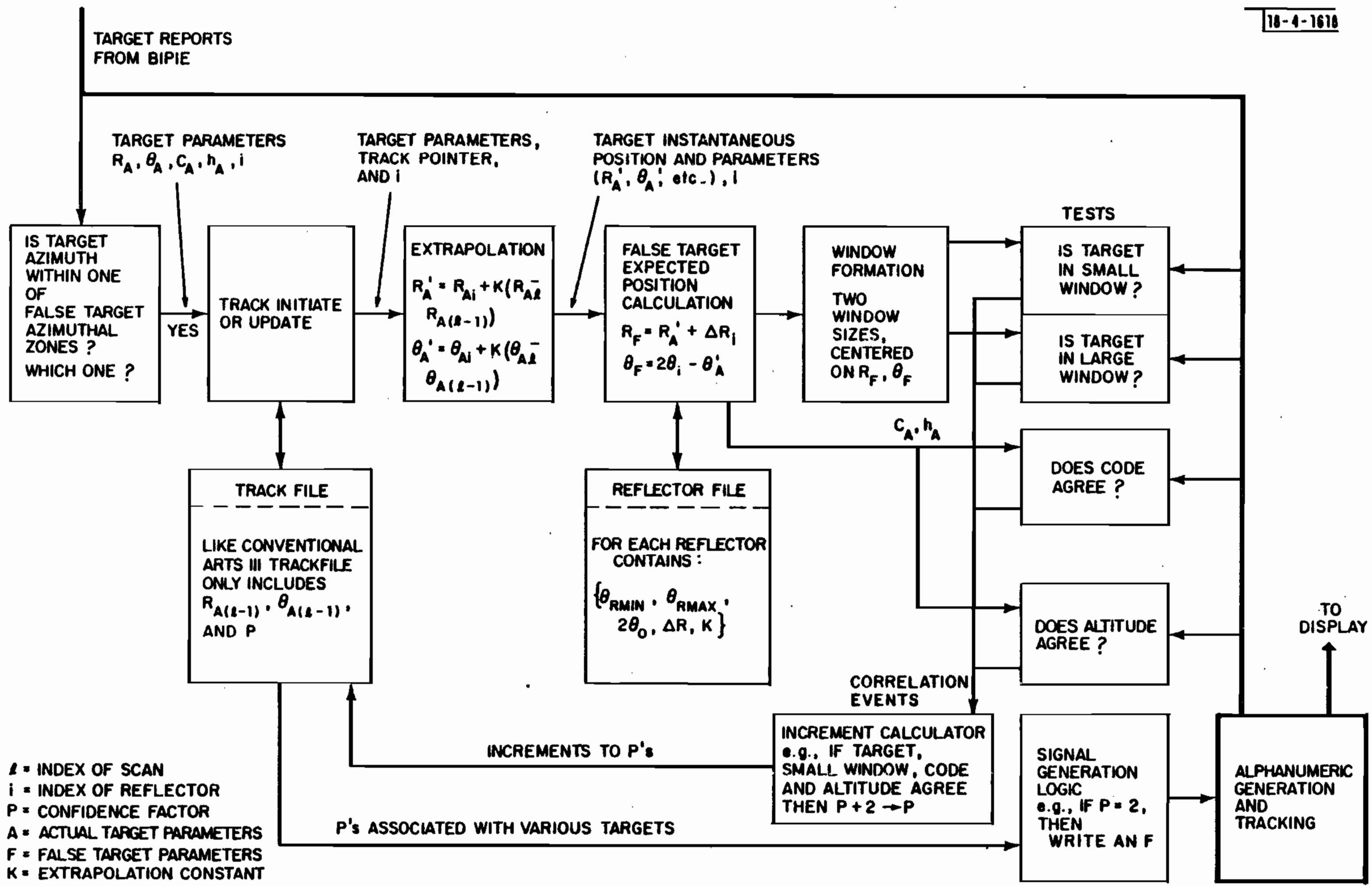


Fig. 14. False target elimination algorithm employing tracking.

It should be noted initially that experience with ARTS-III reply, target declaration, and tracking data has demonstrated clearly that declared target position data yields far higher precision than tracker output data. The only source of noise of the type which tracking can filter out in the range measurement process is quantization; whenever a target is declared, one can be certain that its range is within 1/16 nmi of the proper value. Tracked positions often deviate by more. Thus, only positions associated with target declarations are employed in what follows.

The target report correlation that results from tracking is used to advantage in two ways here: to allow interpolation, thus allowing reduction in the size of the "window," and to allow the use of a running record of the "confidence" that a target is false.

The procedure starts out in a manner similar to the simpler procedure discussed above. Target reports are screened to see if any fit within particular regions, those regions that the various reflectors illuminate. Whenever one comes close to a region (perhaps within 3^o of it), it becomes automatically tracked* (the display need not indicate that this has occurred). On each scan, the parameters δR and $\delta\theta$ are calculated simply by subtracting the R and θ values of the previous declaration from those of the present. A new value of each parameter is calculated for each scan; alternatively, the value of each parameter could be smoothed over several scans. When the

*ARTS-III does not normally track all targets. The procedure described above corresponds to the "Auto Track Initiate" feature of ARTS-III, in which certain targets become tracked automatically. Of course, further study of the appropriateness of the ARTS-III tracker for this task might reveal that a separate tracking algorithm might be better suited to this task.

target actually enters the illuminated area, the predicted false target is now calculated by extrapolation. That is, the actual target position is assumed as $(R + K\delta R,\ \theta + K\delta\theta)$, where K is a constant for each reflector determined by how far away in azimuth (and thus in time) the false target position is from that of the real target. An equivalent way to view this extrapolation process is to look at the δR, $\delta\theta$ as velocities (miles, degrees, per scan), and the K as time (expressed in fraction of a scan). Note K is always less than one.

A brief example is appropriate here. Assume that a particular reflector at an azimuth of 120° is oriented in such a way that it illuminates a wedge of air space centered about 30°. Assume further that an aircraft has just flown into the illuminated area, and that its present and past positions are as follows:

present	29 nmi, 29°
last scan	28 nmi, 28°
previous scan	27 nmi, 27°

and so forth.

Here, δR and $\delta\theta$ are obviously 1 nmi and 1°, and the position of the aircraft extrapolated ahead to the instant the radar points at the reflector is simply (29. 25 nmi, 29.25°), since that occurs one-quarter scan after the legitimate target is detected.

Given the luxury of being able to wait for the target report following false target occurrence, it would be possible to develop a similar process using interpolation rather than extrapolation. This would, of course, result in greater accuracy, since it would account for changes in aircraft heading made subsequent to the target declaration preceding false target occurrence.

However, the degree of difference appears to be so small as to be outweighed by the disadvantage of having to wait several seconds after the occurrence of a false target before being able to decide that it's false.

In a manner similar to that used in the simpler procedure, the instantaneous position determined here is used to determine the position of a "window," which is again searched as the antenna azimuth passes through it for target reports agreeing in code and altitude. In this case, though, the use of correlation that results from tracking allows "softer" decisions to be made; in keeping with this, perhaps two concentric windows should be used. Whenever a potentially false target occurred within these windows, a parameter would be established in the track file corresponding to the actual aircraft in question. This parameter would be similar to the track firmness parameter used in the present ARTS-III tracker, and would be incremented from scan-to-scan as confidence in the decision that the target is false grows; depending on its value on a particular scan, the symbology used to identify the false target might vary.

For example, the confidence parameter might be 3 bits long (8 levels), and be set initially to zero. Two window sizes might be used, say 1/8 nmi by 1° and 1/4 nmi by 2°. Occurrence of a target agreeing exactly in code and altitude within the smaller window might increment the parameter by 2; a target within the larger window agreeing in code and altitude might increment it by 1; a target in the smaller window agreeing in code but not in altitude might increment it by 1. Presence of a target agreeing neither in code nor altitude might not increment it at all. The absence of any target in either window might decrement the parameter by 2. Thus, 4 declarations in a row, each agreeing in code and altitude, and each within the smaller window (implying correlation in range, azimuth, velocity, and heading between the actual aircraft and the suspect false target) would suffice to drive the confidence parameter to its maximum value. More sporadic occurrence of the false target would hold its confidence parameter to a lower value.

The value of the confidence parameter would be used to determine the display symbology associated with the suspect false target. For example, a level of 1 or 2 might cause it to be tagged with a blinking "F." When the level reaches 3 or 4, the symbol might no longer blink. A level of 5 or 6 might cause it to be tagged with a data block stating "CONFIRMED FALSE." In the future, when the decoded beacon video that is displayed on ARTS-III is available to ARTS-III for more sophisticated processing, a higher confidence level might result in the complete elimination of the false target video from the display.

3.3.8 Conclusions

The software correction discussed in Section 3.3.6 should eliminate any false target problems caused by nearby reflectors at Albuquerque. Corrective action of this sort would also be highly appropriate for Milwaukee, Suitland, Andrews AFB, Boston, and virtually every other site in which digital processing of Secondary Radar data is performed. While the simple false target identification algorithm developed in 3.3.6 appears more than adequate for most sites at today's traffic levels, the more complex procedure described in 3.3.7 should be developed for future consideration at busy terminals.

3.4 ONTARIO, CA. (MARCH AFB RAPCON)

3.4.1 Introduction

This FAA Airport Surveillance Radar, whose output is remoted via Radar Microwave Link (RML) to the ARTS-III located at the March AFB RAPCON, approximately 25 nmi away, has been noted for some time as a source of peculiar false targets. Two ARTS-III extractor tapes were obtained from the site by FAA Western Region personnel, and sent to Lincoln Laboratory for analysis. Approximately 80 scans of reply data and 180 scans of target report data from one of these have been analyzed, and several instances of false targets have been found, both conventional (i.e., like the ones at MKE), and quite unconventional. Twenty-four targets were declared on the average per scan. System parameters were typical and are listed in Table 9.

Table 9. Ontario ATCRBS parameters.

Type of Interrogator	ATCBI-4
Output Power	175 W (pk)
Sensitivity (MDL)	-87 dBm
PRF	450
Pulse Staggering	8/6*
Defruiter	Storage-tube
Scan rate	12.5 rpm
Hy_4† (Mode A)	4
(Mode A and Mode C)	6

*That is, the radar employs a pulse stagger pattern that is repetitive every six pulses; the beacon performs a 3:1 or 2:1 countdown of this, such that its sequence repeats itself every eighth beacon pulse.

†Minimum required number of hits to declare a target.

3.4.2 Conventional False Targets

Both the reply and target report data were analyzed for conventional false targets; six different reflection mechanisms were found, and are shown in Fig. 15. Reflector locations are consistent with building locations on obstruction and topographic charts, panoramic photos, and telephone discussion with site personnel. Twenty-four declared false targets resulted from these reflectors during the 180 scans; all could be corrected by ARTS-III software processing of the type described in the previous section.

3.4.3 Peculiar False Targets

In a detailed examination of the 80 scans containing individual reply data, 18 instances of what appeared at first to be ringaround were found: 11 of these resulted in target declarations (not counted in the statistics above on conventional false targets). In each case, two declarations of a single aircraft were made at adjacent azimuths and the same range. Examination of reply data and aircraft tracks revealed that in each instance one declaration corresponded closely to actual aircraft position; the other declaration consisted of relatively short (6 to 10 replies) and tightly-bunched replies: no replies were seen in the space between the 2 sequences: these reply sequences were generally spaced 2 or 3° apart. In most cases, especially those involving fast aircraft, the condition persisted for only a single scan; adjacent scans contained no spurious replies. Several false declarations correlated closely with one another in azimuth. (A tabulation of all the declarations is contained in Table 10.) These factors infer strongly that the false declarations are not

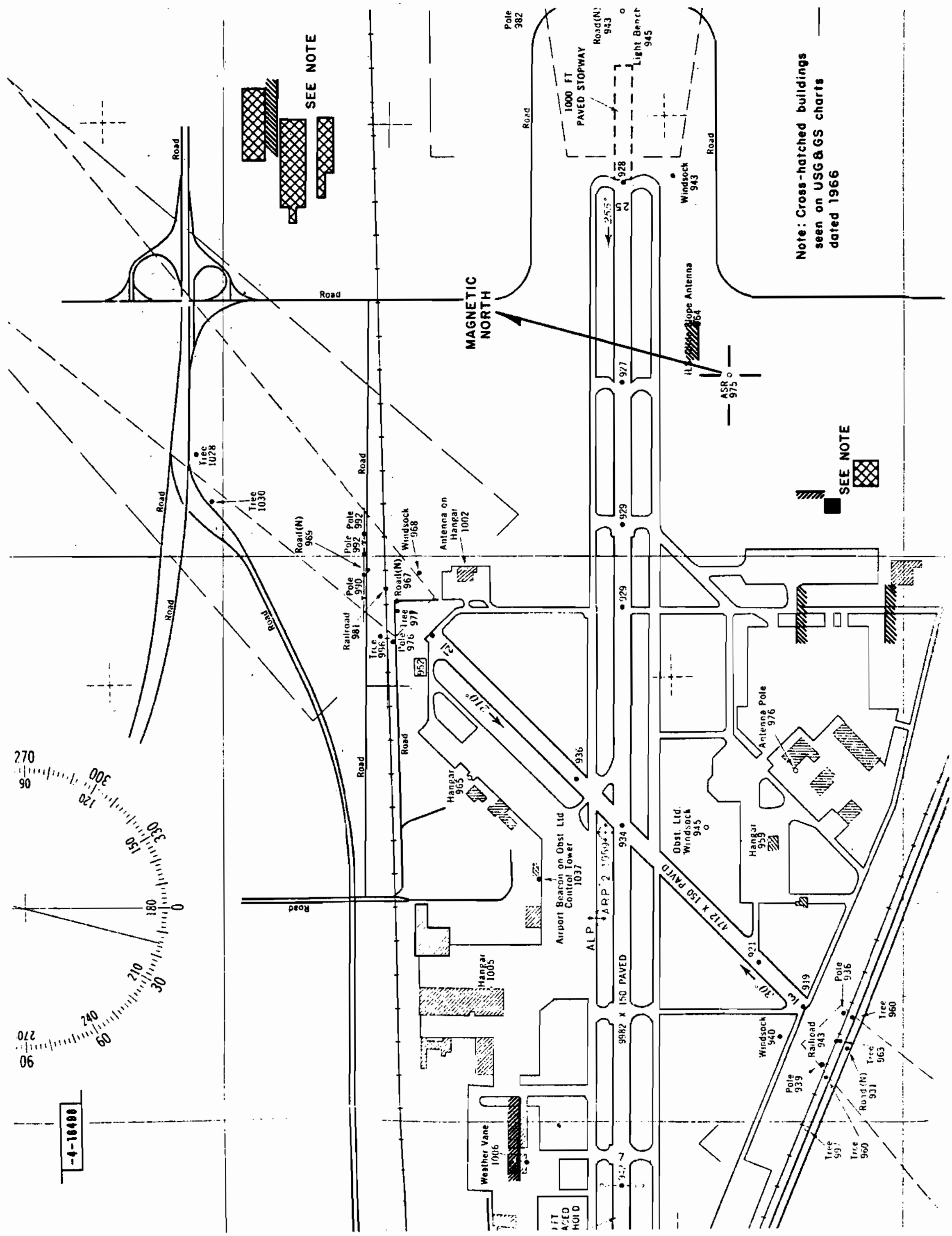


Fig. 15. Reflectors seen at Ontario, Calif. (conventional)

Table 10. Site-peculiar false targets at Ontario (in order of increasing azimuth).

False Target Azimuth (deg)	False Target Length (hits)	Target Range (nmi)	Target Azimuth (deg)	Target Altitude (ft MSL*)	$\Delta\theta$† (deg)
8.1	7	6.06	3.5	low	-4.6
56.1	1	10.75	59.6	6500	3.5
71.5	7	18.44	77.7	low	6.2
73.6	3	1.56	70.0	low	-3.6
75.0	3	1.44	69.8	low	-5.2
78.6	8	6.30	74.0	2800	-4.6
80.9	9	13.69	77.2	?	-3.7
82.6	6	12.81	77.5	?	-5.1
115.8	7	18.94	123.6	9200	7.8
117.25	7	26.44	125.2	14,900	7.95
141.2	3	22.56	136.6	14,200	-4.6
163.0	3	36.38	167.5	?	4.5
183.6	1	25.25	187.0	?	3.4
202.0	7	2.25	208.8	low	6.8
206.5	8	25.75	213.6	13,300	7.1
213.6	6	22.78	206.0	14,500	-7.9
225.6	1	11.5	224.0	5900	-1.6

*Interrogator elevation 952 ft MSL.
†$\Delta\theta$ taken as positive when false target leads actual aircraft (implying ground reflecting to the right).

due to ringaround, but rather to some sort of multipath situation; the fact that the false replies are at the same range as the real ones suggests that the reflecting surface is at close range to the interrogator, and is probably ground. The problem is quite similar to the well-documented [8] situation at the North Platte, Nebraska ARSR (en route) site; at that site, the ground nearby is not flat but rather is made up of numerous rolling hills. This produces an effect different from the vertical lobing which is usually associated with nearby ground reflection, since the ground slope tilts the reflected energy out of the vertical plane of the mainbeam. The result is asymmetrical target stretching or azimuth splits, quite similar to the situation seen in the Ontario data.

In order to determine whether the Ontario situation was the result of similar terrain, a telephone conversation was held with the DSO at the site, who stated that the ground nearby is quite flat and level. When the nature of the terrain was discussed, he noted that the land around the interrogator is a vineyard, and is heavily planted with grapes. The planting is in long straight lines. Several Polaroid photographs taken from the radar tower revealed that significant portions of the nearby ground (out to perhaps a mile in some directions) were regularly furrowed; dimensions were difficult to determine from the photos. Spacing between furrows was about 3 ft; depth was perhaps 6 to 12 in. Small, self-supporting shrub-like grape bushes were planted along the crests of the furrows. A crude estimate of the orientation of the furrows to the east was made; they appeared to run roughly north-south, or perhaps from slightly west of north to slightly east of south (Fig. 16).

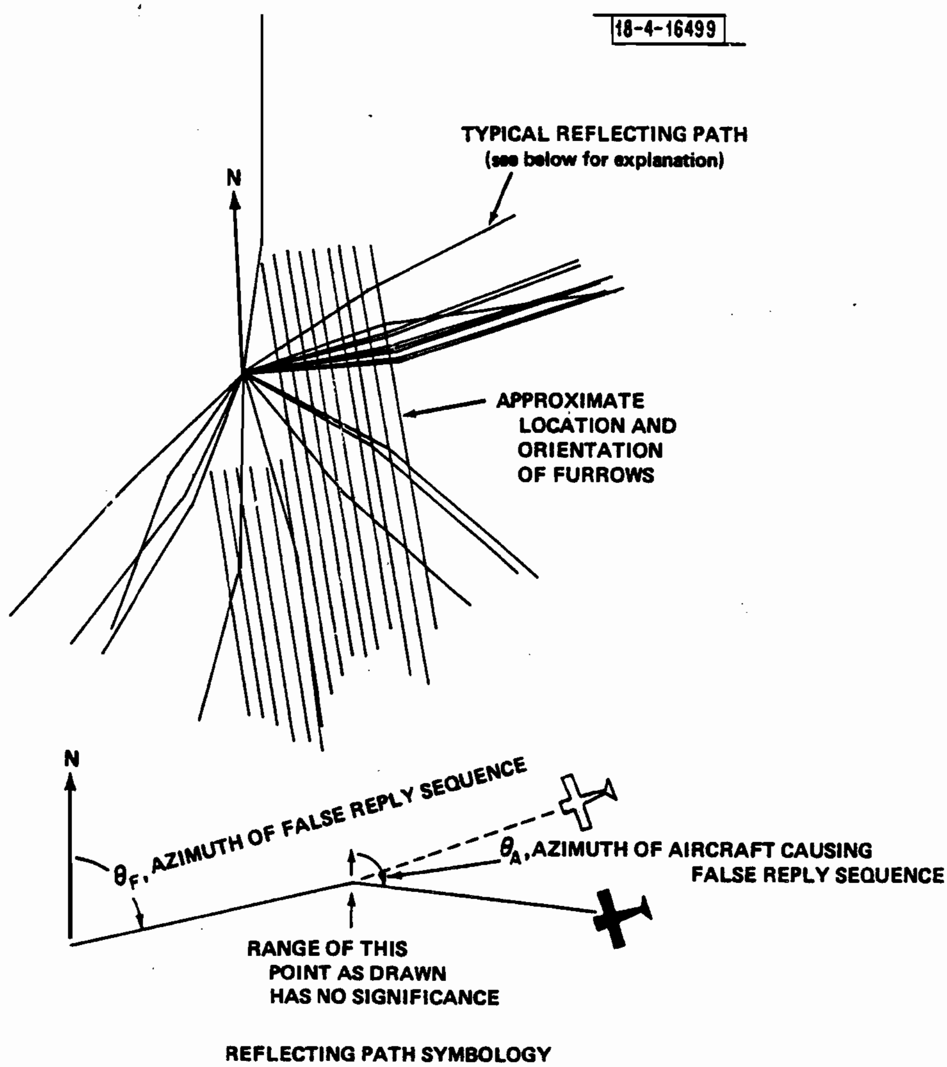


Fig. 16. Peculiar reflection geometry at Ontario.

Several conclusions can be drawn from the available information:

- The peculiar false targets at ONT are attributable to out-of-plane reflections of the ATCRBS mainbeam.
- Since their range is that of the actual target (to within the 1/16 nmi range precision of ATCRBS), the excess pathlength involved is quite short.
- Therefore, the reflections must be from nearby ground (the situation that usually results in vertical lobing), and the fact that they are not in the plane of the mainbeam must be attributable to the anisotropy of the ground.

Qualitatively, the furrowed ground appears to be acting like a giant diffraction grating. Diffraction gratings certainly have the capability to reradiate some incident energy out of plane; due to the limited quality and quantity of information available about terrain details, it was not possible to verify analytically whether the particular terrain parameters should have caused grating lobes at the particular angles observed. The merits of further pursuit of the issue are probably small, since the solution to the problem appears relatively straightforward, and independent of the details of the diffraction process.

3.4.4 A Possible Solution

The elevation angles of the aircraft involved varied between 2 and 6° (and possibly outside that range, since many were not squawking altitude). This range of angles corresponds to distances from the interrogator to the point on the ground where reflection occurred ranging from 400 to 1200 ft. It would appear that a row of trees, planted at a distance of perhaps 600 ft from the interrogator site, with sufficiently dense foliage, would effectively break up the reflected radiation. A more expensive solution which is probably not warranted is a radar fence. Both techniques have been proposed by Spingler, [5] and discussed in some length.

3.5 AN AUTOMATED PROCESS FOR DETERMINING REFLECTOR PARAMETERS

An automated process capable of sensing false targets caused by discrete-code aircraft, and solving for reflector location and orientation, was developed for eventual use with the TPA. The process was tested and debugged using the ARTS III data tape from Milwaukee which was discussed in Section 3.1. This section describes the algorithms employed and presents a sample of the output.

3.5.1 Procedure

The manual process employed in the previous sections of this chapter separates logically into two distinct parts: determination of apparent false target location (and actual target location at the same instant), and calculation of reflector parameters from that data. It appeared reasonable to separate the automated procedure similarly. The first part searches through the data, detects instances of false returns, and tabulates data associated with each. Data includes:

False target apparent position (ρ, θ).

Actual target position* at the instant the false target occurs (ρ, θ).

Actual target altitude.

Actual target code.

*Alternatively, position on previous and subsequent scans is tabulated, and interpolation to instantaneous position performed downstream.

The second part determines the geometry of the reflection mechanism (on the basis of whether or not the actual target is within antenna sidelobe range), and solves for reflector location using straightforward but rather tedious algebra. Locations are stored over the course of an entire run and, at the option of the operator, those which appear highly correlated (i.e., resulting from the same reflecting surface) can be averaged to gain increased precision. Alternatively, each time a false target is seen, the location of the responsible reflector can be plotted.

The first step in processing taped reply data involves separating target reports due to reflections and legitimate reports from one another. All target reports are stored in a first-in, first-out stack (Fig. 17), holding slightly more than one scan's worth of target reports (shortly after a new target report has been declared the one from the previous scan is dropped). The "stack" is examined for false targets on a running basis.

The technique for false target detection can be best explained by a simple example. Assume that only a single aircraft is in view of the interrogator. His position might appear as the sequence of 0's shown in Fig. 18 representing his position over several adjacent scans. (Note that the hypothetical target shown in Fig. 18 is decreasing in azimuth, and increasing in range, and is, therefore, flying roughly to the west.)

Assume now that a reflecting surface (say, a building) located east of the I/R is oriented so as to cause this aircraft to generate false targets. (Represented by the X's in Fig. 18.) Due to the excess pathlength the reflected signals will always appear at greater range than the actual aircraft; this allows the processor to differentiate between the actual and false targets.

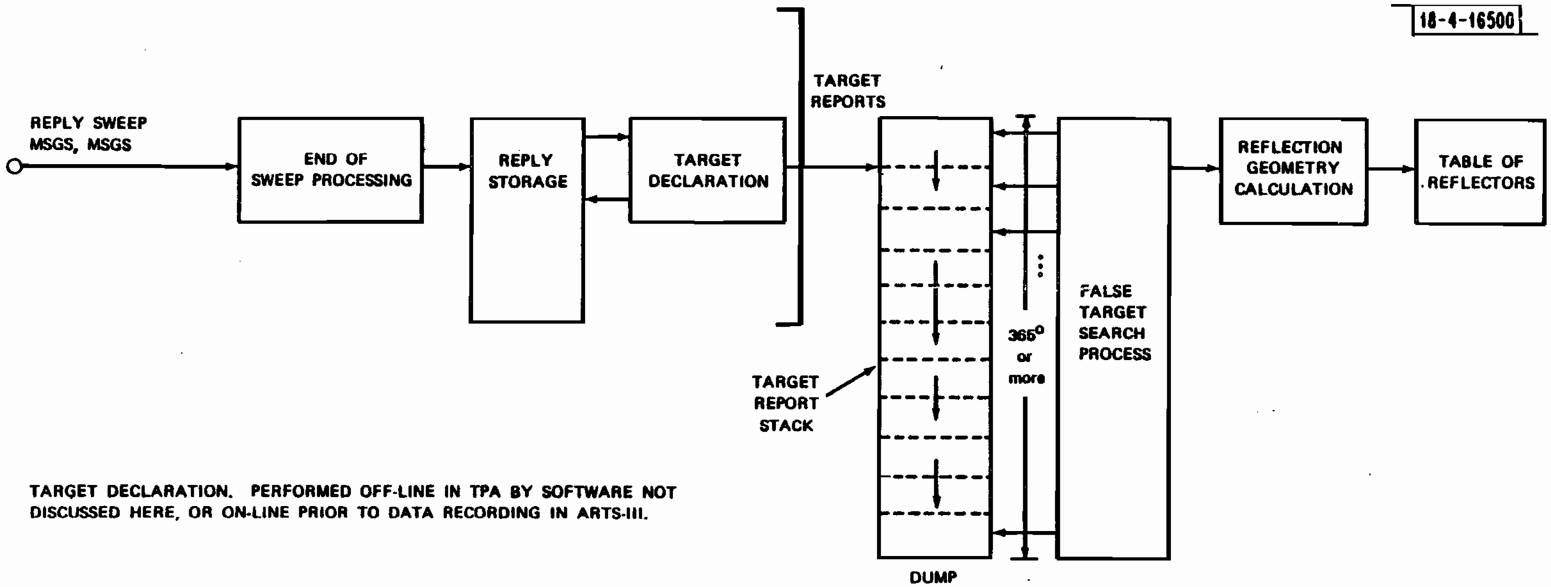


Fig. 17. Target report generation and processing.

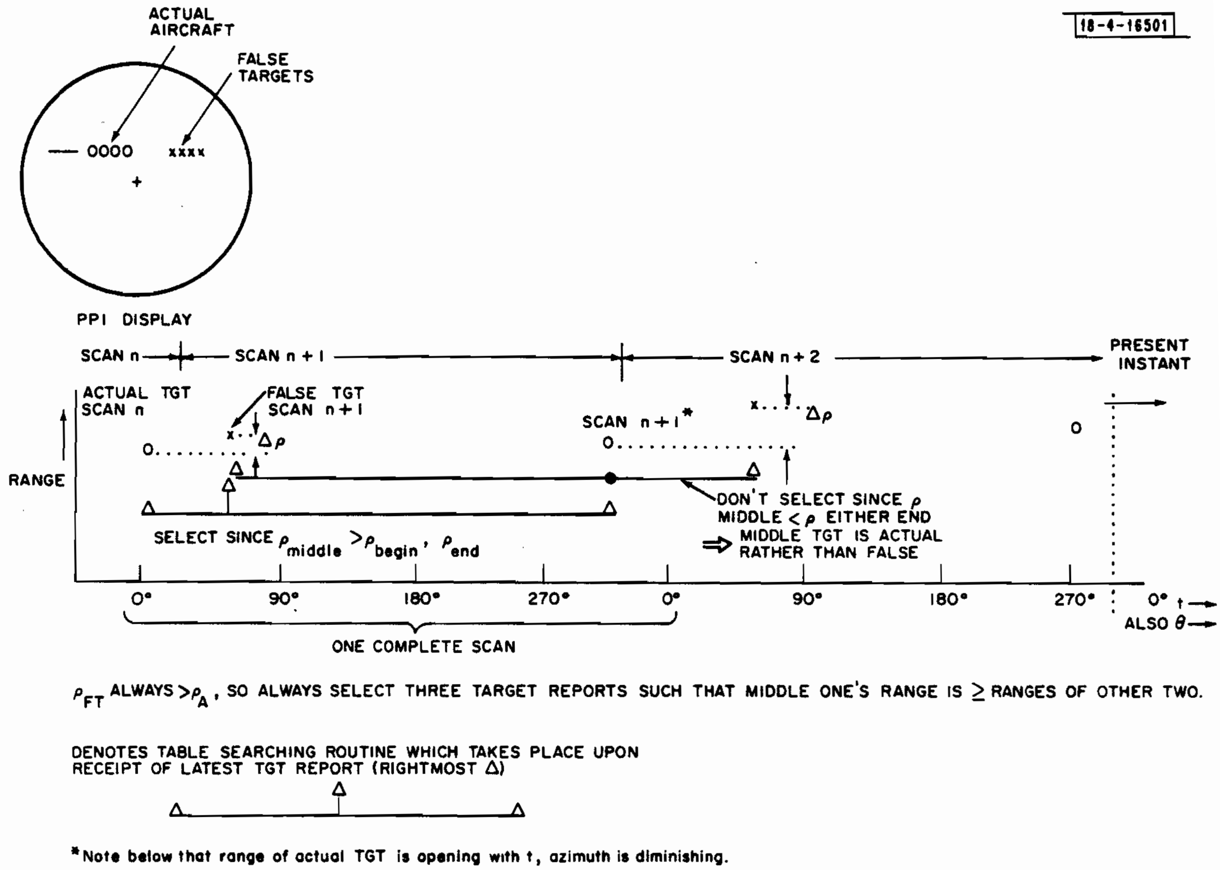


Fig. 18. A typical false target situation.

By scanning the record of target reports on a particular code, the processor determines that a false target is present (on the basis of whether that code is declared at different azimuths on the same scan), and, if so, it determines which target is false and which is real (on the basis of which has the greater range). The information needed to determine reflector geometrical parameters includes false target location (ρ_F, θ_F) and actual aircraft position at the instant the false target was received. This latter data is determined by interpolation of the measured aircraft positions prior to and subsequent to the false target declaration. The output from the false target determination process is, therefore, a set of three locations, that of the actual target prior to generation of the false target, that of the false target, and that of the aircraft subsequent to generation of the false target. The process is as follows:

- Upon the entry of every target report onto the stack, all previous reports with the same code occurring during the last 370° are examined. If only one such report is found (i. e., the actual target report from the previous scan), then no further action is taken. If more than one such report is found, the process continues as described below.
- If the particular code is unique, the extra report (i. e., not the report just received nor the one corresponding to it on the previous scan, but the one received in between the two) is examined to determine if its range exceeds that of the report just received. If it does, it is presumed to be a false target, and the three reports are stored for further analysis. (Recall that the three represent actual aircraft position before false target occurrence,

false target position, and actual aircraft position after false target occurrence.) If its range <u>does not</u> exceed that of the other two, then <u>they</u> are probably false targets, and <u>it</u> is the declaration of a legitimate aircraft; in this case, no further action is taken. The mechanism responsible for the false targets will be (or will have been) caught when one of <u>them</u> is the middle report.

- If the code is in widespread use, we run the risk of incorrectly declaring actual aircraft as false targets associated with other aircraft squawking the same code, and erroneously declaring many reflectors (most likely, a new one on every scan) that are not, in fact, there. In order to minimize the incidence of this, the process described above could be modified to allow further filtering of data. The processor presently ignores certain nondiscrete codes (e.g., 1200) completely; this can easily be changed. The marginal increase in information that might be gained from analysis of data from many aircraft with the same code is probably small compared to the difficulty in determining whether various target declarations are in fact false, what aircraft they correspond to, and so forth. Advantage could be taken of the fact that there is some a priori knowledge about the reflection process. Thus, in order for a group of nondiscrete codes to get stored for further processing, the "middle" target might have to satisfy the additional conditions of being within one of several azimuthal wedges corresponding to known or suspected reflector azimuths (which could be preprogrammed into the computer memory), and would have to be at a range less than some small number of miles (say, eight) greater than that of the other (assumed actual) targets. This range difference relates to the range of the reflector, and is rarely more than a few miles. Information on these parameters would be determined by visual examination of the site or panoramic photos, or could be derived from a previous pass of the tape in which processing was limited only to discrete codes. The added complexity of processing codes used by multiple aircraft does not appear warranted in light of the high quality and quantity of data derived from unique codes; therefore, none of the above processes for analyzing nonunique codes have been incorporated in the program at the present time.

The result of this process is sets of triple (or quadruple, or higher) target reports, all presumably arising from a single target and various reflection mechanisms, the first and last of which being the actual positions of the target, and hence, at lower range than all those in-between. This process thus identifies the potential false targets (the one(s) in the middle of the sequence) and the actual target position prior to and subsequent to the generation of the false targets (the ones on the ends) (see Fig. 19). This process appears to find all false targets, even those persisting for only a single scan; that is frequently the case when target aircraft are changing azimuth rapidly. It simply ignores garbled reports; this appears appropriate initially.

The type of false target reflection geometry (Fig. 7) is determined as follows:

- If the false target azimuth is within $\pm 5^{\circ}$ of that of the actual target, put in "mainbeam" category.

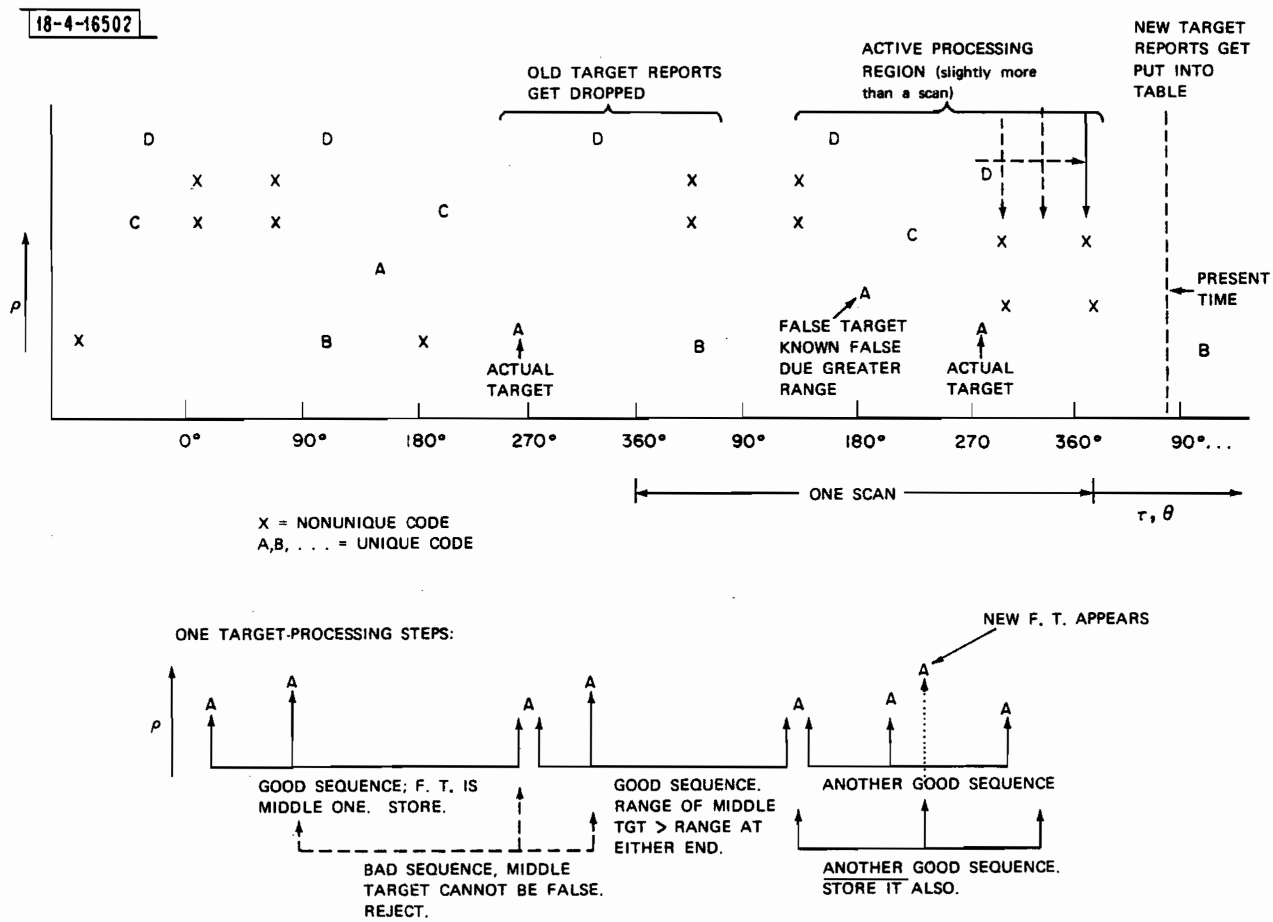


Fig. 19. Discrete-code false target processing.

- If the actual target is within the sidelobe reply range of the interrogator (say, eight miles), and more than one false target is noted at one or more azimuths, then put in "sidelobe" category.
- If in either of the above, put in "conventional" category.

Further processing is as follows:

Conventional case: In the case of multiple false targets, each one is processed individually along with the previous actual position (first target report) and subsequent actual position (last target report). For each (Fig. 20), the program:

1. Interpolates between the previous and subsequent position to determine the actual position at the instant the false target was sensed. This is done purely on the basis of time differences (as inferred from azimuth differences), and done separately and independently for range and azimuth (Fig. 21).

2. Processes θ_A, ρ_A, θ_F, ρ_F as shown in Fig. 20 to determine ρ_R, θ_O; stores the following in a "reflector" table:

   θ_O - the reflector orientation

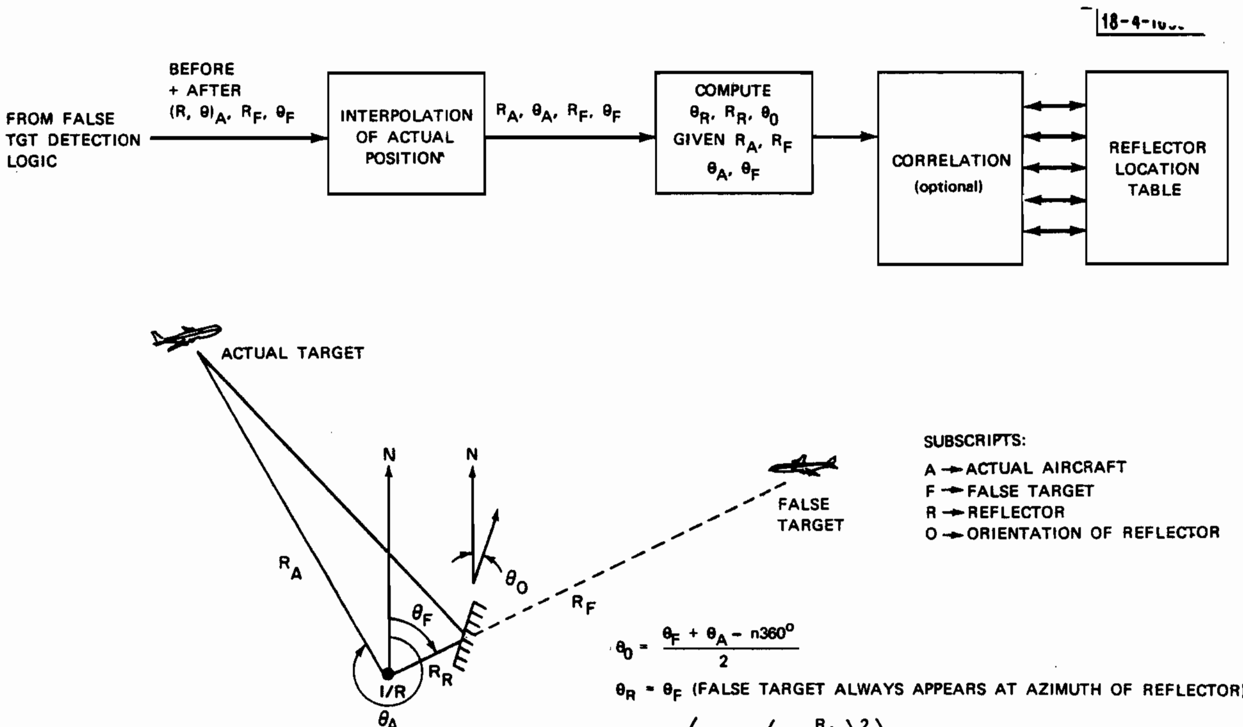
   θ_F - the reflector azimuth

   ρ_R - the range to the reflector

   ρ_A - the aircraft range

3. Upon completion of analysis plots the conventional reflectors. Represents each by a straight line of nominal length and orientation θ_O, centered on the position (ρ_R, θ_F).

4. (Optional; not implemented in current program). Correlates like reflectors. Whenever multiple reflector solutions appear closely aligned in ρ_R, θ_R, and θ_O, they are probably due to a single reflector.



$$\theta_O = \frac{\theta_F + \theta_A - n360^\circ}{2}$$

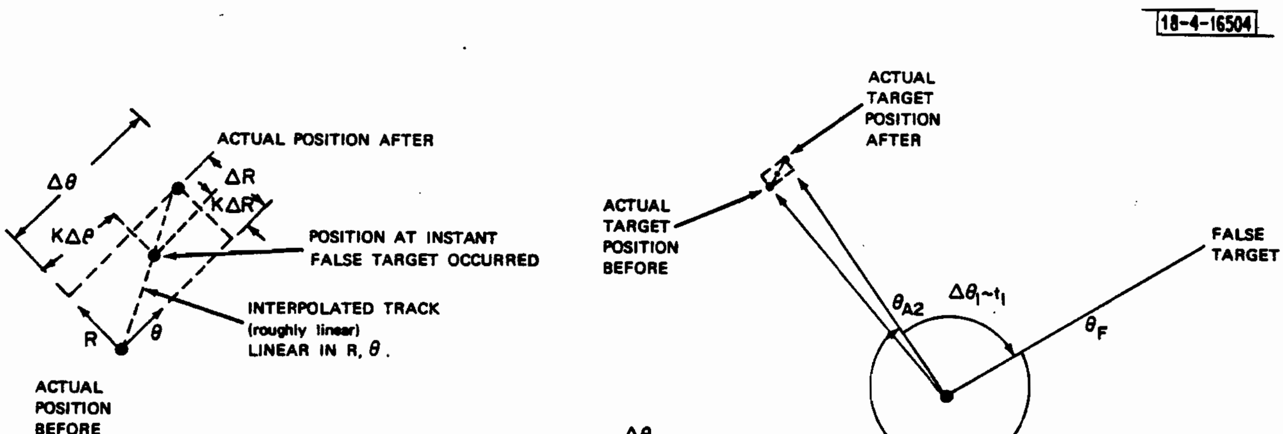
$\theta_R = \theta_F$ (FALSE TARGET ALWAYS APPEARS AT AZIMUTH OF REFLECTOR)

$$R_R = \frac{\left(\frac{1}{2}\ R_F\left(1 - \left(\frac{R_A}{R_F}\right)^2\right)\right)}{1 - \frac{R_A}{R_F}\cos(\theta_F - \theta_A)}$$

EQUATION OF AN ELLIPSE IN POLAR COORDINATES $R_F \longleftrightarrow 2a$, $R_A \longleftrightarrow 2ae$

NOTE: ρ_A IS ASSUMED TO BE $\gg \rho_R$, SUCH THAT TARGET AZIMUTH AS SEEN FROM THE REFLECTOR EQUALS θ_A. WHEN THAT IS NOT THE CASE, THE EXPRESSION FOR θ_O BECOMES MORE COMPLEX. THIS ADDED COMPLEXITY IS RARELY NEEDED IN MOST SITUATIONS.

Fig. 20. Conventional flase target processing.



$$R_A = R_{A1} + K(R_{A2} - R_{A1})$$
$$\theta_A = \theta_{A1} + k(\theta_{A2} - \theta_{A1})$$

$$K = \frac{\Delta\theta_1}{\Delta\theta_1 + \Delta\theta_2} = \frac{\theta_F - \theta_A + n360°}{360°}.$$

n such that $0 \leq K \leq 1$

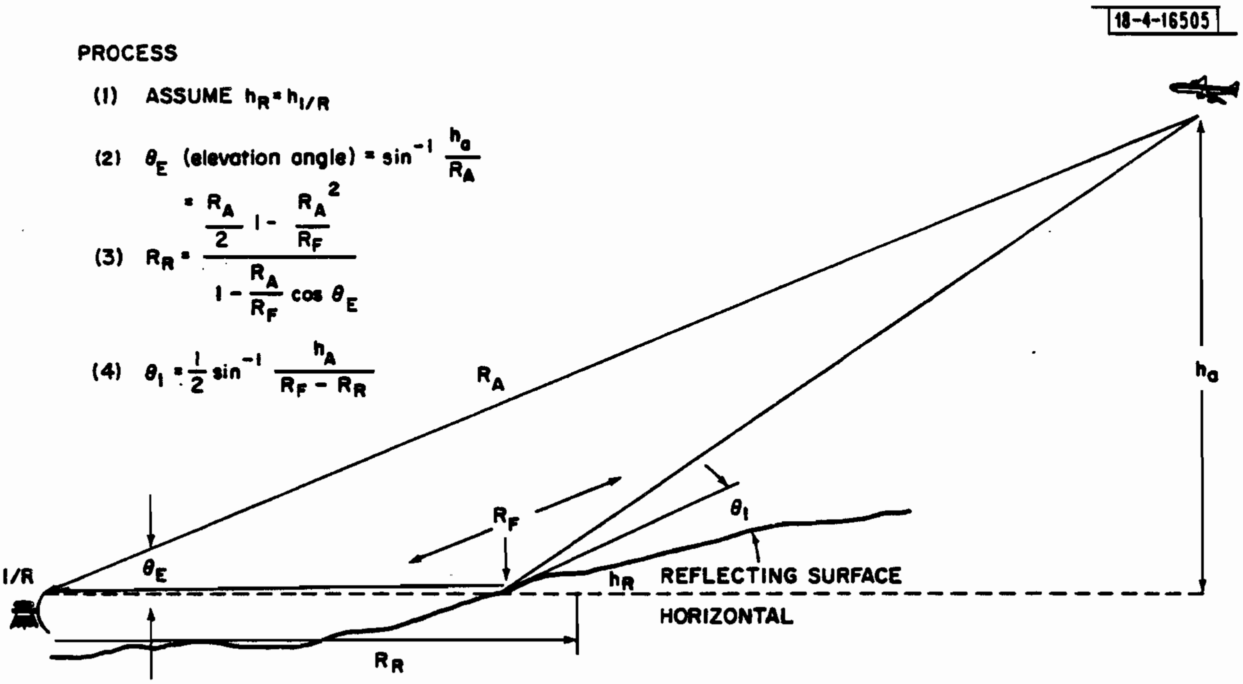
$\frac{d\theta}{dt}$ = CONSTANT DUE TO UNIFORM SCAN RATE

Fig. 21. Actual target position interpolation.

A highly precise estimate of that reflector's parameters could be obtained by averaging the parameters of the individual "samples". Accordingly, starting with the first reflector, ρ_R, θ_F, and θ_O are examined for each. If any are within $\pm 3^{\circ}$, ± 0.25 nmi, and 1° of the first reflector, a composite set of data are formed by averaging the parameters of the two. The length of the line representing the reflector could be modified by the amount of difference in θ_R, to account for building length (in cases where length is comparable to a Fresnel zone, such that different portions of the building illuminate the aircraft at different locations on adjacent scans); line length will then serve as a crude representation of reflector extent. The process would continue down the list, updating the composite data whenever a new sample is within $\pm 3^{\circ}$, $\pm .25$ nmi. Note that this will require a running count of how many samples are included in the composite, in order to properly weigh new data.

Mainbeam Case: The following process could be used to solve for reflecting surface orientation and location in the mainbeam case. It was not implemented in the present program since the complexity involved seems to outweigh the returns derived.

1. Determine aircraft height above interrogator level. This involves decoding mode C replies, and will probably not be possible initially with TPA. Corrections are needed for local barometric pressure (manual input, simple algorithm as in ARTS III), interrogator elevation above or below reflector level, and earth curvature (small).



$h_a = h_{reported} + h_{earth\ curvature} - h_{I/R}$

$h_{correction}$ CONVERTS FOR BAROMETRIC VARIATIONS AND NEED BE APPLIED ONLY TO AIRCRAFT IN THE PCA. ARTS III REFERENCES THEM TO 29.92" vs ACTUAL BAROMETRIC

Fig. 22. Mainbeam reflection geometry.

2. Determine reflector range and inclination from ρ_A, ρ_F, h_A, as in Fig. 22. Note that small differences in reflector elevation (relative to interrogator elevation) result in large errors in reflector range. It is not presently clear how corrections in this should be made. Some sort of interactive process with an operator who is reading a topo map appears appropriate initially.

3. Determine reflector skew (See Fig 8(c) for definition).

4. Store the following in a "reflector table":

   θ_R - reflector azimuth

   ρ_R - range of reflector

   θ_I - reflector inclination

   θ_S - reflector skew ("tilt" in the plane normal to ρ_R)

   ρ_A - aircraft range

5. Tabulate above data in order of increasing θ_R, and print. It does not appear appropriate initially to refine the output format further. Since reflecting surfaces are not generally planar in this case (hills are not flat, like buildings), an averaging process such as that described above does not seem appropriate either. This entire process is summarized in Fig. 23.

Sidelobe case: It was noted in Section 3. 3 and in previous Boston work [1] that when aircraft are within a few miles of the interrogation, and are being interrogated by a usual reflection process, sequences resulting from direct reception of their replies through interrogator antenna sidelobes are likely to be stronger than conventional reply sequences. Accordingly, whenever the aircraft is at sufficiently close range:

1. False target reports are examined to determine if two or more overlap in azimuth.

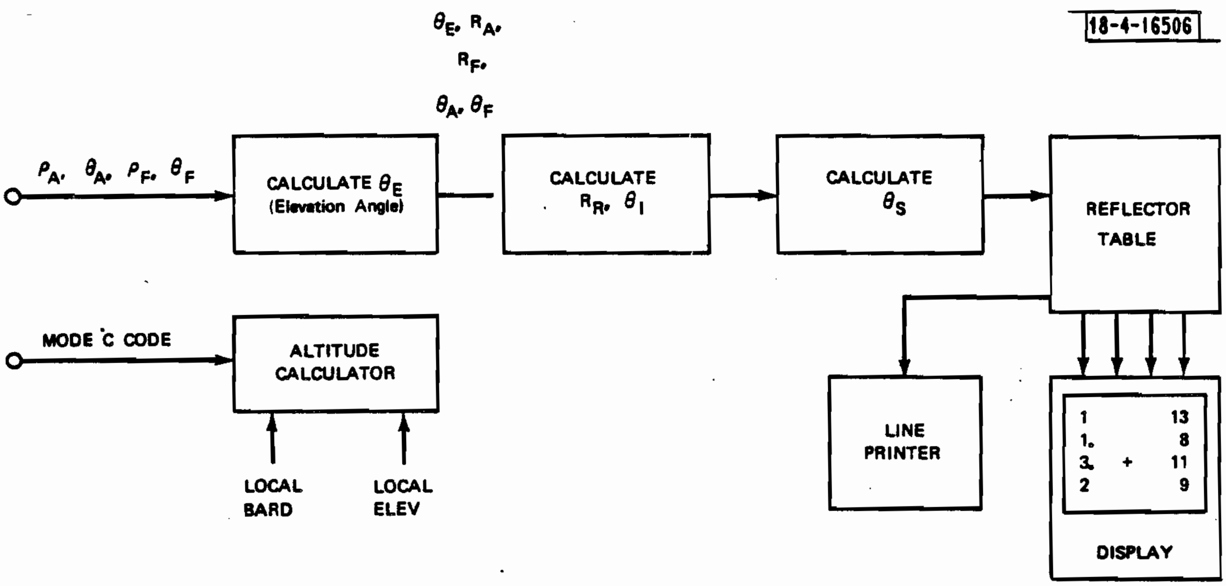


Fig. 23. Mainbeam reflection processing.

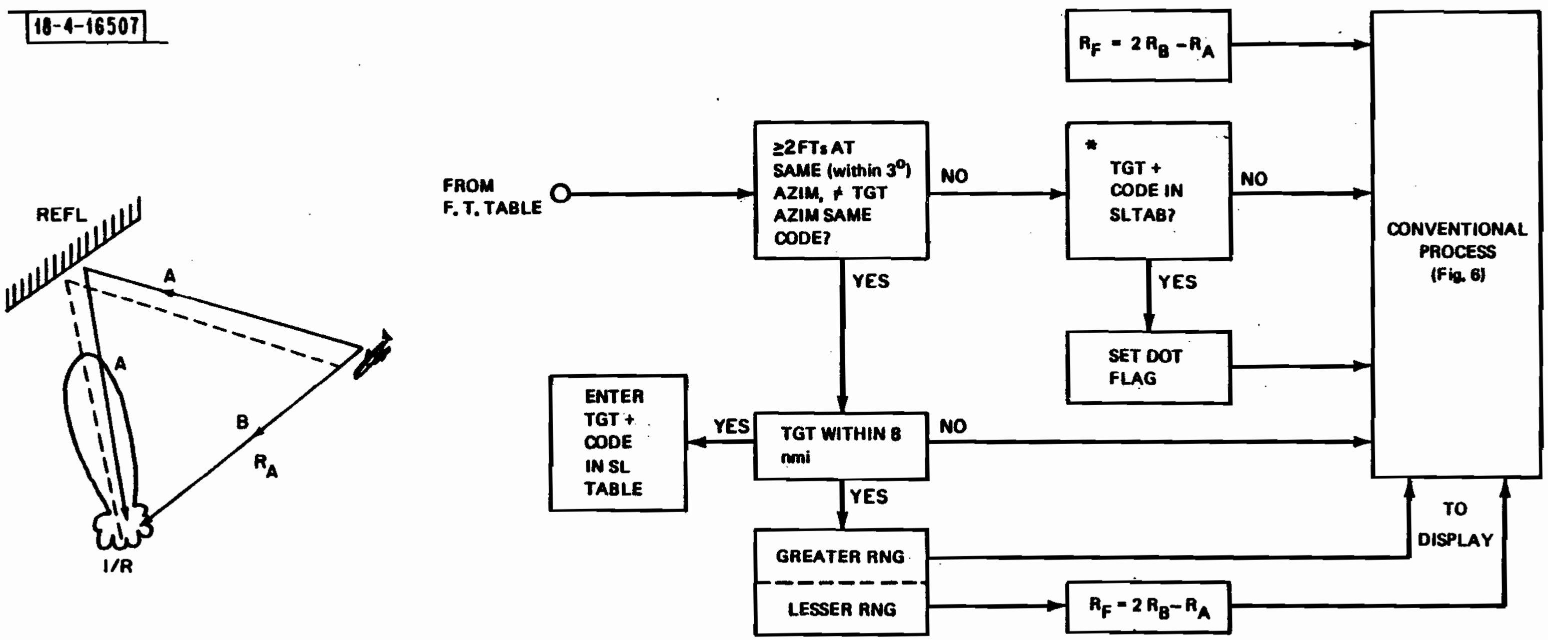
2. If so, then the report at greater range is treated as a conventional false target, and processed as such. The report at lesser range is treated as a sidelobe report (resulting from the geometry of Fig. 24), and should be ignored.

3. If only one false target report is noted at a particular azimuth, then it is not clear whether it is caused by one or the other mechanism. Both mechanisms are assumed, and reflector locations corresponding to both are determined. If one or the other correlates well with a reflector noted on other data, it can be combined with it, and the other can be dropped.

3.5.2 The Program

A FORTRAN program has been written which performs the algorithms described above. As noted above, the program operates on all discrete codes found on the tape and can be easily modified to handle all unique nondiscrete codes as well; when aircraft are within a specified distance, it solves for reflector positions assuming both conventional and sidelobe false target reflection mechanisms. Mainbeam reflections were not considered a sufficiently severe problem to warrant the additional complexity their solution would require. Fig. 25 is a flow diagram of the program.

To determine the capability of the program to compute false target producing reflector parameters, we fed it the ARTS-III tape from Milwaukee which was discussed in Section 3.1. A sample of the output tabulation is shown in Fig. 26 and the entire output over 160 scans is displayed graphically, superimposed on an obstruction chart of the site, in Fig. 27. (Compare with Fig. 2, which was prepared manually.) It should be noted that the reflectors to the north and west correlated well with buildings observed on aerial photographs which are not shown on the obstruction chart.



FALSE TARGETS DUE TO RETURN PATH A CAN BE PROCESSED AS CONVENTIONAL

FALSE TARGETS DUE TO RETURN PATH B MUST FIRST HAVE APPARENT RANGE CORRECTED: $R_F = 2R_B - R_A$
WHERE R_B = MEASURED RANGE R_F = RANGE OF F. T. TO BE INPUT TO CONV. PROCESS

*This will be true when R_A of Target < 8 nmi. In interests of maximum processing speed, it might be appropriate to sort on range first and do table search only for TGTs at close range.

Fig. 24. Sidelobe reply processing.

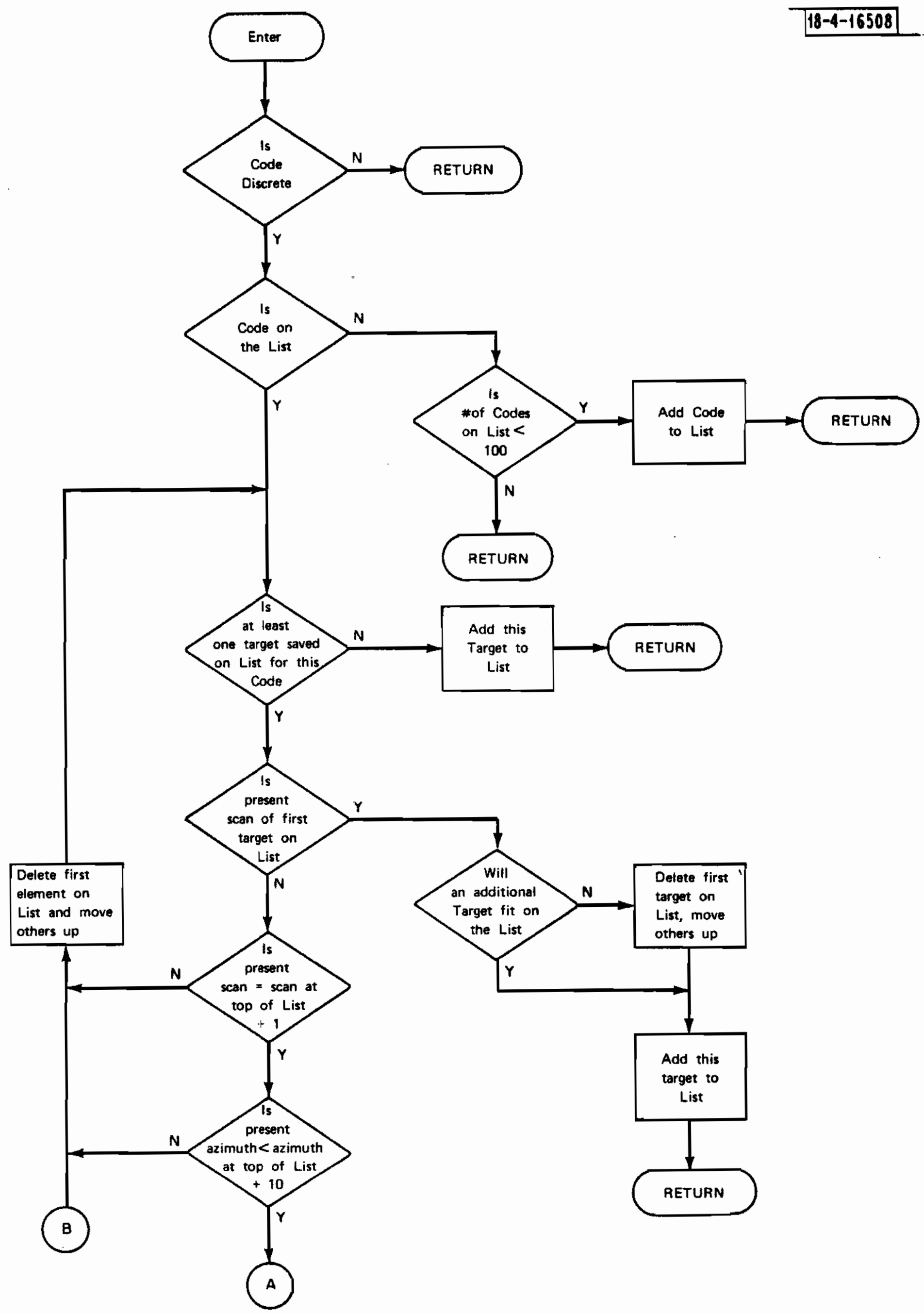


Fig. 25. Program flow chart*.

*This flow chart and the entire program discussed in section 3.5.3 are due to Ms. Regina Rutberg, whose capable assistance is acknowledged.

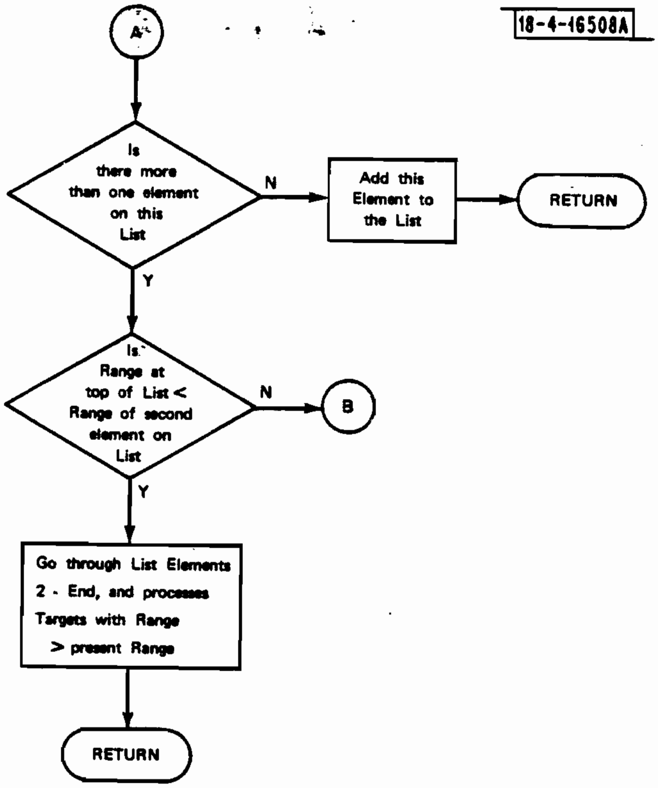


Fig. 25. (continued).

-4-16509

```
    32      162.07        15.31          740
ANGLE OF REFLECTOR= 226.93  RANGE OF REFLECTOR=    0.55   ORENTATION  14.50
QUESTIONABLE GROUP CODE=    1705
SCAN 31  θ= 179.65      R = 44.50                 AIRCRAFT BEACON CODE
    32        0.88        45.31
    32      180.00        44.37            1705
    ANGLE OF REFLECTOR=    0.88  RANGE OF REFLECTOR=    0.44   ORENTATION  90.35
    ADDITIONAL CODE=     2647
    QUESTIONABLE GROUP CODE=    1705
        32      180.00        44.37                        TWO SAMPLES OF THE
        33        1.41        45.12                        SAME REFLECTOR
        33      179.47        44.19          1705
    ANGLE OF REFLECTOR=    1.41  RANGE OF REFLECTOR=    0.42   ORENTATION  90.57
    QUESTIONABLE GROUP CODE=    1631
        33      175.61        35.50
        34        4.22        36.44
        34      175.43        35.62          1631
    ANGLE OF REFLECTOR=    4.22  RANGE OF REFLECTOR=    0.44   ORENTATION  89.87
    QUESTIONABLE GROUP CODE=    1631
        34      175.43        35.62
        35        4.04        36.56
        35      175.43        35.75          1631
    ANGLE OF REFLECTOR=    4.04  RANGE OF REFLECTOR=    0.44   ORENTATION  89.74
    ADDITIONAL CODE=     2665

    QUESTIONABLE GROUP CODE=      74
        35      162.25        15.12
        35      226.76        15.44
        36      162.25        15.06          740
    ANGLE OF REFLECTOR= 226.76  RANGE OF REFLECTOR=    0.55   ORENTATION  14.50

    QUESTIONABLE GROUP CODE=    1631
        35      175.43        35.75
        36        3.87        36.75
        36      175.08        35.94          1631
    ANGLE OF REFLECTOR=    3.87  RANGE OR REFLECTOR=    0.45   ORENTATION  89.56

    QUESTIONABLE GROUP CODE=    2636
        36      303.75        17.69
        37       70.31        18.50
        37      304.63        17.37          2606
    ANGLE OF REFLECTOR=   70.31  RANGE OF REFLECTOR=    0.58   ORENTATION   7.19

    QUESTIONABLE GROUP CODE=    2636
        37      304.63        17.37
        38       70.14        18.25
        38      305.51        17.12          2606
    ANGLE OF REFLECTOR=   70.14  RANGE OF REFLECTOR=    0.61   ORENTATION   7.54

    QUESTIONABLE GROUP CODE=    2664
        38      225.00        28.44
        39      147.48        29.50
        39      224.65        28.75          2664
    ANGLE OF REFLECTOR= 147.48  RANGE OF REFLECTOR=    1.03   ORENTATION   6.10
```

Fig. 26. Tabular output data.

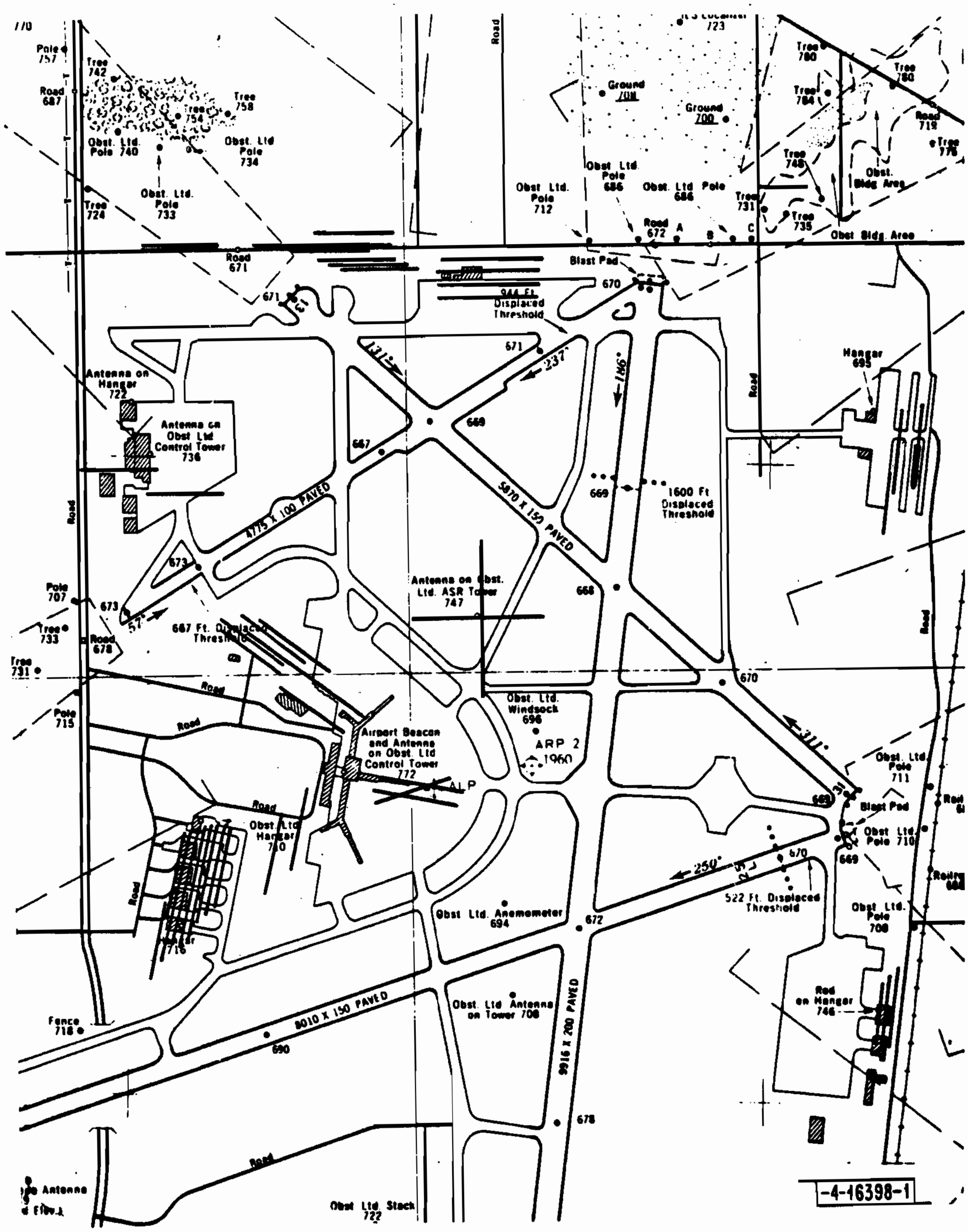


Fig. 27. Processor outputs (straight lines) superimposed on obstruction chart.

SECTION 4

ASYNCHRONOUS INTERFERENCE

Interference due to receipt of replies elicited by other interrogators is frequently cited as a source of present-day ATCRBS problems. When the PRF's of closely-located ATCRBS interrogators have been properly assigned, these extraneous replies (which are known as "fruit") appear asynchronous to the victim interrogator's timebase. Devices which use this fact to advantage to remove the fruit (defruiters) have long been a standard part of the FAA's inventory of beacon system related equipments. Defruiters simply filter out all pulses not received in synchronism with pulses on the previous sweep of the same mode. While this process eliminates virtually all fruit, it also degrades legitimate reply sequences by removing all legitimate replies not preceded by other legitimate replies (i.e., the first reply in the sequence of each mode, and any reply following a missed reply of the same mode). The effects of this in terms of a reduction in the probability of proper identity and altitude decoding, a reduction in the probability of target declaration, and an increase in azimuthal error have prompted suggestions that defruiters be removed, at least from ARTS-III input lines.

We have been able to obtain several ARTS-III extractor tapes from various sites, recorded while the defruiters were bypassed. One such tape was discussed in [1]; the remainder are discussed here. The clear conclusion one reaches upon examination of the (albeit limited) data on these tapes is that at many sites with today's traffic levels, the quantities of fruit observed are so low as to warrant consideration of proposals to remove defruiters.

Past literature [9], undoubtedly well-documented, has shown frequent cases of such high levels of fruit as to render the manual ATCRBS system inoperative. These fruit levels would certainly do the same to ARTS-III. That they were not observed in ARTS-III data is most likely due to five factors, all of which have resulted recently:

- The incidence of non-Interrogation Sidelobe Suppression (ISLS) equipped interrogators and aircraft has neen reduced significantly, and continues to approach zero. One interrogator-aircraft pair, in which one or the other is non-ISLS equipped such that ringaround results can cause one hundred times more fruit than the situation when ISLS is employed.
- The peak power radiated from an ATCRBS site has been reduced significantly over the past several years. Nominal peak power was once 1.5 kW (equating to over 300 kW ERP radiated from the antenna); certain military interrogators radiated even higher powers. Today, it is not surprising to see an FAA terminal secondary radar operating at 150 W; one such installation operates with a peak power of 75 W. Military installation power levels have generally been similarly reduced.
- The interrogation repetition frequencies which interrogator sites employ have only recently been regulated and coordinated.

In the past, it was not uncommon for a military installation to allow PRF adjustment until the "best picture" resulted. A present program, almost completed, has assigned PRF values at nearby sites such that interference is minimized.

- The widespread use of pulse staggering in FAA radars further randomizes the effects of near-synchronous interrogators.
- Auxiliary devices, most notably ramp testers, have been drastically reduced in power and controlled in PRF. Formerly, these operated at such high power (radiated omnidirectionally) and PRF that a single one could cause significant increases in the fruit levels nearby an airport.

These improvements have been brought about primarily through the action of the Joint FAA/DOD Beacon Management Team, whose work has now extended into the development of new devices and systems for detecting and tracking down residual interference. The undefruited data that has been analyzed here not only indicates that their program has been largely successful, but also suggests that these tapes can be used to advantage in the process of tracking down interference sources.

Asynchronous interference has been analyzed in detail from tapes made at the Logan International Airport (Boston, Mass.), and Wold-Chamberlain Airport (Minneapolis, Minn.) ARTS-III sites. Additional undefruited data from other sites has been examined briefly and appears consistent. The Boston and Minneapolis data typify the two extremes seen in the FAA secondary radar system. Fruit levels at Boston were quite high; those at Minneapolis were surprisingly low.

4.1 BOSTON

4.1.1 Introduction

Analysis of undefruited data obtained from Boston was performed in several steps, the first few of which were completed in time for inclusion in [1]. Briefly, that work involved determination of gross fruit arrival rates (roughly 466 fruit per scan; 26 aircraft within the coverage area, 7 of which were within 10 nmi), and associated various fruit replies with various aircraft, on the basis of reply code. Roughly 14% of the fruit was found to be received through the antenna mainbeam; of the remaining sidelobe fruit replies which could be associated with aircraft in the coverage region, all but one were from aircraft within 10 nmi of the interrogator. More than 25% of the total fruit was caused by a single aircraft; the combination of this aircraft's close range (4 nmi) and sufficient altitude (1500 ft) to be illuminated by a number of interrogators was responsible. Since this aircraft's fruit replies were received virtually throughout the interrogator antenna scan, it appeared that their study might shed some light on the uplink interrogation process, as seen from this aircraft.

4.1.2 Discussion

It was possible to reconstruct from the data both the instantaneous arrival rate of fruit from the particular nearby aircraft (which should bear some relation to the interrogation arrival process), and the instantaneous total fruit rate. Before discussion of what was actually observed, it is worthwhile to consider what might be expected.

An interrogator with properly operating ISLS elicits a short burst of replies from a particular SLS-equipped aircraft on each scan, which would appear as fruit to our interrogator. If both the interrogator and the aircraft are Mode-C equipped, we would expect each interfering terminal interrogator to elicit from the aircraft a burst of perhaps sixteen to twenty fruit lasting for perhaps 40 msec, and repeating every 4 sec. Each en route radar would produce forty or so fruit replies in bursts of about 100 msec duration, recurring roughly every 10 sec. (See Fig. 28.)

In an area where the overall interrogation rate is so low that reply rate limiting is not active and reply probability remains high, we would expect the time-pattern of fruit from our selected aircraft to be roughly the superposition of many such (40 or 100 msec) bursts, occurring at intervals corresponding to the various radar scan intervals (Fig. 28). In the simplest situation where all interrogators run at fixed rates (i. e., no pulse staggering), we would expect further that a sequence of fruit replies due to one radar would appear at our radar at ranges whose difference from one sweep to the next is constant (corresponding to the difference between the pulse repetition intervals of the two systems). Thus, we should be able, in principle, to separate the fruit contributions from the various contributing radars in a low-fruit situation, and to measure the scan rate and PRF for each, given fruit arrival data and the parameters of our radars. This process is, in fact, successfully followed with the Minneapolis data, and is discussed in the next section. Pulse-staggering in the Logan Airport radar precluded its application here.

The previous discussion concerned the fruit from a single aircraft. We would expect the <u>total</u> fruit to exhibit similar variations, but to be

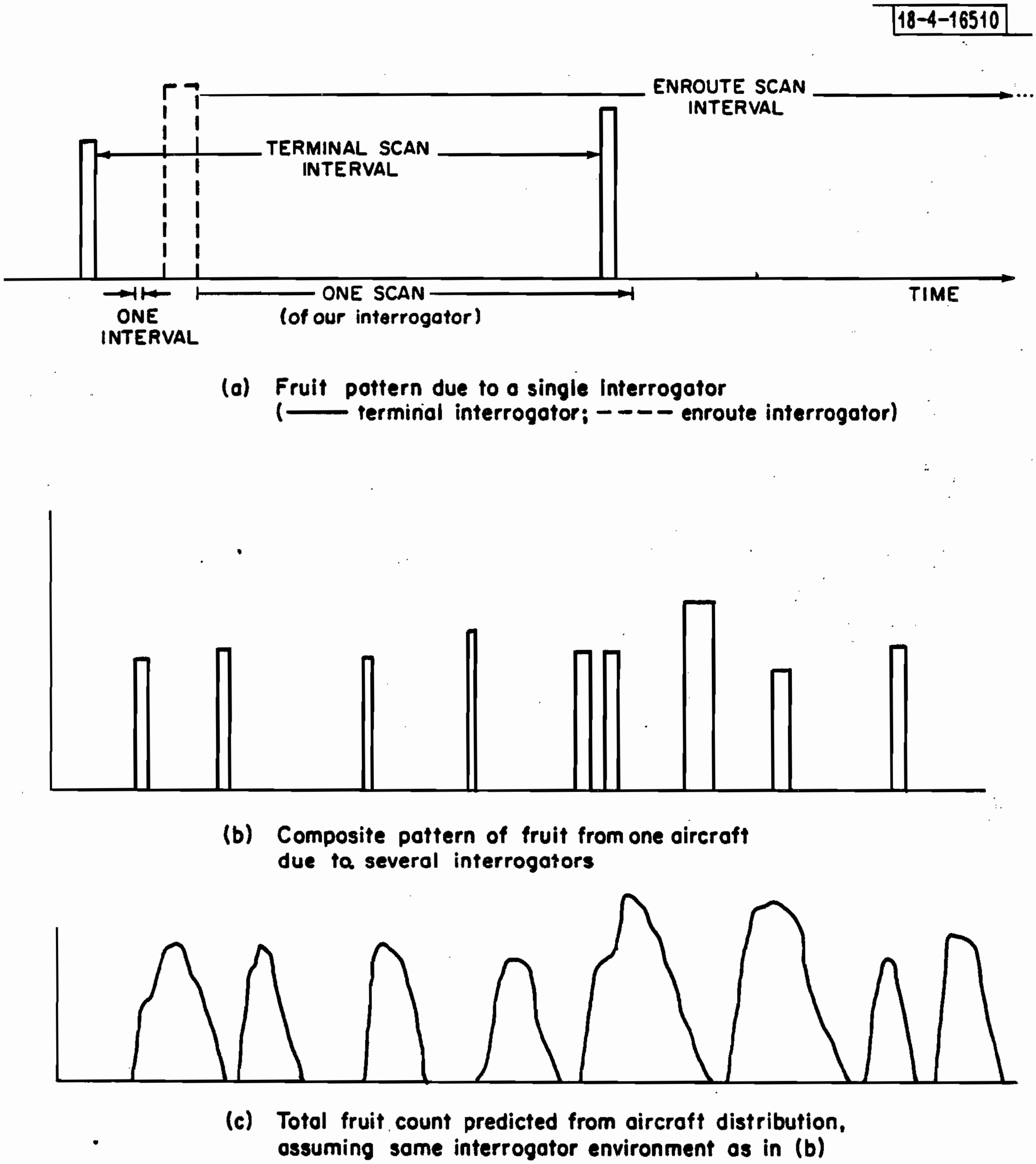


Fig. 28. Idealized fruit patterns.

considerably smoothed relative to that of an individual aircraft. Recall from the original analysis of Boston data that roughly 14% of the total fruit was mainbeam, that the remainder was sidelobe fruit, and that this sidelobe fruit was due almost entirely to the seven aircraft within ten miles of the Logan radar. Thus, we would expect each single interfering interrogator to produce longer, somewhat irregular bursts of (sidelobe) fruit with short-term rates roughly equal to multiples of the interrogator PRF (depending on how many aircraft are illuminated at the instant of concern); the duration of the composite "burst" would correspond to the time taken by the interfering beam to sweep through the population of aircraft within the 10 nmi circle, and would, of course, relate to the distance of the interfering interrogator. Total mainbeam fruit should depend primarily on the orientation of our interrogator antenna relative to the traffic, and should therefore be synchronous with our scan rate; since mainbeam fruit comprises only a small fraction of the total fruit at Boston, we would not expect this synchronous variation to be especially noticeable in that data.

Several real-life factors work to complicate the actual data, and render the previous conclusions only partially valid. First, the fruit seen by ARTS-III is only that fruit received during the intervals in which the interrogator receiver was on (roughly 650 μsec out of each 2530 μsec interval between interrogations). STC action during the first few microseconds of the on-time further confuses the issue. If interrogations occurred purely randomly, we could say that the effect of the 25% receive duty cycle would be merely to reduce the measured rates below the actual by a factor of four. Since they are not random, but are in fact carefully chosen to be roughly periodic and asynchronous with our interrogator, we would expect the reception (or non-reception) of fruit caused by a particular interfering interrogator to occur in fairly long sequences, since it takes several sweeps for fruit from an interrogator whose PRF is close to ours to "walk" through the entirety of our range.

4.1.3 Boston Fruit Data

Ten and one half scans of undefruited Boston data were printed and examined (some of this data was analyzed and reported in Ref. [1]). The defruiter was switched out during the third scan; over the remaining eight scans, all fruit replies were identified and separated from synchronous replies. Those fruit replies coming from the nearby aircraft which contributed more than 25% of the fruit were also identified. That aircraft was on final approach to rwy 27 at a range that diminished from 4.75 to 3.5 nmi during the course of the ten scans. Its altitude decreased from 1800 ft to 1400 ft between scans 3 and 10. It was squawking code 0215, and altitude codes* 0072, 0076, 0074, 0064, and 0066 (in that order during the course of the data). Thus (during the instant its altitude was 1700 ft (code 0076)), the following reply codes were attributable to it:

On Mode A Sweeps:

0215 (Mode A replies)

0730 (Mode C replies)

On Mode C Sweeps:

5024 (Mode A replies)

0076 (Mode C replies)

* Altitude codes are presented in the ARTS-111 BDAS Mode C Output format, which differs from the Mode A Output format. Section 5.3 discusses these formats in detail.

No other aircraft in the system produced fruit with similar codes; accordingly, any replies with codes which differed from the above in only one pulse were also assumed to be due to that aircraft.

During the course of data collection, it was frequently noted that the same code would be received twice on the same sweep at close range (within 2 nmi) of one another. This could not be attributed to multiple replies (since transponder dead times preclude them), and was rather concluded to be due to multiple reception of a single reply due to reflections from objects on the ground (which were probably in the antenna mainbeam at the time). Wherever noted, these double replies were counted only as a single reply in the data.

"Instantaneous" fruit arrival rates were determined by breaking up the observation interval into subintervals of 111.8 msec duration. This is the time in which the ACP count changes by 100; during that period there are on the average 40 or so interrogations; there are 41 (actually 40.96) such intervals per scan. During each interval, both the number of fruit replies due to aircraft 0215 and the total number of fruit replies were counted. This data is shown in Fig. 29. The lower (shaded) curve represents the fruit due to aircraft 0215; the upper curve represents total fruit (including that of aircraft 0215). Numbers on the horizontal axis refer to scan number (where noted), and to the first two digits of the ACP counter (otherwise).

Note that a substantial portion of scan 7 is devoid of any fruit whatsoever. This was originally assumed to be a result of the (assumed) low number of interrogators in the vicinity; no fruit was sensed simply because no other interrogators happened to be interrogating the aircraft within 10 nmi during

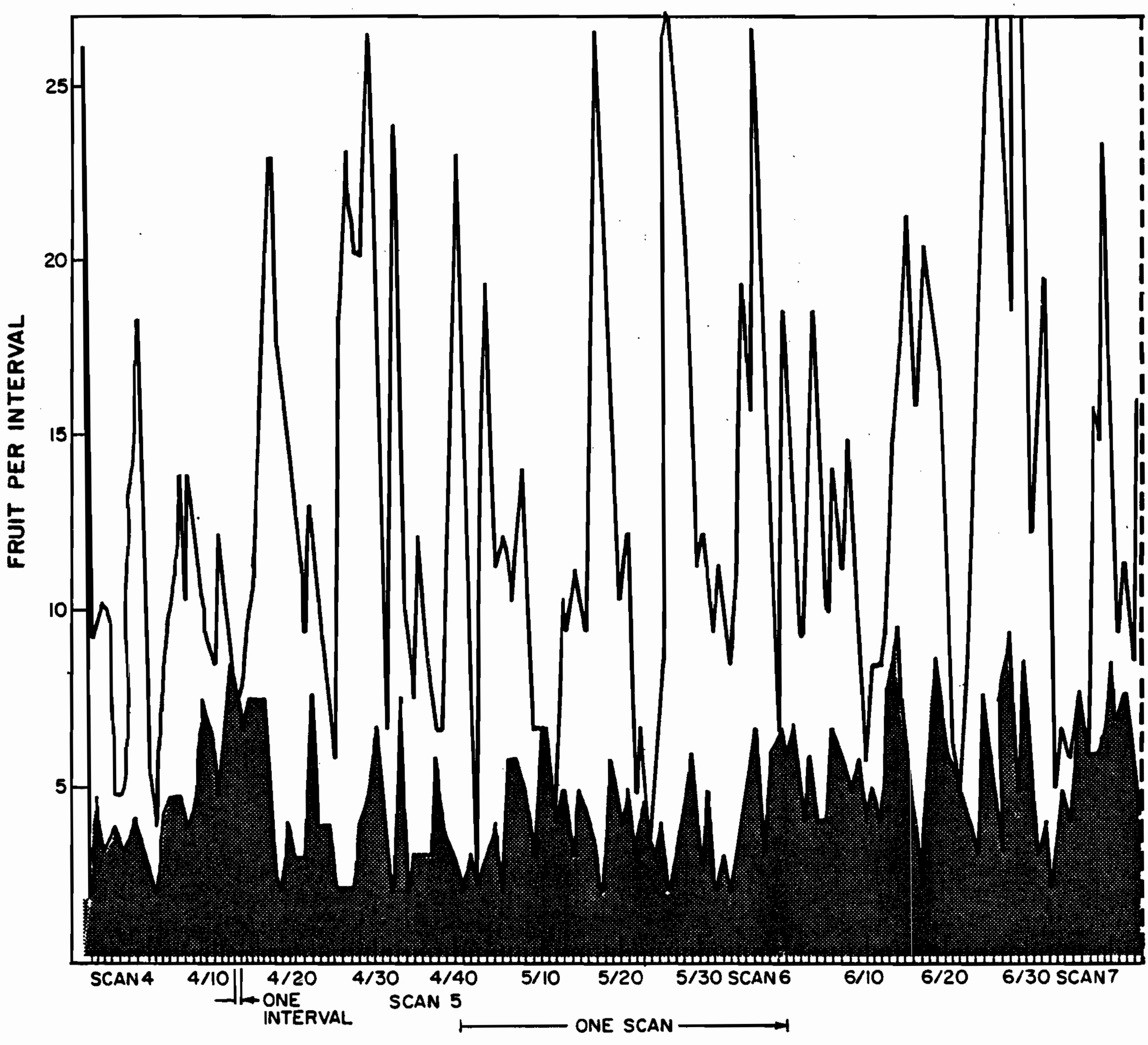


Fig. 29. Fruit arrival rates versus time.

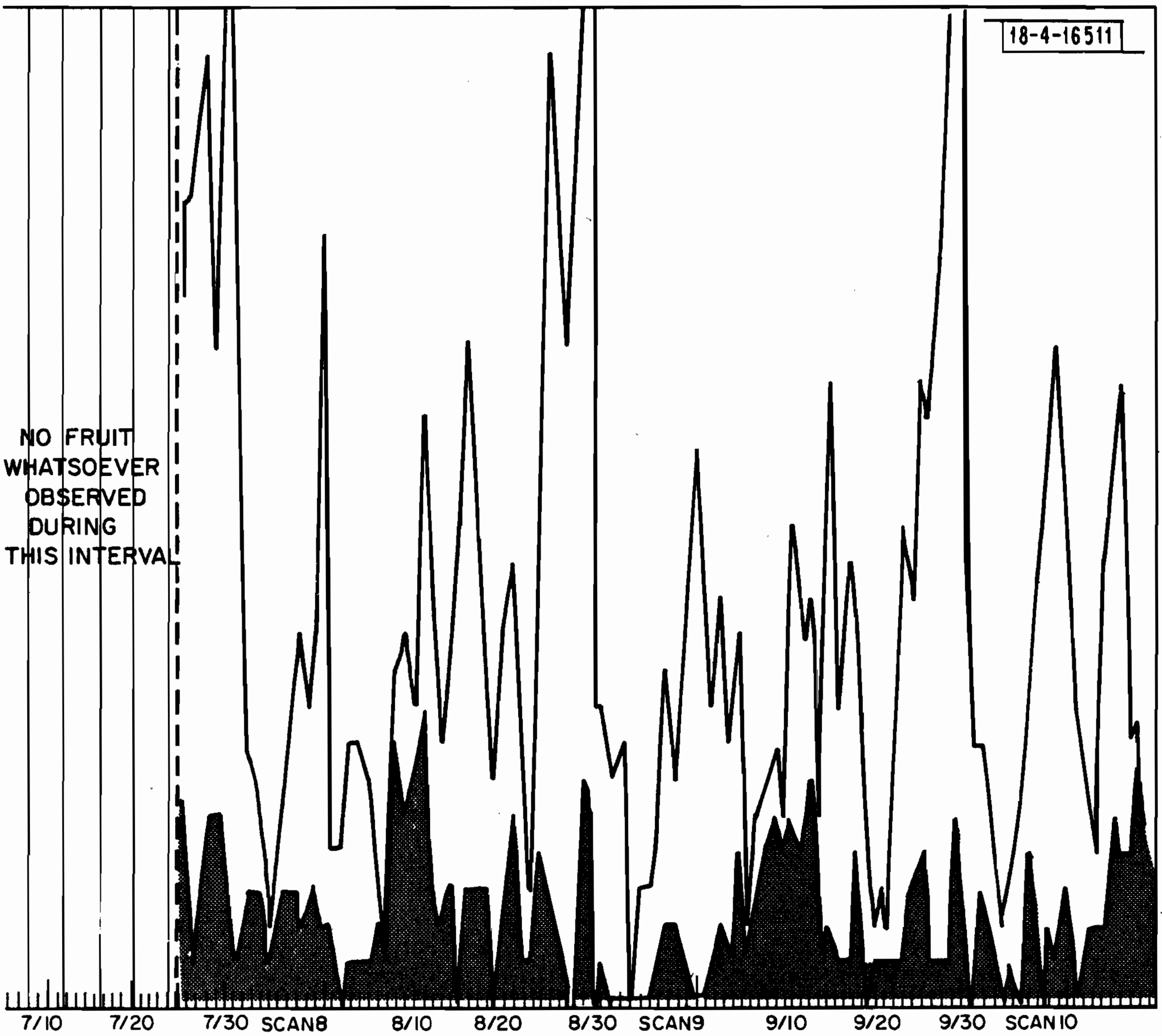


Fig. 29. (continued).

that period. Cursory examination of the data in Fig. 29 reveals that this is extremely unlikely; the dead time is probably due to inadvertent switching of the defruiter back into the system for a brief period. Note that it happened only twelve seconds after the defruiter was initially switched out (the technician at the radar site most likely still had his hands on it then).

4.1.4 Analysis

Several interesting points are apparent from the data:

- The average number of replies from aircraft 0215 is 3.5 per interval. This corresponds to roughly 140 replies per scan. Since on a long term average basis, the ARTS-III receiver sees only one fourth of the total fruit, we would expect a total fruit per scan count of approximately 560, corresponding to roughly 130 fruit per second. Assuming that all interfering interrogators are operating at 400 ips, and have 5.4° effective beamwidths, we would expect that each would elicit (on a long term average) six or so replies per second. The fact that 130 fruit per second were noted suggests that in excess of twenty interrogators had the aircraft under surveillance. This is surprising, considering that the aircraft was below 1800 ft.
- The average number of total fruit was roughly ten per interval, which means that aircraft 0215 was responsible for over one-third of the total fruit during these ten scans. While this appears surprising at first, it is consistent with data

observed before which shows that fruit contributions diminish rapidly with increasing range, to the point where practically no sidelobe fruit whatsoever is received from aircraft more than 10 nmi away. This is a consequence of the marginality of the RF path from the aircraft to the interrogator via the sidelobes; the path parameters are such that the probability of reception of a sidelobe fruit reply (during a time when the receiver is active) diminishes rapidly with increasing range (and approaches zero at 10 nmi). In the analysis of aircraft 0215 above, it is assumed that all fruit produced are received; it is difficult to verify that assumption from the data.

- The high long-term average fruit rate for the one aircraft is roughly consistent with direct measures of the uplink environment made in this vicinity by Lincoln Laboratory [10]. These measurements were made at 8000 ft. The fact that similar interrogation rates are seen at 1500 ft suggests either a concentration of interrogators in the vicinity of Boston, or that perhaps an interrogator in the vicinity is not SLS equipped, and is thus responsible for far more than the average 6 interrogations per second. Measured fruit levels are not consistent with the notion that the aircraft is causing a complete ringaround on that interrogator's display, but partial ringaround certainly appears likely. If this were so, however, we would expect to see some periodicity in the 0215 data, at the scan rate of the non-SLS equipped interrogator (corresponding to the density of replies versus azimuth of the partial ringaround). Since no such periodicity is evident, it appears more likely that the high overall fruit level is perhaps partly due to several less than ideal interrogators.

- Some periodicity is apparent in the total fruit count; the high peaks all occur when the antenna is pointing approximately West (which is where several of the aircraft with large sidelobe fruit counts and most of the aircraft contributing to mainbeam fruit were). This is consistent with the notion that since sidelobe levels generally rise in the vicinity of the mainbeam, the probability of a fruit reply being successfully received also rises; all of the aircraft within 10 nmi were undoubtedly transmitting fruit at rates comparable to that of aircraft 0215; however, these replies were received with high probability only periodically (i.e., when the antenna was pointing in their general direction). Aircraft 0215, on the other hand, was almost due East (ACP 1000); only slight regular peaking in that direction can be seen in its fruit rate. This further confirms the notion that most of its fruit was being received, regardless of antenna orientation.

4.1.5 Interfering Interrogator Location From Fruit Data

Since large quantities of information are contained in fruit data, the question arises whether that information can be used to advantage to reconstruct the fruit generation model, and from its geometry, to determine the locations of the various interrogators responsible. Several approaches come to mind: when pulse staggering is not employed, the sweep-to-sweep timing information allows determination of PRF rates, and thus association of particular fruit sequences with particular interrogators. Given enough data of this sort involving several aircraft, the locations of the interfering interrogators can be found. This process was employed quite successfully in the analysis of the data from Minneapolis, which is discussed in the next section. In the case of Boston data, however, eight-pulse staggering was employed by the Boston ASR. As a result, it was not possible to associate particular fruit sequences with particular interrogators. For example, in one instance a specific aircraft contributed side-lobe fruit on eight sweeps in a row. Differences in range from one sweep to the next were compared; none were within a mile of any other, and thus it could not be determined which fruit came from which interrogator. Clearly, another approach is needed.

Another approach was found, which is based on information derived from those occasions where several fruit replies from several different discrete-code aircraft occur on a single sweep. Whenever that occurs, in an environment where total fruit levels are moderate, it can be assumed that the several fruit result from a single interrogation. Since the positions of the aircraft are known, the information contained in apparent differences in ranges of the fruit from pairs of aircraft can be used to determine the relative timing of the interrogation as it arrived at the aircraft. This, in turn defines a pair of arrival angles (Fig. 30); this process, applied pairwise to three aircraft, resolves angular ambiguity, and results either in a bearing to the interfering interrogator or a fix of its position if it is closeby (Fig. 30).

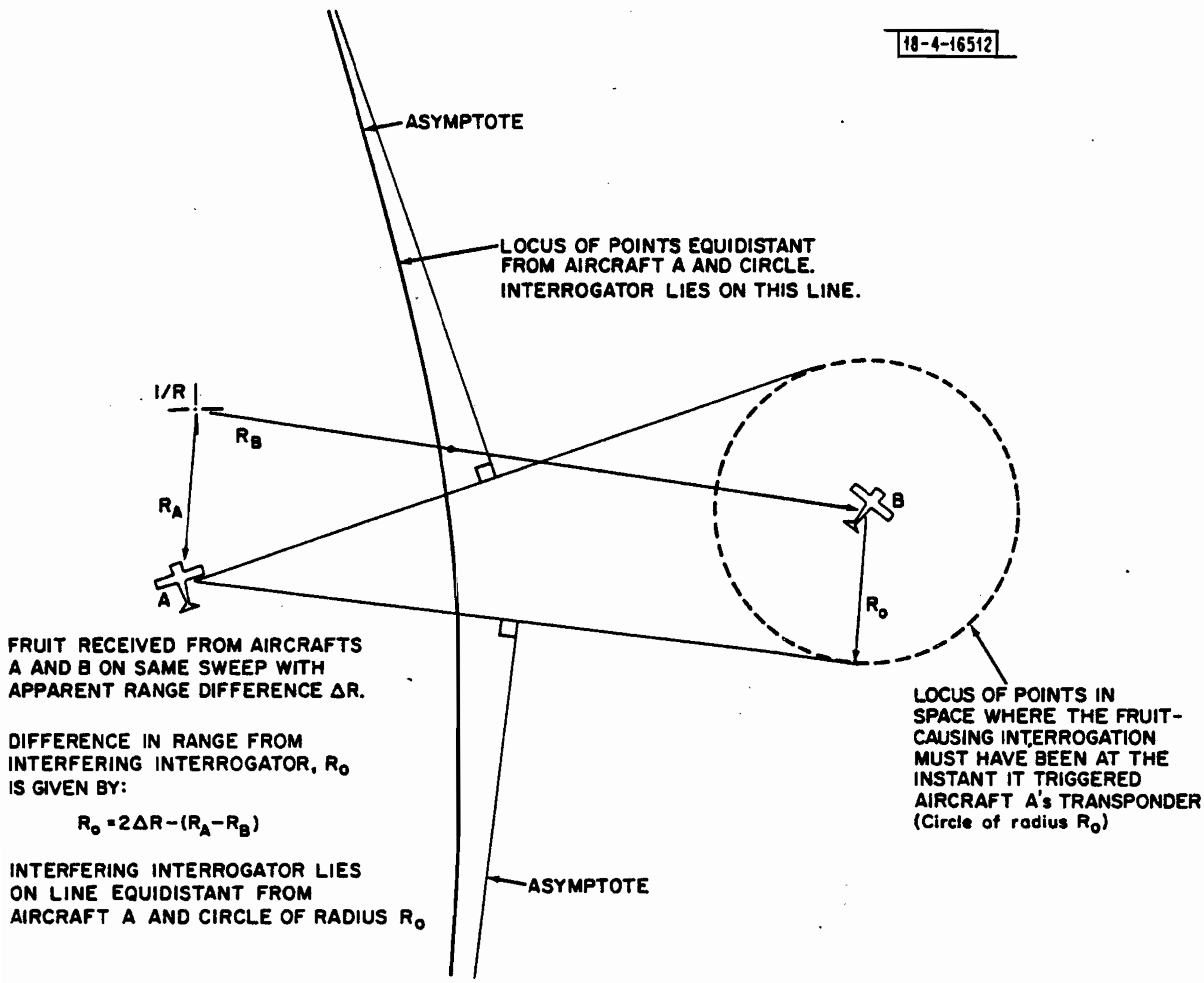


Fig. 30. Direction-finding from multiple fruit on a sweep.

Three attempts at locating interfering interrogators were made using Boston data. Each indicated a particular location, roughly consistent with known interrogator locations. Each was the result of a different interrogator; this is not surprising given the large number of interferors measured in the Boston data.

4.2 MINNEAPOLIS (MSP)

4.2.1 Introduction

A telephone conversation with UNIVAC personnel who have made similar analyses of ARTS-III data resulted in a pair of tapes, one defruited, the other undefruited, made simultaneously at the ARTS-III test facility, which derives its surveillance data from the ASR at Wold-Chamberlain Airport, Minneapolis, Minnesota. It should be noted that, in contrast to the other sites discussed Minneapolis is relatively free from problems. Analysis of data from Minneapolis, provides an interesting contrast to what has been seen elsewhere.

4.2.2 Minneapolis Data

Sixty-four scans of undefruited reply data were printed out, corresponding to a four-minute sixteen-second interval beginning at 1701, local time. A similar volume of defruited reply printout was obtained; cursory examination revealed a close correspondence between it and the undefruited data. That is, single misses in undefruited reply sequences usually resulted in double misses in the defruited data; first replies were also missing in the defruited data. The only analysis in which defruited data was employed extensively is the angular accuracy analysis discussed below, in which direct comparison was made between target reports. It was noted that ranges in defruited data were consistently one or two range increments (one increment = 0.0625 nmi) greater than those in the undefruited data. Whether this is due to improper defruiter alignment or to incorrect timing in the related ARTS-III channel is not known.

During the time of interest, there were an average of thirteen aircraft within the coverage area (max. range 54 nmi), of which twelve were usually declared each scan; these targets are listed in Table 11. Since UNIVAC used these tapes, an unusually large volume of supplementary information was available from UNIVAC personnel, which is presented in Table 12. Target tracks are shown in Fig. 31 for scans 20 to 40.

4.3 FALSE TARGET EXAMINATION

Twelve reply sequences resulting from reflections were noted; most were only one to three replies long, but persisted over several scans. None was sufficiently long to result in a false target declaration. Five of these corresponded closely with one reflector; the remaining seven, with another. The two reflector locations and orientations are shown in Fig. 32.

Discussion with UNIVAC revealed that both are small general-aviation hangars; the one to the northeast has doors on the south wall which were open at the time of the test. This is consistent with the extremely short runlengths seen on its reflections.

4.4 FRUIT ANALYSIS

The data was scanned manually for instances of replies not synchronous with those of actual targets. Very little ringaround was occurring (probably

Table 11. Aircraft present at MSP-Scan 6.

Code	Altitude*	Range	Azimuth	Strength†
1200→1210	-	2.19	104.4^{o}	N
1000	00	44.5	109.7^{o}	
1500→0104	-	34.25	125.0^{o}	
1200	-	39.75	129.2^{o}	W
1200	-	42.56	150.1^{o}	
2000	00	26.75	185.8^{o}	
0107	00	29.5	198.8^{o}	W
0277	66	8.56	213.9	
2000	00	44.19	221.5	
1207	00	21.5	231.9	W
1200	00	40.75	276.3	W
1000	-	50.75	309.9	W
1200	65	11.75	333.1	

* - signifies no mode C replies, 00 signifies empty brackets, other numbers give altitude in hundreds of feet, corrected.

†N signifies not declared, W signifies declared weak.

Table 12. Parameters during extraction - MSP.

ATCBI	
PRF:	375 ips
Stagger:	None
Scan rate:	4.0 sec per scan
Peak power:	316 W
Peak SLS (omni) power:	1290 W
Sensitivity:	- 87 dBm (Minimum Discernible Signal)
STC:	+ 45 dB
Envrionment	
Time:	1700 local
Temp:	84^{o}
Date:	30 June 1972
Rel. Hum.	33%
Weather:	Dry and clear
Wind:	300^{o}/10 kt

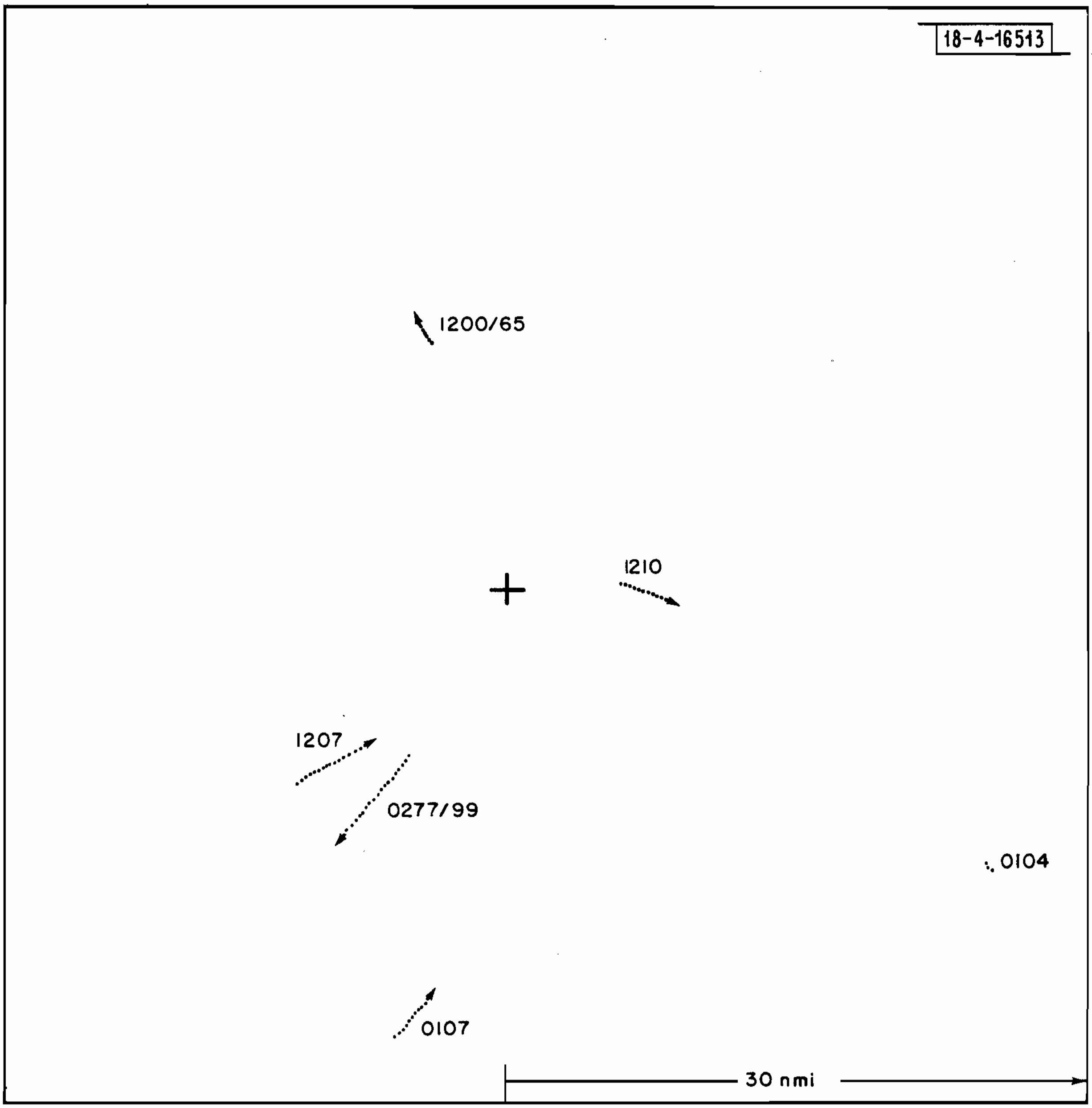


Fig. 31. Aircraft tracks - MSP scans 70-40.

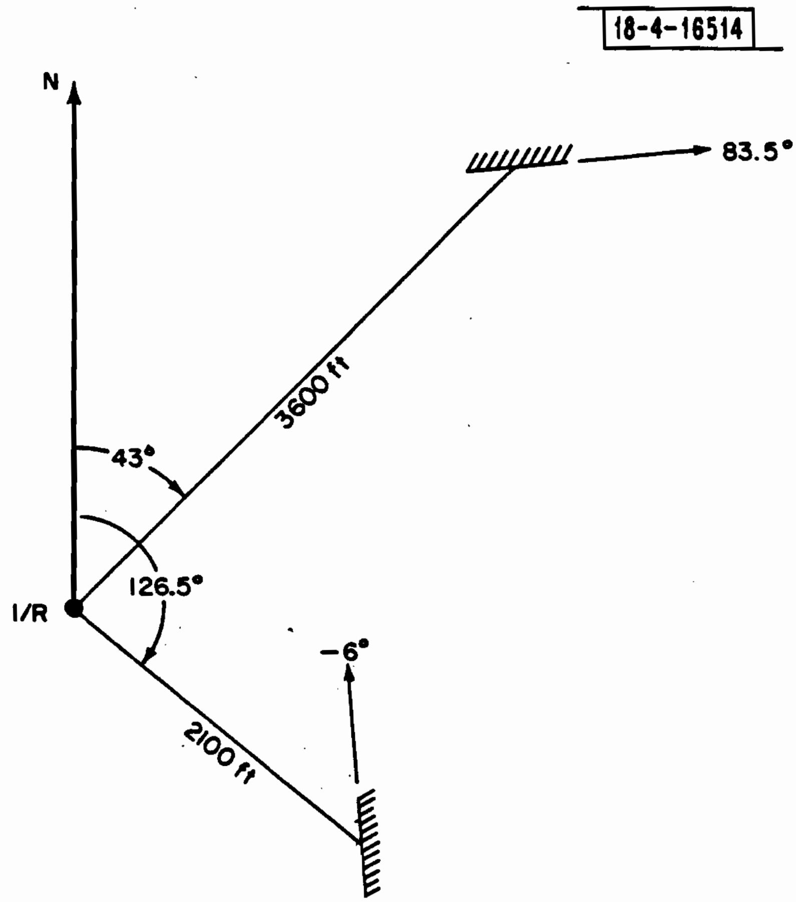


Fig. 32. Reflectors at MSP.

because of the excessively high SLS power; see Table 12); therefore, target reply sequences were tightly bunched and it was straightforward to note any replies at different ranges. All such replies, except those due to the false target mechanisms noted above and another exception which will be discussed later, were concluded to be fruit. Fruit replies were further classified as mainbeam or sidelobe fruit, depending on whether they agreed in code and/or altitude with target codes being received synchronously on the sweeps when the fruit was seen. Several fruit were observed with common codes (in particular, 1100, 1400, 2100 and 2300) which did not correspond to any codes of aircraft within the coverage. In each case, fruit of a particular code would occur consistently at a particular azimuth over a number of scans. These were concluded to be mainbeam fruit due to aircraft at ranges beyond the maximum range of the system. Whenever a fruit reply with a code the same as that of one of the aircraft within system coverage was noted, while that aircraft was not within the mainbeam, that fruit was counted as sidelobe fruit, despite the fact that it could have come from another aircraft with the same code in the mainbeam beyond the system maximum range. In only two cases were fruit replies with discrete codes matching those of aircraft in the system found in the "sidelobe" region; in both cases, they were at azimuths within three degrees of the target, and occurred just before or after the target legitimate reply sequence. No other fruit replies which could definitely be shown to be sidelobe fruit were noted in sixty scans.

The total number of fruit replies of both types observed during 64 scans was 246; the average <u>per scan</u> was thus 3.8. This corresponds to the same arrival rate, 3.8 fruit per sec, since the receiver duty cycle is 0.25 (max.

range = 54 nmi, PRF = 375) and the scan time is 4 sec. The maximum number of fruit replies received on any scan was 20; on only three scans were more than ten fruit received; no fruit at all was received during twelve scans. The total number of possible sidelobe fruit seen was twelve (out of 246, less than 5%). In every case in which more than six (mainbeam) fruit were received in one scan, they did not arrive randomly, but rather in a quite noticeable pattern, tightly bunched in azimuth.

Figure 33 shows one such pattern. It is evident that the pattern generated by the fruit is a segment of a spiral, such as those typically produced on secondary radar displays from fruit generated by an interrogator whose PRF is fairly close to that of the victim. While this sort of fruit pattern is hardly surprising, this is its first instance of occurrence in our ARTS-III data, since all other undefruited tapes that have been analyzed here were made from interrogators with pulse staggering, which effectively randomizes the fruit arrival times. The MSP interrogator operates at a fixed PRF of 375. From the spacing of the fruit replies, 2.65 nmi, it can be seen that (assuming they are due to an interrogator whose PRF is somewhere between 300 and 500) the pulse repetition interval of the interrogator producing them differs from that of the MSP interrogator by $2.65 \times 12.358 = 32.75$ μsec; hence, the interferor's PRI is 2699.5; this corresponds to a PRF of 370.45. Discussion with UNIVAC and examination of ECAC E-file data [11] revealed that the Minneapolis ARSR has an assigned PRF of 370.

Another point which is evident from Fig. 33 is worth mention. Note that on sweeps 81 and 83 the synchronous reply is suppressed, because the synchronous interrogation follows too closely after the interrogation of the ARSR. Similarly, on sweep 86 the fruit reply is suppressed because it follows

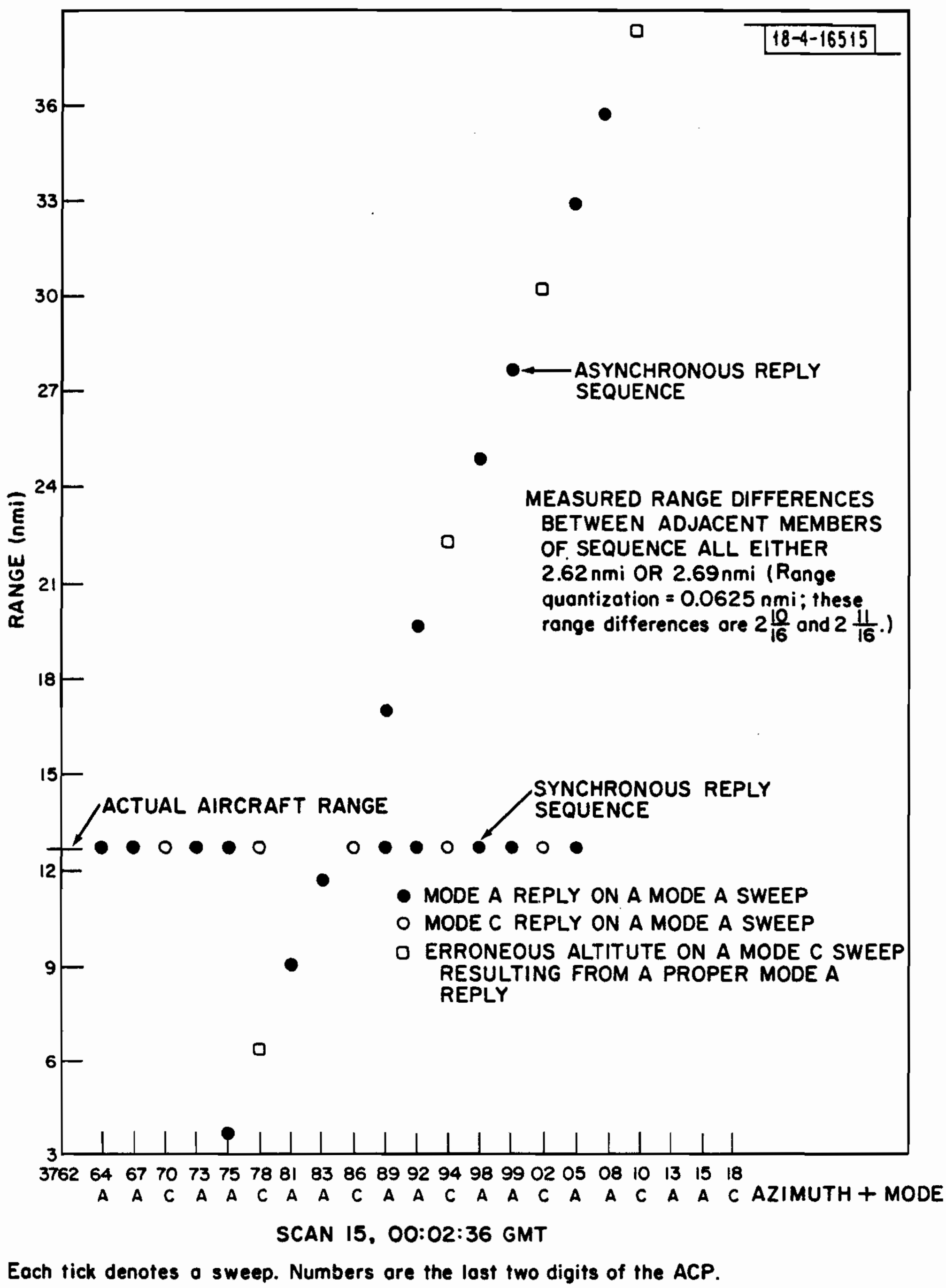


Fig. 33. Fruit pattern - MSP.

too closely behind the ASR (synchronous) interrogation. From the numbers involved, we see that these facts constrain the deadtime of the particular transponder to between 46.3 and 52.5 μsec.

Of the twenty fruit sequences observed in the data, twelve had range differences of 2.62 to 2.69, and were therefore due to the Minneapolis ARSR. Other range differences noted were 5.62, 5.88, 12.31, -3.31, and -3.02 nmi; all but the fourth were seen more than once. These range differences correspond to PRF's of 365.5, 365.0, 355.0, 380.0, and 380.3. Thus, at least six interrogators contributed to the fruit seen at MSP.

Since several reply sequences presumably from the Minneapolis ARSR were located fairly close to one another in time in the data, they were tabulated (Table 13) for further analysis. Note from that table that in two instances particular aircraft caused mainbeam fruit on two occasions five scans (or 20 sec) apart. This implies that the scan time of the interferor is probably 10 sec (actually a little more, since the center of the second fruit sequence is somewhat more clockwise than that of the first; also, no fruit was produced five scans earlier or later). This data is also consistent with scan intervals of 5 or 20 sec; however, the assumption of 10 sec, typical of ARSRS, gave results that appeared reasonable in the analysis which follows.

In Table 13, time is measured in terms of scan number (coarse time) and azimuth (fine time). Actual timing data was available in the printout; however, it was felt to be more convenient to work with scan and azimuth information. The assumption of 10 sec scan intervals for the interferor, together with the relative timing of the fruit produced by the two aircraft squawking 1200 and 0104, lead through simple arithmetic to the conclusion that the interferor's

Table 13. Occurrences of fruit from ARSR.

Timing Data

Scan	Azimuth	Aircraft	Location
10	332°	1200/65	12.5 nmi, 333°
14	125°	0104	33 nmi, 125°
15	333°	1200/65	12.5 nmi, 333°
19	125°	0104	32.5 nmi, 126°
32	194°	0107	25/5 nmi, 196°

mainbeam azimuth while illuminating aircraft 0104 is greater by 124° than its azimuth while illuminating the aircraft squawking 1200. Extrapolating the azimuth ahead to the time of the fruit return sequence from aircraft 0107 gave an azimuth still greater by 109°; for this a scan rate of exactly 6 rpm was assumed for the interferor: a more exact determination could have led to somewhat greater precision.

Since the positions of the three aircraft relative to the ASR are all known, it is a simple exercise in triangulation to find the location relative to that of the ASR at which the azimuths of the various aircraft bear the proper relationships to one another (Fig. 34). This must be the location of the interferor. This process results in an interferor position approximately 10 miles slightly east of south from the ASR; tabular information from ECAC gives the actual position of the Minneapolis ARSR as 8.75 nmi, slightly east of south.

4.5 COMPARISON WITH BOSTON FRUIT ANALYSIS

Although the fruit arrival rate observed in the MSP data is more than one hundred times less than that observed at Boston, the differences between

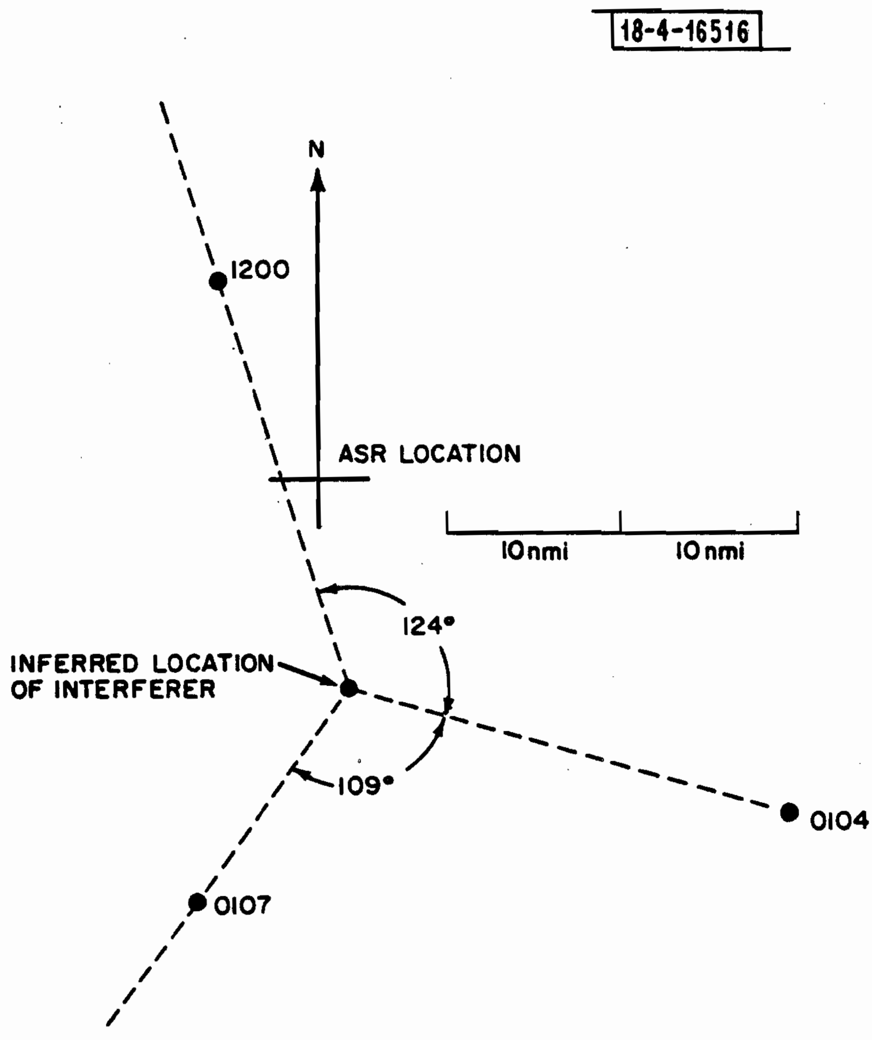


Fig. 34. Determination of interferor location.

the two situations account almost fully for the rate differences; the two results are not inconsistent. At Boston, twenty-six aircraft were within the coverage area, and the data suggested that perhaps fifteen interrogators were involved. Assuming that total fruit arrival rates are proportional to the aircraft-interrogator product would result in an expected difference factor of five (i.e., twice as many aircraft, two and one-half times as many interrogators at Boston).

A far more significant distinction between the two sets of data is evidenced in the differences in the relative numbers of sidelobe fruit. At Boston, the bulk of the total fruit was received from nearby aircraft which, despite their low altitudes, were illuminated by a large number of sensors; at MSP, only a very few fruit replies were received via the sidelobes. This is apparently due to both the aircraft position distribution difference, and the difference in interfering interrogator locations. Only two aircraft at MSP were within 10 nmi (close enough to cause sidelobe fruit); what little sidelobe fruit that occurred appears traceable to them. They did not produce more probably because their altitudes were low and there is only one potentially interfering interrogator close to them.

Roughly seventy <u>mainbeam</u> fruit per scan were seen in the Boston data, as opposed to 3.8 at MSP (i.e., virtually all the MSP fruit). Gross correction for the differences in aircraft-interrogator product brings the two data to within a factor of four of one another. This factor can only be attributed to the slightly higher sensitivity of the Boston beacon receiver, and the hypothesis that most of the interfering interrogators at MSP were so far away that they only affected aircraft in their vicinities, rather than all the aircraft in the MSP area. That more than half of the MSP fruit received in sequences was traceable to the single nearby ARSR, would tend to support this hypothesis.

Perhaps the most significant conclusion that can be drawn from the comparison of BOS and MSP fruit is that oversimplified rules of thumb such as "total fruit per second equals some system constant times number of interrogators times number of aircraft" are likely to yield answers which differ from reality by more than a factor of ten.

4.6 AN INTERESTING PHENOMENON

A target appeared and was declared for three consecutive scans in the midst of the undefruited data, whose reply sequences are typified by the sequence shown in Table 14. The target range changed by roughly 0.5 nmi per scan. Note from Table 14 that only one mode A reply is sensed between adjacent mode C replies; the interrogation interlace pattern is AAC. From the azimuthal differences between replies (which should always be either 2 or 3 ACP), we see that the first mode A reply after the mode C reply is the one that is regularly missing. Such regularly alternating misses in a particular mode are usually attributable to defruiter tube spots, since the defruiter tube in use also alternates regularly. However, no defruiter was in the system for this data.

Two clues to this puzzle can be seen: the reply code, 2300, is reserved for aircraft operating above FL340, and yet the indicated altitude is only 12,500 ft; further, the code actually being received on the mode C sweeps, resulting in the 12,500 ft altitude decode, is in fact, 2300. What we have here

Table 14. A strange reply sequence.

Mode	Code	Range	Azimuth
C	025	29.00	1546
A	2300	29.00	1551
C	125	29.00	1554
A	2300	29.00	1560
C	125	29.00	1562
A	2300	29.00	1568
C	125	29.00	1571
TGT	29.00 nmi	136.93° 0 alt.	2300 code

is apparently a second-time-around-reply sequence. That is, a sequence due to an aircraft at such great range that his replies are not received until the sweep following that of the particular interrogation. Thus, the second mode A reply results from the first mode A interrogation, the erroneous altitude results from receipt of a 2300 reply to the second mode A interrogation, and the missing reply on each first mode A reply results from failure of the aircraft to respond to mode C interrogations either because the link is marginal or because it is not mode C equipped.

This mechanism would require the aircraft to be at a range corresponding to 2666 μsec (the MSP pulse repetition interval) plus the indicated range, a total of 245 nmi. This range is not unreasonable, since, in the absence of deep fading, received signal levels are sufficient on both links, and the radio horizon at above 34,000 ft is over 240 nmi.

4.7 AZIMUTHAL ACCURACY ANALYSIS

Since two sets of data, differing only in the presence of a defruiter in one, were available, and since the defruiter is frequently blamed as a source of azimuth error, a comparison was made of the azimuth estimations made by the two systems.

A single target squawking both modes departing radially at relatively long range was tracked over twenty scans (from about 42 to 51 nmi). The target radial velocity held constant at 412.5 kt. Figure 35 plots the azimuth of the aircraft on each scan as determined by both systems. Making the somewhat questionable assumption that the aircraft actual azimuth remains constant at its average as seen in the undefruited data, we see that, for the data, the maximum azimuthal error in 20 scans is 0.175° (about 2 ACP's), and the rms error is 0.11° (about 1.25 ACP's). Corresponding values for the defruited data are 0.35° maximum (about 4 ACP's) and 0.192° rms (about 2.18 ACP's). These figures take into account the bias error introduced by leading reply suppression in the defruiter, and are worse for exactly the reasons one would expect: occasional missed initial mode C replies tended to make the leading edge "noisier," and holes in the reply sequence due to suppression were doubled in size by the defruiter. This latter phenomenon impacts on ARTS-III performance because of the center-of-gravity beamsplitting procedure employed. It should be noted that the reply probability of the aircraft in question was exceedingly high (> 98% from Fig. 24) and a lower reply probability would tend to make both processes noisier, especially, in the defruited case.

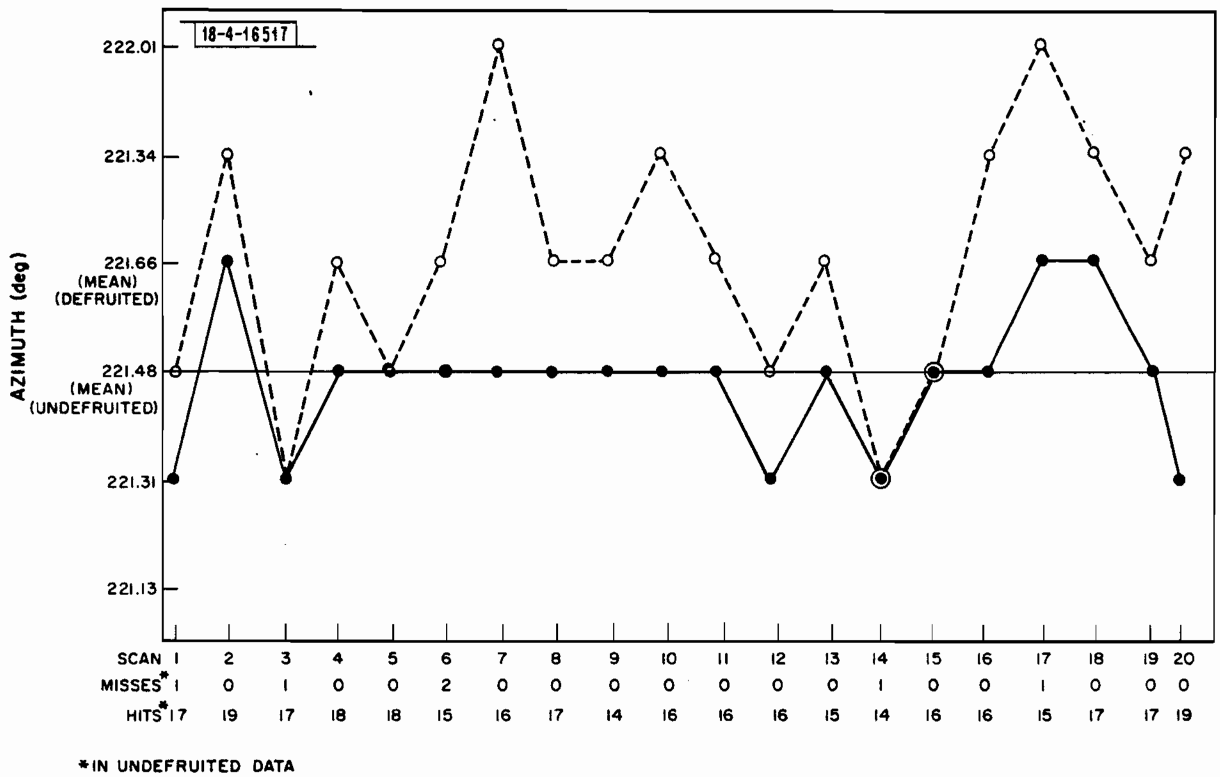


Fig. 35. Azimuthal accuracy.

4.8 CONCLUSIONS

The results of this analysis show that variations in parameters that impact upon ATCRBS performance are indeed extreme from one site to another, in fact, far more extreme than one would predict based upon simple models. This points out the need for additional study of data from other sites as a means of refining ATCRBS performance models, and suggests that quite sophisticated models are necessary to come even within 3 dB of actuality. The analysis also demonstrates that it is feasible, and in fact, simple to determine the PRF's and other parameters of the individual interrogators responsible for fruit, when working with undefruited individual-reply data taken on an interrogator that does not employ pulse staggering. In short, there is much detailed knowledge to be gained from the study of ATCRBS as it operates today, and examination of ARTS-III tapes is an extremely fruitful source of that knowledge.

SECTION 5

ERRONEOUS DECODING

5.1 BOSTON

5.1.1 Introduction

During the discussions with Logan Airport personnel which led to our initial studies there, they noted another possibly related problem: apparently good reply sequences were being declared as targets, but were not being tracked properly. In addition, severe errors in displayed altitudes were occurring so frequently that controllers were reluctant to use this data. Examination of target declarations in cases where tracks were dropped had revealed that target reply codes (mode 3/A) were decoded incorrectly. Controllers had noted that codes 1100 and 1200 (the most commonly seen reply codes), when incorrectly decoded, were regularly decoded as codes 1540 and 1620, respectively. This was consistent with the observed track failures, since ARTS-III requires correlation in code in order to maintain track. Logan maintenance and automation personnel had no explanation for the phenomenon, but suspected some sort of multipath reflection on the reply path.

5.2 The Data

Examination of the approximately 150 scans of ARTS-III reply data which was obtained for the false target analysis revealed that, indeed, incorrect decoding occurs repeatedly. One particular aircraft, squawking code 1201, was tracked over 140 scans; during that period, code 5621 appeared on approximately 25% of the individual replies. On many scans, the declared reply codes were incorrect as a result; occasionally, all replies in a sequence were correctly decoded as 1201. No reply code other than 1201 or 5621 was noted, except during two scans where synchronous garbling occurred; during these, the garble pattern was entirely consistent with the actual codes involved. Similar behavior was observed on several other aircraft reply sequences. Still other aircraft tracks exhibited no anomalies. The fact that only a single anomalous reply code (or, in some cases, a very small, closely related set of anomalous codes) was associated with each legitimate code, and the anomalies occurred regularly over a wide range of azimuths and distances appeared to rule out multipath as a cause.

The anomalous codes observed in the data are listed in Table 15, along with their associated legitimate code.

5.3 Analysis

A brief examination of the "difference" column (which shows those pulses which when added to the legitimate code transform it into the anomalous code) reveals that its pulses are related to those of the original code in the following, surprisingly straightforward manner:

Whenever A_1 is set in the original code, B_4 is set in the anomalous code.
Whenever A_2 is set in the original code, B_2 is set in the anomalous code.
Whenever B_1 is set in the original code, C_4 is set in the anomalous code.
Whenever B_2 is set in the original code, C_2 is set in the anomalous code.

Table 15. Anomalous codes observed in Boston data.

Legitimate Code	Anomalous Code	Difference
1100	1540	0440
1110	1554	0444
1112	3556	2444
1102	3542	2440
1200	1620	0420
1201	5621	4420
1202	3622	2420
1212	3636	2424
2003	6203	4200
2004	3204	1200
0300	0360	0060

Whenever C_1 is set in the original code, D_4 is set in the anomalous code.
Whenever D_1 is set in the original code, A_4 is set in the anomalous code.
Whenever D_2 is set in the original code, A_2 is set in the anomalous code.
Whenever D_4 is set in the original code, A_1 is set in the anomalous code.

No original codes were observed in which A_4, B_4, C_2, or C_4 were set, but it appears reasonable to infer from examination of the above listing that these pulses most likely would cause B_1, C_1, D_2, and D_1 to be set.

The pattern by which these pulses are related is shown in Fig. 36. The arrows point from the actual pulse which must be present in the original code to the incorrect pulse which it causes in the anomalous code; note that the relationship is non-reciprocal.

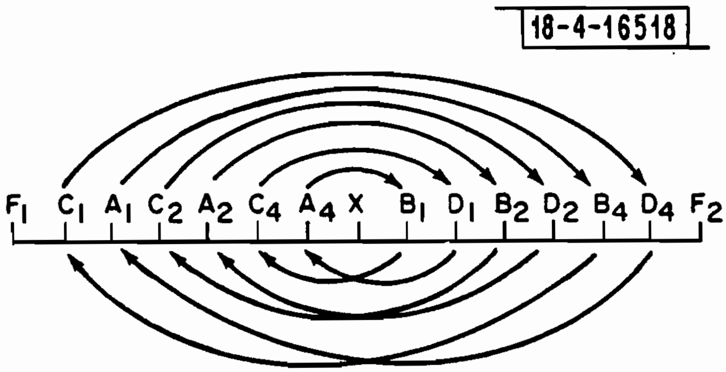


Fig. 36 Relationship between anomalous and legitimate reply pulses.

While the relationships among the pulses are certainly regular and consistent, it is apparent from the diagram that they cannot be explained by any simple mechanism which could be related to multipath phenomena such as a fixed delay, or a combination of delays. However, the manner in which a) D, A, B, and C pulses, respectively, cause anomalous A, B, C, and D pulses and, b) pulses 1, 2, and 4 cause anomalous pulses 4, 2, and 1 strikes a familiar note.

During the study of altitude garbling reported in [1] which included ARTS-III mode C readout codes and the altitudes they represented, it was noted that the mode C codes delivered from the ARTS III-Data Acquisition Subsystem (DAS) were rearranged in the form DABC, and in reverse order of subscripts. In fact, examination of the DAS/DPS (Data Processing Subsystem) Message Format [12], reveals that bits 15-26 of the mode 3/A and mode C reply words are formatted in the order shown in Table 16.

Table 16. Reply word formats.

Bit Number	15	16	17	18	19	20	21	22	23	24	25	26
Mode 3/A	D_1	D_2	D_4	C_1	C_2	C_4	B_1	B_2	B_4	A_1	A_2	A_4
Mode C	C_4	C_2	C_1	B_4	B_2	B_1	A_4	A_2	A_1	D_4	D_2	D_1

Comparison of the above table and the previous table relating original code pulses to anomalous pulses shows that in every case the relationship between a mode C and mode 3/A pulse here is exactly the same as that between an original code bit and an anomalous bit.

Given this fact, one can speculate with reasonable soundness on what is causing the anomalous codes in the Logan ARTS-III. The System Description manual [12] does not present detailed logic diagrams of the entire DAS, but does indicate in the DAS detailed block diagram (Fig. 3. 2-7) a functional unit (called the "Code Transformation Gates") which formats DAS reply words. That unit is hard-wired to read out the code bits in either of the above formats. Telephone conversations with Burroughs personnel reveal that circuitry of the sort shown in Fig. 37 (a simple "toggle") is employed (only the circuitry for bit #15 is shown for clarity):

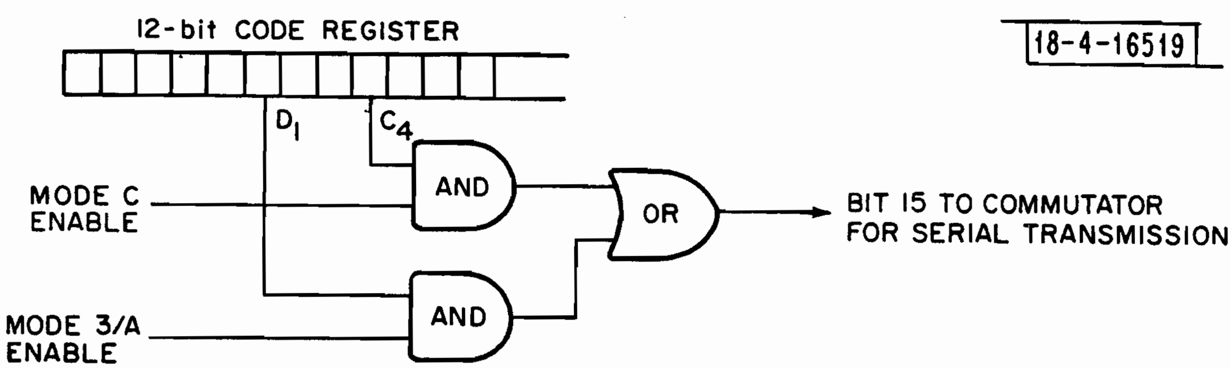


Fig. 37 ARTS III Reply Code Readout Circuitry

The enable lines are driven by a set of flip-flops, which are set at the beginning of each sweep, and reset by the maximum range pulses. Any improper enabling signal on the wrong enable line would allow the C_4 bit (if present) to pass the and-gate, and appear in bit position 15 (where the D_1 pulse would be expected in a mode 3/A data word). Intermittent existence of such an enabling signal would cause intermittent presence of an anomalous pulse in the D_1 (or any other) position of a mode 3/A reply word whenever the C_4 pulse (or whatever pulse in the mode C line of the above table corresponded to that particular position) was present. This is precisely the behaviour that was displayed in the data.

This tie-in between faulty mode enable signals and the improper decoding behavior was pointed out to Logan Airways Facilities Service personnel, who discovered that the wrong modes were, in fact, being improperly enabled in a random fashion, and traced the source of the problem to excessive cross-talk from the data line to the triggering line.

The ARTS-III installation at Logan employs separate data lines for transmission of synchronizing and triggering pulses and the actual surveillance data; this is believed to be a fairly common situation. ARTS-III can also employ a single data line, in which case triggering pulses are made to appear with negative voltage and data with positive voltage. Clipping and filtering circuits are employed in this situation in the ARTS-III front end to separate the two. In either case, whether one or two lines are used, actual replicas of the P_1 and P_3 interrogate pulses are sent down the line and their separation used to determine mode. In the Logan situation, every time a set of pulses spaced 8 μsec apart appeared on the trigger line, mode 3/A was set, and whenever a set 21 μsec apart appeared, mode C was set. Pulses with these spacings frequently resulted from the crosstalk situation, thus causing the problem. They were easily filtered out purely on the basis of amplitude by proper level adjustments in the line drivers and amplifiers; this eliminated the problem completely.

SECTION 6

CONCLUSIONS

Although the data whose analysis led to [1] was quite limited in overall quantity and in the number of sites, it was possible to draw several tentative conclusions from it which were listed and discussed in [1]. The additional data reported here has provided a much firmer basis for these conclusions, which can now be particularized and strengthened.

Sections 6.1 through 6.3 discuss the conclusions presented in [1], and modify each in light of the additional insight gained during the course of this study.

6.1 DEVELOPMENT OF A COMPREHENSIVE ATCRBS DATA BASE

During the course of study which led to [1], it became apparent that relatively little hard data on ATCRBS performance existed, and that the bulk of the data upon which system modifications had been based in the past was subjective and qualitative. This caused no severe difficulties during the period when initial modifications (e.g., Sidelobe Suppression, Improved SLS, defruiting, etc.) were implemented, since in each case, qualitative evaluation of the problem sufficed to determine its source and suggest the proper modification. Indeed, use of controller-derived qualitative performance information was especially appropriate, since controllers were so intensely tied into the surveillance process; it was often sufficient to fix what controllers thought to be the problem. With the advent of automated processing of beacon data, and the addition of new automated processes which make use of that data, this process of gathering performance data has become of somewhat questionable utility. Asking the controller what he thinks is wrong no longer suffices; rather, it is necessary to determine what the computer (which is usurping the controller's role of tracking and determining target validity) "thinks" the problem is. And, asking the controller what he thinks the computer "thinks" the problem is generally results in little new information. In the semiautomated system, it has become evident that symptoms perceived on the display which resemble symptoms that were noted in the manual system, frequently have origins in completely different areas.

Only a few properly-instrumented tests have been performed on the operational ATCRBS system in the past several years; they are discussed in [1]. That more were not conducted, is, no doubt, due to the high costs and large quantities of manpower needed to define, develop, perform, and analyze the results of the sort of large-scale test that was seen as necessary with the manual system to gather enough data to determine the sources of perceived problems.

Indeed, no systematic procedure exists today to diagnose the performance of the system, determine the problems associated with various sensors, rank these in order of severity, and develop solutions for them. Today, when a problem arises, a team of NAFEC engineers is dispatched to investigate and eliminate the problem. That they have been able to maintain the high performance level of the system attests to the skill and ingenuity of these individuals. The TPA and similar devices under NAFEC development will provide assistance in the future in the problem determination area.

As the level of automation in the system continues to increase, however, this skill and ingenuity will be severly taxed. As noted above, problems can manifest themselves in new and different ways in the semiautomated system. Additional data, closely connected to data processor performance, is needed to evaluate ATCRBS performance and identify the sources of problems. It is in this area that analysis of ARTS data tapes can play a key role.

It is noteworthy that the FAA ATCRBS Improvement Program [13] pcints to definite shortcomings in the system and emphasizes the need to improve its performance level. Improvements are recognized as necessary if the presently-planned levels of automation are to succeed. The ATCRBS Improvement Program recognizes the need to collect data on system performance (suggesting the development of several systems for this purpose), and also recognizes the need to implement several corrective improvements. However, the plan makes no mention of the process which must necessarily occur to transform the data gathered into clearly-defined requirements for specific improvements. The program should include a mechanism by which the proper improvements can be determined from the data that has been gathered, and justified. Indeed, a mechanism which is more quantitative than the present means of identifying problem sites appears essential.

6.1.1 The "Denver Patch"

A preliminary attempt at the measurement of automated system performance, the Denver Patch (now known as "BRATS") provides ARTS-III statistical summaries in real time, from which overall performance levels can be inferred. Outputs include averages of various validity target declarations per scan, percentage of strong/weak targets, and numbers of active, coasting, and suspended tracks. The process is useful in spotting adverse trends at particular sites, and comparing overall performance levels of many sites. However, it sheds little, if any, light on the reasons which various performance parameters have particular values. For example, knowledge that the level of dropped tracks has increased might alert site maintenance personnel that a problem exists (assuming the controllers had not already informed them). There are numerous reasons why track drop levels might increase, ranging from target declaration failures due to external parameters to reduced code validity due to equipment problems. Little insight into where the particular cause might lie is provided by BRATS.

While it is clear that BRATS is not suitable by itself for diagnosis of beacon system problems, it is certainly of value in the initial screening of these problems; similar processes should be incorporated into future surveillance processing systems.

6.1.2 En Route Data Collection

The en route data processing system, comprised of the Production Common Digitizer (PCD) at the radar site and the NAS computers at the ARTCC is similar in many respects to the ARTS-III processors used in terminal areas. In the area of data extraction, however, there is a significant difference. There is no present capability in the en route system for the extraction of data on individual replies; only target reports are readily available from the PCD. While these suffice for the analysis of some problems (e.g., Section 3.2), individual reply data is essential in the analysis of many others. The addition of high-speed recording equipment (and the necessary buffering) would allow retrieval of this data, and should be seriously considered for all en route radar sites. In some cases, the TPA could be employed to collect individual reply data.

6.1.3 A Data Processing and Analysis Facility

This report and [1] have demonstrated the potentially large benefits in terms of system performance improvements that can result from the relatively straightforward and inexpensive process of analysis of digital data derived from surveillance processors. What once required large-scale expensive tests, with much associated planning and coordination, can now be accomplished by analysis of digital data recorded with only minimal planning. Our experience has demonstrated that sufficient data to properly analyze most problems can be obtained using targets of opportunity. The fact that the two tapes made at Albuquerque yielded similar data on reflectors suggests that results are rather insensitive to time and the particular environment. The only planning that appears necessary is to decide the type of environment desired (e.g., busy hour), and to request that a recording be made a day ahead of time. Most of the sites analyzed in this report were never even visited by Lincoln Laboratory personnel; tapes were simply mailed to us.

To derive large-scale benefits for FAA, the analysis process followed in this report and [1] should be implemented on a regular systematic basis. In the past, it has been difficult for FAA to study more than a handful of sites per year. The extremely large improvement in efficiency which results from use of the techniques described here (made possible by the advent of digital data recording in conjunction with automated data processors) makes it quite practical to examine the entire FAA Secondary Radar system on perhaps a two-year cycle. The total engineering time spent on the analyses reported here and in Ref. [1] was less than one man-year. These analyses were performed almost entirely manually. Automated assistance could reduce the time required for thorough analysis of a site to perhaps one man-week.

It therefore appears highly appropriate for FAA to establish an ATCRBS data analysis center, which receives data tapes from all automated surveillance facilities including TPA on a regular basis, analyzes them to determine the problems that most affect the various sites, and formulate a specific program to correct the problems. Data analysis and problem identification could probably be performed at a practical rate by a staff of, perhaps, six. This staff would coordinate with FAA SRDS personnel to determine specifications for new equipments, and with local personnel to correct problems not requiring new equipments. The savings realized simply by applying new "fixes" only where the need for them can be substantiated by data rather than on a blanket basis throughout the system would far exceed the costs associated with a center of this sort.

6.1.4 The Role of Automation in Data Analysis

It is clearly appropriate to employ automation in the process of analyzing digital ATCRBS/ARTS performance data. The analyses reported here and in [1] could clearly be performed far more rapidly if data were available to the analyst in a more comprehensible form. On the other hand, our studies have shown the importance of being able to examine the data 'microscopically'; small nuances in the data can often infer important conclusions that would otherwise go unnoticed. Automation of the analysis process, rather than of the routine statistical processes associated with it, will be very difficult, with the associated risks of losing or misinterpreting much significant data. For example, tabulation of fruit rates, such as in Section 4. 1. 3, is an attractive candidate for automation. Determining which replies are fruit and which are not is a much more difficult process for automation to handle. One study of ARTS data [14] which purported to identify fruit automaticaly found an average of 66. 3 fruit per scan when examining defruited video. Our study of data taken at sites with comparable rates suggests that this rate of leakage is far too high. (See [1], Section III F-4, for a discussion of this point.) While it is quite improbable that this many fruit replies were received, it is quite common to note this many replies per scan that are not correlated with targets declared by ARTS-III. Close examiniation of the data would likely reveal them to be highly correlated among themselves, and with established target tracks (i. e., they are for the most part legitimate replies from targets too weak to be declared). Other phenomena which are seen occasionally are partial ringaround replies and occasional short reply sequences attributable to various false target mechanisms. Categorization of these replies is straightforward but tedious. Attempts at automating the process which detemines which replies are fruit and which are not would be exceedingly difficult, and impractical for initial implementation at a data analysis center; it is, however, an attractive long-term goal.

Similar pitfalls exist in the automation of measuring false target levels; examination of data which led in one study to the conclusion that there were more than one false target per scan revealed that this result obtained from the fact that two aircraft had apparently been assigned the same discrete code.

A similar situation was noted in our early Andrews AFB data, but caused little confusion, since it was readily apparent that the two tracks with identical codes did not bear the proper relationship to one another.

It appears that automation can be applied to the ATCRBS data analysis task most profitably in the areas of displaying data effectively to the analyst, and tabulating (and processing, when appropriate) data identified by the analyst as being of interest. A display similar to an ARTS-III scope which shows individual replies (and their associated codes when desired), but whose scan rate can be varied (to speed up, slow down, and reverse time as necessary) would provide far more readily digestible information to the analyst. Proper interaction between the analyst and the display would allow him to examine particular data in greater detail, or store it for future reference. Various subroutines similar to the manual processes used in this analysis could be called as needed. For example, if a target is spotted whose width appears to be fluctuating, the analyst should be able to identify the target to the processor, and obtain from it a plot of runlength versus scan for the duration of its track. Thus an automated tracking subroutine would be needed. Similarly, the system should be capable of providing assistance in the false-target area by tabulating and flagging multiple targets with the same discrete codes, and performing the necessary interpolation and geometrical reduction when called upon.

No attempt has been made here to configure an automated system to aid in data reduction. This preliminary discussion suggests that its cost and complexity would be comparable to those of an ARTS-III installation, perhaps with fewer displays but a greater printout capability.

6.2 DEVELOPMENT OF APPROPRIATE SOFTWARE-BASED IMPROVEMENTS

Ref. [1] concluded that major improvements in ATCRBS/ARTS-III performance could be brought about by development of special-purpose software. The data analyzed revealed that substantial improvements in the areas of false target identification, weak target enhancement, reply code processing, and azimuthal accuracy were possible.

6.2.1 False Target Identification

During the course of the false target studies reported here, it became apparent that the false target problem is the most severe problem in the system today; it will undoubtedly frustrate future attempts to increase levels of automation. Therefore, the recommendation made in [1] was pursued to the point of developing the algorithms discussed here in Section 3.3.6 and 3.3.7. Other algorithms are under consideration at present under the ARTS enhancement program, and it appears that an appropriate software process for identifying false targets will be implemented in the future.

6.2.2 Weak Target Enhancement

With regard to weak targets, it is appropriate to reinforce the points made in [1]. That is, correction of false targets allows straightforward improvements in weak target performance to be made. There are two reasons for the presently high thresholds used in the target declaration process (e.g. typically six or more correlated hits are required for target declaration). One of these concerns the generation of erroneous target declaration which FAA feared might result in areas of high fruit; this phenomenon appears to pose no threat, and will be discussed in Section 6.3. The other reason why high threshold levels are employed is that they are felt to help in discrimination of false targets, since false targets are generally short in runlength. Unfortunately, many legitimate targets are also. The elimination of false targets by other means will allow thresholds to be set back to two or three, thus improving the situation significantly.

6.2.3 Reply Code Processing

While the reply code processing capability of today's ARTS-III BDAS is sufficient for today's traffic levels, there is some concern that future growth in traffic might result in such high levels of synchronous garbling that the likelihood of obtaining correct code and altitude reports will drop to an unacceptably low level. Use of improved reply code processing is an attractive means of correcting this situation. Since only very low levels of synchronous garbling (and even lower levels of erroneous decoding) were noted in the data presented here, there is little factual basis at this stage for determining optimal degarbling procedures. Our data does show, however, that processes such as Automatic Leading-Edge Insertion are susceptible to excessive pulsewidth, due either to the external environment (e.g., Las Vegas) or improper alignment of receiving equipment (e.g., Albuquerque). Future implementation of advanced reply processing techniques which are sensitive to pulsewidth will require that pulse stretching be held to an absolute minimum, and will probably be quite difficult to implement at problem sites such as Las Vegas.

6.2.4 Azimuthal Accuracy

Section 4.2.7 suggested that improvements in this area could be obtained by removing the defruiter from the ARTS-III input line; this topic will be discussed further in Section 6.3. Limited examination of our data reveals that the most significant remaining source of azimuthal error is diffraction caused by objects projecting above the horizon. This mechanism appears quite deterministic, and while it would be theoretically possible to compensate for it in software, the value of such compensation is questionable relative to the expense and complexity involved; it has therefore not been pursued.

6.3 HARDWARE CHANGES

6.3.1 The Defruiter

The data in [1] supported the notion that removing the defruiter from the ARTS-III input line would most likely result in a net improvement in system performance. Data analyzed since then reinforces that notion. No degradation of ARTS-III performance was noted in any undefruited data examined; indeed azimuthal accuracy improvements were seen. In addition, it can be argued that the additional replies received would improve decoding performance. Of course, fruit levels in the data analyzed here were surprisingly low, and it is likely that sufficiently higher levels could adversely affect ARTS-III decoding performance. While no data of that sort was obtained, Laboratory tests [14] have concluded that improvements in weak target detection and azimuth accuracy performance occur with removal of the defruiter, and performance degradation due to overloading of the processor does not occur for fruit levels up to 20,000 fruit/second. Analyses such as those described in [1], Section III. F.4, suggest that with appropriate parameter settings (e.g., MY3 low to preclude overloading, HY3 = HY4 = 3), the rate of generation of false targets due to excessive fruit can be held to an acceptable level. Indeed, a small number of nearly synchronous interrogators would appear to pose a far greater problem than many asynchronous interrogators. This can be controlled operationally, and by increased use of pulse staggering. Our data is certainly consistent with this high predicted performance level; both suggest that steps should be taken to remove the defruiter from the BDAS input.

While this appears simple in principle, it is somewhat more complicated in practice, since defruiters are located at the radar site, and there is generally only one video transmission line from the site to the ARTS-III area. Thus, it is generally not possible to simultaneously furnish the ARTS-III with undefruited video and the controller displays with defruited video. This can be corrected either by moving the defruiters to the ARTS-III area, or by employing the ARTS-III BDAS as a source of display video; fairly straightforward modifications to the ARTS-III will allow this. Conversely, arguments can be made for retention of separate defruiters for feeding the displays in case of ARTS system failure.

In either case, provisions should be allowed for switchover (perhaps automatic) to defruited video input in the event of an ARTS-III BDAS overload.

6.3.2 New Antennas

The issue of antennas with improved vertical patterns was also addressed in [1]. It was noted there that the effects which such antennas were expected to cure (i.e., vertical lobing - related effects) were not noted in any of the data.

While the data discussed in this report was not examined methodically for vertical lobing (a good example of analytical work that would be quite tedious without some automated assistance), if it was present, it certainly did not cause any severe problems. Regular disappearance (or fading to a level where target detection fails) of certain targets would have been noted had it occurred.

The principal conclusion emerging from this study with regard to the use of new antennas with vertical aperture is that while such antennas are undoubtedly needed at <u>some</u> sites, they are clearly not needed at <u>all</u> sites; associated costs appear to preclude universal application. The methods of analysis discussed here and in [1] would seem ideal for determining which sites need improved antennas and which do not.

6.4 CONCLUDING REMARKS

The ease with which high-quality, high-information-content digital data can be extracted from FAA Secondary Radar sites employing automated processing is about to revolutionize the field of ATCRBS performance data analysis. Measurements of performance parameters that were once elusive and equivocal can now be made straightforwardly with a minimum of planning and coordination. Reflection sources can be pinpointed, parameters of interfering interrogators can be measured precisely, and qualitative performance factors can be quantified. Elusive pieces of information, which cannot easily be captured with counters or scope photography, appear automatically in the digital data, where they can be examined in detail.

While the trend toward increasing use of digital data for ATCRBS performance analysis should continue at a rapid pace, it should be noted that many processes for performing this analysis using high levels of automation are not using available data to full advantage; important pieces of data are being lost, just as they were with the old techniques. The full benefits of automation in ATCRBS data gathering will be reached only through a careful and comprehensive program of data analysis, in which a human analyst plays a key role; automation can furnish the analyst with much assistance to speed his task. The benefits which can be derived from a program of this sort are truly great, especially in light of its modest cost.

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