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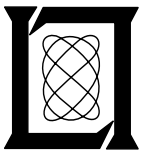
ATCRBS Uplink Environment Measurements Near Jacksonville, Florida

F. Nagy, Jr.

25 September 1981

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LEXINGTON, MASSACHUSETTS



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16. Abstract

Airborne measurements of the Air Traffic Control Radar Beacon System (ATCRBS) 1030 MHz uplink environment are described. Measurements were made using the AMF, a special purpose airborne sensor-recorder, during a 23 May 1979 flight in the greater Jacksonville, Florida area. The 2-way flight covered the 450 nm coastline between Fayetteville (NC) and Vero Beach (FL) first at 10,000 then at 25,000 feet.

Data recorded at 61 locations have been analyzed to plot combined pulse, interrogation and suppression rates for all locations and individual rates, received powers and angles for 37 locations. Fifty-nine ground interrogators were detected and a list included serves as an all-interrogator/all location (59 × 37) visibility matrix. PRI/PRF distributions of interrogations received are shown at three selected measurement locations. A pulse-by-pulse plot of over 50 Mode 4 interrogations shows their effect on a typical transponder.

A "worst" location is examined for peak instantaneous interrogation rates capable of causing transponder reply-rate limiting (RRL), desensitization and track loss. Durations and periods of recurrence of "synchronous jamming" for 23 near-equal scan periods are computed. Probabilities of multiple mainbeam coincidences ("multi-PRF jamming") are also calculated. Airborne (AMF) and ground based (FAA En-Route) coverages are compared, and reported operational problems (target splits, lost tracks, poor coverage) are addressed.

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ORGANIZATION OF REPORT

Section 1 serves as an introduction. It describes the purpose of the uplink measurements in the Jacksonville area; it outlines the functions of the AMF and of the uplink analysis program in the recording and processing of the measurements; it shows the two legs of the flight path, the places where measurements were made, and major interrogators of the area.

Section 2 gives combined results on the Jacksonville area uplink environment in which individual interrogators are not yet separated. Total pulse, suppression and interrogation counts are tabulated and plotted for all measurement locations. The number of interrogators seen is given at 38 of the 61 measurement locations.

Section 3 enumerates the basic parameters (PRI, PRF, mode interlace, scan period, stagger length) of the 59 interrogators observed during the flight. It also gives an all-location/all-interrogator visibility matrix, and a master list of local individual interrogator results. This includes interrogations per minute, angle-of-arrival, average and peak power, PRI/PRF distributions, and a (partial) list of reflections and Mode 4 interrogations. A pulse-by-pulse plot of over 50 Mode 4 interrogations is presented. These pulses are applied to a model of a nominal transponder to determine their effect on the civil beacon environment. Some observations of high instantaneous interrogation and suppression rates are considered next; these are investigated from the point of view of reply rate limiting (RRL) and percentage un-availability of a transponder.

Section 4 treats the "busiest" measurement location seen (loc. 2M+, 24nm east of Whitehouse ARSR, at 25,000 ft) where 31 interrogators were observed. First an average "effective" beamwidth (which includes all sidelobe interrogations) is calculated (to be used subsequently for the multiple-interrogation probability calculations of Appendix A). A set of figures showing (high) instantaneous interrogations around two consecutive mainbeams of five en-route interrogators of the Jacksonville Center is examined from the point of view of reply rate limiting and possible track loss. Finally, a plot of over 3000 mainbeam passages, extrapolated from the 31 scan periods measured at loc. 2M+, is presented. Duration, and repetition frequency of the Jedburg/Patrick and Patrick/Whitehouse mainbeam coincidences are calculated. Synchronous jamming at 2M+ is treated in Appendix B.

Section 5 compares AMF "coverage" (visibility) with ground interrogator coverage based on simultaneous FAA recordings at the Jacksonville Center. It shows the two (ground based and airborne) coverages to be in almost 100 percent agreement. It also shows that missing target reports correlate uniquely with marginal uplink (and downlink) propagation.

Section 6 contains a detailed summary of results, including those given in the Appendices.

Section 7 draws some conclusions from the results of the flight. It compares the results with earlier uplink measurements and addresses some of the operational problems (target splits, lost tracks, poor coverage, etc.) noted at Jacksonville Center.

Using the Binomial Distribution as a model, and the average "effective" beamwidth of Sec. 4 as a parameter, Appendix A calculates the likelihood of multiple interrogations at loc. 2M+ (note that the underlying phenomenon is also called "multi-PRF jamming" and "multiple mainbeam coincidence" throughout this report). The effect of possibly un-detected military interrogators without SLS is emphasized.

Appendix B treats synchronous jamming at location 2M+. A figure showing incremental scan periods for 23 interrogators divided between the three most popular scan periods (3.92, 4.70 and 12.01 sec) is presented first. Synchronous jamming is defined, and its minimum and maximum durations and periods of recurrence (based on maximum and minimum scan differences in each of the three groups) are calculated. Two expressions are given for higher order jamming probabilities, with an explanation of their relationship. Some 16 "general" and "special" probability curves (or portions thereof) are presented next. These curves allow the reader to estimate higher order mainbeam coincidence probabilities as a function of the number of interrogators present.

Appendix C provides definitions of the terms interrogations, suppressions, and stray pulses used in the report.

Note: The information contained in this report was derived from airborne measurements made in the Jacksonville, FL, area and therefore much of it is peculiar to that area. However, many of the results are valid for a more general uplink environment. Typical of the latter type of information are:

- The effect of Mode 4 interrogations on typical airborne transponders (Figures 9a-9d).
- The likelihood of multiple mainbeam coincidences as presented in Appendix B (especially in Figure B-2).
- The duration and time of recurrence of mainbeam overlaps on near-equal scan periods (shown in Figure B-1).
- The relationship between deadtime, PRI difference and number of consecutive missing replies (presented in Sec. 7.2.5).

1.0 INTRODUCTION

1.1 Purpose of Measurements

In-flight measurements* of the Air Traffic Control Radar Beacon System (ATCRBS) uplink environment on 1030 MHz were made for the FAA Airways Facilities Service on 23 May 1979 using the MIT Lincoln Laboratory Airborne Measurements Facility (AMF).** These measurements were made for the purpose of:

- Characterizing the pulse, interrogation and suppression environment in the the larger Jacksonville, Fla. area.
- Identifying and characterizing the ground interrogators contributing to the measured airborne environment in the larger Jacksonville area.
- Finding possible causes of target splits, lost tracks and coverage anomalies, especially at the boundaries of the Jacksonville Air Route Traffic Control Center (ARTCC).
- Measuring interrogation "bunching", the degree of reply rate limiting (RRL) and transponder desensitization.
- Measuring suppression bunching and the corresponding transponder unavailability.
- Comparing AMF "coverage" (visibility) with coverage from simultaneous FAA recordings at the Jacksonville Center.
- Showing reflections.
- Showing details of mode 4 interrogations, and their effect on an "average" airborne transponder.
- Describing the worst cases encountered of "synchronous" and "random jamming" (multiple mainbeam and/or sidelobe coincidences with multi-PRF interrogations).
- Permitting the calculation of the probability of occurrence for various degrees of multi-PRF jamming.

*Similar measurements for other areas are reported in (1) "Uplink Coverage Measurements in the Los Angeles Area for Passive BCAS", F. Nagy, Jr., Project Report ATC-81, Lincoln Laboratory, M.I.T. (7 November 1977), FAA-RD-77-134, and (2) "Uplink ATCRBS Environment Measurements Along the Boston-Washington Corridor", F. Nagy, Jr., Project Report ATC-83, Volumes 1 and 2, Lincoln Laboratory, M.I.T. (27 June 1978 and 28 February 1979), FAA-RD-78-33.

**See "The Airborne Measurements Facility (AMF) System Description", G. V. Colby, Project Report ATC-60, Lincoln Laboratory, M.I.T. (25 March 1976), FAA-RD-75-233.

These measurements have provided data which will contribute to the understanding and resolution of existing ATCRBS interference and ATCRBS interrogator site coverage problems. They also serve to define the radiation environment in which beacon-related systems such as BCAS and DABS must operate in the future.

1.2 Recording and Processing of Measurement Data

The beacon uplink environment consists of interrogation pulses (P1 and P3) and sidelobe or suppression pulses (P2) originating from FAA and military interrogators. In addition, pulse energy is transmitted from TACAN equipment operating in or near the 1030 MHz band. The AMF records the level, time of arrival and duration of each of those pulses whose amplitide exceeds a preselected threshold (generally -75 dBm at the bottom-mounted antenna of the AMF) for at least 375 nsec, provided its leading edge rises at least 6 dB in an interval of 125 nsec. An estimate of the relative bearing of the source of each pulse is also recorded. The pulse amplitude information is digitized with 1 dB resolution and recorded, together with aircraft position and time-of-day, for later analysis.

An AMF uplink analysis program, resident in a ground-based computer, then a) associates the valid pulses of ATCRBS interrogation modes and suppression pairs; b) provides amplitude distributions and total event counts for each mode; c) arranges the interrogations in a time-ordered interrogation file; d) calculates all interrogation repetition intervals (PRI's) present in the interrogation data; and e) segregates and associates all interrogations from a given interrogator, thereby permitting identification of interrogator dwell time, beamwidth and scan period. The mode interlace pattern of the interrogator is also determined, and deviations of the actual time of occurrence of the interrogations from the expected time are calculated.

The aircraft in which the AMF was installed was a twin-engine Cessna 421. The Cessna's own transponder and DME were used during the flight, along with the AMF's DME equipment. To prevent their transmissions on 1090 MHz from leaking into the uplink recordings on 1030 MHz, a digital blanking circuit was installed at the AMF input.

The interrogation and suppression rate data presented in this report have been obtained from the output of the uplink analysis program. This program does not simulate either the 35 μs (ave) suppression experienced by a real transponder, or the 60 μs (ave) deadtime following a Mode A or C reply. Thus the AMF measures slightly higher interrogation and suppression rates than an ATCRBS transponder on board would see. The discrepancy is less than 5 percent even at location (1V) where the highest suppression rate was observed.

1.3 Jacksonville Flight Path (Figure 1)

Figure 1 shows the complete flightpath, all measurement locations along it, and all interrogators in the area (from the 26 January 1979 ECAC interrogator file). FAA interrogators are shown by solid circles, military interrogators by broken circles. Double circles (for either category) indicate en-route interrogators.

Wilmington (NC) and Vero Beach (Fla) were the end-points of the flight. The AMF flew south along the coast at 10,000 ft, and then returned to Wilmington flying north over the ocean at 25,000 ft. The southerly leg included part of a 50-nm circle around the Jacksonville VORTAC (JAX), while the northerly leg included a two-way 95 degree radial flight from location H (2H, see below) to JAX and back.

Automatic (1 minute out of 10) recording locations are noted by consecutive letters of the alphabet (A, B, C, etc.). Manual recording locations approximately half-way in-between are noted by a "+" sign (e.g. A+, B+, etc.). Measurement locations along the southerly leg of the flight are preceded by the number "1" (e.g. 1A, 1B, etc.), while measurement locations on the northerly leg of the flight are preceded by the number "2" (e.g. 2A, 2B, etc.).

Latitudes and longitudes are shown in equal increments in Fig. 1. North-south distances are true: each degree corresponds to exactly 60 nmi. East-west distances are exaggerated: 10, 13, and 17 percent, respectively, at the latitudes of Miami, Jacksonville and Wilmington, respectively.

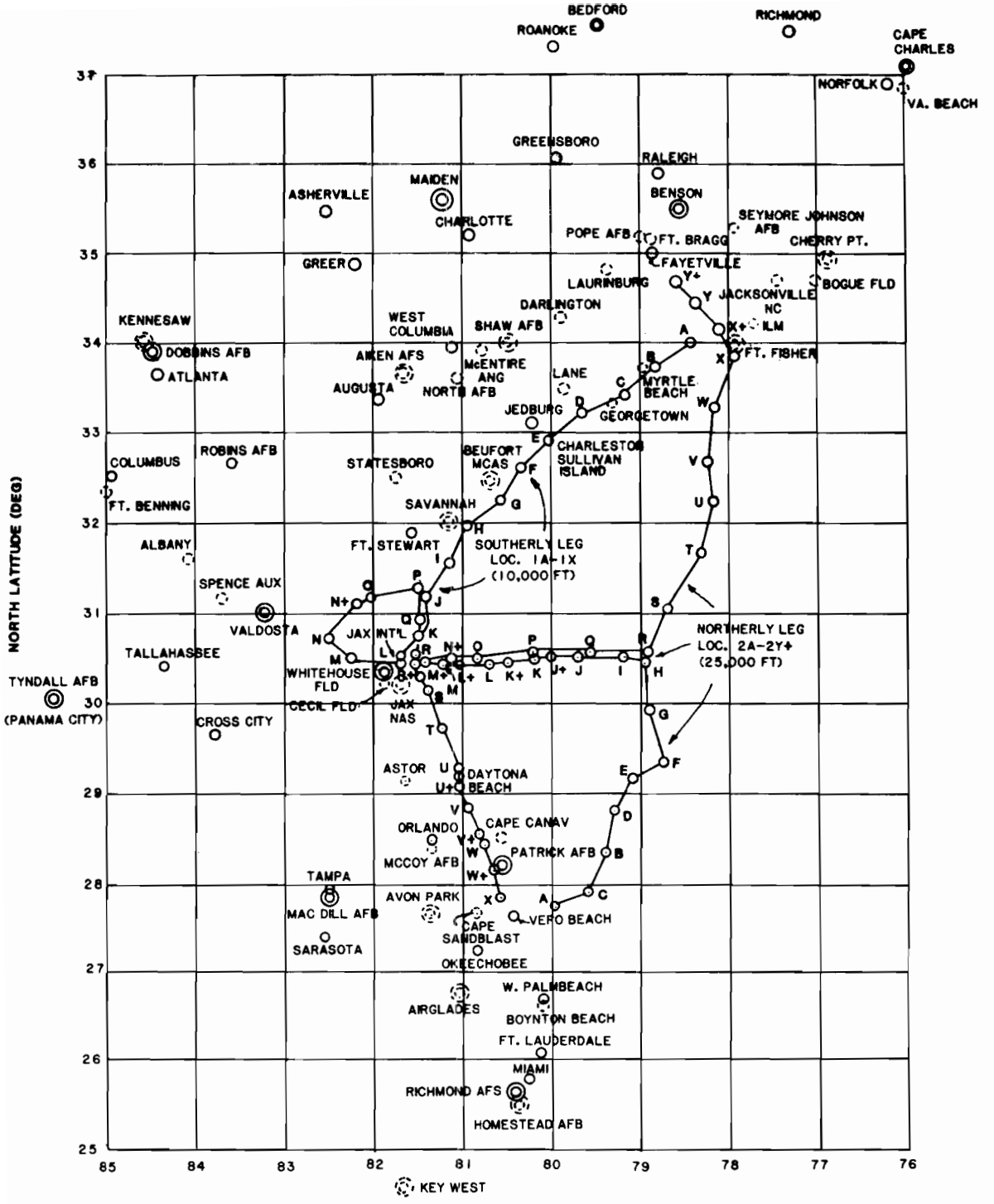
1.3.1 Geographical Symmetry of the Flight

As can be seen from the map the higher altitude (25,000 ft) return flight of the AMF deviated from the lower altitude (10,000 ft) inland flight, by an offset that varied from about 50 to 150 nmi. Exceptions to this occured only during the 50-nmi DME circle around JAX (Jacksonville VORTAC) (locations 1L to 1Q), and during the 150 nmi two-way radial against JAX (locations 2I to 2R).

Some interrogators observed by the AMF at the beginning, middle and end of its southerly flight were observed again at corresponding portions of its return flight, resulting in some degree of mirror symmetry in visibility about the landing at Vero Beach (locations 1X and 2A).

1.3.2 Distance to Horizon (Nominal)

Nominal visibility for the first leg of the flight (at 10,000 ft) was 125 nmi. This increased to 190 nmi for the second leg (at 25,000 ft). This plus transmitted power are the major factors determining the "run lengths" (extents of visibility) for the terminal and enroute interrogators seen during the flight.



DATA RECORDING LOCATIONS FOR 23 MAY 1979
JACKSONVILLE AREA FLIGHT OF THE AMF

FIGURE 1

2.0 OVERALL PULSE ENVIRONMENT FOR ALL INTERROGATORS

Tables 1 and 2 with Figs 2-5 present the overall pulse environment as observed at each measurement location along the flight path. The tables list the lat-long coordinates, start time and duration, total interrogation/suppression counts, and pulse rates (averaged over the observation interval) for each measurement location. They also list the number of interrogators seen for 38 selected locations.

2.1 Total Pulse Rate

Total pulse rates run just under 3000 PPS for the southerly leg of the flight (Fig. 2), with only one large peak of 9000 PPS at loc. 1R+*, about 2 nmi south-east of Craig Municipal Airport in Jacksonville, Fla. A smaller peak of 4000 PPS occurs near Cape Canaveral (loc. 1V).

Pulse rates over the ocean are much lower and are much less uniform (Fig. 4). Only at the nearest points of the JAX radial flight is the rate of 5000 PPS exceeded. A smaller peak of 2000 PPS is observed near Wilmington.

Unassociated (stray) pulses typically make up one-to two-thirds of the total on both legs of the flight. These are probably made up of P2 pulses from military interrogators without improved SLS (ISLS), TACAN pulses, and multipath reflections of all actual pulses.

2.2 Suppression Rates

Suppression rates are typically the least uniform of any of the rates measured by the AMF. The reason for this is that the P2 pulses are transmitted not on the directional antennas of the interrogators, but rather on their omni antennas, with their attendant lower gains and shorter operating ranges.

*At location 1R+ the AMF came within 5 nmi of a powerful television transmitter (WJKS-TV, Ch. 17, 100 KW, visual frequency 500.00 MHz), and probably recorded some of its double-frequency transients. An AMF pulse data dump shows that about half of the data recorded in that area consists of pulses separated, alternately, by 272.25 and 288.25 μs (ave. PRI = 280.25 μs, ave. PRF = 3568.45). Half of these are single pulses, the other half pulse pairs 1 μs apart (widths: 0.5 and 0.375 μs, respectively).

TABLE 1

23 May, 1979 Jacksonville Flight of the AMF
Southerly (Overland) Portion at 10,000 Ft.
(Locations 1A, 1B, Etc).

LATITUDE	LONGITUDE	LOCATION CODE	OBSERVATION TIME START HR	MIN	SC	DURATION (SEC)	TOTAL PULSES	PER SECOND RATES SUPPRESSIONS 2-PLS	3-PLS	INTERROGATIONS MDA	MDC	MD1	MD2	STRAY PULSES	NO. OF INTERROGATORS SEEN
34 00	78 26	1A	7	59	01	58	2287	300	11	149	79	2	61	1042	15
33 43	78 50	1B	8	09	01	58	2672	166	219	156	79	8	60	1032	12
33 25	79 11	1C	8	19	01	58	2140	35	31	140	71	4	62	1387	13
33 13	79 39	1D	8	29	01	58	2655	537	53	79	42	7	31	1075	14
32 55	80 01	1E	8	39	01	58	3062	344	375	62	30	29	22	896	13
32 36	80 20	1F	8	49	01	58	2589	510	70	47	31	36	25	1036	16
32 15	80 34	1G	8	59	01	58	2932	609	34	73	57	65	51	1073	14
31 58	80 58	1H	9	09	01	58	2236	445	14	55	36	68	29	887	19
31 33	81 09	1I	9	19	01	58	1693	190	16	36	25	25	24	1019	18
31 10	81 24	1J	9	29	01	58	2101	163	121	33	22	14	19	1183	15
30 46	81 30	1K	9	39	01	58	2720	347	163	36	24	13	18	1310	14
30 27	81 42	1L	9	49	24	36	3770	317	590	45	28	14	22	1088	10
30 29	82 14	1M	9	59	01	58	2405	209	156	34	24	11	15	1313	10
30 43	82 29	1N	10	09	01	58	3188	322	48	31	19	18	17	2184	10
31 06	82 11	1N+	10	17	02	58	2922	188	107	36	24	20	20	1952	
31 11	82 02	1O	10	19	23	98	2698	226	105	37	25	25	19	1639	14
31 17	81 30	1P	10	29	01	58	1718	24	37	38	26	17	20	1316	15
30 56	81 30	1Q	10	39	01	58	2325	261	94	38	25	21	20	1253	14
30 31	81 32	1R	10	49	01	58	3783	327	260	32	0	17	19	2124	8
30 26	81 33	1R	10	50	30	90	4516	317	381	40	24	17	19	2487	
30 19	81 29	1R+	10	54	10	48	9082	391	352	59	41	33	35	6829	
30 08	81 23	1S	10	59	01	58	3727	260	319	48	29	28	25	1922	12
29 43	81 14	1T	11	09	01	58	2509	124	133	48	31	22	21	1559	13
29 17	81 03	1U	11	19	01	58	3006	626	92	55	30	26	24	1154	18
29 05	81 03	1U+	11	23	20	59	3164	624	172	51	30	26	22	1089	
28 50	80 57	1V	11	29	01	58	4101	1195	107	42	25	31	24	1083	15
28 33	80 49	1V+	11	35	50	43	4116	932	118	47	30	25	30	1546	
28 26	80 45	1W	11	39	01	58	3573	882	212	40	24	28	23	868	17
28 09	80 39	1W+	11	45	11	51	3105	558	412	31	15	20	14	527	
27 56	80 35	1X	11	49	01	58	1948	516	85	15	7	15	10	538	4*

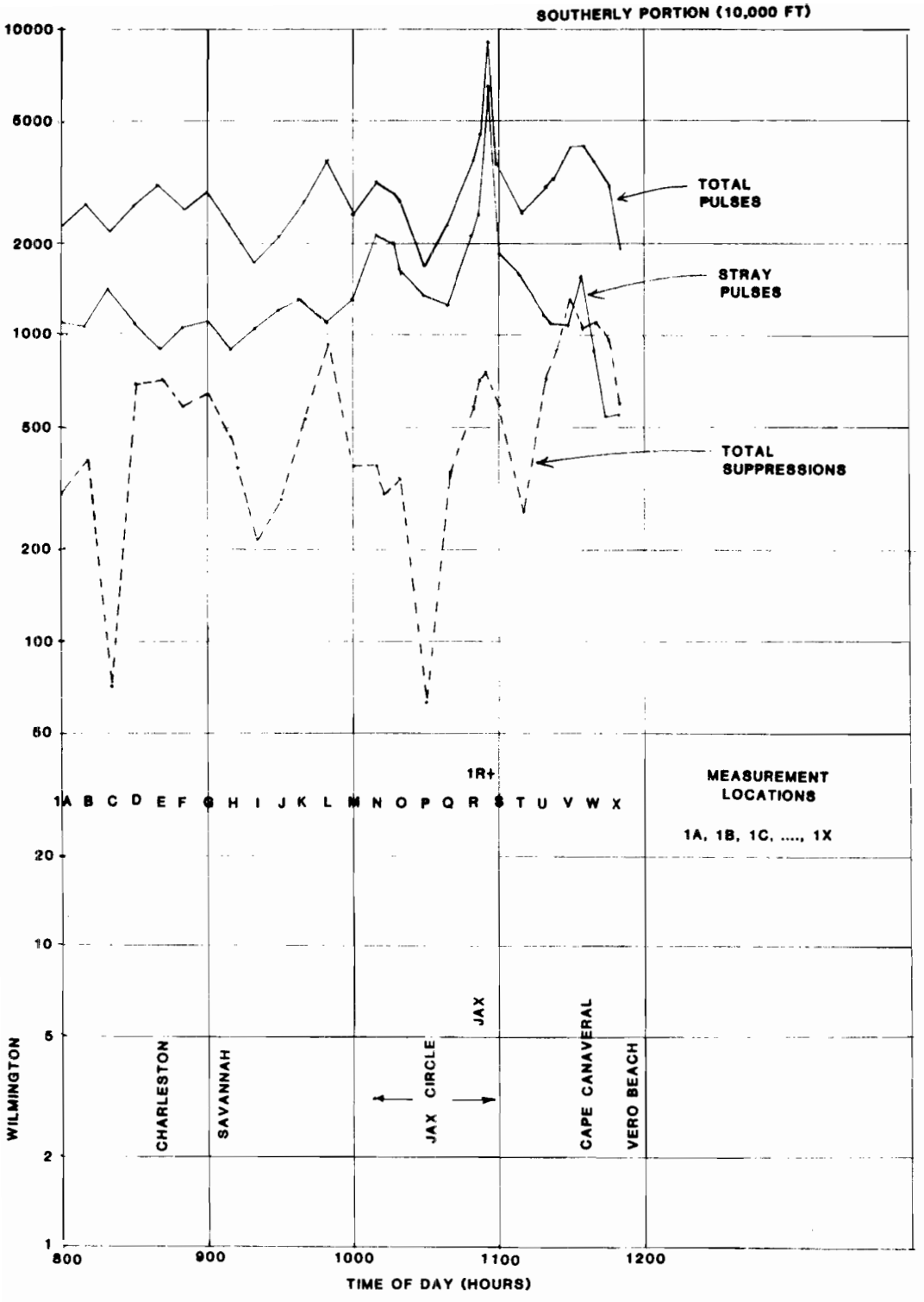
*AMF aircraft at low altitude

TABLE 2

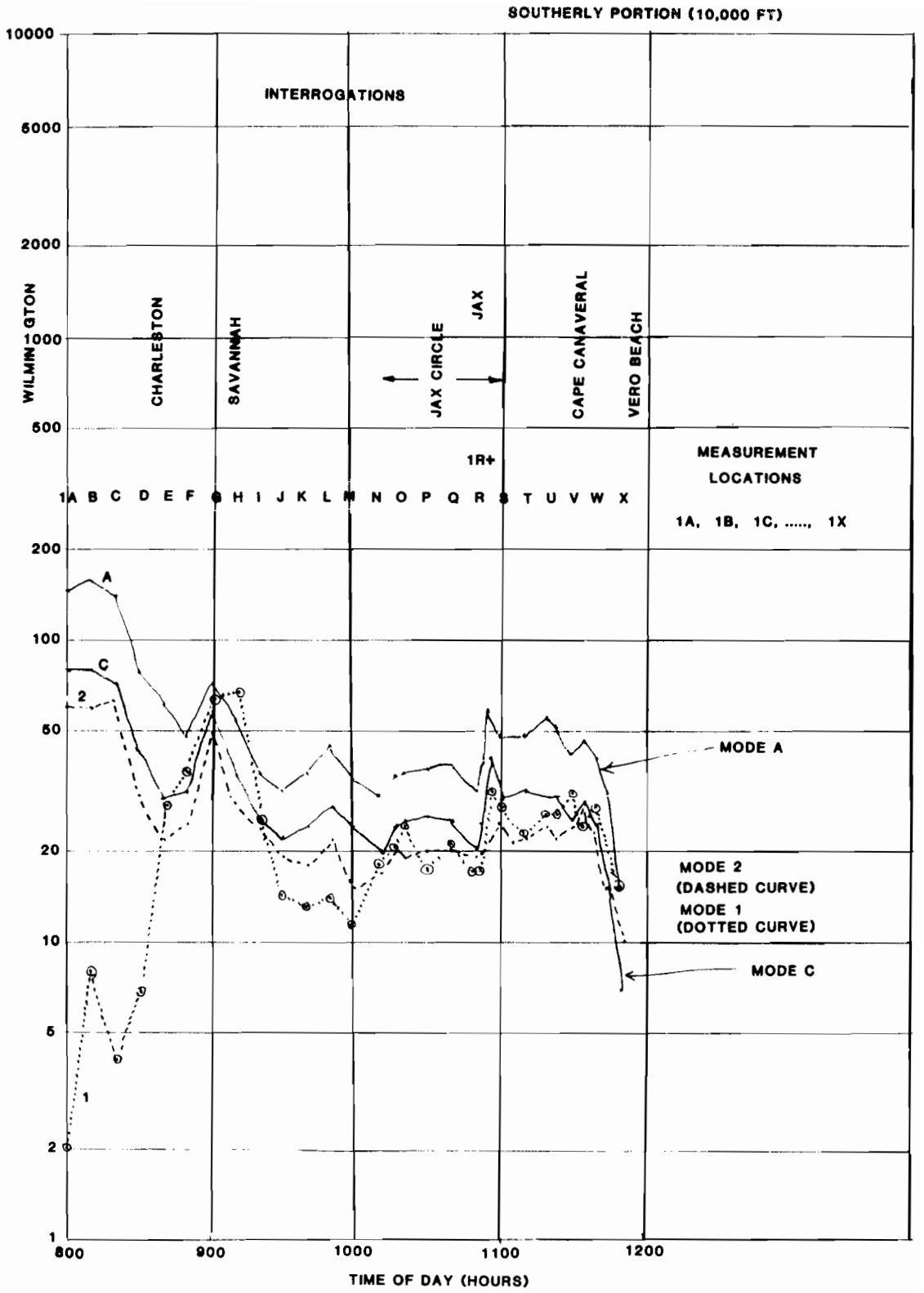
23 May 1979 Jacksonville Flight of the AMF
Northerly Portion at 25,000 Ft. (Over the Ocean)
(Location 2A, 2B, Etc.)

LATITUDE	LONGITUDE	LOCATION CODE	OBSERVATION TIME START HR	MIN	SC	DURATION (SEC)	PER SECOND RATES TOTAL PULSES	SUPPRESSIONS 2-PLS	3-PLS	INTERROGATIONS MD A	MD C	MD 1	MD 2	STRAY PLSES	NO. OF INTERROGATORS SEEN
27 44	79 58	2A	13	19	01	58	894	321	36	11	8	5	3	76	5*
27 55	79 36	2B	13	29	01	58	783	286	10	15	9	1	2	108	
28 21	79 24	2C	13	39	01	58	655	182	2	16	9	2	4	196	9
28 48	79 18	2D	13	49	01	58	1050	177	6	23	14	3	8	554	
29 10	79 05	2E	13	59	01	58	1352	101	10	27	18	5	11	955	12
29 20	78 45	2F	14	09	01	58	273	9	1	24	16	7	10	130	
29 55	78 54	2G	14	19	01	58	525	55	0	21	15	6	11	286	9
30 27	78 57	2H	14	29	01	58	899	61	9	27	17	7	11	594	
30 31	79 12	2I	14	39	01	58	1007	30	40	31	22	12	14	637	15
30 35	79 42	2J	14	49	01	41	1823	71	169	34	22	9	14	974	
30 31	80 00	2J+	14	54	50	70	3356	92	246	53	37	19	29	2084	
30 30	80 12	2K	14	59	01	58	2610	138	316	40	26	7	17	1158	17
30 27	80 30	2K+	15	5	0	60	3836	165	274	56	35	17	23	2367	
30 27	80 42	2L	15	09	01	58	2643	228	194	49	31	13	20	1321	
30 27	81 03	2L+	15	15	42	50	5305	345	143	66	45	24	27	801	
30 28	81 13	2M	15	19	01	58	3627	467	174	73	41	21	20	1782	27
30 27	81 26	2M+	15	24	0	60	4289	624	227	68	47	20	103	1811	31
30 29	81 08	2N+	15	34	47	67	4087	359	156	69	45	21	23	2512	
30 29	80 50	2O	15	39	02	57	2730	235	155	57	37	17	21	1470	26
30 33	80 13	2P	15	49	03	57	2833	236	301	54	38	14	28	1108	
30 34	79 35	2Q	15	59	03	56	1370	17	58	39	23	16	19	927	18
30 34	78 56	2R	16	09	08	52	917	6	15	35	22	14	17	663	
31 02	78 42	2S	16	19	7	53	1012	4	15	42	27	23	26	690	15
31 39	78 19	2T	16	29	06	54	914	4	13	34	24	15	23	652	
32 13	78 11	2U	16	39	05	55	465	3	5	48	17	11	14	248	20
32 40	78 14	2V	16	49	01	58	1036	5	9	66	22	19	17	731	
33 17	78 10	2W	16	59	04	56	1586	44	22	71	26	16	16	1143	20
33 50	77 57	2X	17	09	01	58	1909	363	137	71	26	7	10	518	
34 09	78 07	2X+	17	14	02	59	2100	393	159	48	24	11	10	621	
34 26	78 23	2Y	17	19	01	58	2070	361	42	38	20	2	3	1061	13
34 41	78 36	2Y+	17	24	20	49	1246	91	15	32	17	2	1	882	

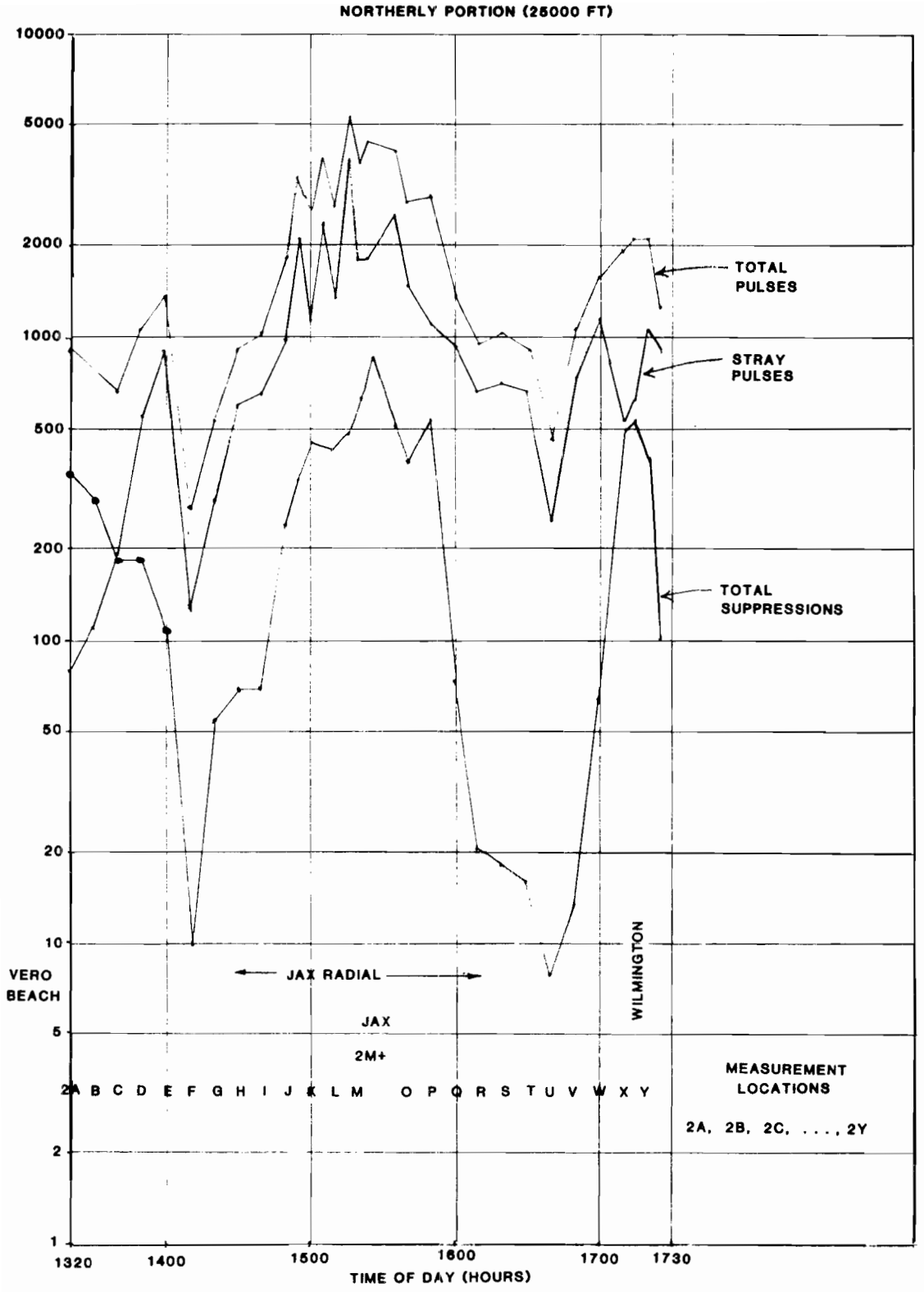
*AMF aircraft at low altitude



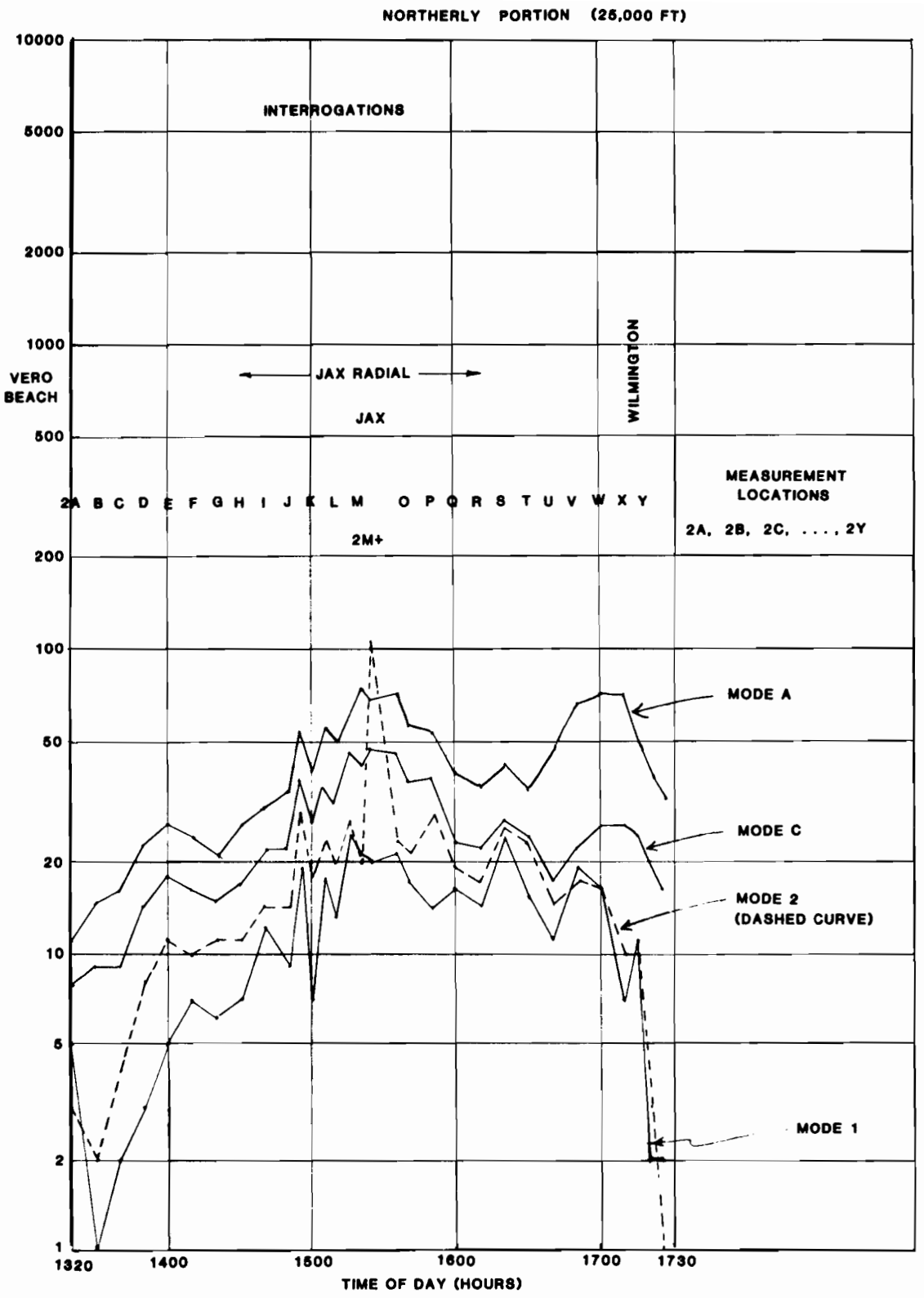
Combined Pulse And Suppression Rates Overland
Figure 2



Combined Interrogation Rates Overland
Figure 3



Combined Pulse And Suppression Rates over the Ocean
Figure 4



Combined Interrogation Rates over the Ocean
Figure 5

Fig. 2 shows a number of small suppression peaks during the southerly leg of the flight. The first one, around 600 suppressions per second (SPS), is in the Charleston-Savannah region. The second peak 900 SPS is at location 1L, near Jacksonville International. The third peak of about 800 SPS is noted again just to the south of JAX on the second approach to that point (after completing the 50 nmi circle). The largest suppression peak of 1300 SPS is observed near Cape Canaveral. The suppression rate remains high as Patrick AFB is passed.

The northerly leg of the flight (Fig. 4) produced only a single suppression peak of about 900 SPS at location 2M+, the nearest point of the 95 degree radial to JAX. The figure displays a number of suppression rate nulls or troughs (10 or less suppression per second at several locations).

To estimate the number of interrogators contributing to the observed rates of suppression, note that a single interrogator using ISLS contributes about 300 SPS to aircraft in its vicinity. There is, of course, always the possibility that only a portion of the suppression pulses from any one interrogator on ISLS are seen, or that a portion of the suppressions come from interrogators using regular SLS.

2.3 Interrogation Rates

Figures 3 and 5 giving the interrogation rates for the two legs of the flight, show two general trends associated with interrogation rates: (1) they tend to remain more uniform than suppression rates do, and (2) Mode A is observed about twice as often as Mode C, and about four times as often as Mode 2. The first trend results from the fact that the P1-P3 pulses are transmitted on the directional antennas, with their higher peak power and longer-range visibility. The second trend results from the preferred FAA interlace modes of AAC for terminal interrogators, and 2ACA for en-route interrogators.

Figure 3 shows that the southerly portion of the flight produced about 40 Mode A interrogations per second (IPS) , with Mode C and Mode 2 -Mode 1 rates correspondingly lower. What appears to be the main exception to the uniformity at the beginning of the flight (between Wilmington and Charleston), is the result of a single military interrogator (the long-range Air Force interrogator at Ft. Fisher, NC), close to the AMF, on 241 PRF, Modes 2ACA, without P2 pulses. 100 percent of its sidelobe interrogations are received at first (120 Mode A's and 60 Mode 2's and Mode C's per second).

Figure 5 shows that the northerly flight at 25,000 ft. produced interrogation rates which increase fairly uniformly to a peak of 60-70 Mode A's at the part of the two-way 95 degree radial nearest to JAX. The one exception is the high burst of Mode 2's at location 2M+, 6-8 nmi cast of JAX. This was due to an interrogator at Mayport, 5 nmi south of the AMF, on 657 PRF. The high Mode A peak near the end of the flight (before Wilmington, locations 2V to 2X) is the result of a single interrogator to the north of the AMF, interrogating on a PRF of 1100 (Mode A, 3.94-sec. scan) contributing 20 Mode A interrogations per second.

2.4 Number of Interrogators Seen

Going south, the number of interrogators observed varied from a low of 8 near Jacksonville International (loc. 1R) to highs of 18 near Daytona Beach (Fla) (loc. 1U) and 19 near Savannah (Ga) (loc. 1H). Going north at 25,000 ft. (and disregarding the endpoints) the lowest number (9) of interrogators was seen at loc. 2G, 200 nmi east of the Coast, and the highest number (31) at loc. 2M+, at the Coast. The averages were 13.5 and 17 for the two legs of the flight.

2.5 Summary of Total Counts

		Observed Average Per Second Rates	
		Southerly Leg	Northerly Leg
Total Pulses	Max. Rate	9082	5305
	Min. Rate	1693	273
Sum of Mode A and C Ingerrogations	Max. Rate	235	115
	Ave. Rate	87	68
	Min. Rate	22	19
Total Suppressions	Max. Rate	1302	851
	Min. Rate	61	8
Number of Interrogators Observed	Maximum	19	31
	Average	13.5	17
	Minimum	8	9

The highest observed civilian (Mode A plus Mode C) interrogation rate (235 IPS) would cause an average transponder to be unavailable for 235 x 60 μs = 0.0141 sec (or 1.41 percent of the time). Similarly, the highest observed suppression rate (1302 SPS), would cause an average transponder to be unavailable for 1302 x 35 μs = 0.0456 sec (or 4.56 percent of the time).

Thus the average interrogation and suppression rates observed are not high enough to cause a problem unless they peak much higher than their measured average values in any measurement interval or unless they are synchronous with the PRI of one of the FAA interrogators of the Jacksonville area. High instantaneous rates are discussed further in Sections 3.9 and 3.10, as well as in Sections 6.8 and 6.9. Synchronous interference is discussed in Section 7.2.5.

3.0 INTERROGATORS OBSERVED DURING THE JACKSONVILLE FLIGHT

3.1 Section Outline

Data on the 59 interrogators observed during the 23 May 1979 flight of the AMF are presented in this section. Specifically included are:

- A list of the interrogators and their major parameters (Fig. 6). This list serves as an all-location/ all-interrogator visibility matrix (37 measurement locations x 59 interrogators).
- A list of the interrogators arranged by PRI (and PRF) (Table 3).
- A list of the actual PRI for interrogators on staggered but not random PRI (Fig. 7).
- A master list of local individual results (Interrogations/min. AOA, Ave and Pk Power) in the form of two inverted visibility matrices where the columns are the interrogators, and the rows are, in the first case, 24 measurement locations 1A, 1B, ..., 1X along the southerly flight of the AMF (Table 4A), and, in the second case, 13 odd measurement locations 2A, 2C, 2G,....2Y along the return flight (Table 4B).
- Three PRI/PRF distributions of the interrogations received in 1 minute at locations 1H, 1U, and 2M+ (Fig. 8 and Table 5).
- A list of the reflections observed during the flight (Table 6).
- A list of Mode 4 interrogations observed during the flight (Table 7).
- Four plots showing pulse-by-pulse plots of over 50 Mode 4 interrogations received from Ft. Fisher, Jacksonville NAS (Interrogator 24) and Patrick ARSR (at locations 1B, 1K, 1S and 1X), with the sequence of effects (interrogations or suppressions) on an average transponder (Figures 9a to 9d).
- Five plots showing the high instantaneous interrogations rates at locations 1G, 1H and 2N+ where reply rate limiting (RRL) and/or track loss may occur (Figures 10a to 10e).
- Three plots showing high instantaneous suppression rates (at locations 1L, 1V, and 1W), which may interfere with transponder availability (Figures 11a to 11c).

3.2. The All-Location/All-Interrogator Visibility Matrix (Fig. 6)

The 2-part Figure 6, headed by the 24 location codes 1A through 1X of the southerly leg of the flight, and by the 13 location codes 2A through 2Y of the northerly leg, is an overall visibility matrix for the 59 interrogators*. A "dot" (.) at any point in the matrix indicates that the interrogator to the right is not visible at the location involved. The visibility numbers represent the approximate local interrogation rate of each interrogator as a power of 2. The exact correspondence between the powers, expressed as hexideximal numbers, and the ranges of the interrogations per minute are shown on the figure (small box along lower edge of part 1). Additional information on interrogator PRI is given in Table 3 and Figure 7.

The visibility matrix may be used to answer the following questions (note that each row of the visibility matrix is an interrogator, each column, a measurement location):

- How many interrogators are present at a given location, and which ones are they? (Examine the corresponding columns).
- Is a given interrogator present at a given location? (Examine a single intersection).
- What is the run length (length of visibility) of a particular interrogator for the complete flight? (No. of entries -- contiguous or otherwise -- in the corresponding row).
- How heavily does a particular interrogator contribute to the interrogation environment? (Examine the actual values of the powers in the corresponding column).
- What interrogators are not using SLS? (Presence of large entries in a particular row).
- Is there a close approach to a non-SLS interrogator? (Presence of a sharp peak in the corresponding row).
- What measurement location is nearest to an interrogator with limited visibility (dots on both ends)? (Middle entry of the row, discounting entries 1L to 1Q (the JAX circle) and entries 2I to 2Q (the JAX radial), if indicated).

*The interrogators were numbered in order of their discovery. The 15 interrogators seen at location 1A, for example, were numbered 1 through 15, and so on (there are a few exceptions to this). Numbers are assigned from 1 to 62, three more than the number of interrogators seen. The reason is that 3 of the 62 (numbers 34, 50, and 53) were found not to be separate interrogators as was first supposed.

1-MINUTE AMF MEASUREMENT LOCATIONS		DESCRIPTION OF INTERROGATORS OBSERVED						
SOUTHERLY (INLAND) LEG	OCEAN LEG							
ABCDEFGHIJKLMNOPQRSTUVWX	ACEGIKMOQSUWY	NO	SUSP. NAME OR LOC	PRI (US)	PRF	MODES	SCAN	ST
8.....	78	1	Airborne Near 2Y	3335	299.8	2*AC	3.86	1
7.....	7	2	Pope AFB	3654	273.6	AAC	3.85	1
85.....	88	3	Bogue MCALF	2676	373.6	AC	3.91	1
8887.....	688	4	Benson ARSR	2700 ±7	370.3	AC	10.12	5
687.....	.....	5	Myrtle Beach AFB	4000-	250.0	1AC	9.31	1
87.....	58	6	Near 2Y	3991 ave	250.6	AC	4.68	3
8868.....	789	7	Jacksonville N.C.	2530	395.2	A	4.04	1
8888.....	578	8	Fayetteville ASR	2625	380.9	AAC	3.92	1
99887.....	.....	9	Myrtle Beach AFB	3331	300.2	AC	4.67	1
67778777.....	.....5.6	10	Shaw AFB	3328(9)	300.4	AC	3.92	1
7.888888.....	.....8.	11	Columbia ASR-7	2245 ave	445.4	AAC	4.68	8
6888A8885.....	....57866778.	12	Charleston ASR	2566	389.6	A	4.70	1
778888887.....7.....	787677787	13	Jedburg ARSR	2901 ±7	344.7	AC	12.02	5
8899B988887....76.....	..67888888898	14	No. Charleston	3040	328.9	2ACA/4	11.75	1
EEDC77.67.....4...	....76..6.888	15	Ft. Fisher	4146	241.2	2ACA/4	11.98	1
..77.....	.....	16	Near Charleston	2458 ±1	406.8	2	3.92	1
..67777674.....5.....	.....65..66.	17	Aiken AFS ARSR	4135	241.8	AC	12.04	1
...9ABDBA99...7A7.....	.....	18	Beaufort MCAS	3251(2)	307.5	12AC	9.82	1
...89999988....96.....	....98898767.	19	Beaufort MCAS	4588 ave	218.0	2*12AC	9.59	12
....89.9999A9AAAA..AA98.	.....AA...	20	Shipborne Near 2K	3133±150	319 ±	4*12AC	3.82	Rm
....88885.....	.....	21	Augusta ASR	2531	395.0	AAC	3.92	1
....89.AA997A.999989A87.	989A99995A99.	22	Shipborne Near 2K	3415 ave	292.8	4*12AC	7.85	9
.....9AB8.....7.....	.....6.6...	23	Statesboro	2440-1	409.7	1	8.83	1
.....579889A98989999987.	.7988988887..	24	Jacksonville NAS	2819	354.7	2ACA/4	12.02	1
.....8877888.7788.....	.....778.5..	25	Savannah ASR	3095 ±7	323.1	A	4.70	5
.....7.....8...9...8.	.....	26	Shipborne Near 2K	4048-9	247.0	4*12AC	7.90	1
.....5.....	.....	27	AWACS	5005-74	200-	2AC		Rm
.....6768887888787....	.....587.....	28	Valdosta ARSR	2700-	370.3	AC	11.98	1
.....68888877888777875.	..77778777...	29	Whitehouse ARSR	2741±7	364.8	AAC	12.02	5
.....788888888878877..	..77878877...	30	Jacksonv.Intern. ASR	2969 ±7	336.8	AAC	4.70	5
ABCDEFGHIJKLMNOPQRSTUVWX	ACEGIKMOQSUWY							

INT/MIN RANGES FOR POWER P	I/MIN P
	24576 E
	12288 D
	6144 C
	3072 B
	1536 A
	768 9
	384 8
	192 7
	96 6
	48 5
	24 4
	12

BASIC INTERROGATOR LIST AND VISIBILITY MATRIX

Figure 6 (1st half)

ABCDEFGHIJKLMNOPQRSTUVWX	ACEGIKMOQSUWY	NO	SUSP. NAME OR LOC	PRI (US)	PRF	MODES	SCAN	ST
.......7888988888888885.	..76888987...	31	Jacksonville NAS	3461	288.9	2AC	3.92	1
........767...787.......	....78888678.	32	Beaufort MCAS	2594	385.4	2/AC	3.93	1
.........7888787788787..	......888....	33	Cecil NAS	2663-4	375.4	AAC	3.92	1
.....	.....	34	(Not Used)					
..........686...4788888.	.78.678777...	35	Daytona Beach ASR	2559.7	390.7	AAC	3.92	1
............77..........	......77.....	36	Tallahassee ASR	2498.5	400.2	AAC	3.92	1
..............47.........	......8......	37	Macon ASR (Robins)	2500.8	399.9	AAC	4.68	1
..................88987.	......87.....	38	Astor Park	2275 ±7	439.5	AC	2.80	Rm
..................778888	88887787776..	39	Patrick AFB ARSR	2776 ±7	360.2	2ACA/4	12.01	5
..................777788	887777777.6..	40	Patrick AFB ASR	3342	299.2	AC	3.92	1
...................88888	788..7777....	41	Orlando ASR	2626	380.7	AAC	4.71	1
....................778.	......77.....	42	Tampa ASR	2884	346.7	AAC	4.70	1
.....................8...	.....	43	Daytona Ramp Tester	3064-5	326.3	A	2.18	1
....................767.	.4....67.....	44	Mac Dill AFB ARSR	4147	241.1	2ACA	11.98	1
.....................6.	.....	45	Sarasota ASR	2564	389.9	AAC	4.04	1
.....................66	767..........	46	W. Palmbeach ASR	3049	327.9	AAC	4.71	1
.....	.6..........	47	Richmond AFS ARSR	2820.0	354.6	2ACA/4	10.11	1
.....	..99999A.....	48	Shipborne Near 2K	3052-61	327 ±	4*12AC	3.80	1
.....	......9......	49	Mayport NS	1522 ±4	657	A/1/2	7.18	Rm
.....	.....	50	(Not Used)					
....................6.8.	......76.....	51	Mac Dill AFB	4000	250.0	2*AC	9.32	1
....................777.	......66.....	52	Mac Dill AFB	3991 ave	250.6	AC	4.70	3
.....	.....	53	(Not Used)					
.....	.........A89.	54	Shipborne Near 2K	4129-30	242.1	4*12AC	7.90	1
.....	..........9A.	55	Near Myrtle Beach	912	1096	A	3.94	1
.....	..........57.	56	Bogue MCALF	7506.4	133.2	A	6.37	1
.....	777	57	Nr Seym.Johnson AFB	3991 ave	250.6	AC	4.68	3
.....	..........6.	58	Charlotte ASR	2626.8	380.7	AAC	4.70	1
.....	7	59	Maiden ARSR	2778 ±7	359.9	AC	12.02	5
.....	.....	60	Panama City ARSR	2818 ±7	354.9	2ACA	12.02	5
.....	.....	61	West of Loc. 2M+	3502-3	285.5	AC	3.94	1
.....	.....	62	South of Loc. 2M+	3650	273.9	AC	3.85	1
ABCDEFGHIJKLMNOPQRSTUVWX	ACEGIKMOQSUWY							

FOR ALL LOCATIONS OF VISIBILITY, INT/MIN ARE GIVEN TO NEAREST POWER OF 2. SUBTRACT 6 FROM GIVEN POWERS (DIVIDE BY 64) TO OBTAIN INT/SEC.

BASIC INTERROGATOR LIST AND VISIBILITY MATRIX

Figure 6 (2nd half)

TABLE 3

JACKSONVILLE AREA INTERROGATORS ARRANGED BY PRI / PRF

PART 1: (PRI under 3000 μs / PRF over 333.3 IPS)

DESCRIPTION OF INTERROGATORS OBSERVED							
NO.	SUSP. NAME OR LOC.	PRI (US)	PRF	MODES	SCAN	ST	PRI ORDER
55	Near Myrtle Beach	912	1096	A	3.94	1	1
49	Mayport NS	1522 ±4	657	A/1/2	7.18	Rm	2
11	Columbia ASR-7	2245 ave	445.4	AAC	4.68	8	3
38	Astor Park	2275 ±7	439.5	AC	2.80	Rm	4
23	Statesboro	2440-1	409.7	1	8.83	1	5
16	Near Charleston	2458 ±1	406.8	2	3.92	1	6
36	Tallahassee ASR	2498.5	400.2	AAC	3.92	1	7
37	Macon ASR (Robins)	2500.8	399.9	AAC	4.68	1	8
7	Jacksonville NC	2530	395.2	A	4.04	1	9
21	Augusta ASR	2531	395.0	AAC	3.92	1	10
35	Daytona Bch ASR	2559.7	390.7	AAC	3.92	1	11
45	Sarasota ASR	2564	389.9	AAC	4.04	1	12
12	Charleston ASR	2566	389.6	A	4.70	1	13
32	Beaufort MCAS	2594	385.4	2/AC	3.93	1	14
8	Fayetteville ASR	2625	380.9	AAC	3.92	1	15
41	Orlando ASR	2626	380.7	AAC	4.71	1	16
58	Charlotte ASR	2626.8	380.7	AAC	4.70	1	17
33	Cecil NAS	2663-4	375.4	AAC	3.92	1	18
3	Bogue MCALF	2776	73.6	AC	3.91	1	19
28	Valdosta ARSR	2700-	370.3	AC	11.98	1	20
4	Benson ARSR	2700 ±7	370.3	AC	10.12	5	21
29	Whitehouse ARSR	2741 ±7	364.8	AAC	12.02	5	22
39	Patrick AFB ARSR	2776 ±7	360.2	2ACA/4	12.01	5	23
59	Maiden ARSR	2778 ±7	359.9	AC	12.02	5	24
60	Panama City ARSR	2818 ±7	354.9	2ACA	12.02	5	25
24	Jacksonville NAS	2819	354.7	2ACA/4	12.02	1	26
47	Richmond AFB ARSR	2820.0	354.6	2ACA	10.11	1	27
42	Tampa ASR	2884	346.7	AAC	4.70	1	28
13	Jedburg ARSR	2901 ±7	344.7	AC	12.02	5	29
30	Jacksonville Int. ASR	2969 ±7	336.8	AAC	4.70	5	30

TABLE 3

JACKSONVILLE AREA INTERROGATORS ARRANGED BY PRI/PRF

PART 2: (PRI over 3000 μs / PRF under 333.3 IPS)

DESCRIPTION OF INTERROGATORS OBSERVED							
NO.	SUSP. NAME OR LOC.	PRI (US)	PRF	MODES	SCAN	ST	PRI ORDER
14	No. Charleston	3040	328.9	2ACA	11.75	1	31
46	W. Palmbeach ASR	3049	327.9	AAC	4.71	1	32
48	Shipborne Near 2K	3060-1	326.7	4*12AC	3.80	1	33
43	Daytona Ramp Tester	3064-5	326.3	A	2.18	1	34
25	Savannah ASR	3095 ±7	323.1	A	4.70	5	35
20	Shipborne Near 2K	3153±150	317.±	4*12AC	3.82	Rm	36
18	Beaufort MCAS	3251 (2)	307.5	12AC	9.82	1	37
10	Shaw AFB	3328 (9)	300.4	AC	3.92	1	38
9	Myrtle Beach AFB	3331	300.2	AC	4.46	1	39
1	Airborne Near 2Y	3335	299.8	2*AC	3.86	1	40
40	Patrick AFR ASR	3342	299.2	AC	3.92	1	41
22	Shipborne Near 2K	3415 ave	292.8	4*12AC	7.85	9	42
31	Jacksonville NAS	3461	288.9	2AC	3.92	1	43
61	West of Loc. 2M+	3502-3	285.5	AC	3.94	1	44
62	South of Loc. 2M+	3650	273.9	AC	3.85	1	45
2	Pope AFB	3654	273.6	AAC	3.85	1	46
6	Near Loc. 2Y	3991 ave	250.6	AC	4.68	3	47
52	Mac Dill AFB	3991 ave	250.6	AC	4.70	3	48
57	Nr. Seym. Johnson AFB	3991	250.6	AC	4.68	3	49
5	Myrtle Beach AFB	4000-	250.0	1AC	9.31	1	50
51	Mac Dill AFB	4000	250.0	2*AC	9.32	1	51
26	Shipborne Near 2K	4048-9	247.0	4*12AC	7.90	1	52
54	Shipborne Near 2K	4129-30	242.1	4*12AC	7.90	1	53
17	Aiken AFB ARSR	4135	241.8	AC	12.04	1	54
15	Ft. Fisher	4146	241.2	2ACA/4	11.98	1	55
44	Mac Dill AFB ARSR	4147	241.1	2ACA	11.98	1	56
19	Beaufort MCAS	4588 ave	218.0	2*12AC	9.59	12	57
27	AWACS	5005-74	200.0	2AC		Rm	58
56	Bogue MCALF	7506.4	133.2	A	6.37	1	59

No. 19 Beufort MCAS (12-Pulse-Stagger)	No. 11 Columbia ASR-7 (8-Pulse-Stagger)	No. 22 Shipborne Near 2K (9-Pulse-Stagger)
3774.5	1805.625	2831.625
3774.625	1885.625	2831.625
3774.625	2295.5	3051.375
6000.875	2858.375	2831.75
3774.375	2235.625	2831.625
3774.5	1845.625	3881.375
3774.5	1905.5	2831.75
4720.0	3128.375	2831.625
3774.375		6810.75
3774.75		
3774.375		
10362.5		
No. 4 Benson ARSR (5-Pulse-Stagger)	**No. 25 Savannah ASR (5-Pulse-Stagger)**	**No. 30 Jacksonville International (5-Pulse-Stagger)**
2693.75	3088.25	2962.25
2704.5	3099.0	2973.0
2701.0	3095.5	2969.375
2697.375	3091.875	2965.875
2708.125	3102.625	2976.625
No. 13 Jedburg ARSR (5-Pulse-Stagger)	**No. 29 Whitehouse ARSR (5-Pulse-Stagger)**	**No. 39 Patrick ARSR (5-Pulse-Stagger)**
2893.75	2734.125	2769.0
2904.625	2745.0	2779.875
2901.0	2741.375	2776.25
2897.375	2737.75	2772.5
2908.25	2748.625	2783.5
No. 6 (Near 2Y) No. 57 Nr. Seymore Johnson AFB No. 52 Mac Dill AFB (3-Pulse-Stagger)	**No. 59 Maiden ARSR (5-Pulse-Stagger)**	**No. 60 Panama City ARSR (5-Pulse-Stagger)**
	2770.875	2810.875
	2781.875	2821.75
3691.25	2778.25	2818.0
4101.0	2774.625	2814.5
4181.125	2785.5	2825.25

Actual PRI of Interrogators on Staggered PRI (μs)
Four Random Staggers Excluded
Figure 7

3.3 Basic Parameters of the Interrogators

In addition to indicating visibility, Figure 6 displays the following parameters for each interrogator:

- Suspected name or location and type.
- Pulse Repetition Interval (PRI in μs). This is an average value, if the PRI is staggered. When possible, the total excursion in PRI is shown (e.g., 5-pulse-stagger ± 7).
- Pulse Repetition Frequency (PRF).
- Mode Interlace with indication of use of Mode 4. Maximum length handled = 16. (4*12AC denotes 11112222AAAACCCC).
- Scan Period (sec) of the antenna.
- Length of the Stagger Period (ST) for interrogators on finite stagger. "Rm" implies random stagger.

The AMF uplink analysis program cannot assign names to the interrogators (internal PRF tracks) it detects at a a given location; neither can it remember interrogators seen at other locations as it goes through its analysis of 60-second recordings at each place. The job of correlating the data provided at each location (no. of interrogations, received power, angle of arrival, mode interlace and scan period for a given PRF) with similar data at other locations, and eventually, with ECAC, IRAC, and FAA-supplied interrogator lists, was done by hand.

3.3.1 FAA Interrogators

Of the 59 interrogators listed in Figure 6, 25 are marked as FAA interrogators. Ten of these are en-route interrogators (ARSR's), eight on a 12-sec scan, the other two (Benson and Richmond) on the faster 10-sec scan. The remaining fifteen FAA interrogators are terminal interrogators (ASR's), with scan periods of: (a) 4.69 sec. (9); (b) 3.92 sec. (5); and (c) 4.04 sec. (1).

FAA terminal and enroute interrogators usually are not colocated. The only exception noted is the pair of interrogators at Patrick AFB.

The FAA has recently been replacing the ASR-7 terminal interrogators (on 8-pulse stagger using one of six crystals tuned one percent apart) with ASR-8's on fixed PRF's. The only ASR-7 remaining in service in the area is located in West Columnbia S.C. (our interrogator 11). This shows that the FAA replacement plan has been almost completely carried out.

Preliminary antenna plots (not included in this report) for some of the FAA interrogators show that the Jedburg and Whitehouse ARSR's use regular SLS, while the ARSR at Patrick AFB uses improved SLS (ISLS). The opposite indication is given for these in the ECAC file.

Antenna plots also show the ASR's at Charleston, Savannah and Jacksonville International using ISLS, and the ASR at Patrick AFB using regular SLS. These four are in agreement with the ECAC file.

The same preliminary antenna plots also showed many sidelobe punch-throughs for Charleston ASR and Patrick ARSR, numerous punch-throughs for Jacksonville International, very few punch-throughs for the Savannah ASR and the Jedburg and Whitehouse ARSR's.

3.3.2 Non-FAA Interrogators

Thirty-four of the 59 interrogators were thought to be non-FAA interrogators. These were located as follows:

(1) Interrogators at Sea

Interrogators numbered 20, 22, 26, 48, and 54 appear to be located on ships in the Atlantic Ocean, about 90 to 100 nmi east of Whitehouse ARSR. All of these used mode interlace 11112222AAAACCCC (they were the only interrogators using this pattern). Interrogators 20 and 48 (both with scan periods of 3.8 sec) may be the same interrogator even though they use different stagger and different PRI, since the two were never seen simultaneously.

Similarly, interrogators 26 and 54 (both with scan periods of 7.90 sec) might actually be a single interrogator using two slightly different PRF's (247.0 vs 242.1) since these two are also not "on" at the same time. Interrogator 22 is on a remarkable 9-pulse stagger noted in earlier flights (see Figure 7 for details).

(2) Beaufort MCAS

Interrogators 18, 19, and 32 seem to be located at Beaufort MCAS. The first one of these, without the benefit of SLS, contributed the second highest interrogation rate seen (133/sec at location 1G, on a PRF of 307.5). The second one (number 19), on an average PRF of 218, demonstrated the most complicated (12-pulse) stagger seen during the flight (see Figure 7 for the details).

(3) Ft. Fisher

The highest interrogation rate observed (240/sec at location 1A came from Ft. Fischer, a long range coastal interrogator near location 2X. Curiously, at the end of the flight, at comparable distance and peak received power, the rate was down to 5/sec. Ft. Fisher apparently has SLS (as indicated in the ECAC file), which it did not use early in the morning, but did use later in the day.

(4) Mayport Naval Station

Interrogator 49, located (perhaps aboard a ship) at Mayport Naval Station, had the second highest PRF (657) observed during the flight. This is like two interrogators on an average PRF. The only reason it did not contribute an excessive amount is because it went "blank" eight times after every four interrogations, lowering its duty ratio to one third. This interrogator was discovered at location 2M with mode interlace AAAA for the first 4 mainbeams and modes 1111 on the 5th mainbeam. At 2M+ it used mode interlace 2222 exclusively.

Interrogator 49 uses no SLS, and it could become a real problem, if it went back to 100 percent duty factor, used civilian modes A and C only for some interval of time, and increased its transmitted power. It is likely to do all these things some of the time.

(5) Interrogator 55 Near Myrtle Beach

This is a very normal looking interrogator transmitting mode A at a scan period of 3.94 sec. It is of interest because it uses the highest PRF (1096 int/sec) seen anywhere during the flight. Note that this PRF is the third harmonic of a popular PRF (365.3), used for example, by Whitehouse ARSR (364.8 exactly). This interrogator does use SLS (at least during the time we observed it), and contributes only 21 int/sec, instead of possibly 50 times as many without SLS.

(6) Bogue and Jacksonville (NC)

Interrogators numbered 3 and 56 were thought to be located at Bogue Field. The second one had the lowest PRF (133.2) of any interrogator seen, and it is suspected to be using the more usual PRF of 2X133.2 = 267 and blanking out every other interrogation. Interrogators 3 and 56 may be located in Jacksonville, NC (Camp Le Jeune) where scan periods and modes are in better agreement with the ECAC file. Angles of arrival gave Bogue a slight preference. With interrogator 7, there could be a total of three interrogators at Camp Le Jeune, as shown in the ECAC file.

3.3.3 Observed PRI/PRF

Figure 6 and Table 3 include (average) PRI and PRF for the 59 interrogators seen. They also indicate stagger lengths for those interrogators which are not on fixed PRF. "Rm" here indicates a non-repeating (random) stagger about some average value. Figure 7 gives measured PRI for all interrogators on staggered but not random PRF. Summary PRI/PRF results follow:

	Number	Percent
12-Pulse Stagger	1	2
9-Pulse Stagger	1	2
8-Pulse Stagger	1	2
5-Pulse Stagger	8	14
3-Pulse Stagger	3	5
Random Stagger	4	7
Staggered PRF's	18	31
Fixed PRF's	41	69
Total PRF's	59	100

Quantity	Interrogator No.	Interrogator Name	PRF (Ave)	Stagger Lengths
Highest PRF's	55	Near Myrtle Beach	1096.0	1
	49	Mayport NS	657.0	Random
	11	Columbia ASR-7	445.4	8
	38	Astor Park	439.5	Random
Lowest PRF's	44	Mac Dill AFB ARSR	241.1	1
	19	Beaufort MCAS	218.0	12
	27	AWACS	200.0	Random
	56	Bogue MCAS	133.2	1
Median PRF	30	Jacksonville International	336.8	5

3.3.4 Observed Mode Interlaces

57 out of 59 interrogators used a single mode interlace pattern; two used more than one. Mayport (number 49) used either A or 1 or 2. Interrogator 32 (Beaufort MCAS) used either mode 2 or mode AC. With the three extra mode interlaces, a total of 59 + 3 = 62 were observed. Summary mode interlace results follow:

Mode Interlace	Number	Percent
AC	16	26
AAC	15	24
A	7	11
4*12AC	5	8
2ACA/4	5	8
2	3	5
1	2	3
2AC	2	3
2ACA	2	3
2*AC	2	3
1AC	1	2
12AC	1	2
2*12AC	1	2
Total	62	100

The most popular mode interlaces are AC, AAC, and A (used mostly by terminal interrogators), and then 2ACA (used entirely by en-route interrogators).

3.3.5 Scan Periods

A scan period was measured for all but one of the 59 interrogators observed. The exception was Interrogator 27 (AWACS), for which only a single mainbeam was seen. The following summary results are arranged by length of time. Scan periods grouped together are usually within ± 0.02 sec of the value given.

Scan Period (sec)	Number	Scan Period (sec)	Number
2.18	1	7.85 - 7.90	3
2.80	1	8.83	1
3.80 - 3.86	6	9.31	2
3.92	13	9.59	1
4.04	2	9.82	1
4.70	12	10.11	2
6.37	1	11.75	1
7.18	1	12.00	10

Two scan periods were under 3 sec, the ramp tester at Daytona Beach (interrogator 43) with its 2.18-sec scan, and Astor Park (interrogator 38) with its 2.80-sec scan.

The table shows that scan periods 3.92 and 4.70 sec are almost equally popular for terminal interrogators. For en-route interrogators, the 12-second scan period predominates. The table also shows a number of odd scan periods for the military interrogators of the larger Jacksonville area.

3.4 Master List (Tables 4A and 4B)

Tables 4A and 4B present, for all interrogators visible at 37 (24 + 13) selected measurement locations, the following major results:

- Number of interrogations per minute;
- Angle of arrival (deg, w. resp. to true North);
- Average received power at the bottom antenna (dBm + 97).
- Peak received power at the bottom antenna (dBm + 97).

Table 4A refers to the southerly (inland) portion of the flight at 10,000 ft.; Table 4B to the northerly portion of the flight over the ocean at 25,000 ft.

NO	1	2	3	4	5	6	7	8
NAME	AirbNr2	Pope AFB	BogueMCA	BensonAR	MyrtleAF	Near 2Y	JacksvNC	FaytvASR
PRI	3335	3654	2676	2700±7	4000-	3991 ave	2530	2625
PRF	299.8	273.6	373.6	370.3	250.0	250.6	395.2	380.9
MODES	2*AC	AAC	AC	AC	1AC	AC	A	AAC
SCAN	3.86	3.85	3.91	10.12	9.31	4.68	4.04	3.92
STAG	1	1	1	5	1	3	1	1
1A	199 31 95 34	116 23 10 23	228 35 95 41	225 33 8 36	84 40 250 44	240 31 0 39	247 38 85 43	232 32 355 38
1B			34 24 85	200 29 3 38	223 34 242 60	120 25 34 31	280 36 79 43	263 31 27 37
1C				222 34 13 40	129 40 81 44		67 26 77 27	249 27 10 34
1D				145 22 35 28			223 22 73	203 28 36
1E								
1F								
1G								
1H								
1I								
1J								
1K								
1L								
1M								
1N								
1O								
1P								
1Q								
1R								
1S								
1T								
1U								
1V								
1W								
1X								

23 May 1979 Jacksonville Area Flight of the AMF (Inland, South, 10,000 Ft)

Quantity Plotted Above:

INT/MIN	AVE.P
AOA	PK.P

(Powers: dBm at Bottom Ant + 97)

TABLE 4A (p.1)

NO	9	10	11	12	13	14	15	16
NAME	MyrtleAF	Shaw AFB	ColASR-7	CharlsAS	JedbrgAR	NoCharls	FtFisher	NrCharls
PRI	3331	3328(9)	2245 ave	2566	2901±7	3040	4146	2458 ±1
PRF	300.2	300.4	445.4	389.6	344.7	328.9	241.2	406.8
MODES	AC	AC	AAC	A	AC	2ACA/4	2ACA/4	2
SCAN	4.67	3.92	4.68	4.70	12.02	11.75	11.98	3.92
STAG	1	1	8	1	5	1	1	1
1A	404 36 252 49	59 27 288 39	180 30 280	56 25 247 29	110 28 242 30	313 34 247 47	13246 30 104 59	
1B	431 46 244 66	168 30 268 36		254 31 242 35	185 34 238 39	300 39 243 47	12565 22 93 49	
1C	209 50 87 57	173 31 315 36	310 34 293	272 33 243 40	200 37 240 42	389 37 245 48	12125 21 89 49	153 30 234 33
1D	201 31 69 40	165 29 334 35	240 30 303	308 38 235 46	242 44 267 50	444 42 235 58	3214 17 80 39	153 34 230 40
1E	130 26 78 28	196 29 4 40	350 37 322	788 49 273 60	233 52 314 59	2297 46 215 71	163 21 76 28	
1F		190 33 354 38	208 24 358	274 37 50 46	220 43 21 49	551 36 55 56	159 24 75 30	
1G		101 25 7 33	272 23 336	268 40 66 46	210 34 38 40	354 41 58 51		
1H		127 26 12 30	310 29 330	226 29 48 36	195 29 62 34	289 37 49 46	68 15 62 31	
1I				32 21 43 25	175 34 54 40	193 24 37 34	177 26 62 37	
1J					58 23 58 26	206 27 54 33		
1K						110 18 46 25		
1L								
1M								
1N								
1O								
1P					122 22 32 33	187 30 30 39		
1Q						65 20 43 24		
1R								
1S								
1T								
1U							21 20 27 21	
1V								
1W								
1X								

23 May 1979 Jacksonville Area Flight of the AMF (Inland, South, 10,000 Ft)

Quantity Plotted Above:
TABLE 4A (p. 2)

INT/MIN	AVE.P
AOA	PK.P

(Powers: dBm at Bottom Ant + 97)

NO	17	18	19	20	21	22	23	24
NAME	Aiken AR	BeauftMC	BeauftMC	ShipNr2K	AugustAS	ShipNr2K	Statesbo	JacksvNAS
PRI	4134	3251(2)	4588 ave	3133±150	2531	3415 av	2440-1	2819
PRF	241.8	307.5	218.0	319 ±	395.0	292.8	409.7	354.7
MODES	AC	12AC	2*12AC	4*12AC	AAC	4*12AC	1	2ACA/4
SCAN	12.04	9.82	9.59	3.82	3.92	7.85	8.83	12.02
STAG	1	1	12	Rm	1	9	1	1
1A								
1B								
1C	55 27 291 29							
1D	110 42 301 49	506 29 227 34	280 28 229 33					
1E	140 33 311 38	863 38 237 43	453 36 239 41	305 254 26	222 27 299 30	214 23 222 27		
1F	98 37 316 41	1940 32 246 49	420 43 250 49	430 246 31	247 30 303 36	400 27 217 30	646 28 265 35	42 29 221 46
1G	103 30 349 34	8208 28 341 57	416 44 343 53		260 29 352 34		1019 25 301 31	175 28 225 34
1H	86 32 351 39	2506 25 18 45	402 35 17 40	600 191 36	212 23 252 31	795 32 192 41	2240 28 311 44	655 34 218 47
1I	115 28 346 35	833 36 53 43	485 34 54 40	400 185 37	46 22 333 27	850 30 183 41	347 22 346 31	339 42 211 51
1J	23 22 15 26	462 27 60 32	281 26 69 30	500 142 48		755 38 144 49		270 46 220 56
1K		556 19 42 25	330 18 43 22	400 110 50		460 36 118 44		424 46 195 58
1L				800 78 46		149 33 78 40		1032 46 191 66
1M				600 120 46		1086 35 114 50		557 40 115 60
1N				1200 76 40				383 33 114 47
1O		167 26 30		900 89 49		552 37 86 42	110 23 355 30	514 39 150 52
1P	27 18 355 23	695 31 32 39	414 30 31 35	840 145 44		726 39 148 48		223 46 177 53
1Q		178 16 34 21	56 16 35 18	800 125 46		728 42 125 50		479 45 195 61
1R						770 32 95 43		443 49 202 65
1S						327 31 65 35		734 41 284 66
1T				900 45 43		630 29 32 40		598 43 332 62
1U				800 23 34		890 26 21 37		482 33 3 48
1V				600 25 39		215 30 26 37		244 39 10 48
1W				300 28 28		134 22 31 29		171 29 14 40
1X								

23 May 1979 Jacksonville Area Flight of the AMF (Inland, South, 10,000 Ft)

Quantity Plotted Above:
TABLE 4A (p. 3)

INT/MIN	AVE.P
AOA	PK.P

(Powers: dBm at Bottom Ant + 97)

NO	25	26	27	28	29	30	31	32
NAME	SavnnhAS	ShipNr2K	AWACS	ValdosAR	WhitehAR	JackInAS	JacksNAS	BeauftMC
PRI	3095±7	4048-9	5005-74	2700-	2741 ±7	2969 ±7	3461	2594
PRF	323.1	247.0	200-	370.3	364.8	336.8	288.9	385.4
MODES	A	4*12AC	2AC	AC	AAC	AAC	2AC	2/AC
SCAN	4.70	7.90		11.98	12.02	4.70	3.92	3.93
STAG	5	1	Rm	1	5	5	1	1
1A								
1B								
1C								
1D								
1E								
1F	212 32 253 37	178 27 227 33						
1G	225 40 265 46		30 355 24		58 25 213 27			
1H	132 39 295 42			52 27 242 29	195 35 215 41	190 29 218 32	137 27 215 34	
1I	191 37 345 42			121 27 256 33	195 39 208 48	217 31 208 40	237 33 208 44	152 32 53 41
1J	202 30 26 36			70 25 271 31	234 40 213 49	271 37 216 45	206 31 217 40	64 25 61 28
1K	194 30 26 37			259 30 285 39	203 49 227 56	285 41 231 55	226 34 191 51	125 16 40
1L	198 20 31			205 32 292 38	225 228 60	282 53 334 62	546 42 190 61	
1M				321 36 303 49	182 51 118 59	283 39 105 49	242 43 112 51	
1N	133 27 31 31			180 42 293 49	170 40 113 49	223 36 84 44	206 34 108 43	
1O	172 30 30 37	369 41 89 50		337 31 248 40	218 39 152 49	250 36 127 43	291 31 145 41	140 27 27 31
1P	228 30 44 34			280 35 259 43	218 37 185 47	256 31 174 40	294 34 175 47	219 29 32 37
1Q	208 32 45 38			267 35 271 43	197 41 241 52	295 38 208 47	363 32 192 43	160 17 28 24
1R				153 27 289 34	149 55 232 62	186 51 264 57	297 43 198 60	
1S		526 26 70 37		235 29 291 38	187 47 282 56	264 35 338 45	207 49 284 60	
1T				134 21 301 27	161 44 328 53	262 33 355 44	241 47 334 53	
1U					226 32 337 41	154 26 15 28	212 37 0 43	
1V					146 32 5 42	188 28 19 34	195 27 9 34	
1W		360 20 26 29			41 18 0 20		24 22 13 26	
1X								

23 May 1979 Jacksonville Area Flight of the AMF (Inland, South, 10,000 Ft)

Quantity Plotted Above:
TABLE 4A (p. 4)

INT/MIN	AVE.P
AOA	PK.P

(Powers: dBm at Bottom Ant + 97)

NU	33	34	35	36	37	38	39	40
NAME	CecilNAS	Not	DaytonaB	TallaASR	MaconASR	AstorPk	PatrckAR	PatrckAS
PRI	2663-4	Used	2559.7	2498.5	2500.8	2275 ±7	2276 ±7	3342
PRF	375.4		390.7	400.2	399.9	439.5	360.2	299.2
MODES	AAC		AAC	AAC	AAC	AC	2ACA/4	AC
SCAN	3.92		3.92	3.92	4.68	2.80	12.01	3.92
STAG	1		1	1	1	Rm	5	1
1A								
1B								
1C								
1D								
1E								
1F								
1G								
1H								
1I								
1J	145 27 212 31							
1K	203 31 239 37		88 25 177 27					
1L	306 37 206 44		264 25 150 34					
1M	273 32 149 42		72 19 165 26	181 29 268 34				
1N	170 20 125 30			137 21 261 27	23 22 338 24			
1O	224 23 149 28				176 21 315 27			
1P	179 27 178 31							
1Q	186 30 211 35		23 23 175 25					
1R	216 35 228 47		120 25 173 29					
1S	273 33 305 41		214 32 155 38			198 27 195 28	187 29 181 33	141 29 159 34
1T	131 30 314 38		247 34 175 40			266 31 213 37	162 33 177 40	164 31 174 39
1U	220 27 333 31		314 52 167 60			502 35 257 42	211 34 164 43	156 31 166 38
1V	96 19 0 22		248 42 16 51			372 26 294 30	301 39 172 51	171 34 172 43
1W			246 31 22 37			146 22 339 25	282 52 152 64	221 48 152 58
1X							322 44 9 59	312 35 8 51

23 May 1979 Jacksonville Area Flight of the AMF (Inland, South, 10,000 Ft)

Quantity Plotted Above:

TABLE 4A (p. 5)

INT/MIN	AVE.P
AOA	PK.P

(Powers: dBm at Bottom Ant 97)

NO	41	42	43	44	45	46	51	52
NAME	OrlndoAS	TampaASR	DaytRamp	McDillAR	SarasoAS	WPalmBAS	McDill	McDill
PRI	2626	2884	3064-5	4147	2564	3049	4000	3991 ave
PRF	380.7	346.7	326.3	241.1	389.9	327.9	250.0	250.6
MODES	AAC	AAC	A	2ACA	AAC	AAC	2*AC	AC
SCAN	4.71	4.70	2.18	11.98	4.04	4.71	9.32	4.70
STAG	1	1	1	1	1	1	1	3
1A								
1B								
1C								
1D								
1E								
1F								
1G								
1H								
1I								
1J								
1K								
1L								
1M								
1N								
1O								
1P								
1Q								
1R								
1S								
1T	194 31 190 37							
1U	224 38 202 42	127 26 242 30	280 25 162 29	107 36 218 43			50 23 224 25	108 27 222 31
1V	230 42 245 48	121 26 252 32		71 35 238 41				144 30 242 37
1W	274 43 305 50	232 32 253 40		96 41 247 47	50 24 243 26	68 24 155 38	236 33 248 36	122 33 247 38
1X	236 42 312 49					68 24 148 28		

23 May 1979 Jacksonville Area Flight of the AMF (Inland, South, 10,000 Ft)

Quantity Plotted Above:
TABLE 4A (p. 6)

INT/MIN	AVE.P
AOA	PK.P

(Powers: dBm at Bottom Ant 97)

NO	1	2	3	4	5	6	7	8
NAME	AirbNr2Y	Pope AFB	BogueMCA	BensonAR	MyrtleAF	Near 2Y	JacksvNC	FaytvASR
PRI	3335	3654	2676	2700 ±7	4000-	3991 ave	2530	2625
PRF	299.8	273.6	373.6	370.3	250.0	250.6	395.2	380.9
MODES	2*AC	AAC	AC	AC	1AC	AC	A	AAC
SCAN	3.86	3.85	3.91	10.12	9.31	4.68	4.04	3.92
STAG	1	1	1	5	1	3	1	1
2A								
2C								
2E								
2G								
2I								
2K								
2M								
2O								
2Q								
2S								
2U				65 23 355 29			123 28 353 34	35 25 355 27
2W	123 28 22 30		221 32 55 37	201 30 3 36		25 292 35	224 33 10 42	138 27 346 30
2Y	220 37 49 42	186 32 308 36	248 34 49 43	195 39 332 44		221 223 44	448 34 106 51	263 36 299 42

23 May 1979 Jacksonville Area Flight of the AMF (Ocean Leg, North, 25,000 Ft.)

Quantity Plotted Above:

INT/MIN	AVE.P
AOA	PK.P

TABLE 4B (p. 1)

(Powers: dBm at Bottom Ant + 97)

NO	9	10	11	12	13	14	15	16
NAME	MyrtleAF	Shaw AFB	ColASR-7	CharlsAS	JedbrgAR	NoCharls	FtFisher	NrCharls
PRI	3331	3328(9)	2245 av	2566	2901 ±7	3040	4146	2458 ±1
PRF	300.2	300.4	445.4	389.6	344.7	328.9	241.2	406.8
MODES	AC	AC	AAC	A	AC	2ACA/4	2ACA/4	2
SCAN	4.67	3.92	4.67	4.70	12.02	11.75	11.98	3.92
STAG	1	1	8	1	5	1	1	1
2A								
2C								
2E						49 24 9 28		
2G						165 31 341 36		
2I				34 22 345	187 27 343	205 30 347	128 23 10	
2K				140 20 4	200 28 22	307 28 2	70 14 21	
2M				236 21 34	100 23 28	339 28 30		
2O				88 23 27	95 26 17	197 28 26		
2Q				75 20 7	141 22 349	200 28 7	52 23 24	
2S				154 25 342 33	129 27 341 33	285 32 338 44		
2U		60 25 328 28		181 27 296 31	181 31 301 36	288 34 297 43	215 37 357 45	
2W			240 29 298 35	224 22 278 28	219 26 275 34	388 27 278 39	241 45 16 55	
2Y		80 23 240 35			116 24 221 28	282 34 224 43	290 40 138 55	

23 May 1979 Jacksonville Area Flight of the AMF (Ocean Leg, North, 25,000 Ft.)

Quantity Plotted Above:

INT/MIN	AVE.P
AOA	PK.P

TABLE 4B (p. 2)

(Powers: dBm at Bottom Ant + 97)

NO	17	18	19	20	21	22	23	24
NAME	Aiken AR	BeauftMC	BeauftMC	ShipNr2K	AugustAS	ShipNr2K	Statesbo	JacksvNAS
PRI	4135	3251(2)	4588 ave	3133±150	2531	3415 ave	2440-1	2819
PRF	241.8	307.5	218.0	319 ±	395.0	292.8	409.7	354.7
MODES	AC	12AC	2*12AC	4*12AC	AAC	4*12AC	1	2ACA/4
SCAN	12.04	9.82	9.59	3.82	3.92	7.85	8.83	12.02
STAG	1	1	12	Rm	1	9	1	1
2A						528 23 16 27		
2C						222 26 347 30		191 28 311 36
2E						498 30 341 38		392 33 292 42
2G						789 34 315 42		360 31 283 41
2I			405 30 321 37			671 39 279 47		312 34 282
2K			280 26 332			425 53 34 60		404 43 262 52
2M	85 28 341		337 23 0			447 39 98 45		364 51 247 61
2O	38 24 357		440 27 26			576 44 77 53	49 17 0	351 47 261 59
2Q			302 21 343	1200 295 44		60 29 290 34		356 34 287 43
2S			178 25 299 27	1260 270 38		980 30 271 43	80 24 305 27	256 31 280 44
2U	75 28 300 33		50 24 274 26			660 29 252 38		173 19 242 24
2W	79 30 292 35		153 18 263 22			613 24 217 30		
2Y								

23 May 1979 Jacksonville Area Flight of the AMF (Ocean Leg, North, 25,000 Ft.)

Quantity Plotted Above:

INT/MIN	AVE.P
AOA	PK.P

TABLE 4B (p. 3)

(Powers: dBm at Bottom Ant + 97)

NO	25	26	27	28	29	30	31	32
NAME	SavnnhAS	ShipNr2K	AWACS	ValdosAR	WitehAR	JackInAS	JacksNAS	BeauftMC
PRI	3095 ±7	4048-9	5005-74	2700-	2741 ±7	2969 ±7	3461	2594
PRF	323.1	247.0	200-	370.3	364.8	336.8	288.9	385.4
MODES	A	4*12AC	2AC	AC	AAC	AAC	2AC	2/AC
SCAN	4.70	7.90		11.98	12.02	4.70	3.92	3.93
STAG	5	1	Rm	1	5	5	1	1
2A								
2C								
2E					185 29 290 36	160 21 305 27	145 23 294 34	
2G					102 30 288 37	167 28 297 33	88 34 282 38	
2I					150 37 283	200 31 275	216 30 279	183 31 321
2K				31 28 304	179 39 265 48	187 32 267	265 36 260	215 29 333
2M	154 25 358			202 33 311	214 46 269 53	272 42 270 51	256 45 247 53	196 24 359
2O	152 20 9			150 28 293	190 41 263	253 37 300 46	450 34 252 52	210 26 26
2Q	205 23 335				172 33 286	162 28 290	289 33 288 42	204 22 344
2S					176 27 272 34	134 20 276 27	170 23 274 33	84 24 299 28
2U	35 280 27							191 27 276 33
2W								212 24 263 29
2Y								

23 May 1979 Jacksonville Area Flight of the AMF (Ocean Leg, North, 25,000 Ft.)

Quantity Plotted Above:

INT/MIN	AVE.P
AOA	PK.P

(Powers: dBm at Bottom Ant + 97)

TABLE 4B (p. 4)

NO	33	34	35	36	37	38	39	40
NAME	CecilNAS	Not	DaytonaB	TallaASR	MaconASR	AstorPk	PatrckAR	PatrckAS
PRI	2663-4	Used	2559.7	2498.5	2500.8	2275 ±7	2776 ±7	3342
PRF	375.4		390.7	400.2	399.9	439.5	360.2	299.2
MODES	AAC		AAC	AAC	AAC	AC	2ACA/4	AC
SCAN	3.92		3.92	3.92	4.68	2.80	12.01	3.92
STAG	1		1	1	1	Rm	5	1
2A							215 32 318 42	248 28 315 41
2C			131 26 300 33				268 28 275 43	198 23 280 37
2E			201 16 275 24				224 35 246 45	158 24 244 34
2G							198 20 233 29	175 22 234 29
2I			92 25 251				131 30 196	117 28 194
2K			128 24 225				152 32 186	170 29 185
2M	210 30 256		193 26 197	142 27 267 35	206 31 305 36	310 26 190	202 27 179	173 28 179
2O	209 31 252		181 27 178	162 19 290 37		99 22 191	172 30 176	119 28 178
2Q	289 33 288 42		165 23 205				189 29 221	137 24 220
2S			182 24 226 29				110 16 225 23	
2U							68 200 26	51 24 317 27
2W								
2Y								

23 May 1979 Jacksonville Area Flight of the AMF (Ocean Leg, North, 25,000 Ft.)

Quantity Plotted Above:

INT/MIN	AVE.P
AOA	PK.P

(Powers: dBm at Bottom Ant + 97)

TABLE 4B (p. 5)

NO	41	42	43	44	45	46	47	48
NAME	OrlndoAS	TampaASR	DaytRamp	McDillAR	SarasoAS	WPalmBAS	RichmdAR	ShipNr2K
PRI	2626	2884	3064-5	4147	2564	3049	2820.0	3052-61
PRF	380.7	346.7	326.3	241.1	389.9	327.9	354.6	327 ±
MODES	AAC	AAC	A	2ACA	AAC	AAC	2ACA/4	4*12AC
SCAN	4.71	4.70	2.18	11.98	4.04	4.71	10.11	3.80
STAG	1	1	1	1	1	1	1	1
2A	169 21 290 26					186 29 206 37		
2C	242 28 295 36			21 14 282 19		66 12 221 17	56 14 209 19	
2E	217 25 284 30					153 23 202 33		739 25 341 35
2G								660 33 317 42
2I								696 41 280 49
2K	184 29 208							575 50 36 61
2M	156 27 193	158 26 190		56 27 187				631 39 100
2O	189 29 191	149 22 217		112 26 202 32				864 42 77 51
2Q	134 16 201							
2S								
2U								
2W								
2Y								

23 May 1979 Jacksonville Area Flight of the AMF (Ocean Leg, North, 25,000 Ft.)

Quantity Plotted Above:

INT/MIN	AVE.P
AOA	PK.P

TABLE 4B (p. 6)

(Powers: dBm at Bottom Ant + 97)

NO	49	50	51	52	53	54	55	56
NAME	MayportN	Not	McDill	McDill	Not	ShipNr2K	NrMyrtle	BogueMCA
PRI	1522±4	Used	4000	3991 ave	Used	4129-30	912	7506.4
PRF	657		250.0	250.6		242.1	1096	133.2
MODES	A/1/2		2*AC	AC		4*12AC	A	A
SCAN	7.18		9.32	4.70		7.90	3.94	6.37
STAG	Rm		1	3		1	1	1
2A								
2C								
2E								
2G								
2I								
2K								
2M	400 32 249 40		141 25 188	75 26 181				
2O			58 20 201 23	50 205 27				
2Q								
2S						1024 26 272 42		
2U						314 22 251 27	750 24 317 31	40 40 27
2W						486 25 216 34	1252 33 299 39	120 55 31
2Y								

23 May 1979 Jacksonville Area Flight of the AMF (Ocean Leg, North, 25,000 Ft.)

Quantity Plotted Above:

INT/MIN	AVE.P
AOA	PK.P

(Powers: dBm at Bottom Ant + 97)

TABLE 4B (p. 7)

NO	57	58	59	60	61	62		
NAME	NrSeyJoh	CharltAS	MaidenAR	PanamaAR	W.of 2M+	S.of 2M+		
PRI	3991 ave	2626.8	2778±7	2818±7	3502-3	3650		
PRF	250.6	380.7	359.9	354.9	285.5	273.9		
MODES	AC	AAC	AC	2ACA	AC	AC		
SCAN	4.68	4.70	12.02	12.02	3.94	3.85		
STAG	3	1	5	5	1	1		
2A								
2C								
2E								
2G								
2I								
2K								
2M								
2O								
2Q								
2S								
2U	120 31 347 36							
2W	140 18 33	65 24 312 29						
2Y	168 40 40		112 26 320 29					

23 May 1979 Jacksonville Area Flight of the AMF (Ocean Leg, North, 25,000 Ft.)

Quantity Plotted Above:

INT/MIN	AVE.P
AOA	PK.P

TABLE 4B (p. 8)

(Powers: dBm at Bottom Ant + 97)

3.4.1 Master List Organization

Each column of these tables corresponds to one of the 59 interrogators; each row is headed by a location code: a letter of the alphabet, preceded by "1" for the first, and by "2" for the second leg of the flight. For Table 4A, dealing with the first leg, these are 1A, 1B, 1C,....., 1X. For Table 4B, dealing with the second leg, they are 2A, 2C, 2E, ..., 2Y (every other location only is included). As noted at the bottom of each page the four entries for each location/interrogation (column/row) intersection are:

INT/MIN	AVE. P
AOA	PK. P

3.5 PRI/PRF Distributions for Locations 1H, 1U, and 2M+ (Fig. 8)

Figure 8 presents three PRI/PRF distributions of the interrogations received in 1 minute from all interrogators visible at locations 1H, 2M+, and 1U. The distribution for location 2M+ is shown in the middle (Figure 8b), since this location is geographically between the other two, and since it has more than a dozen interrogators in common (mutually visible) with the other two (top and bottom) locations.

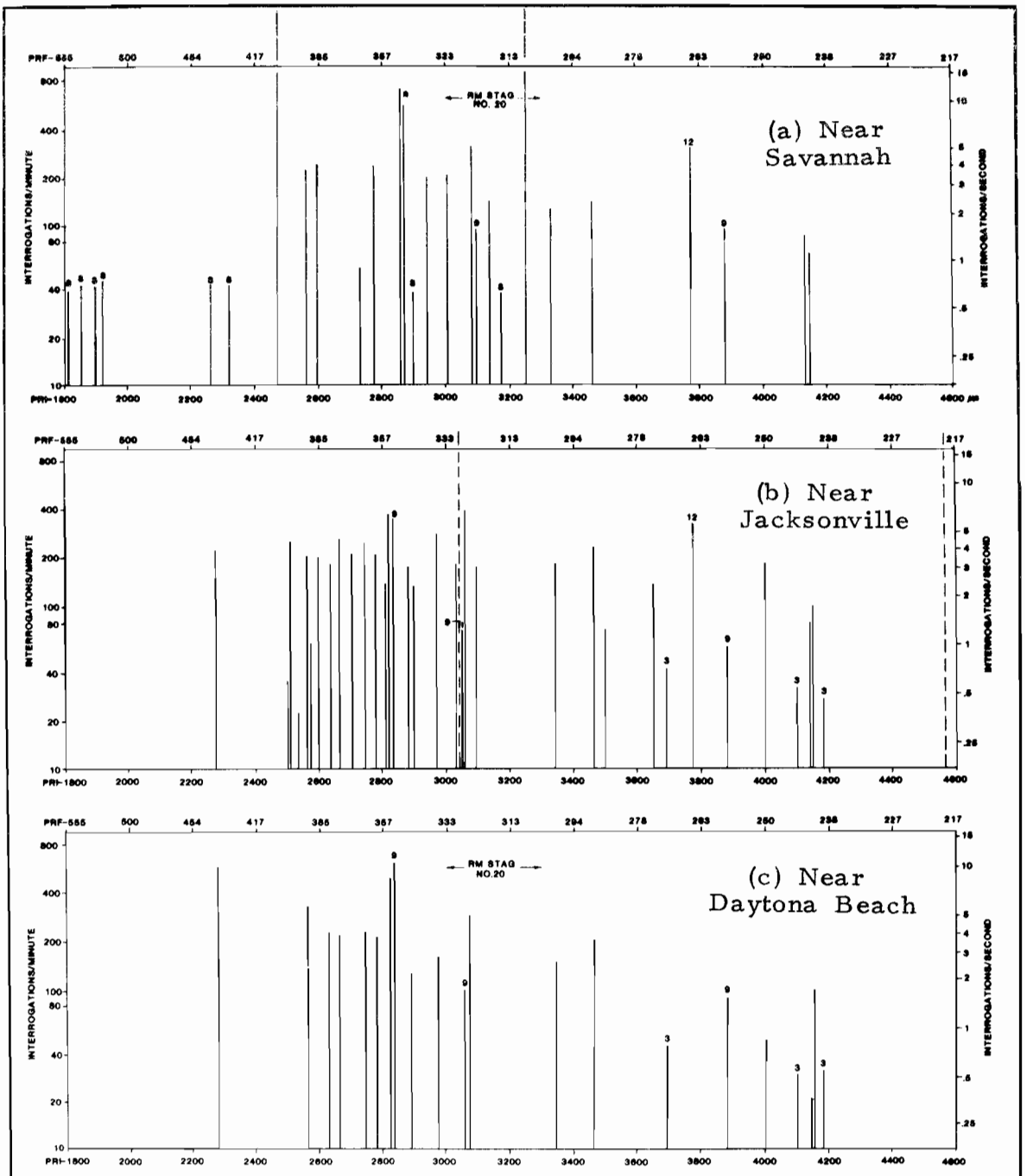
Interrogations marked by the numbers "8", "9", "3", and "12" show all the PRI received from the same four interrogators on staggered PRI. The corresponding interrogators are:

8:	8-Pulse Stagger	No. 11	Columbia ASR-7
9:	9-Pulse Stagger	No. 22	Shipborne Near 2K
3:	3-Pulse Stagger	No. 52	Mac Dill AFB
12:	12-Pulse Stagger	No. 19	Beaufort MCAS

All of the PRI of the 9-Pulse-Stagger (P-S) and of the 3-P-S are within the range of the plots but one of the PRI of the 9-P-S (6810 μs) is off scale (see Figure 7). The 9-P-S (Int. 22) actually uses only 4 different PRI (2831, 3051, 3881, and 6810 μs), but it does not repeat these until 9 PRI later, which gives the 9-pulse stagger designation.

Similarly, Int. 19 (on 12-P-S) actually uses only 4 different PRI (3774, 4720, 6000 and 10362 μs, see Figure 7), but it does not repeat these until 12 PRI later (hence the designation: 12-pulse stagger). Note that only one of its PRI (3774 μs) is within the range of Figure 8, but that three-quarters of all interrogations are received on this single PRI.

Table 5 gives a list of shared and un-shared interrogators among the three PRI/PRF distributions of Figure 8. From the table, 5 are common to all three parts, 13 to parts (a) and (b), 14 to parts (b) and (c), and the rest are un-shared. Interrogators seen at locations 1H and 1U may easily be found from the visibility matrix (left half) of Figure 6. Note that Table 5 gives a list of interrogators seen at loc. 2M+ (a location not included in other figures or tables).



8: 8-P St. No.11 Columbia ASR-7
9: 9-P St. No.22 Shipborne Near 2K
3: 3-P St. No.52 Mac Dill AFB
12: 12-P St. No.19 Beaufort MCAS

Three PRI/PRF Distributions (Near Savannah, Jacksonville And Daytona Beach), Plotted from 60-Second Recordings on 23 May 1979 by the AMF
Figure 8

TABLE 5

SHARED AND UN-SHARED INTERROGATORS
IN THE THREE DISTRIBUTIONS OF FIGURE 8

(1) Interrogators Common to the Three Locations

		PRI
No. 29	Whitehouse ARSR	2741 μs
No. 24	Jacksonville NAS	2819 μs
No. 30	Jacksonville Intnl	2969 μs
No. 22	Shipborne Near 2K	3415 μs (ave. 9-P-S)
No. 31	Jacksonville NAS	3461 μs

(2) Interrogators Common to Locations 1H, and 2M+

		PRI
No. 21	Augusta ASR	2531 μs
No. 12	Charleston ASR	2566 μs
No. 28	Valdosta ARSR	2700 μs
No. 29	Whitehouse ARSR	2741 μs
No. 24	Jacksonville NAS	2819 μs
No. 13	Jedburg ARSR	2901 μs
No. 30	Jacksonville Intnl	2969 μs
No. 14	No. Charleston	3040 μs
No. 25	Savannah ASR	3095 μs
No. 22	Shipborne Near 2K	3415 μs (ave. 9-P-S)
No. 31	Jacksonville NAS	3461 μs
No. 17	Aiken AFS ARSR	4135 μs
No. 19	Beaufort MCAS	4588 μs (ave. 12-P-S)

(3) Interrogators Common to Locations 2M+ and 1U

		PRI
No. 38	Astor Park	2275 μs
No. 35	Daytona Beach ASR	2559 μs
No. 41	Orlando ASR	2626 μs
No. 33	Cecil Fld NAS	2663 μs
No. 29	Whitehouse ARSR	2741 μs
No. 39	Patrick AFB ARSR	2776 μs
No. 24	Jacksonville NAS	2819 μs
No. 42	Tampa ASR	2884 μs
No. 30	Jacksonville Intnl	2969 μs

TABLE 5 (Continued)

		PRI
No. 40	Patrick AFB ASR	3342 μs
No. 22	Shipborne Near 2K	3415 μs (ave. 9-P-S)
No. 31	Jacksonville NAS	3461 μs
No. 52	Mac Dill AFB	3991 μs (ave. 3-P-S)
No. 44	Mac Dill AFB ARSR	4147 μs

(4) Unshared Interrogators at Locations 1H, 1U, and 2M+

(a) Interrogators seen at 1H, but not at 2M+ (with the 13 shared ones, they make up the 19 seen at 1H)

		PRI
No. 11	Columbia ASR-7	2245 μs (ave. 8-P-S)
No. 23	Statesboro	2440 μs
No. 20	Shipborne Near 2K	3133 μs (ave. Random)
No. 18	Beaufort MCAS	3251 μs
No. 10	Shaw AFB	3328 μs
No. 15	Ft. Fisher	4146 μs

(b) Interrogators seen at 2M+, but not at 1H (with the 13 shared ones, they make up the 31 seen at 2M+)

		PRI
No. 49	Mayport NS	1522 μs (2nd + 3rd Harm's)
No. 38	Astor Park	2275 μs (ave. Rm)
No. 36	Tallahassee ASR	2498 μs
No. 37	Macon ASR (Robins)	2500 μs
No. 35	Daytona Beach ASR	2559 μs
No. 32	Beaufort MCAS	2594 μs
No. 41	Orlando ASR	2626 μs
No. 33	Cecil Fld NAS	2663 μs
No. 39	Patrick AFB ARSR	2776 μs
No. 60	Panama City ARSR	2818 μs
No. 42	Tampa ASR	2884 μs
No. 48	Shipborne Near 2K	3060 μs

TABLE 5 (Continued)

		PRI
No. 40	Patrick AFB ASR	3342 μs
No. 61	West of Loc. 2M+	3502 μs
No. 62	South of Loc. 2M+	3650 μs
No. 52	Mac Dill AFB	3991 μs (ave. 3-P-S)
No. 51	Mac Dill AFB	4000 μs
No. 44	Mac Dill ARSR	4147 μs

(c) Interrogators seen at 1U, but not at 2M+ (with the 14 shared ones, they make up the 18 seen at location 1U)

		PRI
No. 43	Daytona Ramp Tester	3064 μs
No. 20	Shipborne Near 2K	3133 μs (ave. Random)
No. 51	Mac Dill AFB	4000 μs
No. 15	Ft. Fisher	4146 μs

3.5.1 PRI/PRF Distributions

(1) Distribution at 1H (Figure 8a)

Even though most of the interrogations fall into a third of the range shown (2440 to 3460 μs), all PRI are in the "clear" (they do not overlap each other). The main reason for this is the small number of interrogators seen at location 1H (18 in all). Even the Columbia ASR-7 on 8-pulse stagger dovetails with the rest of the interrogators. Its PRI (shown in Figure 7) indicate the use of a so-called P-Crystal.

(2) Distribution at 2M+ (Figure 8b)*

As might be expected, the distribution at location 2M+, where the transmissions from 31 interrogators were heard, has a number of problems. Tallahassee (on 2498.5 μs) is surrounded by Macon ASR on (2500.8 μs) which uses 5-pulse stagger here. Jacksonville NAS (Int. 24 on 2819 μs) is similarly surrounded by Panama City ARSR (Int. 60 on 2818 μs) which also uses 5-pulse stagger.

The second harmonic of Mayport NS (Int. 49 on 1552 ± 4 μs) extends from 3055 to 3050 μs. This range of random PRI surrounds No. Charleston (Int. 14 on 3040 PRI). It is also within 1 μs of one of the PRI received on 9-pulse stagger (3051 μs), and is within 3 μs of Int. 48 (Shipborne near 2K) which is coming in on 3053 μs here, about 7 μs below its highest PRI observed elsewhere.

Some near coincidences, which cause no problem, are the Daytona Beach/Charleston ASR's and the Aiken AFS/Mac Dill AFB ARSR's. The PRI differences involved here are 6 and 12 μs, respectively. The third harmonic of Mayport (4546 to 4571 μs) is also all in the clear.

(3) Distribution at 1U (Figure 8c)

The small number of interrogators (19) observed here make this distribution very similar to the one at 1H. With the exception of the interrogations from Ft. Fisher and Mac Dill ARSR (which are within 1 μs of each other), all interrogations are in the clear.

*Note that Section 7.2.5 contains a thorough discussion of synchronous interference observed during the Jacksonville flight.

3.6 Reflections Observed (Table 6)

Reflections observed during the flight are listed in Table 6 with the following data:

- Location where reflection was seen;
- Interrogator number;
- Name of interrogator responsible for the refelctions;
- Number of reflections per scan;
- Reflection delays (μs);
- Peak-to-peak loss (dB) with respect to mainbeam;
- Estimated distance from antenna to reflector surface (ft);
- Estimated azimuth of reflector (deg); and
- Angular location of reflections from the mainbeam (deg).

The reflections listed come from four military interrogators which probably use regular SLS. The latter is deduced since the use of ISLS (improved SLS) would probably suppress the reflections, and because the use of no SLS would probably yield much higher interrogation rates in the vicinity of these interrogators.

Interesting reflections occur at location 1Q. The 4.5-μs reflections from interrogator 31 at Jacksonville NAS have sometimes almost no loss associated with them --a highly unusual situation. The fact that the peak power received from interrogator 31 at location 1O is about 10 dB lower (at -54 dBm) than expected, compared to the power received at neighboring locations (see page 4 of Table 4A), suggests that the direct interrogations undergo distructive interference, while the reflected signals (over a slightly different path) are reinforced (arrive in-phase).

3.7 Mode 4 Interrogations Observed (Table 7)

Mode 4 interrogations observed during the flight are listed in Table 7. Each line of the table contains the following information:

- Location where Mode 4 was observed;
- Number of interrogator responsible;
- Name of interrogator responsible for Mode 4;
- Duration of Mode 4 (sec);
- Angular location of Mode 4 in scan w. resp. to mainbeam (deg);
- Distance of interrogator transmitting Mode 4 from the AMF (nmi).

The table shows 15 occurrences of Mode 4 interrogations at a dozen different locations (two separate cases occur at locations 1I, 1K and 2A). The 5 interrogators responsible for Mode 4 are Ft. Fisher, Jacksonville NAS (number 24), Patrick ARSR, Richmond ARSR and No. Charleston.

TABLE 6.

REFLECTIONS OBSERVED

Loc. Code	Interrogator No.	Interrogator Name	Reflections per Scan	Delay (μs)	Loss (dB)	Reflector Dis(')	Reflector Az(°)	Loc. of Refl. in Scan
1A	9	Myrtle Beach	15 18 17 15 18 18	1.8	18	900	250	MB + 177
1B	"	"	22 18 12 25	1.7	37	800	234	MB + 170
1H	24	Jacksv.NAS	38 38 36	9	15	9000	221	MB + 163
1M	"	"	29 39 40 46	3.8	29	2000	76	MB + 121
1R	"	"	19 24 18 8	1	30			
1T	"	"	130 (total)	1,3,4	32	3000	40	MB - 112
1O	"	"	15	1.3	20		13	MB + 43
1Q	31	Jacksv.NAS	14 13 14 14 14 13 10 11	4.5	0.15	2200	150	MB + 148
1R	"	"	6 8 12 12 7	4.5	32	2200	157	MB + 139
2Y	14	No. Charleston	4 14 17	2.2	17	1100	70	MB + 207

TABLE 7.

MODE 4 OBSERVED

Loc. Code	Interrogator No.	Interrogator Name	Length (sec)	Location in Scan	Approximate Distance (nmi)
1B	15	Ft. Fisher	0.10	MB + 21	50
1I	15	Ft. Fisher	0.08	on MB	215
"	"	"	0.22	on MB	215
1K	24	Jacksonville NAS	0.09	MB + 45	35
"	"	"	0.10	MB + 68	35
1S	24	Jacksonville NAS	0.30	MB - 17	16
1T	24	Jacksonville NAS	0.46	MB - 22	36
1W	39	Patrick AFB ARSR	0.25	MB + 46	15
1W+	39	Patrick AFB ARSR	0.37	MB + 167	5
1X	39	Patrick AFB ARSR	0.13	MB + 195	18
2A	39	Patrick AFB ARSR	0.19	on MB	42
"	"	"	0.19	on MB	42
2C	47	Richmond AFS ARSR	0.09	on MB	65
2D	14	No. Charleston	0.20	on MB	250
2N+	24	Jacksonville NAS	0.40	MB - 19	35

Observed durations vary from a low of 0.08 sec. to a high of 0.46 sec. Average duration is 0.215 sec, corresponding to about 70 interrogations.

A surprising fact shown in Table 7 is that a majority of the Mode 4 interrogations were received not on the mainbeams of the interrogators, as one might have supposed, but on their sidelobes. The reason is, of course, that these are called at random times, not when the interrogators are pointing at the AMF, and that they are not SLS protected in the usual way. The Mode 4 from Ft. Fisher (at 1B) is received on the sidelobe at 50 nmi and this is probably nowhere near maximum distance for sidelobe reception.

The Mode 4 was received from No. Charleston (at 2D) on the mainbeam at a distance of 250 nmi. This is probably also nowhere near maximum distance for receiving the mainbeams.

3.8 Effect of Mode 4 on a Typical Transponder (Figs. 9a-9d)

In order to evaluate the detailed effect of Mode 4 interrogations on an average airborne transponder (with a 35-μs suppression time and 60-μs* dead time), a pulse-by-pulse plot was made of over 50 Mode 4 interrogations, received from Ft. Fisher, Jacksonville NAS and Patrick ARSR (at locations 1B, 1K, 1S, and 1X) (see Figures 9a through 9d).

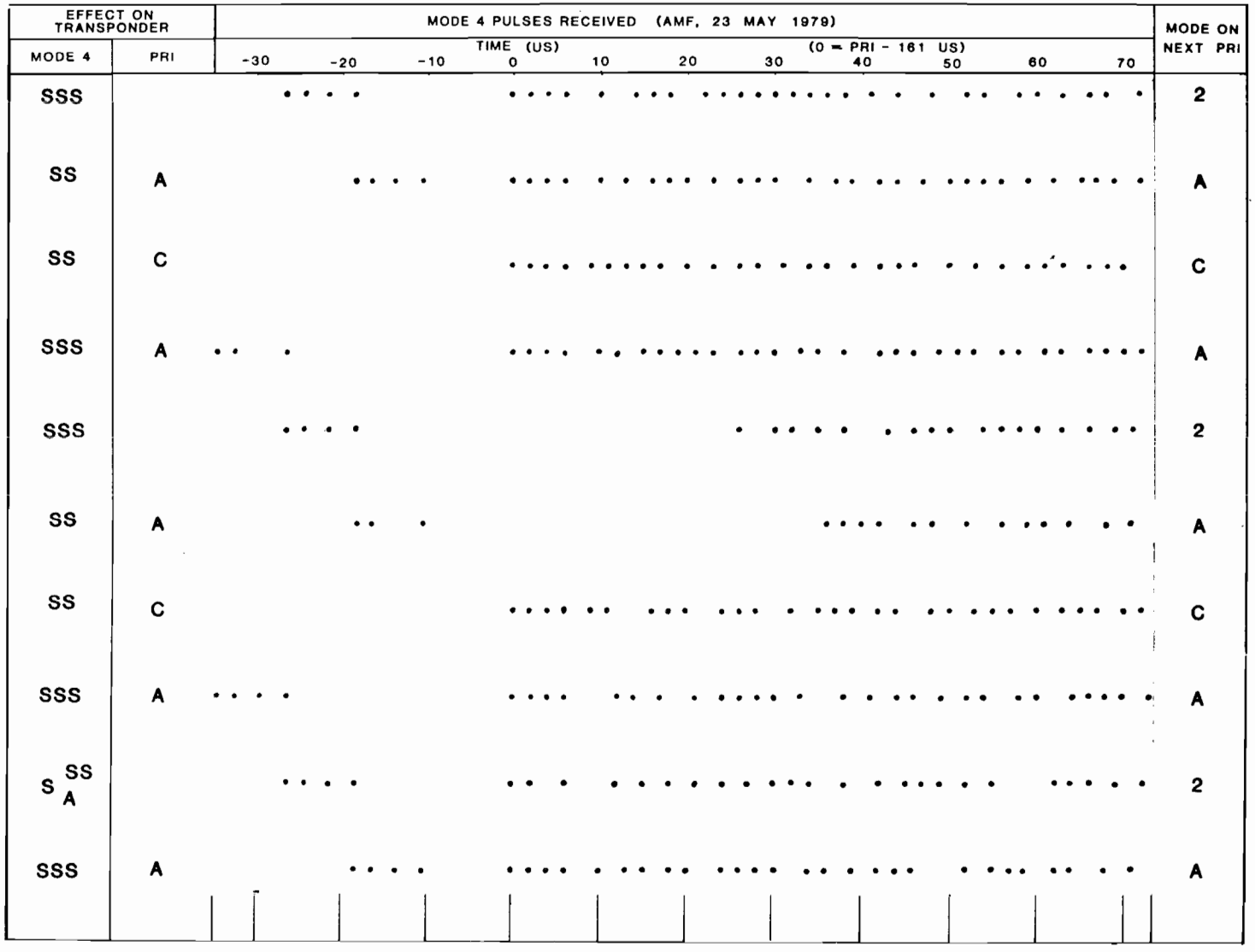
As these plots show, there are two parts to each Mode 4. The major portion is the second portion, starting at zero time, and having sometimes as many as 30 pulses in it. This part always starts with either 4 or 5 pulses 2-μs apart, and these always precede the P3-pulse on the actual PRI of the interrogator by 161 μs. The rest of this pulse group consists of pulses 2,3, or 4 μs apart.

The major group is preceded by 4 pulses separated by 2, 3, and 4 μs, occurring 35, 27, or 19 μs before the main group, in a cyclic manner (or by no pulses at all). The up-coming mode on the PRI is indicated by one of the symbols "2", "A", "C", "A" on the right of each plot (at the end of each line of pulses).

The pulse rate that may be produced by a single interrogator using Mode 4 is very high. For example, if 34 pulses per interrogation occur at an average PRF of 330, this rate exceeds 11,000 PPS.

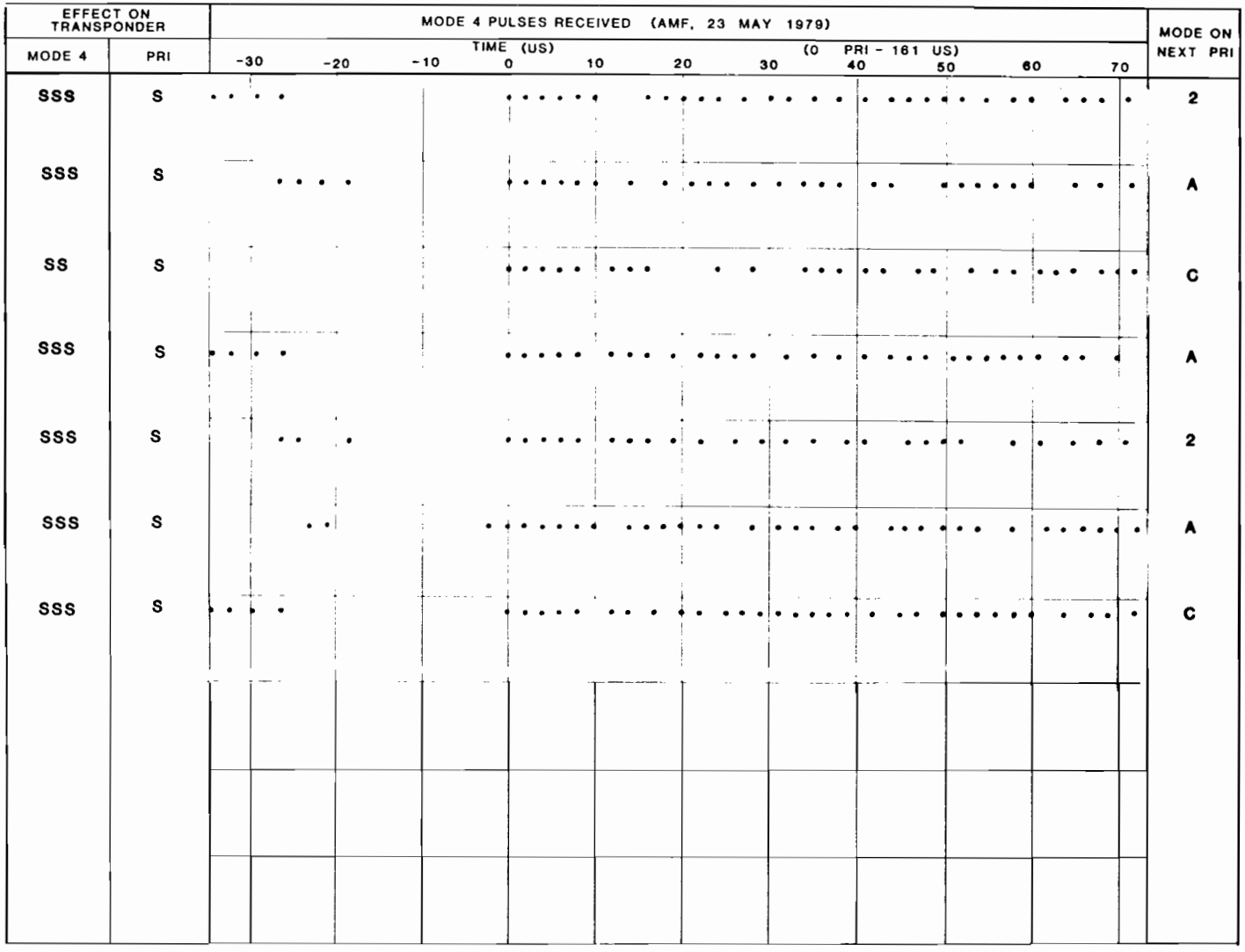
Note that the SLS control pulse (the P2 pulse mentioned in the last three figures for Jacksonville NAS and Patrick ARSR) is actually transmitted in the fifth position for interrogators using SLS. It is shown larger than the other pulses, since on the sidelobes shown here it is transmitted with greater power than are the other pulses. The SLS pulse (the fifth pulse) is missing entirely in the first figure, since Ft. Fisher is not using SLS at the moment.

*Note that the 60 μs dead time was chosen for a mix of civilian and military transponders whose individual dead times average about 35 and 100 μs, respectively, following Mode A/C interrogations. Note that average suppression lasts 35 μs for both types of transponders.

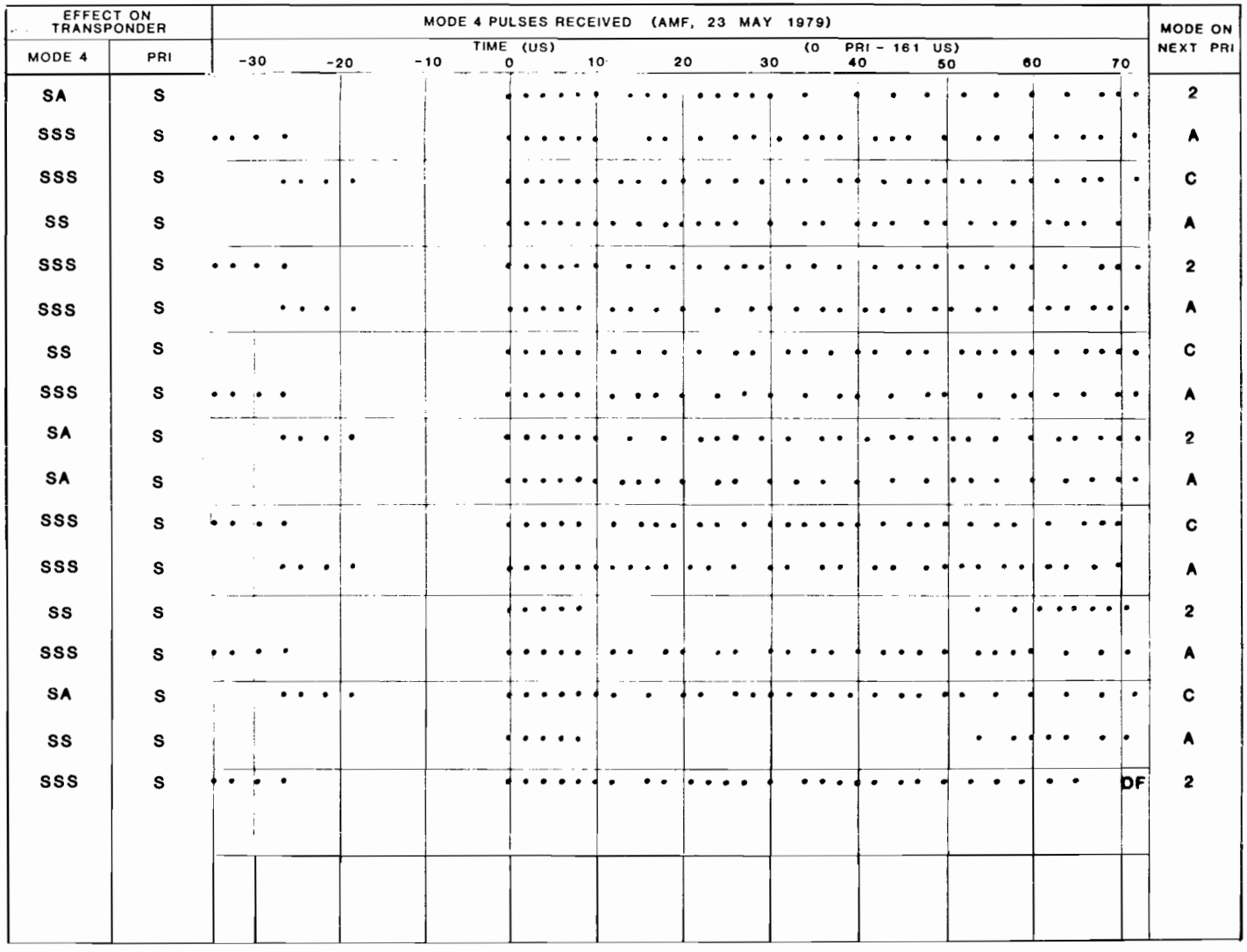


LOC. 1B 50NM WSW OF FT FISHER (INT. 15) MB + 21° NO SLS

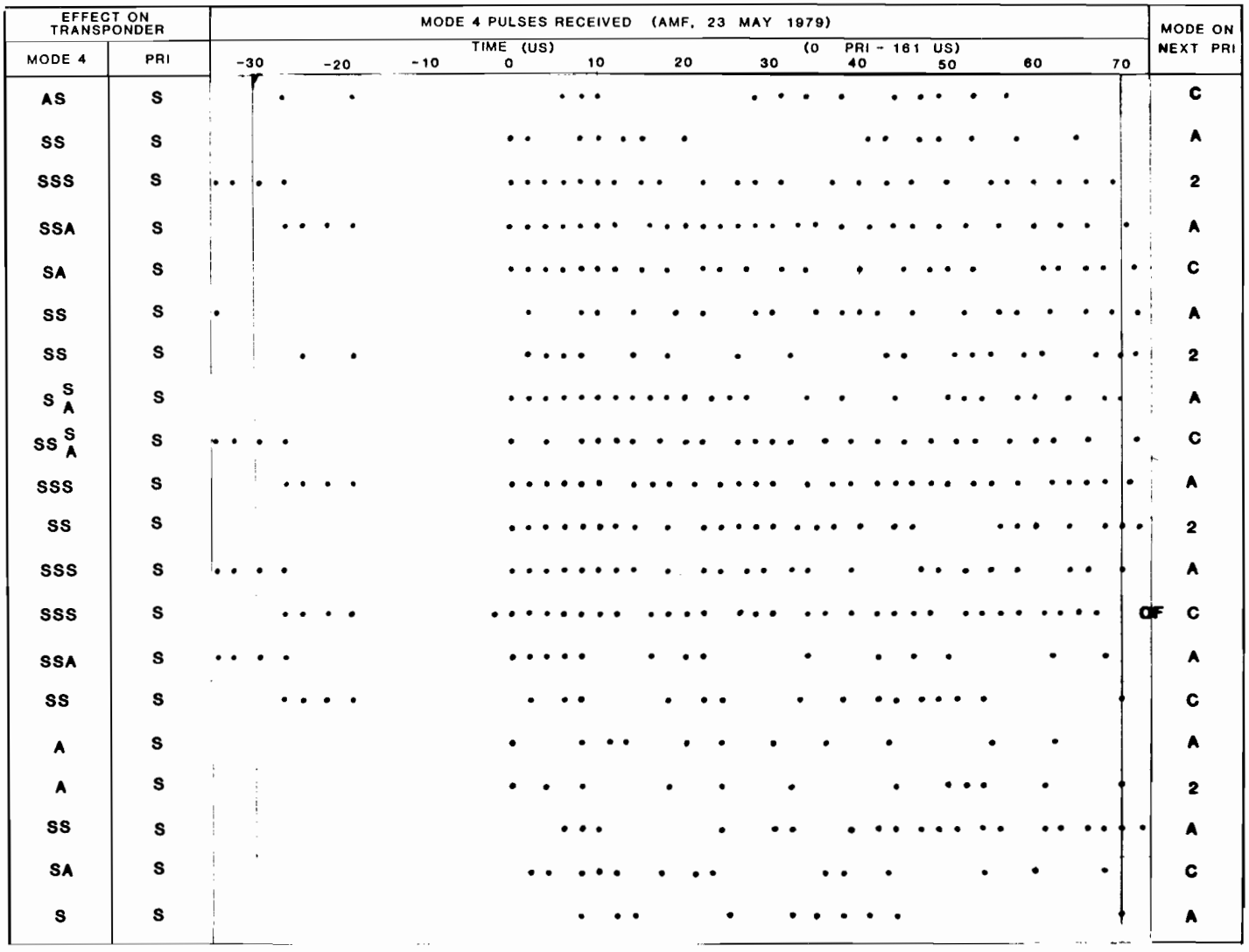
FIGURE 9a



LOC. 1K 35NM WSW OF JACKSONVILLE NAS (INT. 24)
REGULAR SLS MB + 68° P2 - P1 = 10DB
FIGURE 9b



LOC. 1S APPROX. 16NM ESE OF JACKSONVILLE NAS (INT. 24)
SUPPR. REGION 17° BEFORE MB P2(= -58dBm) 5 TO 10dB > P1
FIGURE 9c



LOC. 1X 18NM S OF PATRICK ARSR (5-P STAG, ABANDONED FOR FIXED PRF OF 360.2 DURING MODE 4) MB + 195° TOP = BOT + 3 DB P2 = P1 + 6 DB

FIGURE 9d

(1) Suspension of 5-Pulse Stagger During Mode 4

The Patrick ARSR is one of the 8 FAA interrogators on 5-pulse stagger seen during the Jacksonville flight. Its staggered PRI (shown in Figure 7) was confirmed repeatedly at each recording location by the "PRI Table" of the uplink analysis program.

An interesting observation was made while examining Mode 4 pulse-by-pulse data from Patrick: all Mode 4 transmissions occurred on the fixed PRI of 2776.25 μs, the central PRI of the 5-pulse stagger (corresponding to a fixed PRF of 360.2).

The most likely reason for going to a fixed PRF during Mode 4 is the desire to avoid another level of synchronization at the ground receiver, in addition to normal Mode 4 synchronization. Because of this, it is probably possible to generalize the Patrick example to all en-route interrogators on 5-pulse stagger.

(2) Effect of Mode 4 on Typical Transponder

The more than 50 sequences of pulses shown in Figures 9a through 9d were input into a hypothetical "average" transponder, by sliding it along the pulses from left to right, and ignoring those pulses which happened to fall into the 35 μs suppression time and/or 60 μs deadtime of the transponder. The ensuing sequence of suppression or interrogation events are noted by the symbols "S", "A", or "C" on the left side of the plot (at the beginning of each line of pulses).

The last event on the left (somewhat separated from the others) stands for the suppression or interrogation occurring on the up-coming PRI of the interrogator (161 μs after zero time).

The symbols on the left side of these plots show that the average effect of Mode 4 on the average airborne transponder is a sequence of 2 or 3 suppressions. Occasionally a Mode A occurs, when the coded information in the Mode 4 happens to produce three pulses with inter-pulse spacing of 4 μs each, just when the transponder is coming out of suppression or deadtime. A second mechanism producing Mode A (or even Mode C) is marginal reception, with a large fraction of Mode 4 pulses below transponder threshold (selective reception of the right pulses).

To find the percentage of time an average transponder may be unavailable to an en-route interrogator as a result of Mode 4 interrogations by some other interrogator, the length of half a suppression (20 μs) was added to the 100 μs average pulse lengths in Figures 9a through 9d. The resulting 120 μs divided by a PRI of 3030 μs (corresponding to an average PRF or 330) comes out to almost exactly 4 percent. This increases to 5 percent, if we add one more suppression on the regular PRI of the Mode 4 interrogator, and to 6 percent, if this is considered to be an interrogation.

3.9 Instantaneous Interrogation Rates (Figs. 10a-10e)

Instantaneous interrogation rates measured at locations 1G, 1H, and 2N+ are shown in Figs. 10a through 10e. The rates shown include those of military modes 1 and 2, as well as civilian modes A and C. The left-hand scales show interrogation rates (per second) measured at time increments of 0.01 secs. The right side shows the percentage of time a typical transponder with 60 μsec deadtime would be unable to reply in the presence of these rates. Since high instantaneous rates usually result from the overlapping in time of "bunches" of mainbeam and/or sidelobe interrogations such a condition is commonly referred to as "bunching".

The worst case of bunching observed, that at location 2M+, 24 nm east of Whitehouse ARSR, is not shown in Fig. 10 but is treated separately in Section 4.

It is unfortunate that the AMF data, and the plots, do not include all interrogation rate peaks. This is caused by the need to restrict the amount of data recorded by the AMF during its extended periods of flight. As operated in the Jacksonville area the AMF was set to record for only one minute out of each 10-minute period. Thus only 10% of the environment was observed. In addition, so as to not overload the printer buffer capacity of the ground-based data reduction computer, a further limit was placed on the period of any one run. The net result is that less than 5% of the uplink was available to show instantaneous interrogation rates.

3.9.1 Comments on Bunching at Locations 1G, 1H, and 2M+

(1) Location 1G

The first figure for location 1G includes the mainbeams (MB's) for two ASR's, Augusta and Columbia, in addition to the MB's of two military interrogators, and the sidelobe (SL) of another one. Since the minumum rate (1200 interrogations/sec) that might start reply rate limiting (RRL) in a transponder is reached and exceeded, momentary RRL will occur in the figure.

The second figure for location 1G includes the MB's of one ASR (Charleston) and one ARSR (Jedburg), in addition to the SL of Beaufort MCAS (no. 18). Instantaneous rates here remain below RRL.

Figure 10a

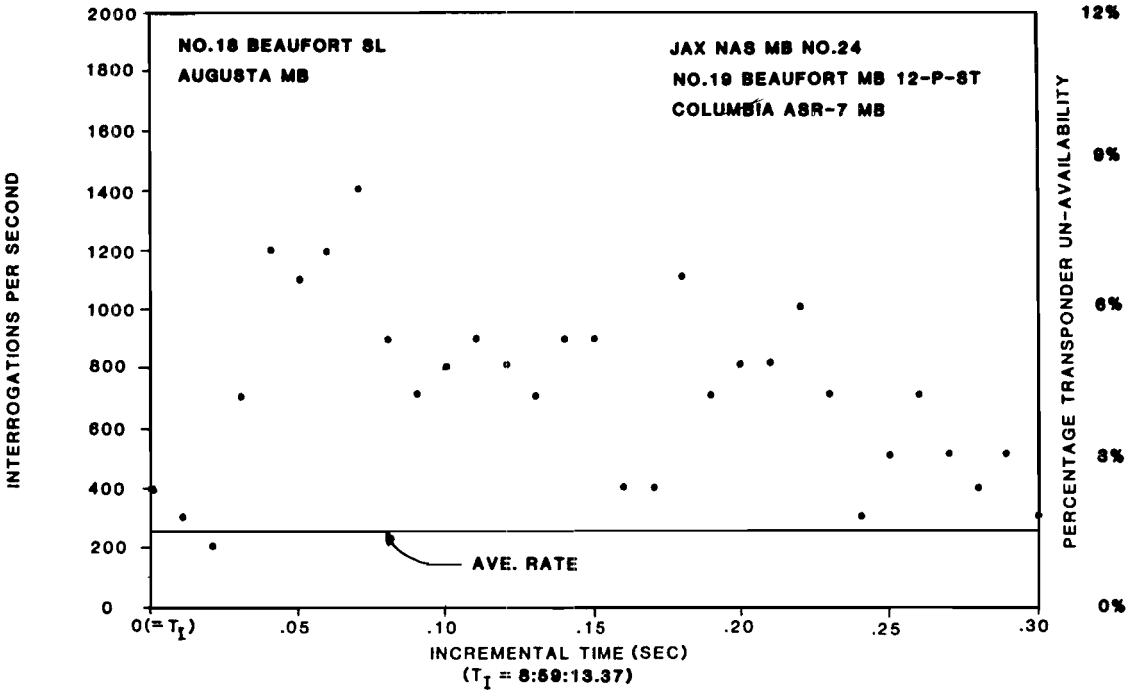
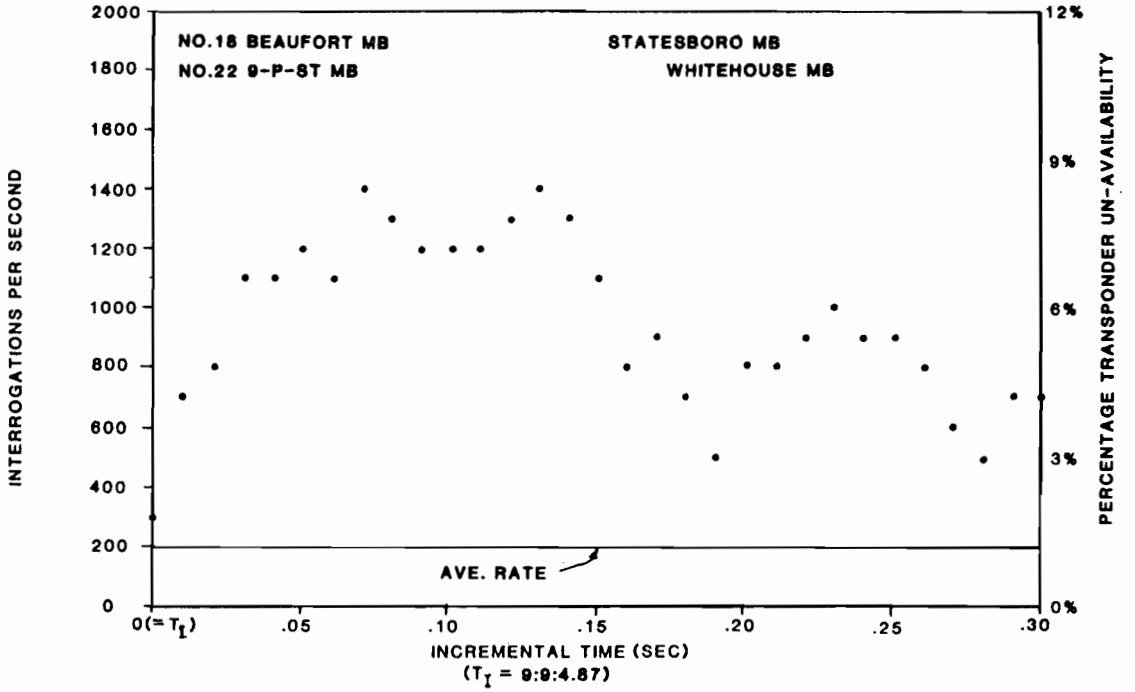
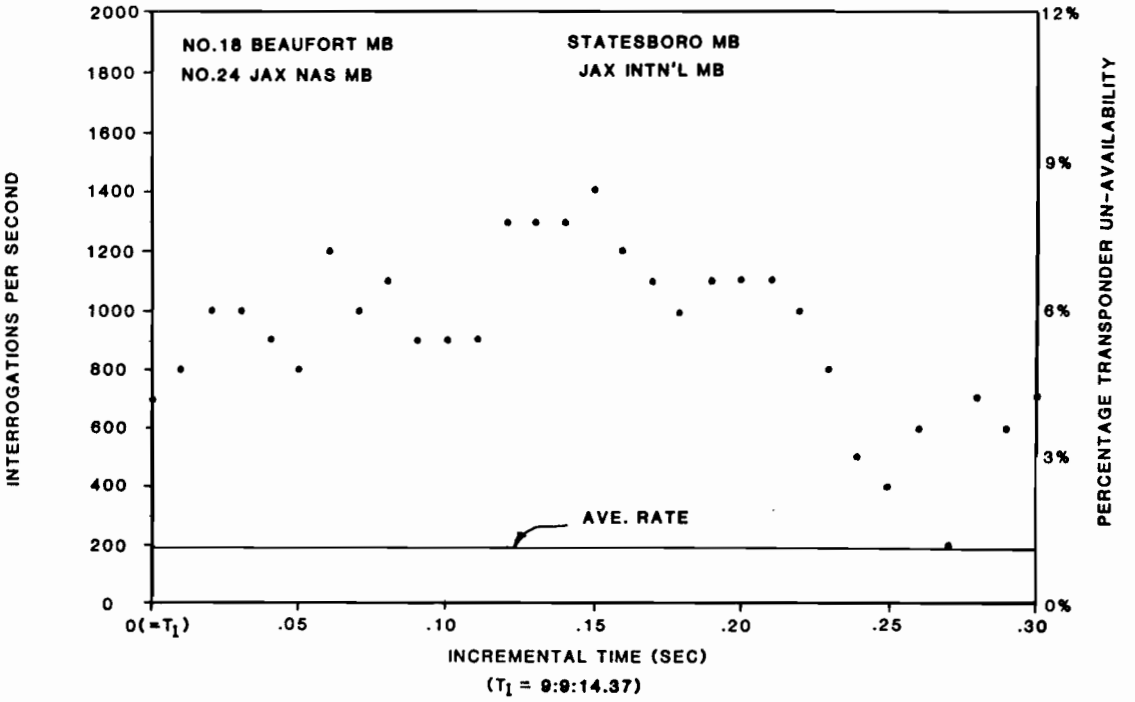


Figure 10b

Figure 10c

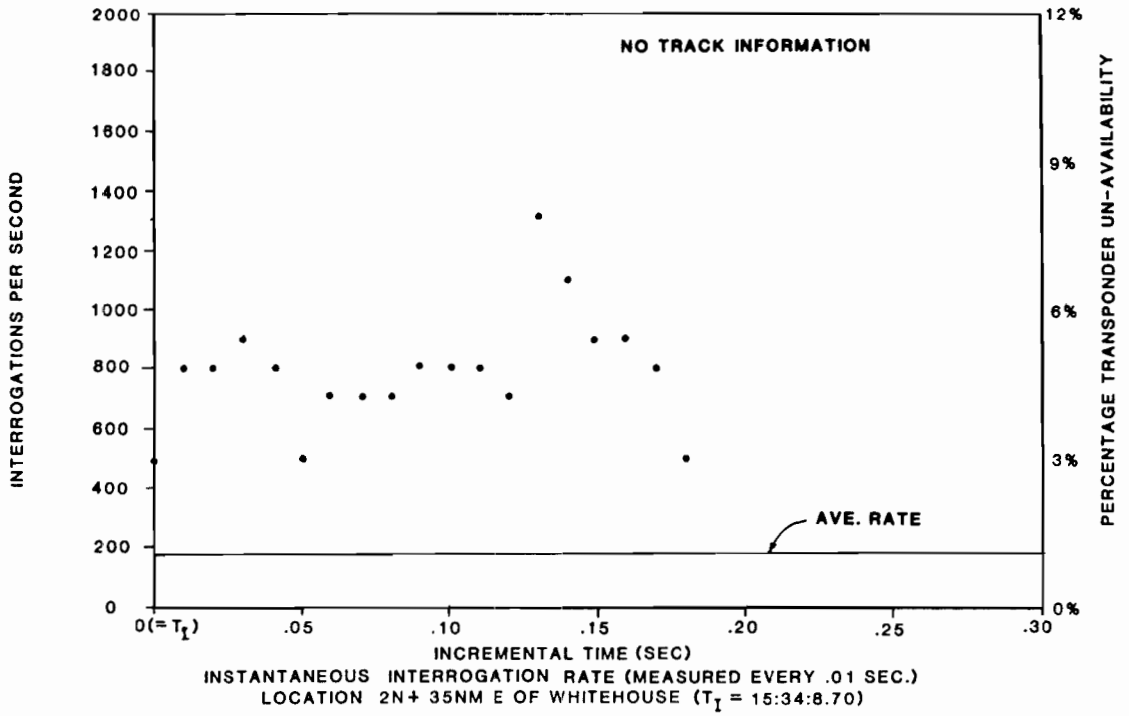




INSTANTANEOUS INTERROGATION RATE (MEASURED EVERY .01 SEC.)
LOCATION 1H 16NM SE OF SAVANNAH

Figure 10d

Figure 10e



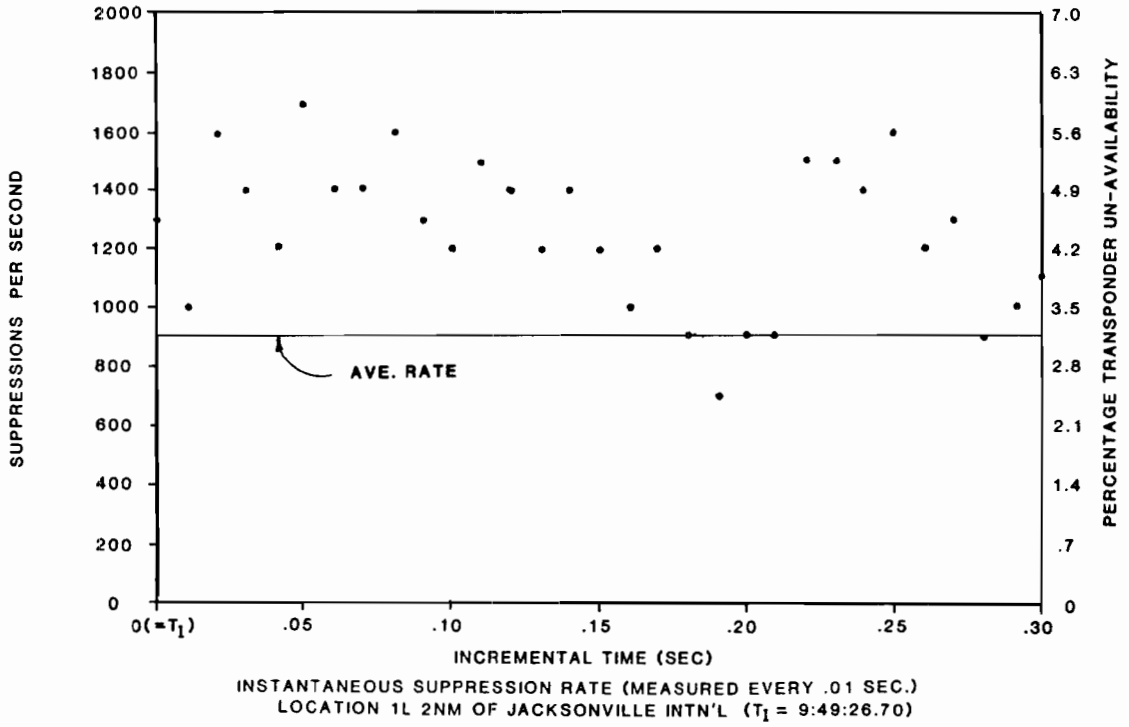
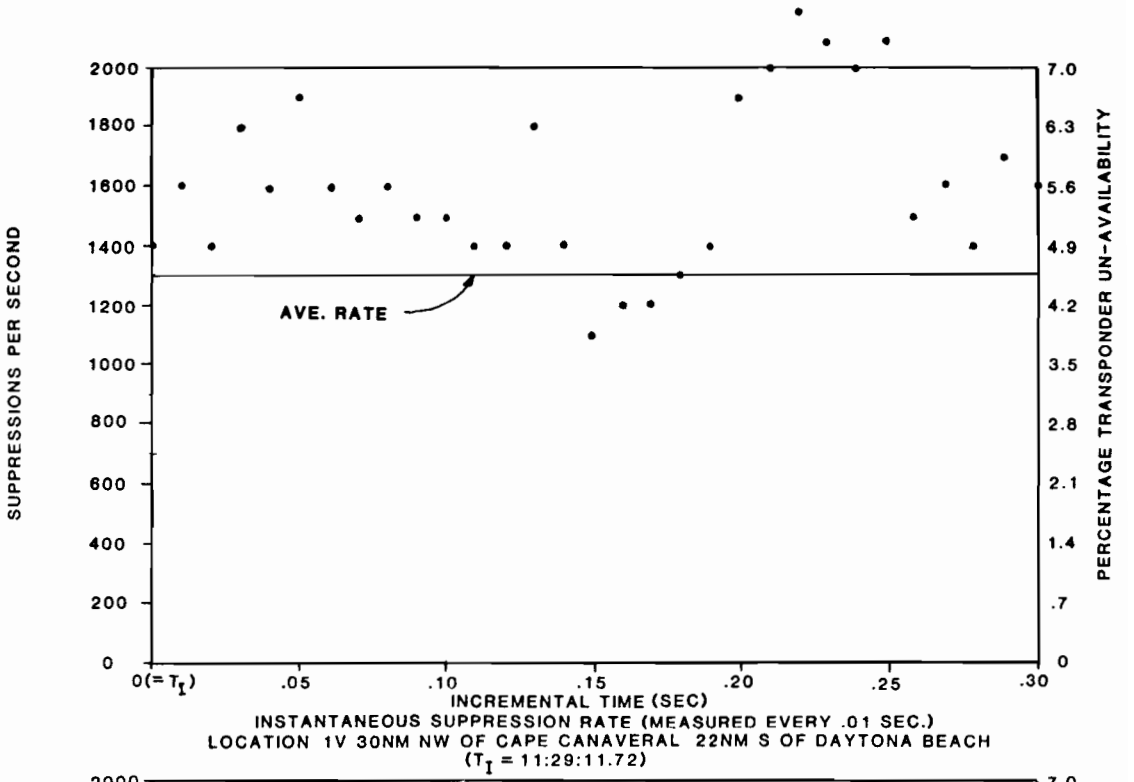


Figure 11a

Figure 11b



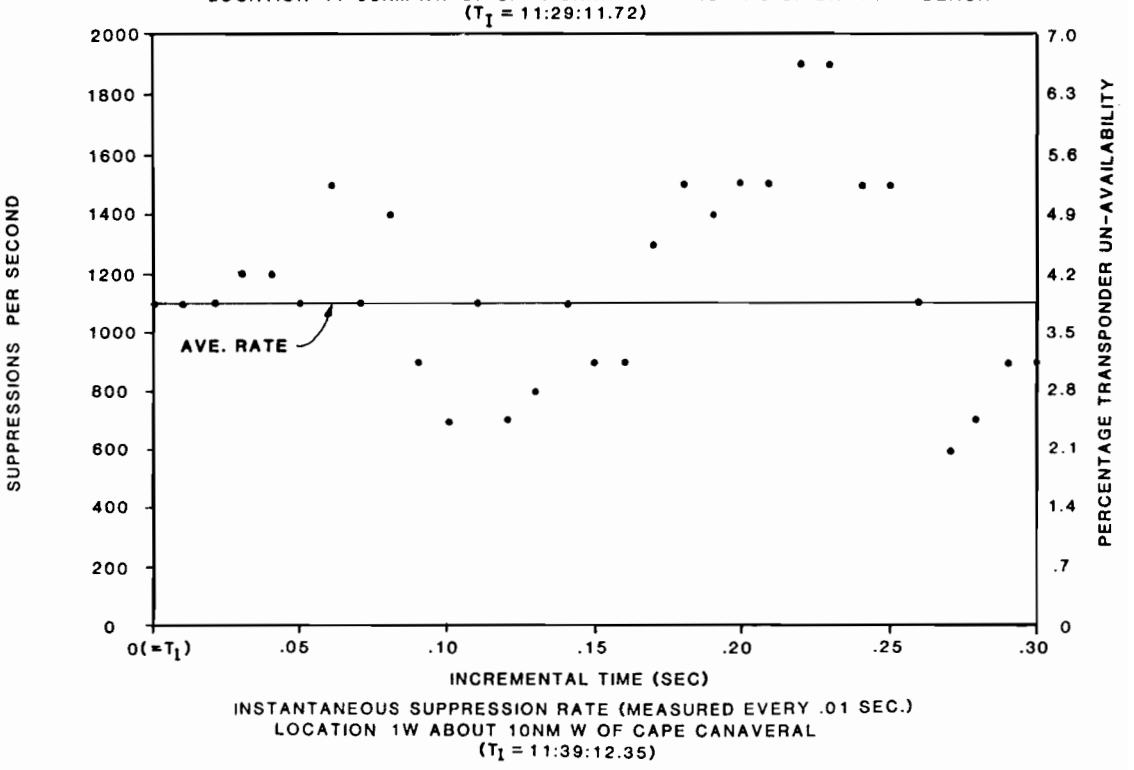


Figure 11c

(2) Location 1H

The first figure for location 1H includes the MB's of Whitehouse ARSR and three military interrogators. RRL may occur for a tenth of a second here, and pose a threat for almost the whole sample period.

The second figure for location 1H shows the MB's of three military interrogators and one ASR (Jacksonville International). RRL is briefly exceeded, and it is a threat for about 0.2 seconds.

(3) Location 2N+

The figure for location 2N+ threatens with reply rate limiting for about 0.15 seconds. Interrogators could not be identified here, since the uplink analysis program did not run to completion.

Transponder unavailability in these figures runs from about 2 to 8 percent for the assumed "average" transponder with 60 μs deadtime. The 8 percent level of unavailability is fairly significant by itself. It may become quite significant due to reply rate limiting, resulting in possible target report and track loss.

Even though these measurement locations were selected to show the occurrence of severe bunching, bunching is more widespread than indicated. In fact, it occurs at most locations where a dozen or more interrogators, some without SLS, are present, regardless of the possibly low average interrogation rate at that location. In the five figures shown here, average rates are exceeded by factors of 5 or 6.

Reply rate limiting is usually not evident in the observed data directly, but rather as a threat only. Frequently bunching occurs at a deceptively low level of perhaps 800-900 IPS. A potential threat to situations like these is the sudden turning on of a military interrogator (without SLS) in the vicinity (which was dormant, and therefore undetected, on the day of the flight). The sidelobe of even one of these could then increase the existing moderate bunching into reply rate limiting and possible track loss.

3.10 High Instantaneous Suppression Rates Observed (Figs. 11a-11c)

Figures 11a through 11c show high instantaneous suppression rates observed at locations 1L, 1V and 1W, which may interfere with normal transponder availability, especially if it should occur together with reply rate limiting. The right hand scales are given in percentage unavailability for an average transponder with 35 μs suppression time.

(1) Location 1L

Location 1L puts the AMF 2 nmi south of Jacksonville International (337 PRF, ISLS), 11 nmi northeast of Whitehouse (365 PRF, SLS), 14 nmi north of the two interrogators at Jacksonville NAS (355 PRF, SLS and 289 PRF SLS), and 16 nmi northeast of the lower-powered interrogator at Cecil NAS (375 PRF,SLS). After subtracting the number of interrogations received from these per second (4 + 4 + 16 + 8 + 4 = 36), the rest of the PRF's add to 1721. This would be the highest average rate we could expect here. We actually get 907, only 53 percent of this. The way this comes about is that we get full suppression from Jacksonville International, no suppression from Cecil NAS, and 50 percent suppression from the other three interrogators with regular SLS (on the peaks of their directional antenna pattern transmitting the P1 pulse, which drops below AMF threshold at the nulls of the directional antenna).

The peak in Figure 11a at a rate of 1700 suppr/sec (6 percent unavailability) confirms the above analysis.

(2) Location 1V

Location 1V places the AMF 22 nmi south of Daytona Beach. The following 7 interrogators have peak received power in excess of -60 dBm here (peak power, PRF and suspected SLS type are shown): Daytona Beach (-49, 391, prob. ISLS); Patrick ASRS (-49, 360, ISLS); Orlando (-52, 381, ISLS); Jacksonville NAS (no. 24) (-52, 355, SLS); Patrick ASR (-57, 300, SLS); Whitehouse ARSR (-58, 365, SLS); MacDill ARSR (-59, 241, prob. ISLS).

Adding all seven PRF's for maximum possible instantaneous suppression rate, we get 2393, just enough to account for the peak shown in Figure 11b (2200 suppr/sec, signifying 8 percent unavailability).

Daytona Beach and Patrick ARSR (on ISLS) contribute about 90 percent of their PRF's (352 + 324 = 676) to the average suppression rate of 1302 suppr/sec here. The rest of the average suppression (1302-676 = 626) is supplied by the remaining 5 interrogations in decreasing percentages.

(3) Location 1W

Location 1W places the AMF 14 nmi north of Patrick AFB. The following 6 interrogators have peak received power equal to or exceeding -60 dBm here (peak power, PRF and suspected SLS type are shown): Patrick ARSR (-36, 360, ISLS); Patrick ARS (-42, 300, SLS); Orlando (-50, 381, prob. ISLS); MacDill ARSR (-53, 241, prob. ISLS); Tampa (-60, 347, prob, ISLS); Jacksonville NAS (no. 24) (-60, 355, SLS).

Adding all six PRF's for maximum possible instantaneous suppression rate, we get 1984, just enough to account for the peak shown in Figure 11c (1900 suppr/sec, corresponding to almost 7 percent unavailability).

We may assume that Patrick ARSR so near, using ISLS, contributes 99 percent of its PRF, or 356 suppressions, to the average suppression rate of 1094 here. The rest of the average suppression (738) is supplied by the remaining five interrogators in decreasing percentages.

4.0 WORST CASE OBSERVED

4.1 Introduction

This section describes location 2M+, where the largest number of interrogators (31) were observed at the same time. As might be expected, this occurred at the point of nearest approach to Jacksonville on the 25,000 ft. radial toward JAX VORTAC, 24 nmi east of Whitehouse ARSR. The section includes:

- A list of the 31 interrogators present at 2M+, with their effective beamwidths (Table 8);
- Plots of the high instantaneous interrogation rates around 2 consecutive mainbeams of Jedburg, Patrick, Aiken, Whitehouse, and Valdosta ARSR's (Figures 12a to 12h);
- A graphical representation of instances of mainbeam coincidence for the 31 interrogators at 2M+, for the 10 minutes following the measurements at 2M+, extrapolated from scan periods measured at the start (Figure 13).

4.2 Average Beamwidth for Interrogators at 2M+ (Table 8)

Table 8 gives a list of the 31 interrogators seen by the AMF at location 2M+, with their "effective" beamwidths which include all sidelobe interrogations.

TABLE 8

"EFFECTIVE" BEAMWIDTHS (DEG) OF 31 INTERROGATIONS SEEN AT LOC. 2M+
(includes all sidelobe interrogations)

Interrogator No.	Name	Effective Beamwidth
12	Charleston ASR	1.56
13	Jedburg ARSR	3.52
14	No. Charleston	4.79
17	Aiken AFS ARSR	2.35
19	Beaufort MCAS	15.01
21	Augusta ASR	.93
22	Shipborne Near 2K	12.70
24	Jacksonville NAS	9.80
25	Savannah ASR	3.08
28	Valdosta ARSR	3.93
29	Whitehouse ARSR	4.19
30	Jacksonv. Intern. AR	5.09
31	Jacksonville NAS	6.07
32	Beaufort MCAS	3.90
33	Cecil NAS	4.65
35	Daytona Beach ASR	4.17
36	Tallahassee ASR	2.75
37	Macon ASR (Robbins)	4.31
38	Astor Park	2.96
39	Patrick AFB ARSR	2.97
40	Patrick AFB ASR	4.13
41	Orlando ASR	3.05
42	Tampa ASR	3.65
44	Mac Dill AFB ARSR	2.37
48	Shipborne Near 2K	21.03
49	Mayport NS	58.00
51	Mac Dill AFB	8.97
52	Mac Dill AFR	3.00
60	Panama City ARSR	1.90
61	West of Loc. 2M+	2.64
62	South of Loc. 2M+	4.37

4.2.1 "Effective" Beamwidths Include Sidelobes

Sidelobe interrogations, when present, increase the probability of being interrogated above the value based solely on the beamwidth of an interrogator. To account for the difference to first order, the beamwidth given by the program must be multiplied by the ratio of total interrogations to mainbeam interrogations (per scan). All but 12 of the 31 entries in Table 8 show "effective" mainbeams widened in this manner.

Before the calculation of average beamwidth needed for the probability calculations below, interrogator 49 (Mayport Naval Station) with a beamwidth of 58 deg was replaced by two interrogators with beamwidths of 29 deg each. This was done because it had a PRF (657) double the usual value, and because the division gives another degree of freedom to the strong sidelobes of Mayport.

The average effective beamwidth for the interrogators in Table 8 is 6.59 deg. Dividing this by 360, we obtain $p = 0.0183$ for the probability of being interrogated by an average interrogator at some instant of time. The value $p = 0.0183$, with $q = 1-p = 0.9817$ will be used below (see Appendix A).

4.3 FAA ARSR Mainbeams at Location 2M+

Marginal instantaneous interrogation rates* (at the time of occurrence of the mainbeams of five FAA enroute interrogators) are described next. Often these rates are not high enough to cause actual reply rate limiting (RRL nominally starts at 1200 IPS, some transponders possibly being set lower). Marginal rates also arise during multi-PRF "synchronous jamming" between interrogators on near-equal scan periods, discussed in Appendix B. The addition of even a single close-by military intrrogator without SLS (which was silent during data recording) would force all marginal situations with incipient RRL into active RRL with all its implications (desensitization, track loss, etc).

The eight figures described here (Figures 12a through 12h) show (high) instantaneous interrogation rates near 2 consecutive mainbeams of the Jedburg, Patrick, Aiken, Whitehouse and Valdosta ARSR's and suggest reply rate limiting (RRL) and the possibility of missed target reports and/or track loss. (Transponder unavailability given below must be incremented by 3 percent due to the 850 suppr/sec at location 2M+.)

The instantaneous rates reported included all modes ("1", "2", "A", "C").

(1) The Jedburg Mainbeams (Fig. 12a-12b)

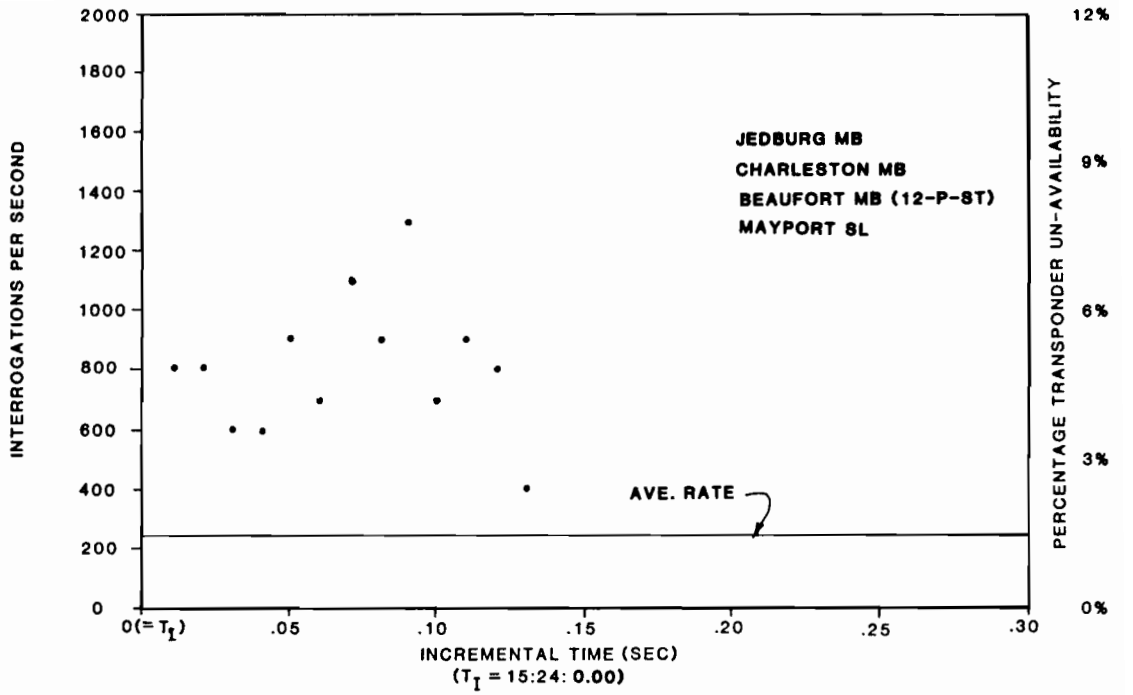
Figures 12a and 12b show only a single point (at 1400 IPS) where reply rate limiting (RRL) would occur, but a strong threat of RRL in the sense described above (via the addition of an interrogator without SLS) exists throughout.

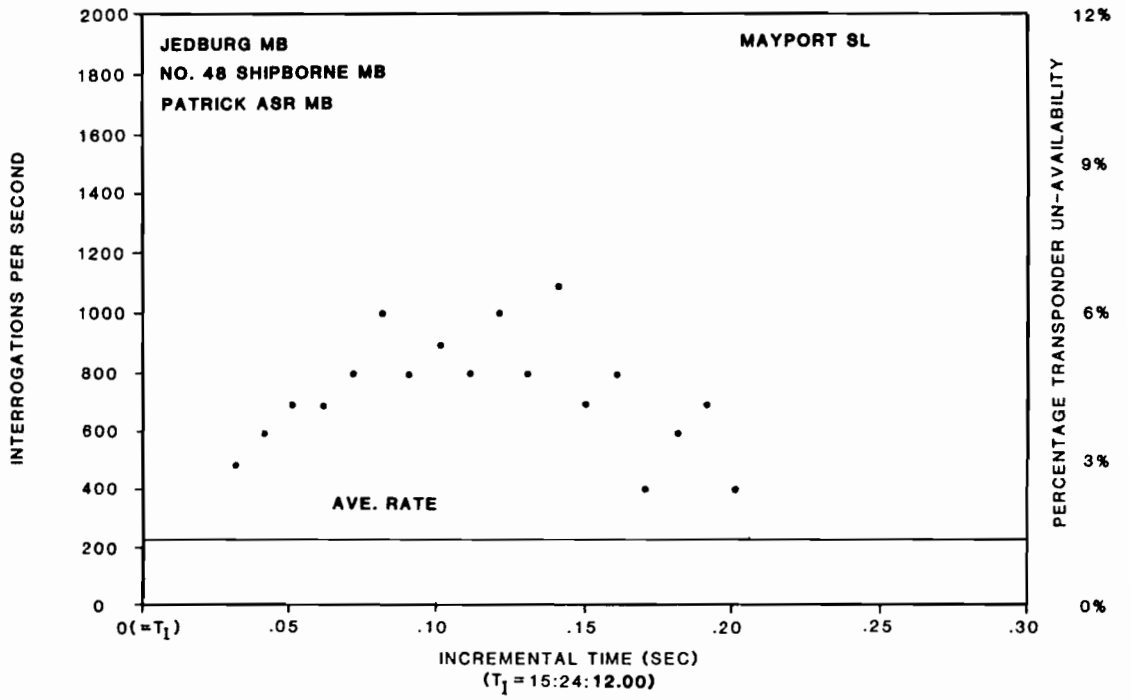
Something unusual happens to Jedburg at this location: its third mainbeam is missing. Peak received power drops by 5 dB from the first mainbeam to the second (-67 dBm vs -72 dBm at the bottom antenna of the AMF). There is another 9 dB loss from the second mainbeam to the three or four interrogations present on the third mainbeam (at -72 dBm). None of this is due to aircraft maneuvering and Jedburg certainly could not be counted on for surveillance here.

(2) The Patrick and Aiken Mainbeams (Fig. 12c-12d)

Figures 12c and 12d include 2 consecutive mainbeams of Patrick and of Aiken, which follow the Patrick mainbeam by about 0.16 sec. This separation between the two mainbeams is increasing, since the interrogator having the later mainbeam (Aiken) also has a 0.005 sec longer scan period than does Patrick, making it that much later every scan.

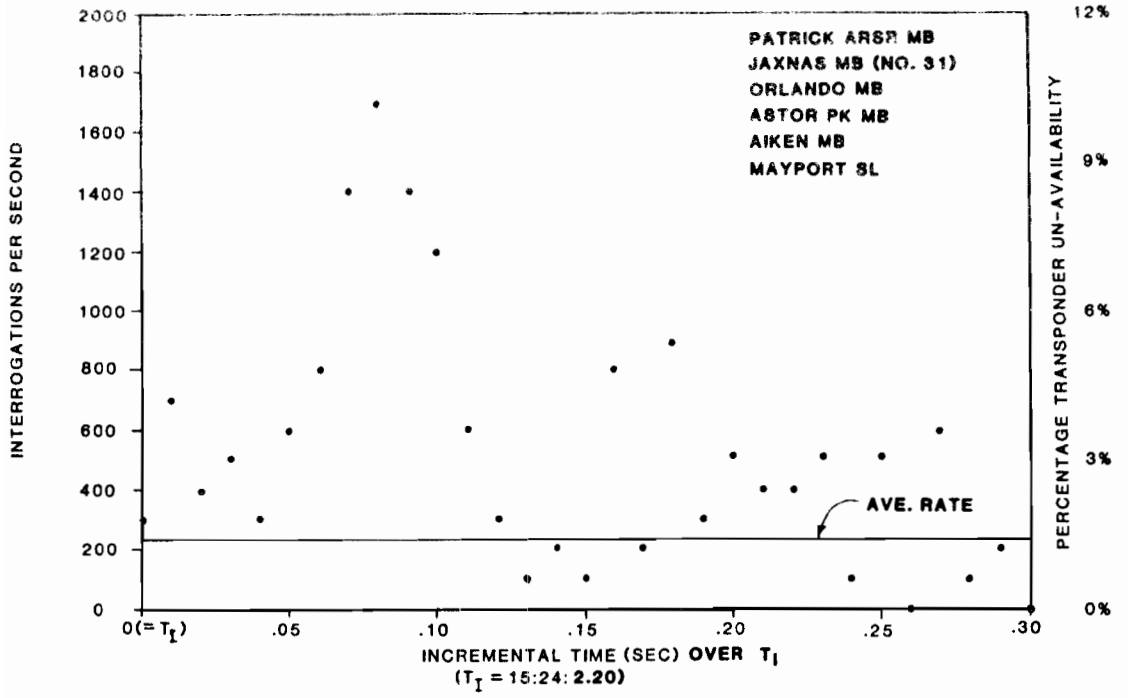
*Rates that approach reply rate limiting.

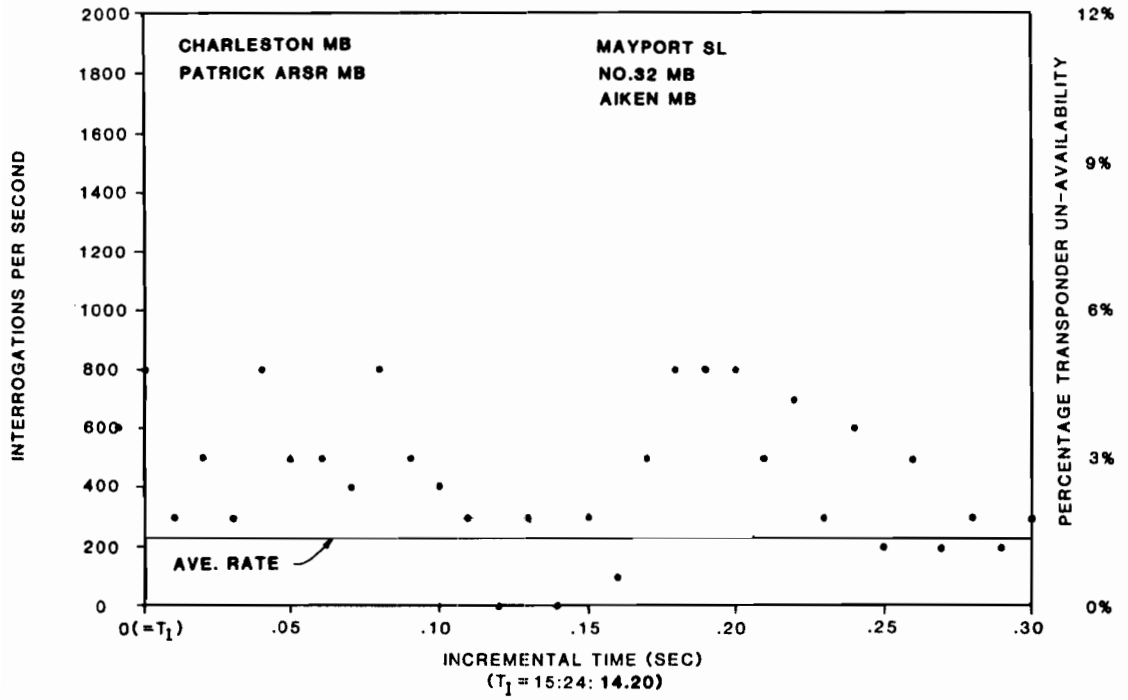




INSTANTANEOUS INTERROGATION RATE (MEASURED EVERY .01 SEC.)
LOCATION 2M+ 13 NM E OF JACKSONVILLE INTN'L

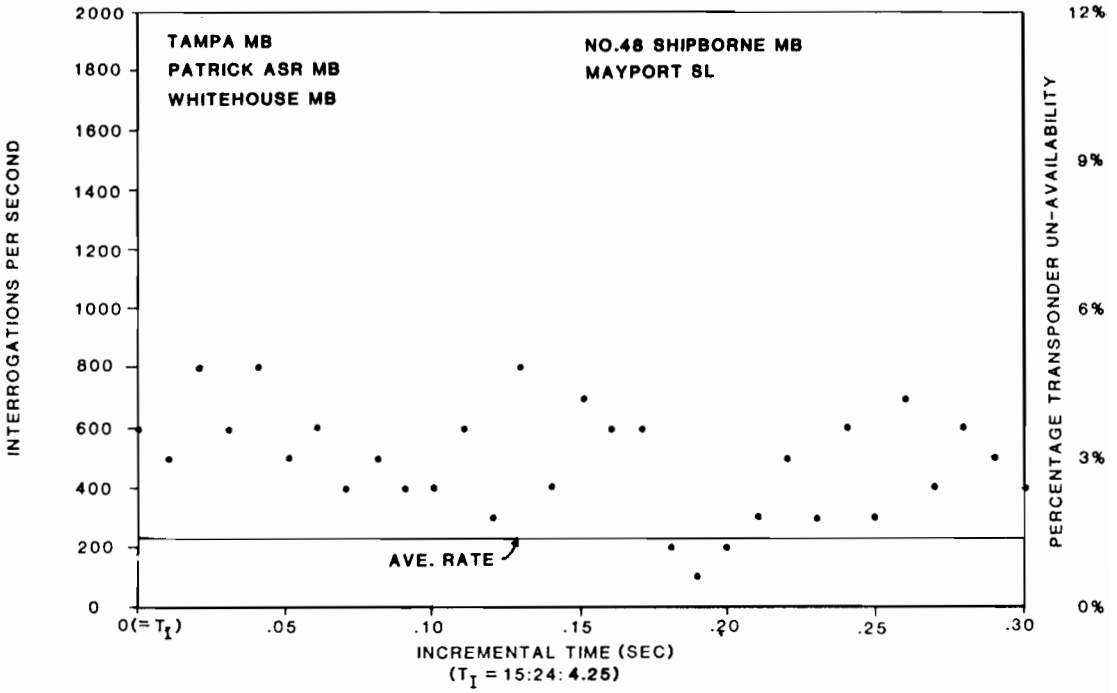
The Jedburg Mainbeams
Figure 12a-b

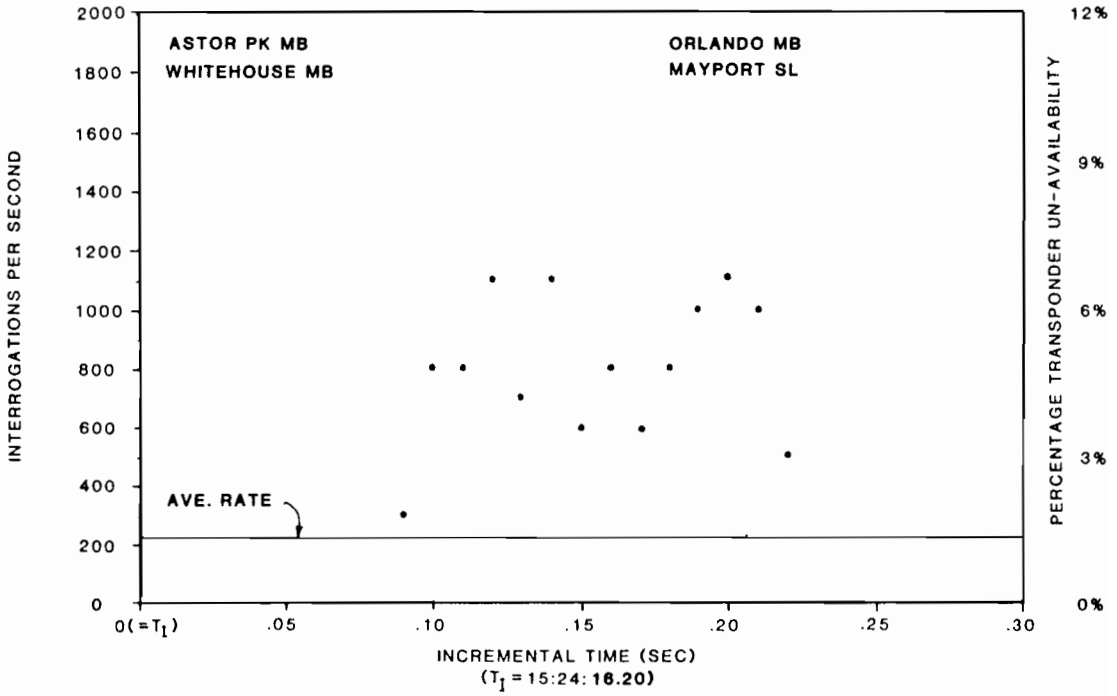




INSTANTANEOUS INTERROGATION RATE (MEASURED EVERY .01 SEC.)
LOCATION 2M+ 13 NM E OF JACKSONVILLE INTN'L

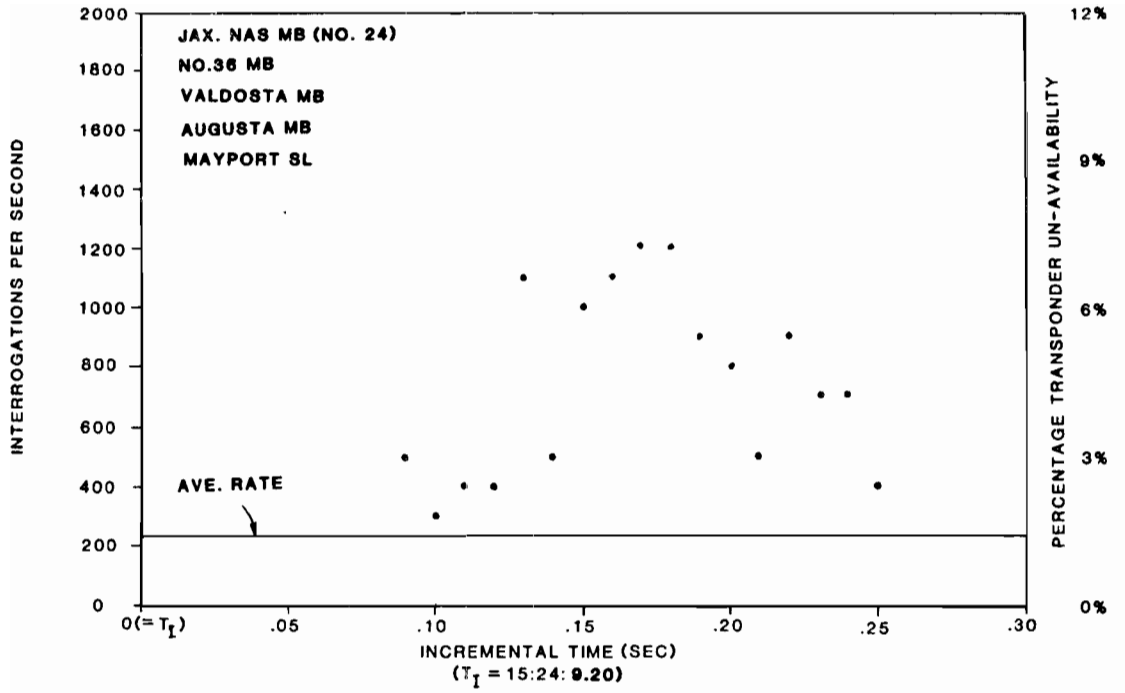
The Patrick/Aiken Mainbeams
Figure 12c-d

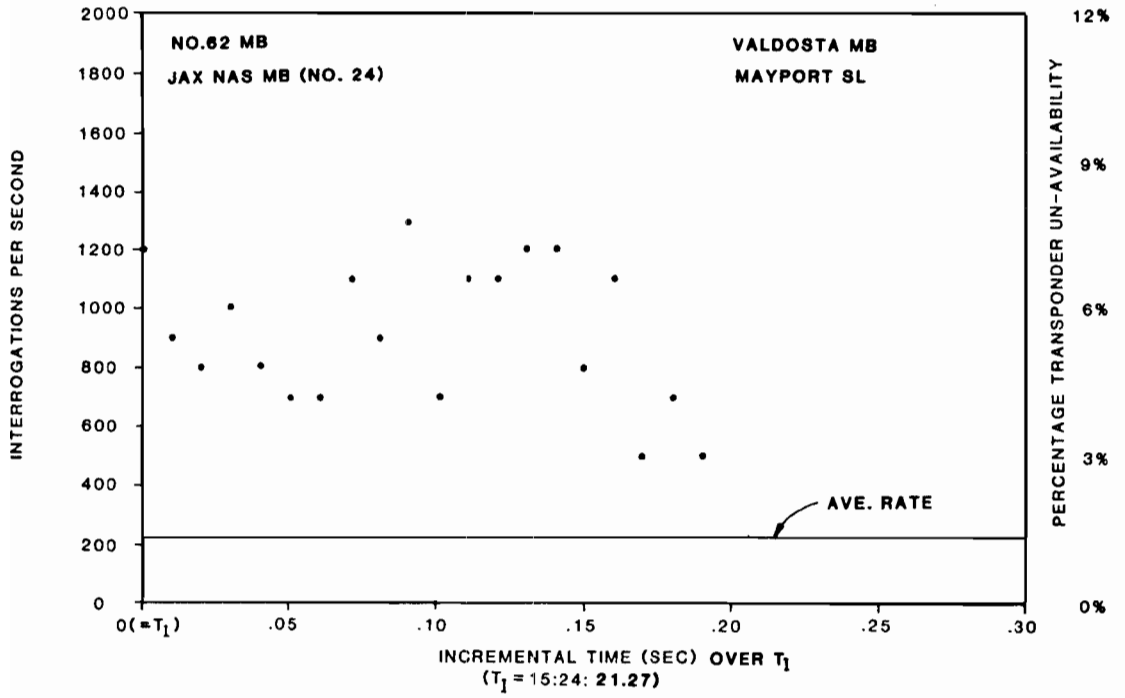




INSTANTANEOUS INTERROGATION RATE (MEASURED EVERY .01 SEC.)
LOCATION 2M+ 13 NM E OF JACKSONVILLE INTN'L

The Whitehouse Mainbeams
Figure 12e-f





INSTANTANEOUS INTERROGATION RATE (MEASURED EVERY .01 SEC.)
LOCATION 2M+ 13 NM E OF JACKSONVILLE INTN'L

The Valdosta Mainbeams
Figure 12g-h

The first figure shows a 40 ms region (peaking at 1700 IPS) where RRL would cause a desensitizing of the transponder threshold. This, in turn, would eliminate replies to Patrick, which is weak here (-72-and -75 dBm peak on the two mainbeams). The Aiken mainbeams are a little more powerful (at -67 and -68 dBm peaks). Neither Patrick nor Aiken could be counted on for surveillance here.

(3) The Whitehouse Mainbeams (Fig. 12e-12f)

Figures 12e and 12f for Whitehouse show a double mainbeam coincidence for the first mainbeam (600 -800 IPS), but also a strong threat of RRL for the second mainbeam. Whitehouse is probably assigned primary surveillance responsibility at location 2M+. In the instances shown, this role would not be seriously threatened, since its powerful mainbeams (both at -43 dBm peak) would overcome a slight desensitization of the airborne transponders.

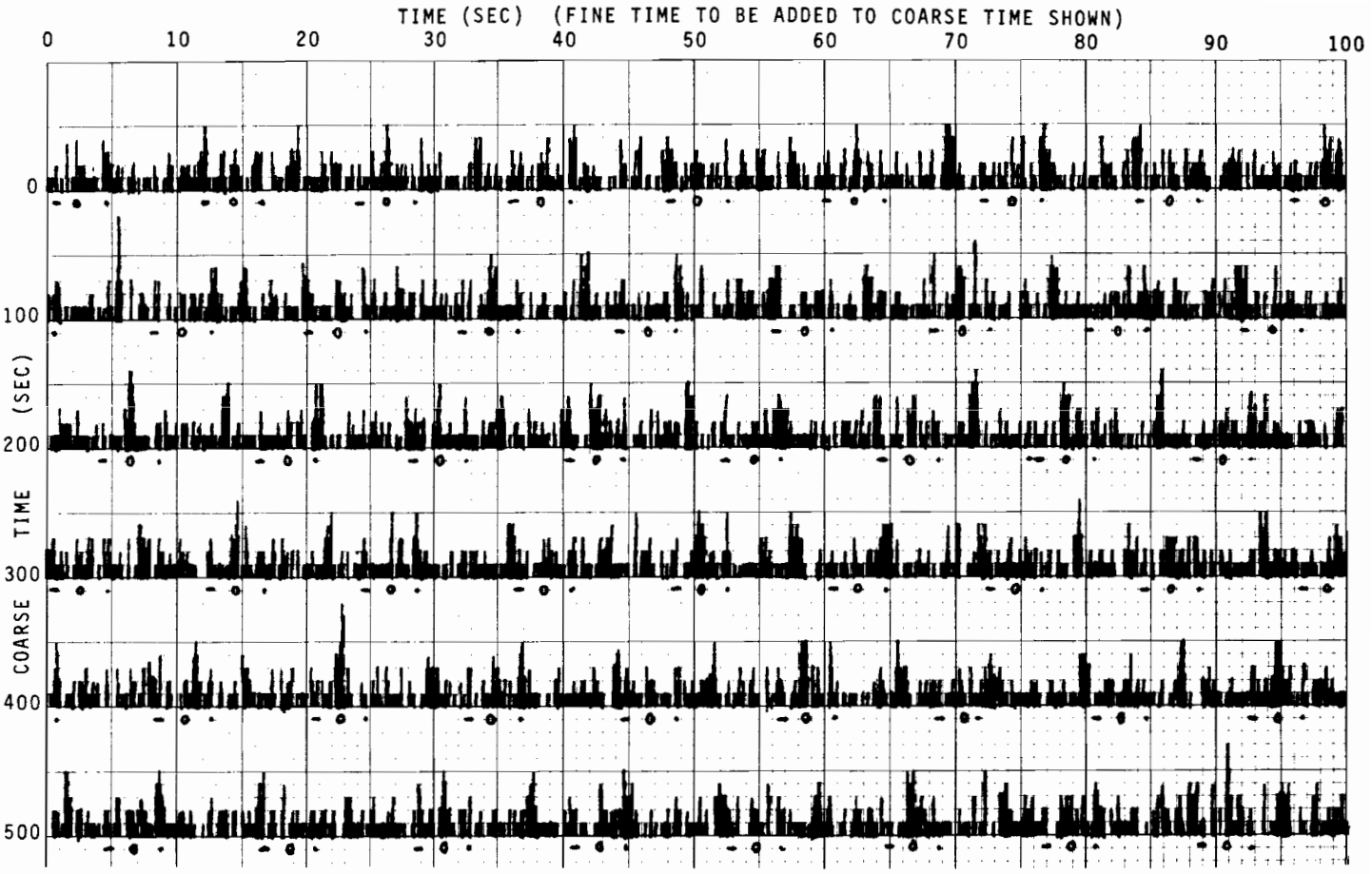
(4) The Valdosta Mainbeams (Fig. 12g-12h)

Figures 12g and 12h show the 1200 IPS level exceeded, or approached, for both mainbeams of Valdosta, making some RRL and transponder desensitization a strong possibility. Valdsota power tops out at about 15 dB below Whitehouse power here (-58 and -57 dBm peak, at the bottom antenna of the AMF). In Valdosta's likely task of secondary surveillance responsibility at location 2M+ modest cases of desensitization might be handled but not strong cases.

4.4 Mainbeam Coincidences for 31 Interrogators at 2M+ (Fig. 13)

Figure 13 shows more than 3000 mainbeams for the 31 interrogators for 10 minutes following the measurements at 2M+, extrapolated from scan periods measured at the start. Mainbeams are superimposed (plotted vertically) for better visibility for (near) coincidences. Jedburg (-), Patrick (o) and Whitehouse (•) mainbeams are marked as shown. Each horizontal division is 1 sec. One line represents 100 sec of "fine" time. A "coarse" time of 100 sec must be added to each successive line. The number of mainbeams plotted for 600 sec total time represented by the figure is inversely proportional to the scan periods. For the most popular scan periods of 3.93, 4.70 and 12.00 sec, these are: 153, 128, and 40 successive mainbeams.

The presence of a mainbeam is shown by a mark one vertical division in height. The only exception is Mayport with its double PRF, which is plotted twice as high. An attempt was made to let the width of each mainbeam indicate the number of interrogations on it. This was not always successful, especially for the narrower mainbeams. The widened "effective" mainbeams shown in Table 8 were also used here.



MAINBEAM COINCIDENCES FOR THE 31 INTERROGATORS OBSERVED BY THE AMF AT LOCATION 2M+ 24 NM EAST OF WHITEHOUSE ARSR (AT 25,000 FT) DURING THE 10-MINUTE INTERVAL 15:24 TO 15:34, EXTRAPOLATED FROM SCAN PERIODS MEASURED AT THE START (23 MAY 1979) JEDBURG (-), WHITEHOUSE (·) AND PATRICK AFB (o) ARSR MAINBEAMS ARE MARKED

FIGURE 13

The fixed scan periods of Figure 13 were used to extrapolate the 31 mainbeams for the 600 sec shown in the figure. Actual scan periods, however, are not absolutely fixed. They change with time, according to the changes in the tangential component of aircraft velocity. Changes are most noticeable in the scan periods of the nearest interrogators.

The unchanging scan periods in Figure 13 actually are scan periods that would be observed by aircraft hovering at 2M+ or entering 2M+ for the 10 minutes following the measurements.

4.5 Discussion of the 3000 Mainbeams

4.5.1 General Remarks

Figure 13 shows that about half of the baseline has at least one mainbeam occupying it. This is in fairly good agreement with the probability of being interrogated by at least one interrogator (P(I) = 0.446) calculated in Appendix A.

Double, triple, and higher order mainbeam coincidences are more and more exaggerated in the plot with respect to their calculated values. But, since the calculations are based on a 5 to 10 percent sample of the uplink on a day when only one third of the military interrogators listed in the ECAC file for the area were observed, it was felt that the unmeasured 90 to 95 percent would have produced "worst case" multiple mainbeam coincidences every bit as bad as the figure even on the day of the flight, not to mention flights on days of really heavy military activity.

As may be imagined, a single military interrogator without SLS, near enough for 100 percent sidelobes reception, would raise the whole plot vertically by the height of one mainbeam (1 division), and two such interrogators, or one on a "double PRF" like Mayport NS, would raise the plot by 2 divisions. Therefore a more accurate extrapolation of the "worst case" into an actual worst case might produce a strong increase in single and double interrogations there. Note that double or higher interrogations would probably produce triple or quadruple interrogations of the same frequency in the hypothesized worst case.

4.6 Predicted Mainbeam Coincidences for ARSR's

Examination of Figure 13 reveals that the relative positions of the mainbeams of the three interrogators marked in the figure remain almost unchanged during the 10 minute period covered by the figure. This happens because of their near-equal scan periods. Numbering these 1 (Jedburg), 2 (Patrick) and 3 (Whitehouse), the following will be calculated (for both the first and the second pair):

- Time to complete mainbeam coincidence;
- Number of partially "jammed" mainbeams before clearance;
- Repetition time of mainbeam coincidences.

For the calculations the following items are needed: the time of occurrence (T1, T2, T3) of the mainbeams, the scan periods (S1, S2, S3) of the interrogators, and the dwell times (W1, W2, W3) of the interrogators (actually we need only the time differences T2-T1 = DT21, T3-T2 = DT32, and the differences in scan period S1-S2 = DS12 and S2-S3 = DS23).

Jedburg	T1 = 0.059 sec	S1 = 12.018803 sec	W1 = 0.117 sec
Patrick	T2 = 2.252 sec	S2 = 12.011305 sec	W2 = 0.099 sec
Whitehouse	T3 = 4.358 sec	S3 = 12.006673 sec	W3 = 0.133 sec

DT21 = 2.193 sec DS12 = 0.007498 sec

DT32 = 2.106 sec DS23 = 0.004632 sec

4.6.1 Time-to-Go for Mainbeam Coincidences

Since S1 is greater than S2, each scan brings MB1 closer to MB2 by DS12 sec, the difference between the scan periods. Therefore the number of scans needed to close the time gap of DT21 sec between MB2 and MB1 is just DT21/DS12, the time difference divided by the scan difference. Multiplying this by the scan period S1 gives the time to go in seconds. Thus, for the time to go to the Jedburg/Patrick overlap:

$$\frac{DT21}{DS12} = \frac{2.193}{.007498} = 292.48 \text{ scans or } 3515.23 \text{ sec or } 0.976 \text{ hours}$$

Similarly, for the time-to-go to the Whitehouse/Patrick overlap:

$$\frac{DT32}{DS23} = \frac{2.106}{.004632} = 454.66 \text{ scans or } 5461.10 \text{ sec or } 1.517 \text{ hours.}$$

4.6.2 Number of Partially "Jammed" Mainbeams (Duration)

If the duration of each overlap is defined as lasting from the time the mainbeams first touch to the time they completely separate again, the duration is given by the sum of the dwell times for the two interrogators (W1 + W2 = L12 and W2 + W3 = L23 in our case). We again have to divide these by the differences in the scan periods to express them in terms of the number of scans they last. Thus, for the duration of the Jedburg/Patrick overlap:

$$\frac{L12}{DS12} = \frac{0.216}{0.007498} = 28.8 \text{ scans or } 346.23 \text{ sec or } 5.77 \text{ minutes}$$

Similarly, for the duration of the Whitehouse/Patrick overlap:

$$\frac{L23}{DS23} = \frac{0.232}{0.004632} = 50.1 \text{ scans or } 601.6 \text{ sec or } 10.03 \text{ minutes.}$$

The number of partially jammed mainbeams is 29 for the Jedburg/Patrick overlap, and 50 for the Whitehouse/Patrick overlap. This result has disturbing implications, especially for a pair of enroute interrogators having primary and secondary surveillance responsibilities for a given area. The extended length of "synchronous jamming" makes the interrogators involved vulnerable to "pop-up" military interrogators as well as other synchronous jammers (interrogators of near-equal scan period).

4.6.3 Repetition Time of Mainbeam Coincidences

Finally, we want to calculate the repetition time of mainbeam coincidences for the above interrogators. In this connection we know that, for a pair of interrogators, the overlaps repeat whenever we go through n scans, such that n times the longer scan period equals (n+1) times the shorter scan period. In our two cases we have nxS1 = (n+1)xS2 and mxS2 = (m+1)xS3, since S1>S2>S3. The first equation is equivalent to nx (S1 -S2) = S2 and to n = S2/(S1-S2) = S2/DS12. Thus we get for the repetition time of the Jedburg/Patrick mainbeam coincidences:

$$n = \frac{12.011305}{0.007498} = 1602 \text{ scans or } 19253 \text{ sec or } 5.34815 \text{ hours}$$

Similarly, for the repetition time of the Patrick/Whitehouse mainbeam coincidences:

$$m = \frac{12.006673}{.004632} = 2592 \text{ scans or } 31135 \text{ sec or } 8.64852 \text{ hours}$$

4.6.4 Percent "Jammed" Mainbeams

Having now obtained both the lengths of the partial overlaps (346 and 602 sec) and their periods of repetition (19253 and 31135 sec), the first set can be divided by the second set to arrive at some percentages. The results are 1.8 and 1.9 for the overall percentage of mainbeams partially jammed by the Jedburg/Patrick and Patrick/Whitehouse overlaps, respectively.

5.0 AMF COVERAGE DATA COMPARED WITH FAA ENROUTE RECORDINGS

5.1 Target Reports From the FAA Enroute Interrogators

FAA enroute interrogators generate "target reports" which include range, azimuth, transponder code, mode C altitude and a time of validity for each aircraft within their area of coverage. These are generated when the narrow pencil beam of the antenna points directly at the aircraft. Target reports for any given aircraft are, therefore, separated from each other by the scan period of the interrogator (usually 12 seconds).

5.2 Tape Recordings of Multi-Site Target Reports

The FAA is equipped to make magnetic tape recordings of target data for a number of interrogators at the same time for any length of time. Each tape includes target reports for all aircraft "seen" by the interrogator. It is possible to extract only those having a specified transponder code. If that code has been assigned to a single aircraft only, a printout may be generated of the target reports of that aircraft alone. In this manner, printouts were generated using the unique code of the Cessna 421 flying the AMF.

5.3 Coverage Measured Two Ways (Ground-Based and Airborne)

If a ground recording is started before an interrogator first acquires an aircraft, and it is continued beyond the time it loses the aircraft again, a record is made of the total "coverage" (visibility) along the air route flown by the aircraft. If the aircraft involved is capable of recording the interrogations arriving from the ground, and, through computer analysis, converting these into a coverage measurement of its own (as is the AMF aircraft), the two (airborne and ground-based) coverage measurements may be directly compared.

Two important questions that may be asked are:

(1) Do the coverages (visibilities) measured in two different ways yield the same results?

(2) Can missing target reports on the ground be explained through the data recorded by the AMF?

5.4 The Extent of the Two Coverages Compared

Ground interrogators provide surveillance information by decoding replies sent to them by the airborne transponders installed on all aircraft. In the case of the Cessna 421 flying the AMF, the transponder was a King KXP-775 with a sensitivity of -70 dBm at the antenna (mounted at the bottom of the aircraft, about 12 ft. from the bottom antenna of the AMF).

The AMF records all pulses at 1030 MHz (the ground interrogator channel), with their time of arrival, angle of arrival, width, and power received on the top and bottom antennas. After the flight, the AMF uplink analysis program first converts these pulses into a set of interrogations, then (using the underlying PRF's) detects the presence of all the individual interrogators at the point where the measurements were made. For the interrogators detected this way, we say that their AMF-measured coverage extends to the point in question. (Bottom antenna power was selected by the program over a threshold of -75 dBm.)

During the southerly (inland) leg of the AMF flight at 10,000 ft., complete coverage recordings were made for the following enroute interrogators of the Jacksonville Center:

Jedburg, SC.,
Aiken, SC.,
Whitehouse, FL., and
Valdosta, GA.

Note that these are arranged in the order they were first observed by the AMF, as can been seen from Figure 6. Individual coverage comparisions follow. Nominal zero-degree visibility at 10,000 ft is about 125 nmi.

(1) Jedburg Coverage Compared

The visibility matrix of Figure 6 shows that the AMF observes Jedburg from location 1A to 1J. The FAA printout starts when the AMF is at 93 nmi (between 1A and 1B), and it ends when the AMF is at 140 nmi (5 min past 1J). Solid hits end when the AMF is at 110 nmi (3 min past 1I). The two coverages are almost identical.

(2) Aiken Coverage Compared

The AMF observes Aiken from 1C to 1J and again at 1P (a location very near 1J). The FAA printout starts when the AMF is at 148 nmi (3 min before 1B), and it ends when the AMF is at 126 nmi (1 min before 1I). Solid hits start when the AMF is at 119 nmi (2 min past 1C). The FAA printout also shows 1 min of coverage 4 min before 1P, when the AMF is at 141 nmi. The two coverages are almost identical.

(3) Whitehouse Coverage Compared

The AMF observes Whitehouse from 1G to 1W. The FAA printout starts when the AMF is at 171 nmi (5 min past 1E), and it ends when the AMF is at 113 nmi (4 min pas 1V). Solid hits start when the AMF is at 145 nmi (5 min past 1F). The coverages are almost identical.

(4) Valdosta Coverage Compared

The AMF observes Valdosta from 1H to 1T. The FAA printout starts when the AMF is at 141 nmi (4 min before 1H), and ends when the AMF is at 119 nmi (5 min past 1S). Solid hits start when the AMF is at 115 nmi (2 min before 1I). Once again, the coverages are almost identical.

(5) Partial Coverages at 25,000 ft. Compared

FAA recordings were started for Jedburg and Whitehouse during the northerly leg of the AMF over the ocean at 25,000 ft, 2 min before the AMF reached location 20 (2"0"), as the AMF was heading east, 46 nmi from Whitehouse. The recordings were continued until both sites lost the AMF. Here only coverages from this point on can be compared. Note that nominal visibility at 25,000 ft is about 190 nmi.

Figure 6 shows that both sites are observed by the AMF at location 2"0", and that Jedburg visibility continues to location 2Y, where the last segment of AMF data was recorded, but Whitehouse visibility stops much earlier, at location 2S.

The FAA printout for Jedburg ends when the AMF is at 124 nmi (2 min before 2Y). During the last 7 minutes of the printout the AMF descended to 12,000 ft. in preparation to landing and re-fueling at Fayetteville, NC. Maximum (167 nmi) range from Jedburg is shown by the printout to occur at location 2R. The two coverages are seen to be identical from location 2"0" on.

The FAA printout for Whitehouse ends when the AMF is at 194 nmi (2 min past 2T). Solid hits end when the AMF is at 181 nmi (6 min past 2S). The FAA and the AMF coverages are again identical for the duration of the FAA printout.

Thus the FAA enroute recordings provide an almost 100 percent confirmation of the visibilities observed by the AMF and reported in the present paper.

5.5 Missing Target Reports Are Due to Marginal Propagation

Each target report for the AMF aircraft (the Cessna 421) at a given en-route interrogator corresponds to a mainbeam of that interrogator observed by the AMF at the same time. An extra target report occurs when the transponder of the Cessna replies to interrogations below the threshold of the AMF.

A missing target report occurs when the interrogations on a mainbeam are below the threshold of the Cessna transponder, or replies sent back by the transponder on 1090 MHz are below the threshold of the en-route interrogator. At times like these, the AMF may observe part or all of the corresponding mainbeam of the interrogator.

Since the AMF and the Cessna transponder are independent devices, there is not a one-to-one correspondence between the number of interrogations on any mainbeam as observed by the AMF, and the number of replies sent back by the Cessna transponder - although there is rough overall agreement.

Target reports are separated from each other by the 12-sec scan periods of the en-route interrogators involved. FAA printouts show missing (single or multiple) target reports by virtue of the fact that a "delta time" has a value of some multiple of 12 sec, rather than 12 sec (as is the case for solid reports).

During the course of this investigation, the FAA printouts for Jedburg, Aiken, Whitehouse and Valdosta were examined for missing target reports. Even though the large majority of these occurred in-between AMF recordings, enough of them were found in the common intervals of time to arrive at the following conclusions.

Missing target reports usually mean no AMF visibility, either because of low received power below the AMF theshold, or due to submarginal propagation. For those locations where AMF visibility exists without FAA visibility, the AMF consistently:

- Receives marginal power in the -70 to -75 dBm range;
- Finds fewer interrogations than on neighboring mainbeams;
- Has (almost) complete mainbeams missing.

In other words, missing target reports are consistently due to marginal uplink propagation.

6.0 DETAILED SUMMARY OF RESULTS

Section 6 gives a detailed summary of results presented in the body of the report. Results are summarized in order of their initial presentation.

6.1 Combined Uplink Environment

6.1.1 Southerly Leg at 10,000 Ft

Except for the Jacksonville circle, this leg coincided with the Atlantic coast line almost exactly (see Fig. 1). Pertinent data are shown in Table 1, and are plotted in Figures 2 and 3. Since over half of the high pulse rate recorded near Craig Municipal Airport (at 1R+) came from some transient rather than a bona-fide interrogator, the first leg of the flight produced fairly uniform pulse rate between 2 and 4 thousand PPS, one- to two- thirds of which were unassociated ("stray") pulses--mostly P2's of unimproved SLS used in the area. Suppressions varied more, peaking near Charleston (1E), Jacksonville (1L, 1R) and Daytona Beach (1V) (720 to 1300/sec).

Interrogation modes were fairly uniform, except at the beginning of the flight (1A, 1B, 1C), where Ft. Fisher (on 2ACA, 241 PRF) has essentially contributed 100 percent of its PRF by suspending its use of SLS for a while (it was resumed again by the end of the flight). Otherwise, mode A ran between 30 and 60/sec. Mode C ran 60-70 percent of mode A. Modes 1 and 2 ran 60-70 percent of mode C (except for the "dip" in mode 1 near the start).

6.1.2 Northerly Leg at 25,000 Ft

Pertinent data are shown in Table 2, and are plotted in Figures 4 and 5. The northerly leg over the Atlantic produced lower and less uniform pulse rates than did the first leg, which attained the 2 to 5 thousand PPS range only once near the midpoint of the flight (during the Jacksonville appraoch). A smaller peak of 1350 PPS developed near the start of the flight (at 2E), and a somewhat larger one (2000 PPS) near its end (2Y). Stray pulses, once again, made up 1 to 2 thirds of the total. Suppressions varied even more than they did going south, having their highest peak of 850 PPS near Jacksonville (2M+), two smaller peaks at the two ends, but deep vallies in between, at the two locations most remote from land (at 2F and 2U).

Interrogation rates started low, increased sharply along the Jacksonville radial, to decrease again some towards the end of the flight. Only mode A had a significant peak near the end, due to a single mode A interrogator (No. 55) on 1096 PRF (using SLS), which increased the ambient mode A by 20/sec. Mode A went from 11 to 73/sec from the start to the middle of the flight, to level off around 40/sec thereafter. Modes 1, 2, C and A were in the approximate ratios 1 : 2 : 4 : 8, except at 2M+ (near Jacksonville), where Mayport NS (on a PRF of 657) contributed about 80 mode 2's/sec. The dependence of pulse, suppression and interrogation rates on the distance of the AMF from land and the ground interrogators thereon is quite evident.

6.2 The 59 Interrogators Detected in the Data

6.2.1 Interrogator Parameters

The 2-part Figure 6 lists the 59 interrogators in the order they were discovered. Seven important parameters are shown for each: (1) Number; (2) Suspected Name or Location; (3) PRI; (4) PRF; (5) Mode Interlace; (6) Scan Period; (7) Stagger Period. No two interrogators have all seven parameters the same--each set of parameters is unique. Table 3 shows the interrogators sorted by PRI, while Figure 7 gives actual measured PRI for interrogators on staggered but not random PRI.

6.2.1.1 Suspected Name Or Location

6.2.1.1.1 FAA Interrogators

Twenty-five of the 59 interrogators are marked as ASR's or ARSR's, i.e., are thought to be FAA terminal and enroute interrogators. Eight of the 10 ARSR's are on 12-sec scan, two , on 10-sec scan. Nine of the 15 ASR's are on 4.69-sec scan, five on 3.92-sec scan, and one on 4.04-sec scan. Only one of the ASR-7's on the well-known 8-pulse stagger remains: the interrogator at W. Columbia, SC. The others have been replaced by ASR-8's on fixed PRF's.

The Jedburg and Whitehouse ARSR's use regular SLS, while the Patrick AFB ARSR uses improved SLS (ISLS). The opposite is indicated in the ECAC file. The Charleston, Savannah and Jacksonville International ASR's use ISLS, and the Patrick AFB ASR uses regular SLS. These four are in agreement with the ECAC file.

6.2.1.1.2 Non-FAA Interrogators

Shipborne Near 2K (at Sea). Interrogators 20, 22, 26, 48 and 54 on PRF's of 319, 293, 247, 327 and 242 appear to be located on some ships 90-100 nm east of Whitehouse in the Atlantic Ocean. All of these use mode interlace 11112222AAAACCCC, while no other interrogator uses this exact pattern. Two pairs on the same scan may be a single interrogator (20=48 and 26=54) since they are never "on" at the same time. On the other hand, there may be many interrogators there that did not transmit on the day of the AMF flight.

Beaufort MCAS. Interrogators 18, 19 and 32 seem to be co-located here. No. 18, without the benefit of SLS, contributed 133 int/sec at nearest approach (second highest rate seen). No. 19 has the most complicated (12-pulse) stagger seen during the flight (see Fig. 7).

Ft. Fisher. The highest individual rate seen came from this interrogator (240/sec at loc. 1A). At the end of the flight, at comparable distance and peak power, the rate was down to 5/sec. Ft. Fisher apparently has SLS (as indicated in the ECAC file), which it did not use early in the morning, but did use later on.

Mayport NS. Interrogator 49, located at Mayport Naval Station, has the second highest PRF (657) seen during the flight. This is equivalent to two ordinary interrogators. The reason it did not contribute an excessive amount is because it became inactive for 8 pulse repetition intervals after every four interrogations. It could become a real problem, if it went on 100 percent duty factor and used civilian modes only.

Interrogator 55 Near Myrtle Beach. This interrogator has the distinction of using the highest PRF (1096/sec) seen during the flight. Its PRF is the third harmonic of the popular 367.5 PRF, used, e.g., by Whitehouse ARSR. It used SLS, so it contributed only 21 int/sec, instead of perhaps 50 times as many without SLS.

Bogue and Jacksonville (NC). Interrogators 3 and 56 were thought to be located at Bogue Field. No. 56 had the lowest PRF (133.2) of any interrogator seen. It is suspected to be using the more usual PRF of 2 X 133.2 = 267, and blanking out every other interrogation. These interrogators may alternately be located in Jacksonville, NC (Camp LeJeune), where scan periods and modes are in better agreement with the ECAC file. With interrogator 7 there could be a total of three interrogators at Camp Le Jeune, as shown in the ECAC file.

6.2.1.2 Observed PRI/PRF/Stagger Period

Of the 59 interrogators detected, 41 were observed to use fixed PRF's, while the remaining 18 use stagger. Four of the 18 use random stagger with an "infinite" set of PRF's. The other 14 use finite stagger, which repeats exactly after K PRF's. Stagger lengths (K) observed were: K = 3, 5, 8, 9 and 12. The corresponding measured PRI are shown in Fig. 7. The most numerous stagger observed (8 interrogators) was the NAFEC-type 5-pulse stagger.

Highest PRF's observed (see Table 3) were 1096, 657, 445.4 and 439.5 int/sec, lowest PRF's 133.2, 200.0, 218.0 and 241.1 int/sec.

6.2.1.3 Observed Mode Interlace

Thirteen distinct mode interlaces were observed (see Sec. 3.3.4). Fully half of the interrogators seen use the two most popular mode interlaces AC (sixteen) and AAC (fifteen). Seven interrogators use mode A, five use 11112222AAAACCCC. Five use 2ACA/4 (with Mode 4), two use 2ACA without Mode 4.

6.2.1.4 Scan Periods

The shortest scan periods measured were 2.18 sec (Daytona Beach ramp tester), and 2.80 sec (Astor Park). The longest, a group of en-route interrogators with 12-sec scan. Most popular scan periods for terminal interrogators are 3.92 sec and 4.70 sec. Most popular en-route scan period is 12 sec.

6.2.2 The "Visibility Matrix" of Figure 6

As mentioned before, the 37 left columns of Figure 6, headed by the 24 southerly plus the 13 northerly location codes constitute a "visibility matrix" where "periods" (.) indicate that the corresponding interrogator is not visible at the corresponding location, while (hexadecimal) numbers not only show the presence (visibility) of an interrogator, but also give the interrogations/minute received at that location to the nearest power of 2. There is mirror symmetry in the matrix about the line separating locations 1X and 2A, since the northerly leg essentially re-traced the southerly leg of the flight.

The interogator seen the largest number of times (29 times) is Shipboard Interrogator 22. Jacksonville NAS (No. 24) is seen second most frequently (28 times), followed by Whitehouse (25 times), No. Charleston and Jacksonville NAS (No. 31) (24 times each) and Jacksonville International (23 times).

The interrogators with the highest received local rates are Ft. Fisher and No. 18 Beaufort MCAS. High interrogation rates are also received from No. 22, one of the shipborne interrogators 100 nm east of Whitehouse.

Interrogators 60, 61 and 62 do not appear to be visible anywhere. They are shown because they were seen at loc. 2M+, at the westernmost point of the Jacksonville radial, which is not included in the visibility matrix. Note that the 37 (24+13) locations shown in the visibility matrix are also the locations where four important local results are presented in the Master List of Table 4.

6.3 Master List of Local Results (Table 4)

The 14-page Table 4 is a "master list" of local individual results (Int/min, AOA, Ave Power, Pk Power) at the 37 (24+13) measurement locations shown in the visibility matrix. Each line of Table 4 is a measurement location, each column is one of the 59 interrogators, arranged by number, as in Figure 6. Each interrogator heading includes the seven parameters shown initially in Figure 6. As shown at the bottom of every page of Table 4, the four items in each box are arranged for optimum information content. To convert the power to dBm at the bottom antenna of the AMF, the reader should subtract 100 from the powers, and then add 3 dB.

The exact interrogation rates from Ft. Fisher, Int. 18 (Beaufort MCAS) and Int. 22 (Shipborne Near 2K) are shown on pages 2 and 3 of Table 4A. Note that the corresponding pages of Table 4B show nothing unusual for Ft. Fisher, which apparently went back to using SLS. Beaufort MCAS (No. 18) went off the air during our return flight.

Thus neither the existence of one important military interrogator (No. 18, Beaufort MCAS), nor the propensity of another one to "over-interrogate" would have been discovered by just one leg of the flight of the AMF.

6.4 Three PRI/PRF Distributions

Figure 8 shows the distributions in PRI/PRF of interrogations received in 1 minute near Savannah (at 1H), Jacksonville (at 2M+) and Daytona Beach (at 1U) (the right hand scales show per sec rates). The distribution near Jacksonville is plotted in the middle, since it has more than a dozen interrogators in common (mutually visible) with the other two.

All the received PRI for interrogators on staggered PRI which fit into the PRI range of 1800-4600 μs are plotted, with the period of the stagger shown above the bars.

Savannah Distribution (1H, Fig. 8a). Even though most of the interrogators fall into a third of the range shown (2440-3460 μs), all PRI are in the "clear" (they do not overlap). The main reason is the small number of interrogators here (18 in all).

Jacksonville Distribution (2M+, Fig. 8b). As might be expected, this distribution of 31 interogators has a number of problems. Tallahassee (on 2498.5 μs) is surrounded by Macon ASR on 5-pulse stagger (2500.8 μs). Jacksonville NAS (Int. 24 on 2819 μs) is similarly surround by Panama City ARSR (Int. 60 on 2818 μs) also on 5-pulse stagger.

The second harmonic of Mayport NS (Int. 49 on 1522 ± 4 μs) extends from 3035 to 3050 μs. This range of random PRI surround No. Charleston (Int. 14 on 3040 μs). It is also within 1 μs of one of the PRI received on 9-pulse stagger (3051 μs), and is within 3μs of Int. 48 (Shipborne Near 2K) which is coming in on 3053 μs here, about 7 μs below its highest PRI observed elsewhere.

Daytona Beach Distribution (1U, Fig. 8c). The small number of interrogators (19) observed here make this distribution similar to the one at Savannah. All interrogations are in the "clear", except for Ft. Fisher (on 4146 μs), and Mac Dill ARSR (on 4147 μs), which are within 1 μs of each other.

6.5 Reflections Observed (Table 6)

The reflections are received from four military interrogators (No. 9 Myrtle Beach, No. 24 Jacksonville NAS, No. 31 Jacksonville NAS and No. 14 No. Charleston) which probably use regular SLS. This is concluded since the use of ISLS would tend to suppress the reflections, and the use of no SLS would probably yield much higher interrogation rates in the vicinity of these interrogators.

Interesting reflections occur near Jacksonville International (at 1Q), where the 4.5-μs reflections undergo almost no loss, a highly unusual situation. Observing from page 4 of Table 4A that the peak power received from Int. 31 at 1Q is about 10 dB lower at 43 (=-54 dBm) than expected, compared to the powers received at neighboring locations, we conclude that the direct interrogations undergo destructive interference, while the reflected signals (over a slightly different path) are reinforced (arrive in-phase).

The first reflections from the en-route interrogator at Jacksonville NAS (Int. 24, 12-sec scan, 355 PRF) are seen at a distance of 100 nm from a strong reflector about 1 nm south of the antenna. Reflections also occur with the AMF west, north-west and south-east of the interrogator at closer approach.

6.6 Mode 4 Interrogations Observed (Table 7)

The table lists 15 Mode 4 interrogations received from the 5 en-route interrogators marked by "2ACA/4" in the mode interlace column of Fig. 6. They are: Ft. Fisher, Jacksonville NAS (No. 24), Patrick ARSR, Richmond AFS ARSR and No. Charleston. Observed durations vary from .08 sec to .46 sec. Average duration is .215 sec, corresponding to about 70 interrogations on an average PRF.

A surprising fact displayed in Table 7 is that a majority of Mode 4 interrogations were received not on the mainbeams of the interrogators, but on their sidelobes. The reason is that these are transmitted at random times, not when the interrogators are pointing to the AMF, and that they are not SLS-protected in the usual way. The Mode 4 from Ft. Fisher (at 1B) is received on the sidelobe at 50 nmi, and this is probably far short of maximum distance for sidelobe reception. The Mode 4 from No. Charleston (at 2D) was received on the mainbeam at a distance of 250 nm, probably also nowhere near maximum distance for mainbeam reception.

6.7 Effect of Mode 4 on Typical Transponder (Figs. 9a-9d)

In order to evaluate the detailed effect of Mode 4 on an average transponder (35-μs suppression, 60 μs dead time), as well as to show detailed Mode 4 structure, a pulse-by-pulse plot was made of over 50 Mode 4 interrogations received from Ft. Fisher, Jacksonville NAS and Patrick ARSR at locations 1B, 1K, 1S and 1X (see Figures 9a-9d).

The pulse rate that may be produced by a single interrogator using Mode 4 is very high. If, for example, 34 pulses per interrogation occur on an average PRF of 330, this rate exceeds 11,000 PPS.

The more than 50 sequences of pulses shown in Figure 9 were input into a hypothetical "average" transponder by sliding it along the pulses from left to right, and ignoring pulses both in the suppression and in the dead time regions. The resulting sequence of suppressions ("S") or interrogations ("A" or "C") are noted on the left of each line of the plots.

We have shown (in Sec. 3.8) that the Mode 4 pulses themselves cause an average transponder to be unavailable for 4 percent of the time. A suppression at the regular PRI of an interrogator increases this to 5 percent, and an interrogation at this PRI, to 6 percent. A single Mode 4 interrogator alone would not cause any problems, but it might when added to the ambient environment.

It was noted in Sec. 3.8 that an en-route interrogator on 5-pulse stagger (Patrick ARSR) suspended the stagger while transmitting Mode 4 and reverted to its central fixed PRf of 360.2/sec (corresponding to a fixed PRI of 2776.25 μs). The most likely reason for going to a fixed PRF during Mode 4 is the desire to avoid another level of synchronization at the ground receiver, in addition to normal Mode 4 synchronization.

6.8 High Instantaneous Interrogation Rates (Figs. 10a-10e)

Location 1G (Near Beaufort MCAS) (Figs. 10a-10b). The first figure contains the mainbeams of Augusta and Columbia. It shows the minimum rate (1200 int/sec) which may cause reply rate limiting (RRL) reached and exceeded; momentary RRL occurs in the figure. The second figure contains the mainbeams of Charleston and Jedburg. Instantaneous rates here remain below RRL.

Location 1H (Near Savannah) (Figs. 10c-10d). The first figure includes the mainbeam of Whitehouse. RRL may occur for a tenth of a second here, and it poses a threat for almost the whole plot. The second figure shows the mainbeam of Jacksonville International. RRL is briefly exceeded, and it is a threat for 0.2 sec.

Location 2N+ (50 nm east of Whitehouse) (Fig. 10e). This figure threatens RRL for about 0.15 sec. Interrogators cannot be identified, since the uplink analysis program did not run to completion.

6.9 High Instantaneous Suppression Rates (Figs. 11a-11c)

These figures show high instantaneous suppression rates which could interfere with normal transponder availability.

Location 1L (near Jacksonville International) (Fig. 11a). Suppressions from Jacksonville International, Whitehouse, and two interrogators at Jacksonville NAS and from Cecil NAS reach 1700/sec here, which translates into 6 percent transponder unavailability.

Location 1V (Near Daytona Beach) (Fig. 11b). Suppressions from Daytona Beach, the two interrogators at Patrick, from Orlando, Jacksonville NAS (No. 24), Whitehouse and Mac Dill ARSR reach 2200/sec here (8 percent unavailability).

Location 1W (Near Cape Canaveral) (Fig. 11c). Suppressions from the two interrogators at Patrick, from Orlando, Mac Dill ARSR, Tampa and Jacksonville NAS (No. 24) reach 1900/sec here (7 percent unavailability).

6.10 FAA ARSR Mainbeams at Worst Case Observed (2M+)

Location 2M+, 24 nm east of Whitehouse ARSR, was the nearest point of the second leg of the flight to Jacksonville. It is called "worst" because it had the largest number (31) of interrogators seen anywhere during the flight. Table 8 shows the interrogators visible at this location, and it gives the "effective" beamwidth for each, which includes all sidelobe interrogations.

The average for these beamwidths turns out to be 6.59 deg, or 0.0183 of a revolution (the latter is also the probability p of being interrogated by one of the 31 "average" interrogators; $q = 1 - p = 0.9817$ is then the complementary probability of not being interrogated by one of the 31 average interrogators). This large average beamwidth is due in large part to Mayport NS which has an effective beamwidth of 58 degrees.

Figures 12a-12h show two consecutive mainbeams of five en-route interrogators of the Jacksonville Center of the FAA. Instantaneous interrogation rates (and percentage transponder availability) are plotted around the times of occurrances of these mainbeams, and are investigated from the point of view of reply rate limiting and the possibility of track loss.

The Jedburg Mainbeams (Fig. 12a-12b). These figures show only a single point (at 1400 IPS) where RRL would occur, but a strong threat of RRL in the sense described above exists throughout.

Something unusual happens to Jedburg here: its third mainbeam is missing. Peak received power drops by 5 dB from the first MB to the second (-67 dBm vs. -72 dBm). There is another 9 dB loss to the few interrogations on the third MB. None of this is due to aircraft maneuvering, and Jedburg certainly could not be counted on for surveillance here.

The Patrick and Aiken Mainbeams (Fig. 12c-12d). The figures show a short region (peaking at 1700 IPS) where RRL would cause transponder desensitization. This would eliminate replies to Patrick, which is weak here (-74 dBm). Neither interrogator could be counted on for surveillance here, even though Aiken is 6 dB stronger.

The Whitehouse Mainbeams (Fig. 12e-12f). The figures show only a double coincidence (600-800 IPS) for the first MB, but a strong threat of RRL for the second MB. Whitehouse's probable role of primary surveillance responsibility would not be seriously threatened, since its powerful MB (at -43 dBm) would overcome a slight desensitization of the airborne transponders at 2M+.

The Valdosta Mainbeams (Fig. 12g-12h). The figures show the 1200 IPS level exceeded, or approached, for both MB's of Valdosta, making RRL and desensitization a strong possibility. Valdosta power tops out 15 dB below Whitehouse power here (at -58 dBm). Valdosta might be able to handle modest cases of desensitization but not strong ones, in its likely task of secondary surveillance responsibility at location 2M+.

6.11 Plot of Mainbeam Coincidences at 2M+ (Fig. 13)

Figure 13 is a plot of more than 3000 mainbeams for the 31 interrogators at 2M+ for the 10 minutes following the measurements at 2M+, extrapolated from scan periods measured at the start. Jedburg (-), Patrick (o) and Whitehouse (.) mainbeams are marked. MB's were plotted as 1 vertical division (Mayport was plotted twice as high). Some attempt was made to let the widths be proportional to the number of interrogations on them. The unchanging scan periods simulate a situation that aircraft hovering at 2M+, or aircraft entering 2M+ in the next 10 minutes would observe.

Appendix A calculates the probabilities of being interrogated by exactly 0, exactly 1, exactly 2, etc., of the 31 "average" interrogators, i.e., multiple mainbeam coincidences are calculated. Figure 13 is shown partly for comparison with the calculated probabilities, even though higher order coincidences are more and more exaggerated in it. It is felt that flights executed on other days, as well as measurements made in the 90-95 percent "off" time of the AMF would have produced "worst" cases every bit as bad as the figure.

6.12 Predicted Mainbeam Coincidence for ARSR's

Even though the relative positions of the mainbeams of the three interrogators marked in Fig. 13 remain almost unchanged in the figure, we know that some time in the future they will overlap in pairs. We used the time positions of the mainbeams and the scan periods of the interrogators to calculate (a) the time-to-go to these coincidences, (b) their durations, and (c) their periods of recurrence. These turned out to be:

	Jedburg/Patrick Overlap		Whitehouse/Patrick Overlap	
	Scans	Time	Scans	Time
(a) Time to Go	292	.967 hours	455	1.517 hours
(b) No. Partially Jammed MB's (Duration)	29	5.77 min	50	10.03 min
(c) Period of Recurrence	1602	5.348 hours	2592	8.649 hours
Percent Partially Jammed MB's (b/c)	1.8		1.9	

The large number of partially jammed mainbeams (29 and 50) has disturbing implications, especially for a pair of en-route interrogators having primary and secondary surveillance responsibilities for a given area. The extended length of "synchronous jamming" makes the interrogators involved vulnerable to "pop-up" military interrogators as well as other synchronous jammers.

6.13 FAA and AMF Coverages Compared

A comparison of FAA magnetic tape recordings of target data for Jedburg, Aiken, Whitehouse and Valdosta showed an almost 100 percent agreement between AMF visibility at the ground interrogators ("ground coverage"), and visibility of the same interrogators in AMF recordings ("airborne coverage").

6.14 The Cause of Missing Target Reports

Missing target reports at an FAA interrogator usually mean no visibility of that interrogator at the AMF either, because of low received power below the AMF threshold, due to sub-marginal propagation. For those locations where AMF visibility exists without FAA visibility, the AMF consistently:

- o Received marginal power in the -70-75 dBm range;
- o Finds fewer interrogations than on neighboring MB's;
- o Has (almost) complete mainbeams missing.

Missing target reports are consistently due to marginal uplink propagation.

6.15 Probability of Multiple Interrogations at Loc. 2M+

After dividing the wide-beamwidth, high-sidelobe Mayport NS into two interrogators, some multiple mainbeam coincidence probabilities of degree X were calculated in the presence of N=32 interrogators, each with average interrogation probability p = 0.0183, using the Binominal Distribution for a model. The probabilities of exactly 0, exactly 1, exactly 2, etc., interrogations at a given time turned out to be:

$P(0) = .55$ $P(1) = .33$ $P(2) = .0954$

$P(3) = .0178$ $P(4) = .00204$ $P(5) = .000251$

These probabilities may be read from Fig. B-2 (which gives a plot of some 16 probabilities for all values of N), near the right hand edge of the figure, at N=32.

The addition of military interrogators without SLS (contributing 100 percent of a normal PRF) is to change all the labels for the complexity upwards by one without changing the calculated values, i.e., making such multiple mainbeam coincidence more likely.

6.16 Probability of Synchronous Jamming at Loc. 2M+

Figure B-1 of Appendix B shows incremental scan periods for 23 (8 + 7 + 8) interrogators at location 2M+ which undergo synchronous jamming of different degree around three popular scan periods (3.925 sec, 4.70 sec, 12.015 sec). Since the duration of synchronous jamming is inversely proportional to the differences in scan period, and since some of the scan differences in the figure are almost zero, it is evident from Fig. B-1 that some of these durations are quite long.

Maximum durations of sychronous jamming for the three groups are 1.24 hours, 15.57 min, 1.71 hours.

The corresponding repetition periods are: 122 hours, 12 hours, 150 hours.

Minimum durations of synchronous jamming are usually trivially short: 5.3 sec, 26 sec, 54 sec.

The corresponding (brief) repetition periods are: 9.65 min, 17.0 min, 54.7 min.

The ratios of maximum to minimum repetition periods are: 760, 42, 164.

6.17 Average Duration of Synchronous Jamming

Figure B-1 shows that average dwell time for the 23 interrogators shown there turns out to be 1 percent of a revolution (corresponding to a beamwidth of 3.6 deg). We also pick a reasonable average scan difference of 0.1 percent of the scan period, whatever the scan period.

Using these, we arrive at an average duration of partially jammed mainbeams of 2 percent. The corresponding double-PRF jamming, which is the quantity of concern to us, is 1 percent. The averge number of partially jammed mainbeamns is 20, and the average number of completely jammed mainbeams is 10, whatever the actual scan periods may be.

For two interrogators on the same scan, but of different beamwidths, double PRF jamming depends on the wider beam (it equals the wider beamwidth, if that is expressed not in degrees, but in fractions of a revolution).

6.18 Synchronous Or Random Jamming-All Degrees (Fig. B-2)

Two kinds of probabilities are plotted in Fig. B-2, which address the following questions:

1. What is the probability of mainbeam coincidences of different degrees X at arbitrary instants of time, which are completely uncorrelated with the mainbeams of any interrogator ("general" probability)?

2. What percentage of the mainbeams of a given interrogator undergo synchronous or random jamming of different degrees X at the time of their regular re-occurrence ("special" probability)?

Figure B-2 contains (in addition to a set of curves with the average beamwidths of 0.0183 revolution for the 32 interrogators at location 2M+) five pairs of general and special probability curves of p = 0.01 (the 1 percent beamwidth case). These are the curves separated from each other by 1 interrogator: the special probability curve of one degree greater complexity is plotted just to the right (1 interrogator away) from the general probability curve of one lesser degree of overlap. This expresses the intriguing relationship betwen the two types of probabilities.

Since the relationship is always so simple, the "special" probability curves for the real situation at location 2M+ (the p = 0.0183 case) has not been plotted in Fig. B-2. The reader may visualize these as plotted just one interrogator (1 N) to the right of the general probability curves of one degree lower complexity.

The reader may find it surprising as did the author that the very low probability general multiple mainbeam coincidences are accompanied by synchronous (or random) jamming probabilities which are much higher. For example, in the 3.6 deg (p = 0.01) case, the percentages of the mainbeams of some interrogator experiencing synchronous (or random) jamming are 10 to 100 times greater than are general mainbeam coincidence probabilities of the same order. This is the whole "raison d'etre" for the definition of the special probabilities. We repeat the definitions given earlier (where P is the underlying interrogation probability, x is the degree of overlap and n is the number of interrogators):

$$PG(p,x,n) = \binom{n}{x} p^x q^{n-x} \qquad 0 \leq x \leq n \quad \text{(General)}$$

$$PS(p,x,n) = \binom{n-1}{x-1} p^{x-1} q^{n-x} \qquad 1 \leq x \leq n \text{ (Special)}$$

$$PG(p,x,n) = PS\ (p,x+1,n+1) \qquad \text{(Relation between the two)}$$

7.0 CONCLUSIONS

The remainder of this report compares the uplink results measured in the Jacksonville area with similar AMF measurements made earlier in the Los Angeles area and along the Boston-Washington corridor (see Project Reports ATC-81 and ATC-83, referenced on p. 1 of this report). It also addresses some of the problems (target splits, lost tracks and poor coverage, especially near the hand-off points between the Washington-Jacksonville-Miami Air Route Traffic Control Centers) mentioned by FAA personnel before the flight.

7.1 Comparison with Earlier Results

ATC-81 reports uplink results gathered while the AMF was flying landings and take-offs at the Los Angeles, Van Nuys and San Diego airports, height above ground varying from zero to 1 nm, much lower altitude than even the first leg at Jacksonville (nominal 10,000 ft). A maximum of 12 to 13 interrogators were seen there at the highest altitudes, accompanied by average pulse, suppression and interrogation rates of 2500, 800 and 160/sec, respectively. These are consistent with the Jacksonville results.

ATC-83 reports uplink results based on measurements made along the East Coast between Boston and Washington at 8500 ft, a flight path which was then essentially re-traced at 17500 ft. Here the length of the flight, its altitude and its purpose were much closer to the Jacksonville flight. The results were also quite similar (Jacksonville results are shown in parentheses for comparison): a total of 68 (59) ground interrogators observed; a maximum of 38 (31) interrogators seen at the same place; pulse rate of 2-4 thousand/sec (about the same, lower far off-shore); variable suppression rate of 140-1400/sec (about the same, lower along the ocean leg); Mode A rate of 30-150/sec, Mode C about half of Mode A, Modes 1 and 2, about half of Mode C (again about the same).

7.2 FAA-Reported Problems

Target splits, lost tracks and poor coverage may all be attributed to a single cause: missing transponder replies to an en-route interrogator charged with the responsibility of primary or secondary surveillance for airborne traffic crossing a given area. In the case of the Jacksonville Center, the traffic of concern is the one along the coastal air routes flying from Boston-New York-Washington to Miami.

The missing replies themselves may be due to a variety of circumstances. The most common of these are: (1) a transponder out of sight of the interrogator; (2) received power below threshold because of great distance, low transmitter power or transponder desensitization due to reply rate limiting (RRL); (3) transponder unavailability because of high combined suppression and interrogation rates; (4) more than one interrogator on the same PRI or scan period (including PRI differences small compared to the average duration of suppressions and deadtimes (35 and 60 μs, respectively)). Most of these things get aggravated in the presence of (a) reflections, (b) Mode 4 interrogations, and (c) an unusually large number of interrogators visible at the same time (some without (SLS).

7.2.1 High Concentration of Interrogators

The area around the Jacksonville flight path (Fig. 1) contains one of the highest concentrations of powerful interrogators in the country, due to multiple interrogators (almost all without SLS) at the military sites. The 17 January 1980 ECAC File shows 8 interrogators at Beaufort MCAS, 6 at Cherry Point, 4 at Avon Park, Homestead and Mac Dill AFB's, 3 at Kennesaw, Pope, Shaw and Tyndall AFB's (as well as at Charleston and Savannah), and a set of two at many other places. It lists a total of 126 interrogators at the sites shown in the figure. The 59 interrogators detected by the AMF make up 47 percent of the total. The remaining 69 (all without SLS) were not detected during the flight.

7.2.2 Strong Altitude Dependence of Interrogators Seen

The high concentration of interrogators implies strong dependence of the number of interrogators visible on aircraft altitude. The best illustration of this is the fact that the smallest number (8) and largest number (31) of interrogators seen both occurred at the same geographical location (1H and 2M+), at 10,000 and 25,000 ft, respectively. (These locations are only 5 nm apart).

It is possible that a jet airliner cruising at 40,000 ft (nominal visibility 242 nm) along the coastal route of Florida would have been observed by 40-50 ground interrogators on the day of the flight test, 23 May 1979. Considering the relatively high occurrence of sidelobe interrogations and reflections for military interrogators without SLS, this might have produced an unacceptably high probability of interrogations bunching above the 1200 IPS level--causing RRL and transponder desensitization.

A high altitude situation like this could account for some of the FAA's problems, especially if some of the military interrogators are close to the FAA en-route interrogators in PRF (synchronous fruit).

7.2.3 Coverage Problems in the Jacksonville Area

South-bound air traffic is handed off by Washington Center to Jacksonville Center just north of location 1A. The traffic is similarly handed off to Miami Center 20 nm south of Ormond Beach. Jacksonville Center, therefore, has primary and secondary surveillance responsibility for flight segment 1A through 1U+.

Figure 1 shows that the FAA en-route interrogators of the area are either located right along the coast (like the Jedburg, Whitehouse and Patrick ARSR's), or are offset from the coast about 100 nm to the west (like the ARSR's at Benson, Aiken, Valdosta and Mac Dill AFB). The result is that the offset ARSR's cannot provide surveillance for air traffic below 6,000 ft (less

than 100 nm visibility). Similarly, traffic at 5,000 ft (87 nm visibility) is invisible to the en-route system near Myrtle Beach and Savannah, and traffic at 2,500 ft (visibility 60 nm = 1 deg latitude) has extended gaps in coverage at all these places, plus at Daytona Beach (= Ormond Beach), the point of hand-off to Miami. The traffic most effected by these gaps in coverage is general aviation, which, however, is still the bulk of total traffic.

At location 1A, the AMF received marginal power (about -70 dBm) from Jedburg. According to the 17 January 1980 ECAC File, Jedburg transmits half the power transmitted by such en-route interrogators as Aiken, Mac Dill and Patrick (0.76 KW vs. 1.5 KW). Being the only Jacksonville Center en-route interrogator providing coverage at this hand-off point at 10,000 ft, Jedburg should bring its transmitted power up to the 1.5 KW level.

7.2.4 The Ormond Beach Problems

Considering average transponder deadtimes and suppression times to equal 60 and 35 μs, respectively, we note that a near-by military interrogator without SLS on an average PRF of 330 IPS will make a transponder unavailable for 2 percent of the time. An interrogator (on average PRF) using ISLS in the vicinity of a transponder, will similarly make it unavailable for 1.16 percent of the time. The unavailabilities generally occur at random times and effect isolated single replies only, but they will deny an en-route interrogator many consecutive replies when the PRF's are close enough.

Based on the above, Figure 2 (showing the highest average suppression rate observed for location 1V (1300/sec)) gives a clue to the problems at Ormond Beach. This suppression rate means an a'priori transponder unavailability of 4.55 percent. Figure 11b shows a 50 μs long instantaneous unavailability of over 7 percent for the same location. The possibility that at jet cruising altitudes of 40,000 ft many more than the 15 interrogators seen at 10,000 ft would have been observed, and the possibility that some of the five interrogators listed for McCoy AFB and Avon Park (all without SLS) might intermittently contribute 100 percent of their sidelobes, indicate the possible magnitude of the problems at Ormond Beach. Note that the five interrogators mentioned (one on a double-PRF of 625/sec) could contribute a total of 1300 Mode A's per sec, exceeding the RRL threshold. Reflections from these interrogators, plus the reception of Mode 4 on the sidelobes of nearby interrogators (Jacksonville NAS, Patrick AFB) and the mainbeams of distant interrogators, add yet another dimension to the possible Ormond Beach problems. Unlisted interrogators at Cape Canaveral (again, without SLS) cannot be completely eliminated from consideration.

Note that the only solution to this problem would be to add regular SLS to all interrogators near Ormond Beach which have no SLS at this time, and to change as many FAA interrogators as possible in that area from ISLS to regular SLS--all those that will not develop reflections as a result of the change.

7.2.5 Synchronous Interference Problems

7.2.5.1 Ft. Fisher and Aiken on 241 PRF

At location 1C, where the AMF received 100 percent of the sidelobe of Ft. Fisher (4146 μs PRI = 241.2 PRF), the en-route interrogator Aiken (4135 μs PRI = 241.8 PRF) just 11 μs away in PRI had 5 consecutive replies missing once every 1.56 sec when they occurred in the 60 μs (ave) deadtimes caused by Ft. Fisher interrogations just preceding Aiken interrogations. Air traffic at 40,000 ft would encounter this problem at the additional locations 1A, 1B, 2V, 2W, 2X, 2Y (wherever the Ft. Fisher sidelobes without SLS may be received). The problem is alleviated by about a factor of 30 when Ft. Fisher uses its SLS, which, apparently, is the only solution other than separating the PRI from the current 11 to perhaps 60 μs.

7.2.5.2 Ft. Fisher and Mac Dill on 241 PRF

Mac Dill ARSR (4147 μs PRI = 241.1 PRF) has a PRI which is only 1 μs different from Ft. Fisher. Mac Dill would have 60 of its replies missing in a row (lasting for 0.25 sec) once every 17.20 sec, if it were seen together with Ft. Fisher by high-flying air traffic. Since Ft. Fisher was observed outside nominal visibility of 125 nm at 10,000 ft at locations 1H, 1I and even at 1U, it is probably so favorably located and so powerful as to be visible to coastal traffic at 40,000 ft all the way to Jacksonville and even at the problem area of Ormond Beach, although with a narrow beam under 1 percent. Assuming an equally narrow beam for Mac Dill would seem to make this interference statistically insignificant, if it were not for the identical scan periods for the two, implying many mainbeam coincidences in a row followed by extremely long absence of coincidences. The way this would work is strong interference (perhaps complete mainbeams missing) for a relatively short interval of some minutes followed by freedom from interference for many hours of even days.

7.2.5.3 Benson and Valdosta on 370 PRF

Benson and Valdosta are on identical PRF's of 370.3. Hundreds of their interrogations will overlap whenever they get in phase. They will interfere about the same way as Mac Dill and Ft. Fisher above, with the following differences: (1) both of them are FAA en-route interrogators; (2) their scan periods are different; and (3) they are closer, and, presumable, have more overlap in coverage. Coastal traffic at 40,000 ft in the Charleston -Beaufort area would be most effected.

7.2.5.4 Maiden and Patrick on 360 PRF

Maiden (2778 μs PRI = 359.9 PRF) and Patrick (2776 μs PRI = 360.2 PRF), two en-route interrogators on 5-pulse stagger, have a 2 μs difference in PRI, which eliminates 30 replies in a row for either of them, when they interrogate in the deadtimes caused by the other one. Like Ft. Fisher and Mac Dill, they are on identical scans. Fortunately, only a small segment of the 40,000 ft coastal traffic near Savannah can see both of them. An out-of-phase stagger is some help near the ends of the deadtimes.

7.2.5.5 Jacksonville NAS, Panama City and Richmond on 355 PRF

Jacksonville NAS (2819 μs PRI = 354.7 PRF) is on a PRI which is halfway between the 2 μs separated PRI of Panama City (1818 μs PRI = 354.9 PRF) and Richmond (2820 μs PRI = 354.6 PRF). Jacksonville NAS will therefore interfere with 60 consecutive replies of both of these en-route interrogators. Jacksonville is an unusually powerful and wide beam interrogator with regular SLS, permitting many sidelobe interrogations and reflections out to 100 nm. In addition, it uses Mode 4 liberally, which alone will produce 5 or 6 percent transponder unavailability (see Sec. 3.8) for interrogators on random PRI. For Panama City and Richmond, Mode 4 from Jacksonville NAS becomes synchronous suppression of (possibly) 100 replies in a row from transponders in the larger Jacksonville area. This interference may last 0.282 sec, and it has 1 chance in 28 of happening with the random use of Mode 4.

The AMF observed Panama City well beyond nominal visibility at location 2M+, indicating that this interrogator might be able to see 40,000 ft coastal traffic from Savannah to Ormond Beach. Richmond probably picks up this same traffic somewhere between Jacksonville and Ormond Beach.

Synchronous interference from Jacksonville NAS contributes to the Ormond Beach problems. The solution again is a change of PRF's. Keeping other PRF's in the area in mind, a possible choice would be to put Panama City on a PRI of 2798 (357.4 PRF), and Richmond on a PRI of 2841 μs (352.0 PRF). The resulting plus/minus 21 μs differences from Jacksonville NAS would alleviate the interference problem by more than an order of magnitude.

7.2.5.6 Synchronous Interference for Terminal FAA Interrogators

There are some FAA terminal interrogators on near-identical PRF's in the Jacksonville area. These are not part of the en-route system, and the interference effects only their local traffic. Many of these were observed at more than 100 nm at 10,000 ft. Their almost exclusive use of ISLS means that the majority of the interference will probably occur in the 35 μs suppression times rather than in the deadtimes. Note that close-by traffic may receive suppressions up to 99 percent of the PRF's. The number of missing replies (mr's) in a row (given in parantheses below) will be those due to synchronous suppressions. For the rarer cases of synchronous interrogation deadtimes on the mainbeams, these must be multiplied by a factor of 1.7.

The northernmost pair of interfering ASR's are Charlotte and Fayetteville on a PRF of 381. PRI difference = 1.8 μs (19 mr's). Visibilities extend down to Savannah. Orlando on the same PRF is too far to be a problem.

Daytona Beach and Sarasota on 390 and 391 PRF's have a 4.3 μs PRI difference (8 mr's). Visibilities extend from Jacksonville to Miami. Charleston on the same PRF is too far to be a problem.

Tallahassee and Robins AFB on 400 PRF have a PRI difference of 2.3 μs (15 mrs). Visibilities extend to Jacksonville.

Augusta ASR on 395 PRF and the military interrogator at Jacksonville, NC have a PRI difference of 1 μs. Since this interrogator does not use ISLS, and since the interrogators are far from each other, the synchronous interference is minimal in this case.

APPENDIX A

LIKELIHOOD OF MULTIPLE INTERROGATIONS AT LOC. 2M+

1.0 Probabilities of Multiple Interrogations

It is useful to calculate P(0), P(1), P(2), P(3), etc., the probabilities of being interrogated by exactly 0, exactly 1, exactly 2, etc.,interrogators, given the common probability p of being interrogated by any one of them.

The Binomial Distribution, P(x), is to be used for a probability model. P(x) represents the probability of realizing an event exactly x times (receiving exactly x interrogations) in n independent repeated trials (from n interrogators), such that the probability of success in each trial is given by p. This is done even though the scan-to-scan independence of our interrogators is far from ideal. The Binomial Distribution for P(x) is given by;

$$P(x) = \binom{n}{x} \cdot p^x \cdot q^{n-x} \quad (0 \leq p \leq 1;\ x = 0,1,2,\ldots,n)$$

where;

$$\binom{n}{x} = \frac{n!}{x!\,(n-x)!} \qquad x = 0,1,2,\ldots \leq n = 0,1,2,\ldots,32$$

is the binomial coefficient.

2.0 Probability of Exactly x Interrogations

Substituting (from Sec. 4.2.1) p = 0.0183, q = 0.9817 and n = 32, as per the real-world situation, into the Binomial Distribution, the desired probabilities of being interrogated by exactly 0, exactly 1, exactly 2, etc., of our 32 average interrogators, are given by:

$$P(0) = \binom{32}{0} p^0 q^{32} = 0.5538$$

$$P(1) = \binom{32}{1} p^1 q^{31} = 0.3303$$

$$P(2) = \binom{32}{2} p^2 q^{30} = 0.0954$$

$$P(3) = \binom{32}{3} p^3 q^{29} = 0.0178$$

$$P(4) = \binom{32}{4} p^4 q^{28} = 2.0405 \times 10^{-3}$$

3.0 Mainbeam Coincidence Interpretation

Another way of interpreting the probabilities P(x) (x = 0,1,...,32) calculated above is to look at (independent) instants of time, and ask for the probability of 0, 1, 2, 3, etc., mainbeams of our 32 interrogators (with their different scan periods) coinciding at each instant of time, causing multiple interrogations of the same degree there. We realize that although the relative pointing of the 32 interrogators is quite random at a given instant, their fixed scan periods make them predictable for all future time.

4.0 P(I) - Probability of "Being Interrogated"

Note that the probability P(I) of being interrogated by either 1 or 2 or 3,...., or 32 interrogators at some instant is given by the sum of the probabilities P(1) + P(2) + P(3) + ... + P(32). P(I) can be calculated:

$$P(I) = 1 - P(0) = 0.4462$$

5.0 Probability of More Than x Interrogations

The probabilities of being interrogated by 2 or more, 3 or more, etc., interrogators (denoted here by P(2+), P(3+), etc.) are given by the differences

$$P(2+) = P(I) - P(1) = 0.1159$$

$$P(3+) = P(2+) - P(2) = 0.0204$$

$$P(4+) = P(3+) - P(3) = 0.00269$$

$$P(5+) = P(4+) - P(4) = 0.000274$$

In general,

$$P(N+) = P(I) - P(1) - P(2) - P(3) - \ldots - P(N-1)$$

gives the probability of being interrogated by N or more interrogators at the same time (or, alternately, the probability of N or more mainbeam coincidences).

6.0 Summary of Multiple Interrogation Probabilities

It is clear from the above that at location 2M+, in the presence of 32 (actually 31) interrogators with average beamwidths of 6.59 deg., the probability of not being interrogated (P(0) = 0.55376) exceeds the probability of being interrogated (P(I) = 0.44624) by 24 percent only. The fact that these two events are almost equally likely is of some interest.

A list of probabilities follows, including (in parentheses) the average number of trials needed to realize the events once.

P(0) = 0.5537	(1.8)		
P(1) = 0.3303	(3)	P(I) = 0.44624034	(2.2)
P(2) = 0.0954	(10)	P(2+) = 0.1159137	(9)
P(3) = 0.0178	(56)	P(3+) = 0.20246994	(49)
P(4) = $2.40X10^{-3}$	(416)	P(4+) = $2.678143X10^{-3}$	(373)
P(5) = 2.51X10-^{4}	(3984)	P(5+) = $2.73613\ X10^{-4}$	(3655)
P(6) = $2.10X10^{-5}$	(47492)		
P(7) = $1.46X10^{-6}$	(685926)		

7.0 Effect of Addition of Interrogators Without SLS

It is likely that a number of military interogators without SLS were not discovered during the Jacksonville flight for two reasons: (1) they were never turned on, since they were not part of the military operations on the day of the AMF flight, or (2) they operated in short bursts only during the 90 percent of total time not recorded by the AMF. Interrogators like these can contribute 100 percent of their PRF's to the ambient interrogation environment (as Ft. Fisher did at location 1A). So it is important to ask how the probabilities calculated above would have changed if, one or two of these had been turned on during the few unrecorded minutes just before or just after the recording at 2M+.

One interrogator of this nature (on an average PRF) would change P(1) and P(I) from their currect values of 0.330 and 0.446 to 1 since the AMF would be interrogated all the time. It would also shift all calculated probabilities by one level of complexity. P(2) would take on the current value of P(1) etc).

Two such interrogators would make P(1)= P(2)= P(I)= 1. They would also shift all the calculated probabilites by two levels of complexity.

APPENDIX B

LIKELIHOOD OF SYNCHRONOUS OR RANDOM JAMMING

1.0 Synchronous Jamming at Location 2M+

1.1 Introduction to Figure B-1

Figure B-1 shows a plot of 23 (= 8 + 7 + 8) incremental scan periods for selected interrogators at 2M+, grouped around 3.93, 4.70 and 12.01 seconds. The three heavy vertical arrows in the figure show 1 percent differences in scan period for each group. Interrogator numbers and names are shown at the bottom of each part.

Dwell times (in ms) are given at the top of the figure. From this, three average dwell times are calculated to show that these are approximately 1 percent of the scan periods, regardless of the lengths of the scan periods. From all this, the duration of synchronous jamming (continued mainbeam coincidences), and their frequencies of occurrence may be estimated.

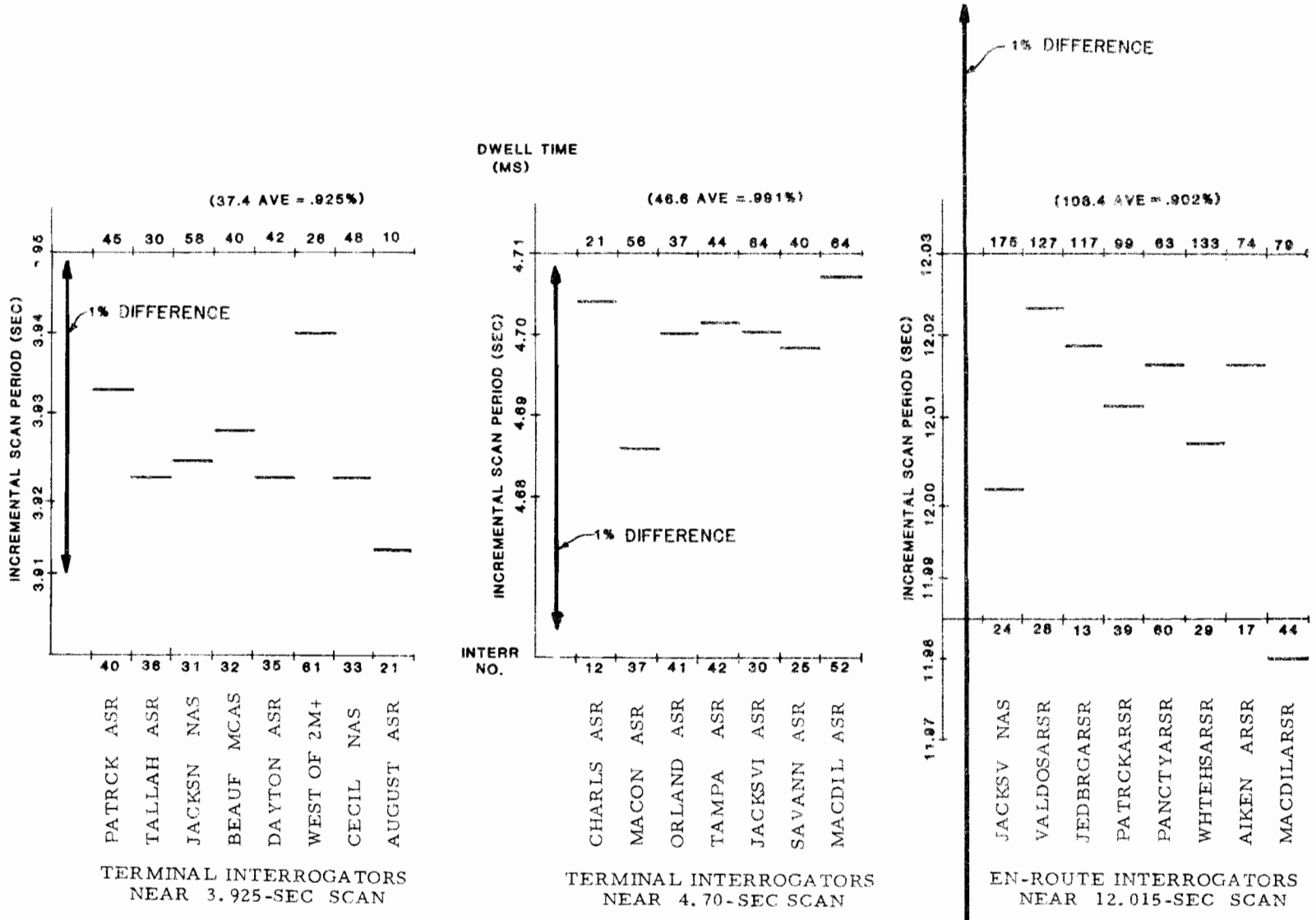
1.2 Synchronous Jamming Defined

When the probability of occurrence of mainbeam coincidences was discussed and calculated in Appendix A, it was based on isolated ("random") events, independent from each other. These were not cases of synchronous jamming.

By definition, synchronous jamming refers to the gradual approach, long overlap and slow separation of the mainbeams of two interrogators with almost equal ("synchronous") scan periods. The word "jamming" describes the interrogations on double PRF occurring during the overlapping portion of the mainbeams, which can last at most as long as the shorter of the two dwell times involved. If there are K interrogators with near-equal scan periods, higher order synchronous jamming (all the way to degree K) will occur with lower and lower probability. Each occurrence of double-, triple-, and higher-PRF interrogation is limited to the shortest dwell time, while its overall probability is determined by the longest dwell time.

An examination of the scan periods of the 31 interrogators seen at 2M+ reveals the presence of 23 interrogators with near-equal scan periods there. These can cause significant synchronous jamming in the sense defined above, in groups of 8, 7, and 8, spread in three tight bands around the scan periods 3.925, 4.70, and 12.015 sec, respectively. These are exactly the interrogators shown in the three parts of Figure B-1.

A calculation of the longest (Tmax) and shortest (Tmin) duration of synchronous jamming for the three groups, as well as the repetition time (period) (Pmax, Pmin) of the occurence of such jamming follows in the next three sections. As long as these durations and periods are measured in "scans", there is no reason to expect differences between the groups, for the average dwell time is about 1 percent for each, corresponding to a 3.6 deg beamwidth, regardless of scan period.



Incremental Scan Periods for 23 of the 31 Interrogators Seen 23 NM East of Whitehouse ARSR (Loc. 2M+) Grouped around 3.925, 4.70 and 12.015 Second Scans. Dwell Times And Their Averages (MS And Percent Scan) Are Shown at the Top, Interrogator No's And Names at the Bottom. Heavy Vertical Arrows Show 1% of a Scan Period for Each Group to Scale.

Figure B-1

1.3 Synchronous Jamming on 3.925 - Second Scan

The durations (T) are given by the sum of the dwell times W1 + W2 (=L12) divided by the positive scan differences S1-S2 (=DS12). Similarly, the repetition periods (P) are given by the shorter scan period (S2) divided by the positive scan differences S1-S2. The small variations in the numerators of these expressions are occasionally completely overshadowed by the near-zero denominators. This is the case when looking for TMax and Pmax among the 8 interrogators on 3.925-sec scan.

Interrogators 33, 35, and 36 (Cecil, Daytona Beach, and Tallahassee) show almost equal scans. Daytona Beach minus Tallahassee is actually smallest (DS12 = 0.000035 sec, L12 = 0.072 sec, S2 = 3.922011 sec), thus:

Tmax = L12/DS12 = 2057 scans = 8074 sec = 134.57 min = 1.2428 hours

Pmax = S2/DS12 = 112057 scans = 439826 sec = 7330 min = 122.174 hours,
= 5.09057 days

Tmin and Pmin will be determined from the greatest difference in scan periods. Interrogator 61 minus interrogator 21 (Augusta) gives DS12= .026540 sec, L12 = 0.036 sec, S2 = 3.913122 sec. From these:

Tmin = L12/DS12 = 1.3564 scans = 5.324 sec

Pmin = S2/DS12 = 147.44 scans = 579 sec = 9.65 min

Pmax/Pmin = 439826/579 = 760

Pmax and Pmin have the very large ratio of 760.

1.4 Synchronous Jamming on 4.70 - Second Scan

Interrogators 30 and 41 (Jacksonville International and Orlando) turn out to have the smallest scan difference among the 7 interrogators of this group. We have DS12 = 0.000508 sec. L12 = 0.101 sec., S2 = 4.700131 sec., thus:

Tmax = L12/DS12 = 198.82 scans = 934 sec = 15.574 min

Pmax = S2/DS12 = 9252 scans = 43485 sec = 724.76 min = 12.0793 hours

Shortest jamming (Tmin and Pmin) comes from the largest scan difference. Interrogator 52 (Mac Dill) minus interrogator 37 (Macon) gives DS12 = 0.021555 sec, L12 = 0.120 sec, S2 = 4.685730 sec. From these

Tmin = L12/DS12 = 5.5672 scans = 26.16 sec

Pmin = S2/DS12 = 217.385 scans = 1022 sec = 17.028 min

Pmax/Pmin = 43485/1022 = 42

1.5 Synchronous Jamming on 12.015 - Second Scan

Interrogators 17 and 60 (Aiken and Panama City) have the smallest scan difference among the 8 interrogators of this group. Aiken minus Panama City gives DS12 = 0.000267 sec, L12 = 0.137 sec, S2 = 12.01628 sec, thus:

Tmax = L12/DS12 = 513.1086 scans = 6165 sec - 102.75 min = 1.7125 hours

Pmax = S2/DS12 = 450 scans = 540733 sec = 9012 min = 150.2035 hours = 6.25848 days

Shortest jamming (Tmin, Pmin) comes from the largest scan difference. Interrogator 28 (Valdosta) minus interrogator 44 (Mac Dill) gives DS12 = 0.043840 sec, L12 = 0.206 sec, S2 = 11.979537 sec. From these:

Tmin = L12/DS12 = 4.699 scans = 56.46 sec

Pmin = S2/DS12 = 273.256 scans = 3283 sec = 54.7195 min

PMax/Pmin = 540733/3283 = 164

Synchronous jamming lasting for 1.7 hours is perhaps an estimate of "worst of the worst" case. Still, things like this could occur, but their more likely mechanism might be the "wandering back and forth" of the mainbeams of two far-away enroute interrogators such as the Aiken and Panama City ARSR's.

1.6 Average Duration of Synchronous Jamming

Earlier it was noted that the average dwell time for the three groups of interrogators shown in Figure B-1 was about 1 percent (corresponding to a 3.6 deg beamwidth) regardless of scan period. It is now assumed that this is true for all interrogators in the figure. In addition, let us pick a reasonable average scan difference of 0.1 percent of the scan period for all three groups. (This means one-tenth of the 1 percent line for each case in the figure).

These assumptions result in the following average values for the duration (TAve) and the repetition period (Pave) of synchronous jamming (mainbeam coincidence) at location 2M+:

Tave = 20 scans (Double PRF: 10 complete mainbeams; see below)

Pave = 1000 scans

Tave/Pave = .02 (2 percent)

(= 1 percent, Double PRF Jamming)

The 20 scans (mainbeams) partially effected by double PRF jamming represent 78.5, 94.00, and 240.3 sec of real time, depending on the scan periods involved. Similarly, the 1000-scan average repetition period represents 3925, 4700, and 12015 sec (or 65.417, 78.333, and 200.25 min, or 1.0903, 1.3055, and 3.3375 hours) of real time, depending once again on the scan periods.

1.7 Double PRF Jamming (1 Percent Average)

Double PRF jamming occurs only during the overlapping portions of the mainbeams. Therefore (for the above average parameters), its length increases linearly by 1/10-th of the widths of the mainbeam (1/1000-th of the scan period) from one mainbeam (scan) to the next one until complete separation.

Thus overlaps last for 0.36, 0.72, 1.08,..., 3.24, 3.60, 3.24, ..., 1.08, 0.72, 0.36, 0 degrees for all interrogators in Figure B-1. These numbers add to 36 degrees (10 mainbeams) for each complete event of synchronous jamming (repeating itself after 1000 scans). Dividing the 10 mainbeams by 1000 scans gives PSJ2 = .01 for the probability of average mainbeam-to-mainbeam synchronous jamming between any two interrogators in Figure B-1 (both chosen from the same group).

2.0 Synchronous Jamming Probabilities

2.1 Results at Location 2M+ Generalized

Synchronous jamming occurs at any location where at least two interrogators on near-identical scan are interrogating the same airborne transponder. The 1 percent value for PSJ2 (second order synchronous jamming probability) is probably also typical, since it corresponds to a beamwidth of 3.6 deg.

The companion probability QSJ2 = 1 - PSJ2 represents the 99 percent of the mainbeams of an interrogator free from synchronous jamming by another interrogator on the same scan.

For a pair of interrogators with equal beamwidths (BW1 = BW2) (and near-equal scan period), the probability of synchronous jamming is always given by PSJ2 = BW1 = BW2, as long as the beamwidths are measured not in degrees but in fractions of a scan (fractions of a revolution).

2.2 The Case of Un-Equal Beamwidths

Assume that BW1 < BW2 (in scans, again) and that the scan difference (Sdif, measured in scans) still equals .001, as above. What happens then is that the faster mainbeam of the interrogator with the larger scan period catches up with, overlaps and then clears the mainbeam with the smaller scan period, regardless of which is the narrower of the two (called BW1 above). We want to determine the number of completely jammed mainbeams (NJ), which is given by the number of complete overlaps (NCO) plus half the number of partial overlaps (NPO). These are given by:

NCO = (BW2 -BW1)/Sdif

NPO = 2 X BW1 / Sdif

NJ = NCO + NPO/2 = BW2 / Sdif

The desired jamming probability (PSJ2) is just the ratio of completely jammed mainbeams (NJ) to total mainbeams in one period of synchronous jamming (PER). Note that PER is also the number of scans in a period, and it is given by PER = 1/Sdif when everything is measured in scans. The result is, that for interrogators with different beamwidths, synchronous jamming probability is given simply by the wider of the two beamwidths (BW2) (expressed in "scans"):

PSJ2 = NJ / PER = NJ X Sdif = BW2 (in scans)

As an example, consider an interrogator with 3.6 deg beamwidth causing synchronous jamming to another one with 4 X 3.6 = 14.4 deg beamwidth with a scan difference of 1/10 of 1 percent. Measured in scans, we then have BW1 = 0.01, BW2 = 0.04, PER = 1/Sdif = 1000, and

NCO = (0.04 -0.01) /0.001 = 30

NPO = 2 X .01 / .001 = 20

NJ = NCO + NPO/2 = 30 + 10 = 40

PSJ2 = 40 / 1000 = 0.04 (4 percent Double PRF Jamming)

QSJ2 = 1 -PSJ2 = 0.96 (96 percent Clear Mainbeams)

2.3 The case of Arbitrary Scan Differences

A scan difference (Sdif) of 0.001 scans was assumed in the above calculations of synchronous jamming probabilities PSJ2. It will now be shown that they do not depend on the scan differences at all (i.e., their dependence cancels out.)

Recall that NJ (the number of completely jammed mainbeams) was given by BW2/SDif; PER (the number of mainbeams or scans in a period) was given by 1/SDif; and that the jamming probability is given by the ratio PSJ2 = NJ/PER = (BW2/SDif)/(1/SDif), where the scan differences obviously cancel.

The only effect of arbitrary scan differences is to lengthen or shorten both the overlap time and the period of synchronous jamming by equal factors, which still leaves the jamming probability PSJ2 depend only on the wider of the two beamwidths involved (BW2, measured in fractions of a scan).

3.0 Synchronous Or Random Jamming

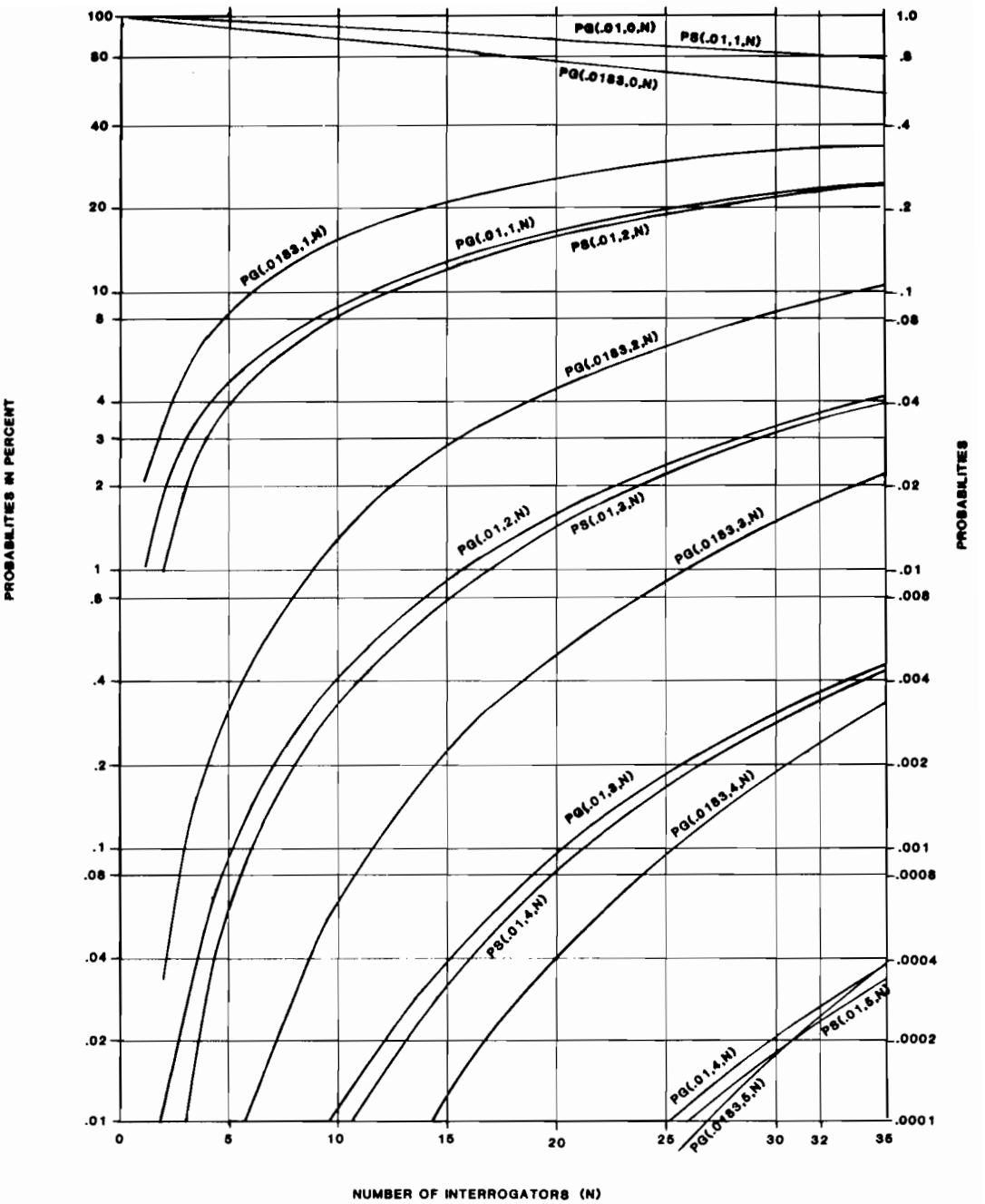
3.1 Introduction to Figure B-2

Figure B-2 shows 16 probability curves to be discussed below. The horizontal scale is n, the number of interrogators seen by the AMF (or any other airborne transponder) at location 2M+ or at some other location with "typical" uplink conditions.

The vertical scale represents probabilities on a logarithmic scale in the range 0.0001 to 1.0, which can also be interpreted as percentages (of, say, mainbeams jammed) in the range .01 to 100 percent.

Eleven of the curves give "general" probabilities ("PG", see below), and the remaining five give "special" probabilities ("PS", again, see below). One set of curves uses basic (average) interrogation probability of p = .0183, the other two sets (of five each) use p = .01 (1 percent). These ten curves serve as handy reference curves for other probabilities above and below 1 percent, but, more than that, they are also quite "typical" for the many locations where uplink interrogator beamwidths average 3.6 deg (1 percent of a revolution).

Different members of each set of curves correspond to increasing degrees x of mainbeam coincidences. Each curve gives the probability of being interrogated by exactly x interrogators, and not being interrogated by the remaining n -x of the total interrogator population n. The probability of not being interrogated by any of the n interrogators (probability of being interrogated be exactly 0 of them) occurs when x = 0.



"GENERAL" AND "SPECIAL" PROBABILITIES OF MULTI-PRF JAMMING
(MAINBEAM COINCIDENCES) (PG(P,X,N) AND PS(P, X, N)
(P: (AVE) BASIC PROB; X: DEGREE; N: NO. OF INTERROGATORS)
(P = .0183, N = 32 REFERS TO LOC. 2M +, 23 MAY 1979 JACKSONVILLE FLIGHT, AMF)

Figure B-2

3.2 "General" and "Special" Jamming Probabilities

Considering either synchronous or random jamming, two different questions may be asked:

(1) What is the probability of mainbeam coincidences of different degrees x at arbitrary instants of time, uncorrolated with the mainbeams of any interrogator ("general" probability)?

(2) What percentage of the mainbeams of a given interrogator undergo synchronous or random jamming of different degrees x at the time of their regular re-occurence ("special" probability)?

The following expressions define "general" and "special" probabilities:

$$PG(p,x,n) = \binom{n}{x} p^x q^{n-x} \qquad 0 \leq x \leq n \qquad \text{(General)}$$

$$PS(p,x,n) = \binom{n-1}{x-1} p^{x-1} q^{n-x} \qquad 1 \leq x \leq n \qquad \text{(Special)}$$

$$PG(p,x,n) = PS(p,x+1,n+1) \qquad \text{(Relation between the two)}$$

The "general" probability PG(p,x,n) applies as follows. When n interrogators with identical individual probabilities of interrogation p are present, this is the probability that exactly x are looking at an aircraft, and n-x are not looking. The number of ways this can happen is given by the binomial coefficient $\binom{n}{x}$, specifying the number of different ways one may select x interrogators out of a total population of n. Since each of the $\binom{n}{x}$ configurations defines a component (event) which is disjoint, the components may be summed to obtain the complete probability of being interrogated by any x of the n interrogators.

The changes observed in the expression for the "special" probability PS(p,x,n) are due to a number of factors. First of all, one of the basic probabilities p must be changed to 1, since the interrogator whose mainbeams we focus on is now certain to interrogate. At the same time, the exponent of p must be reduced by 1 (from x to x-1), since one less interrogator is needed to point at an aircraft for any degree of overlap.

Picking a set of mainbeams not only increases the overlap by one degree of complexity, but also eliminates one of the interrogators remaining to be chosen. The binomial coefficient must be changed from $\binom{n}{x}$ to $\binom{n-1}{x-1}$ to reflect the change.

3.3 "General" and "Special" Probabilities Compared

The third equation above relating the two types of probabilities defined by the first two equations indicates that (for the same base probabilities p) the "general" probability "PG" of mainbeam overlaps of some degree x, in the presence of n interrogators equals the "special" probability "PS" of one degree higher overlap x+1 in the presence of one additional interrogator n+1.

This relationship is very clear in Figure B-2 where each special probability curve of degree x is displaced from a general probability curve of degree x-1 by the space of a single interrogator (is plotted to the right by 1 division in n). Five special probability curves are plotted in this figure for the 1 percent base probability case (p = 0.01), given by the first five members of

$$PS(.01,x,n) = \binom{n-1}{x-1} .01^{x-1} \ .99^{n-x} \qquad 1 \leq x \leq n \text{ (Special)}$$

These may be seen to be displaced to the right by 1 n (one interrogator) from the five companion general probability curves given by the first five members of

$$PG(.01,x,n) = \binom{n}{x} .01^{x} \ .99^{n-x} \qquad 0 \leq x \leq n \text{ (General)}$$

The other six general probability curves in the figure use for their base probabilities the "effective" beamwidths of 1.83 percent (p = .0183) (calculated in Section 4.2.1 of the body of this report) to include all sidelobe interrogations present at location 2M+. These are given by;

$$PG(.0183,x,n) = \binom{n}{x} .0183^{x} \ .9817^{n-x} \qquad 0 \leq x \leq n \text{ (General)}$$

Note that the companion special probability curves (percent mainbeams jammed) have not been plotted in Fig. B-2 for the six p=.0183 general probability curves. The reason is that these may be easily estimated for any X and N from the value of the general probability for (X-1) and (N-1).

For example, the percentage of mainbeams of an interrogator experiencing third degree jamming (X=3) in the presence of ten interrogators (N=10) is about 1 percent, as it is read from the PG(.0183,2,N) curve at N=9, which gives the probability of exactly 2 mainbeam coincidences at any instant of time.

3.4 Discussion of Figure B-2

Initial points of the general probability curves PG(p,x,n) of Figure B-2 occur when n has the minimum value necessary for the degree of overlap considered. Thus the curves start at n = 0, 1, 2, 3, 4, and 5 for overlaps of degree x = 0, 1, 2, 3, 4, and 5.

Here $\binom{n}{x}$ has the value $\binom{n}{x} = \binom{x}{x} = 1$, and q^{n-x} has the value $q^{n-x} = q^{n-n} = q^0 = 1$. Therefore initial values of the general probability PG(p,x,n) are given by;

$$PG(p,x,n) = \binom{x}{x} p^x q^{x-x} = p^x \qquad \text{for } x = 0, 1, 2, 3, 4 \text{ and } 5$$

These initial values are tabulated below.

x = n	p^x	
	p = 0.01	p = 0.0183
0	1.0	1.0
1	0.01	1.8300×10^{-2}
2	0.0001	3.3489×10^{-4}
3	0.000001	6.1285×10^{-6}
4	0.00000001	1.1215×10^{-7}
5	0.0000000001	2.0524×10^{-9}

The sixteen curves plotted in Figure B-2 lie closer to one-another toward the right-hand edge of the figure, as the number of interrogators approaches 35.

4.0 Main Jamming Results at Location 2M+

Figure B-1 shows that about one quarter of the interrogators (8, 7, and 8 out of 32) use near-equal scan periods grouped around the values 3.925, 4.70, and 12.015 seconds, respectively. This means that about one quarter of the total jamming experienced by these interrogators is "synchronous", and three quarters of the jamming is "random". Note that the effects of either type jamming are identical (multiple-PRF interrogations), and the only reason we differentiate synchronous jamming is because it occurs regularly between pairs of interrogators, and because the mainbeams effected are always adjacent ones.

The actual uplink situation at location 2M+ is shown in Fig. B-2 by the vertical line at n=32 interrogators. The special probabilities tabulated below for various degrees of overlap of the mainbeams of a given interrogator have been approximated from the general probability curves PG (.0183) and one less degree of overlap. (They apply exactly for one more (n=33) interrogator.)

Degree of PRF Overlap	Special Probability	Chances Needed to Realize Once
1	0.554	1.8
2	0.330	3
3	0.095	10
4	0.018	56
5	2.404×10^{-3}	416
6	2.510×10^{-4}	3984

The results indicate that every 3rd mainbeam of an interrogator at location 2M+ will on the average have double-PRF jamming, every 10th triple-PRF jamming, every 56th quadruple-PRF jamming. Note that quadruple-PRF usually means over 1300 interrogations/sec. This exceeds the usual threshold (1200 IPS) for reply rate limiting (RRL), therefore it can cause transponder desensitization and possibly track loss.

Note that the special probabilities listed in the results above are identical to the general probabilities PG(.0183,x,32) calculated earlier for overlaps of one degree less complexity. The first line, for example, states that the probability of exactly 1-degree overlap is the same as the probability of not being interrogated (0.554) calculated earlier (Section 4.3.5), when we are already looking at the mainbeam of some interrogator with probability 1.

If we equate RRL with PRF overlap of degree 4, we see that, as far as actual measurements at location 2M+ are concerned, it occurs about 2 percent of the time. Since AMF measurements cover only one day, and even then only 5 to 10 percent of the total uplink, it is quite likely that other days (or even the unmeasured 90 to 95 percent) include pop-up military interrogators on 100 percent PRF (without SLS). One of these would increase RRL probability to 10 percent, two of them, to 33 percent.

Speaking conservatively, we should not rule out even several of these for a "worst case" at 2M+, and should probably include all or part of one even for the "expected" uplink complexity here.

For the three groups of interogators in Figure B-1 which experience synchronous jamming in groups of 7 or 8, a smaller portion of the total jamming is "synchronous". If we assume 1 percent beamwidths for these (as we calculated it above), we may read their synchronous components of degrees 2 and 3 directly from Figure B-2 along the special probability curves PS(.01,x,n) for x = 2 and 3, and n = 7, and 8. Doing this, we find the following values:

Degree x	No. of Interrogators n	Synchronous Jamming Component
2	7	0.05706
	8	0.06590
3	7	0.001441
	8	0.001997

APPENDIX C

DEFINITION OF TERMS

The principal figures and tables of the report are generally self explanatory. However, the following definitions clarify the manner in which the uplink data analysis program handles the pulse data recorded in flight.

Interrogations	A pair of pulses (P1 and P3) within 0.25 μs of the prescribed separation times for Mode 1, 2, A, C (3, 5, 8 and 21 μs, respectively); P3 amplitude must exceed value prescribed by 3.5 dB/μs desensitization; a P2 pulse not exceeding P1 by more than 3 dB may be present.
Suppressions	A pair of pulses (P1 and P2) within 0.25 μs of the prescribed separation time (2 μs) for suppressions and with amplitudes in the range $-3 \leq P1 - P2 \leq +3$; a P3 pulse may also be present (3 pulse suppression).
Stray Pulses	Pulses that cannot be legitimately associated to form interrogations or suppressions; mostly the powerful P2 pulses of interrogators using regular SLS (transmitted on their onmi-directional antennas); also the reflections of real pulses, TACAN pulses, etc.