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INTERIM AUTOMATIC TRAFFIC ADVISORY AND RESOLUTION
SERVICE (ATARS) HARDWARE TIMING ANALYSIS

FEDERAL AVIATION ADMINISTRATION TECHNICAL CENTER
Atlantic City, N. J. 08405



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Final Report

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16. Abstract The objective of Automatic Traffic Advisory and Resolution Service (ATARS) hardware timing analysis is to provide sufficient information on the execution time characteristics of ATARS to: (1) permit prospective contractors bidding on an ATARS request for proposals to realistically estimate the size of the system they are proposing, and (2) to provide the government proposal evaluators with a technical basis for evaluating proposed computer configurations. This report presents the methodology for acquiring the required data and for analyzing the data to satisfy the two objectives. It is concluded that the computer performance monitoring system, which was designed and built to measure the execution time of computer subtasks within the Discrete Address Beacon System (DABS) and to count the occurrence of events within the selected task, is a suitable instrument for collecting the required data. Multiple regression analysis was found to provide excellent execution time models and to provide information required to identify critical subtasks within ATARS.			
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EXECUTIVE SUMMARY

The objective of a hardware timing analysis of the Automatic Traffic Advisory and Resolution Service (ATARS) is to provide information on the execution time characteristics of ATARS to: (1) permit contractors bidding on an ATARS request for proposals to realistically estimate the size of the system they are proposing, and (2) to provide the government proposal evaluators with a technical basis for evaluating proposed computer configurations. This report presents a methodology to satisfy these two objectives.

Data were collected using the Computer Performance Measurement System (CPMS) (appendix A) with surveillance reports generated by the Aircraft Reply and Interference Environment Simulator (ARIES) (appendix B) using the ATARS 400 aircraft capacity scenario. The CPMS provides timing information on the computers being monitored. The ATARS 400 aircraft scenario produces a high volume of potential conflict pairs and proximity warnings and exercises the ATARS software at near capacity.

A multiple regression analysis technique was used to analyze and model execution time of critical subtasks within the ATARS processing chain.

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INTRODUCTION

OBJECTIVE.

This report discusses an approach and application of a timing analysis which can provide information on the execution time characteristics of the Automatic Traffic Advisory and Resolution Service (ATARS) to: (1) permit contractors bidding on an ATARS request for proposals to realistically estimate the size of the system they are proposing, and (2) provide government proposal evaluators with a technical basis for evaluating proposed computer configurations. This report identifies the methodology for acquiring and analyzing the data to satisfy the above two objectives.

BACKGROUND.

The requirement for the development of the Discrete Address Beacon System (DABS) and ATARS was identified in the 1969 Department of Transportation Air Traffic Control Advisory Committee Study (reference 1). The study required modifications to the present Air Traffic Control Radar Beacon System (ATCRBS) which would improve the surveillance accuracy and the reliability of the system. Specifically, a discrete address mode data link function was proposed that would automatically transmit traffic advisories and conflict resolution commands to the pilot. Corresponding controller alert messages would be sent to the air traffic controller. This ground based collision avoidance algorithm, termed intermittent positive control (IPC), would operate in several computer subsystems of the DABS ground equipment.

A single site IPC algorithm was published in October of 1973. Flight tests of this algorithm were conducted by Lincoln Laboratory at the DABS experimental facility at Hanscom Air Force Base, Massachusetts, from October 1974 to February 1977 (reference 2). Concurrent with this testing, a multisite algorithm called IPC change 2 was developed by MITRE Corporation (reference 3). This algorithm, published in September 1974, was implemented in the three DABS experimental model sensors installed at the Federal Aviation Administration (FAA) Technical Center and Elwood and Clementon, New Jersey. The present ATARS system is essentially the original epoch processing IPC single site algorithm, ~~(with changes)~~ based on the results of the Lincoln Laboratory tests, knowledge gained from operation of IPC change 2, and simulation studies of the single site IPC accomplished at the Technical Center and by MITRE Corporation.

SYSTEM DESCRIPTION.

The DABS obtains position information from ATCRBS- and DABS-equipped aircraft by way of a ground-air-ground digital data link between the air traffic control (ATC) system and the aircraft. For DABS-equipped aircraft, a unique DABS address allows direct communication between the ground and specific individual airborne systems.

The DABS engineering model computer system consists of two large memory units (global memories A and B), seven ensembles of computer subsystems, and data buslines connecting these components. Each ensemble consists of an ensemble busline, four identical computer subsystems, two couplers, and a priority board. Since the system uses distributed processing, there is no set of DABS computer subsystems reserved exclusively for the ATARS or any other function within DABS.

The DABS and the ATARS main memories are separate and essentially exclusive. The global busline A and accompanying 360,448 (352K) of global memory are assigned to DABS functions, while global busline B and the accompanying 352K of global memory are assigned to ATARS functions. All ATARS messages transmitted to ATC facilities are handled by global busline B, while all ATARS uplink messages are provided via global busline A to the DABS data link functions.

The system uses a rotating priority scheme such that each computer subsystem in an ensemble gets top priority at least once every four memory cycles. Once an ensemble computer gains access to its ensemble busline, it must wait as the seven ensemble couplers compete to gain access to the global busline. The global busline has a rotating priority scheme similar to that of the ensemble busline. Once a computer has gained access to its own ensemble busline, it gets top priority for access to global memory.

The ATARS software resident in the DABS computers utilizes surveillance information obtained by the DABS to monitor the data and identify aircraft that are proximate and/or potentially in conflict. The ATARS processes the DABS data and continuously provides traffic advisories and, when necessary, conflict resolution advisories to the aircraft receiving ATARS service via the data link. Surveillance information including range, azimuth, altitude, and a 24-bit DABS identity for the aircraft is input to the ATARS software. The identity for an ATCRBS target report includes the mode 3/A code and the surveillance file number which is supplied by the DABS tracker. Nonsurveillance information utilized by the ATARS includes ATC status, pilot response, and aircraft equipage information. The only surveillance inputs accepted by the ATARS have had track correlation performed by the DABS tracker. Presently, only altitude (mode C) equipped aircraft can be serviced by ATARS.

Simulated target input to DABS is provided by the aircraft reply and Interference Environment Simulator (ARIES) (reference 4). This system is designed to simulate a radar beacon environment of up to 400 transponders for the purpose of testing the operation of DABS under heavy load. This equipment is described in greater detail in appendix B.

For purposes of data collection, the Computer Performance Measurement System (CPMS) was interfaced with the DABS computers via existing breakpoint panels. The CPMS monitors the DABS address lines and provides timing information for the computers being monitored. It is described in more detail in appendix A.

DISCUSSION

METHOD OF APPROACH.

ATARS timing data was collected via the CPMS with DABS target inputs generated by the ARIES. These data were used to develop analytical models of the major ATARS tasks. As used in this document, the term analytical model refers to an equation describing the performance of an ATARS task. The independent variables represent the number of executions of code segments within the task and the dependent variable represents total execution time for the task. These models can be used to identify critical segments of the ATARS code, i.e., those elements of the model that correlate highly with total execution time.

DATA COLLECTION.

The following configuration was used for the DABS sensor:

- Load tape - 800N1 (^Interim ATARS system)
- Data extraction cassette - DX14
- Site adaptation cassettes - A103 and E123 (single site/loopback)
- ARIES scenario - ATARS 400 aircraft capacity scenario

The ATARS 400 aircraft capacity senario, designed for use in the DABS factory acceptance tests, produces a high volume of potential pairs, proximity warnings, and conflicts to exercise the ATARS software at a near capacity load.

The raw data tape generated by the CPMS was reduced using a computer program developed for a Digital Equipment Corporation PDP-11/45 computer. This data reduction program summarized the data on an epoch (ATARS processing cycle, nominally 2 seconds) basis. The summary includes:

1. Total time for completion of epoch processing.
2. A count of the number of times each code segment was executed.
3. The sum of all execution times for each code segment during that epoch.

ANALYTICAL MODELS.

A study of the ATARS ^{algorithm} ~~algorithm~~ identified the following tasks as the time critical ATARS tasks:

Add new aircraft processing
Update aircraft processing
Coarse screen processing
Conflict detection processing
Resolve potential pair processing
Resolution command logic processing
Data link message construction processing
State vector delete processing
Outgoing conflict processing

A detailed description of these tasks is given in FAA-EM-74-4, "Multisite Intermittent Positive Control Algorithms for the Discrete Address Beacon System" (reference 3).

A multiple regression analysis (MRA) technique was used to investigate, analyze and analytically model these tasks. The general approach is described as follows:

Let T represent the execution time of the ATARS task under consideration. The task analysis and modeling approach was to model T in terms of a set of variables, X_i , whose choice is motivated by analysis of the task processing algorithm design as well as the experimental data. The model takes the analytic form

$$T = a_0 + \sum_{i=1}^n a_i X_i + E$$

where E, the residual, is a zero mean, normally distributed random variable.

The coefficients, a_i , their variances, and the variance of the residual are calculated using standard MRA techniques (reference 5).

In all the applications that follow, it is important to remember that the coefficients are implicitly a function of the specific structure of the ATARS software design and the ATARS 400 aircraft capacity scenario.

RESULTS AND ANALYSIS

The specific applications of the methodology to task modeling follows. Several task models are discussed in considerable detail, not only for their intrinsic interest but also as an aid in providing a fuller understanding of the modeling approach.

OF ANALYTICAL MODEL FOR AIRCRAFT UPDATE.

Figure 1 displays the experimental data relating total execution time, T , for the aircraft update task and X , the total number of aircraft updated. It is apparent that for the number of aircraft updated less than approximately 250 there exists a linear relationship between T and X . For values of $X \geq 250$ the relationship becomes scattered with an upward turning quadratic trend. This behavior is consistent with an analysis of the software design and is discussed more fully at the end of this section.

Examination of the CPMS data showed that when X reached approximately 250, the epoch time was in excess of 2 seconds. The ATARS system design calls for all epoch processing to be finished in 2 seconds with a "fail-soft" mode allowing an epoch to be extended in time by 2-second increments. When an epoch is greater than 2 seconds, the ATARS algorithm is not keeping up with the processing load.

* - ONE POINT PLOTTED TO PRINT POSITION
 B - TWO POINTS PLOTTED TO PRINT POSITION
 C - THREE POINTS PLOTTED TO PRINT POSITION
 D - FOUR POINTS PLOTTED TO PRINT POSITION
 E - FIVE POINTS PLOTTED TO PRINT POSITION
 F - SIX POINTS PLOTTED TO PRINT POSITION
 G - SEVEN POINTS PLOTTED TO PRINT POSITION

TIME (MIN)

EXECUTION

621638.01
 502638.0
 520238.1
 438080.5
 37567.9
 313695.
 251502.7
 189310.14
 127017.5
 66924.1
 36.00

97.60 128.40 159.20 190.00 220.80 282.60 313.20 344.00

NUMBER OF AIRCRAFT UPDATED

FIGURE 1 SCATTER PLOT FOR AIRCRAFT UPDATE

Given this guide it was found that a piecewise model, linear for $X \leq 250$ and quadratic for $X \geq 250$ provided a good description of the data. While examination of the scatter plot could lead to several reasonable choices for a breakpoint, no other selection provided significant improvement in modeling the execution time.

For the linear region, $X < 250$, an initial choice of the model was the relation

$$T = a_0 + a_1 X + E$$

It was expected from first principles that the coefficient a_0 would be small and have a large relative standard deviation. It was found:

<u>Coefficient</u>	<u>Associated Variable</u>	<u>Coefficient Value (μs)</u>	<u>Standard Deviation</u>
a_0	-	1.88×10^2	2.16×10^3
a_1	X	1.62×10^3	1.40×10^1

It is seen that a_0 is indeed small and very uncertain, the standard deviation being a factor of 10 larger than the mean. This is a justification for dropping the a_0 term and shows in this simple case that the model approach produces reasonable results.

The next step was to consider the refined version for $X < 250$. Here it was found that:

<u>Coefficient</u>	<u>Associated Variable</u>	<u>Coefficient Value (μs)</u>	<u>Standard Deviation</u>
a_1	X	1.62×10^3	5.34×10^0

Comparing these results to those of the previous model shows that the mean value of a_1 did not change and the standard deviation dropped by a factor of 2.

The correlation between predicted and observed values for the refined model was 0.998 and the model accounted for 99.6 percent of the variation in total execution time for the aircraft update task, $X < 250$. Figure 2 shows the cumulative distribution of the residuals and the predicted distribution had they been normally distributed with a zero mean and a standard deviation as estimated by the model. This graph illustrates the close conformity of the distribution of the residuals to a normal distribution.

The results of fitting the quadratic model $T = a_0 + a_1 X + a_2 X^2 + E$ for $X \geq 250$ are summarized below.

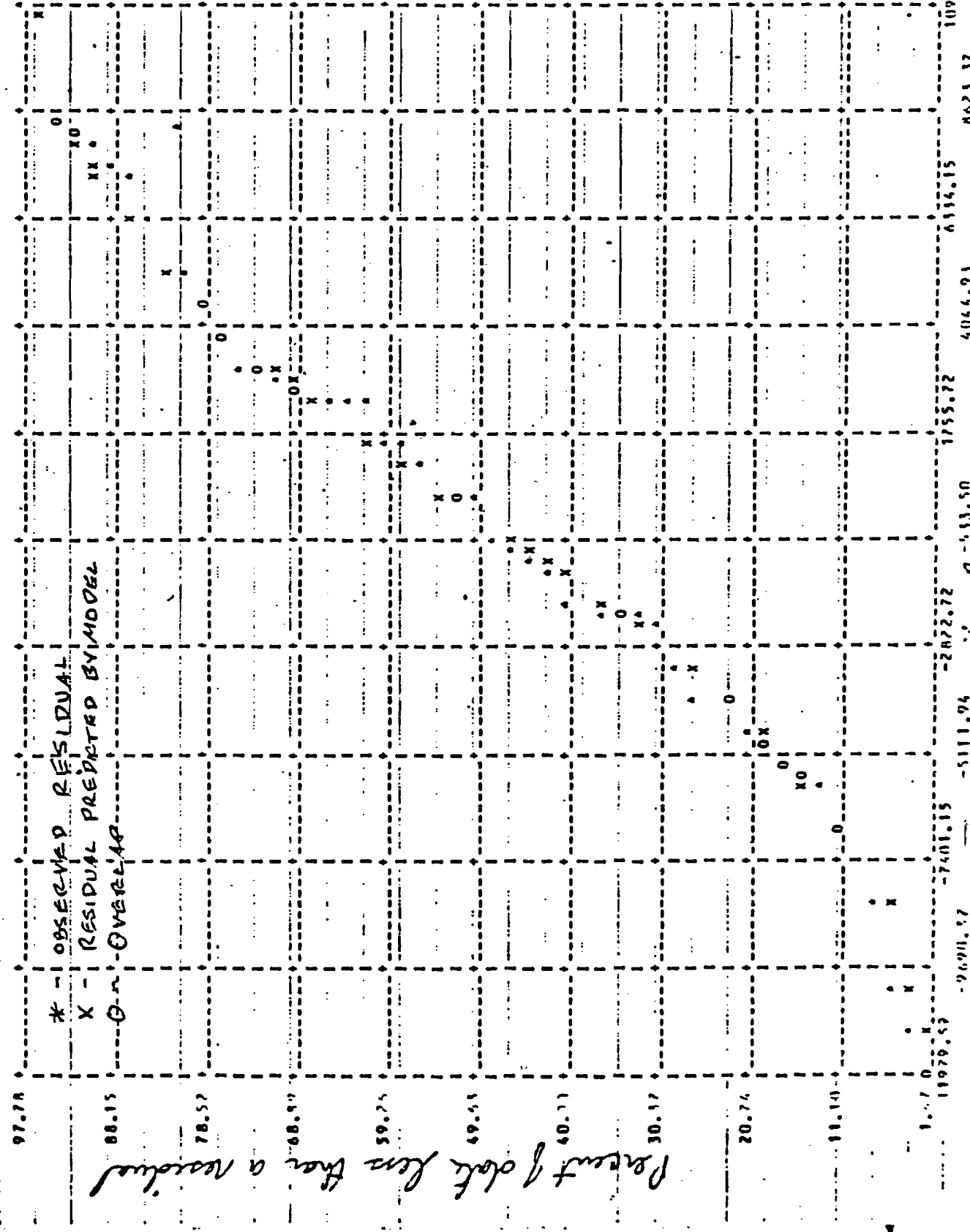
<u>Coefficient</u>	<u>Associated Variable</u>	<u>Coefficient Value (μs)</u>	<u>Standard Deviation</u>
a_0	--	2.540×10^6	1.840×10^5
a_1	X	-1.682×10^4	1.319×10^3
a_2	X^2	3.318×10^1	2.34×10^0

No significance should be attached to the fact that the coefficient of the linear term is negative. Physical interpretation of the coefficients of a nonlinear model is difficult, since it is not possible to vary one variable while holding all others fixed. The model accounts for 86.25 percent of the variation in total execution time for the aircraft update task. Figure 3 illustrates the close conformity between the observed values of the residuals and the values of the residuals predicted by the quadratic model. Figure 4 shows the predicted and observed values of execution time for the aircraft update task.

The piecewise model provides valuable insight into the performance of the aircraft update task. All the aircraft under ATARS service are stored in one of two lists, the X-list and EX-list, and ordered by X-coordinate. This task updates the tracks

FIGURE 2
 CUMULATIVE DISTRIBUTION OF RESIDUALS
 FOR AIRCRAFT UPDATE (LINEAR PORTION)

GRAPHICAL TEST FOR NORMALITY OF RESIDUALS



cal com

EXECUTION TIME	EXECUTION TIME PREDICTED BY AIRCRAFT	OVERLAP	NUMBER OF AIRCRAFT	UPDATED
624008.13		X		
561165.25		O		
498322.38				
435670.50				
372636.63				
309793.75				
246950.88				
184108.00				
121265.12				
58422.25				
36.00				
66.80	128.60	159.20	190.00	251.60
		220.80		282.60
				313.20
				344.00

FIGURE 4
 PREDICTED AND OBSERVED VALUES
 FOR AIRCRAFT UPDATE

of all the aircraft and sorts the X/EX-lists when the relative positions have been changed. Where there are few, widely dispersed aircraft the update will seldom change the order of the aircraft on the X/EX-lists and the sort will require only a single pass. Where there are numerous, densely packed aircraft the update will result in many of them being out of place on the X/EX-lists and the sort will have to make multiple passes through the lists. Since the execution time for a sort is a quadratic function of the number of entries to be sorted, a quadratic segment of the piecewise model was required.

The data were collected in the region $36 \leq X \leq 344$ and extrapolation outside this region should be avoided.

ANALYTICAL MODEL FOR ADD NEW AIRCRAFT.

OF

The following variables were considered:

X = Number of new aircraft under DABS coverage

T = Total execution time for Add New Aircraft

The following was obtained for the Add New Aircraft task:

<u>Coefficient</u>	<u>Associated Variable</u>	<u>Coefficient Value (μs)</u>	<u>Standard Deviation</u>
a_0	--	7.385×10^2	2.481×10^2
a_1	X	7.086×10^2	1.032×10^2

Examination of the standard deviations show that both a_0 and a_1 are significant. This model accounts for 96 percent of observed variation in total execution time. Neither the examination of the data nor the functional design of this task suggested that a piecewise model was required to describe the execution time.

The plot of residuals against the order of occurrence revealed no patterns. A runs test applied to the residuals did not provide a basis for rejecting the hypothesis of randomness. It should be pointed out, however, that the residuals were not normally distributed. The data were collected in the region $1 \leq X \leq 61$ and extrapolation outside this region should be avoided.

^{of}
ANALYTICAL MODEL FOR COARSE SCREEN.

The following variables were considered:

X_1 = Number of pairs in backward search.

X_2 = Number of pairs in forward search.

X_3 = Number of potential pairs generated.

X_4 = Number of aircraft in coarse screen (approximately one-half the total number of aircraft)

T = Processing time for coarse screen (coarse screen execution time minus waiting time for update)

Initially, a linear model $T = a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3 + a_4 X_4 + E$ was fitted to the data. The results obtained were:

<u>Coefficient</u>	<u>Associated Variable</u>	<u>Coefficient Value (μs)</u>	<u>Standard Deviation</u>
a_0	--	9.668×10^3	2.982×10^4
a_1	X_1	2.953×10^1	2.607×10^1
a_2	X_2	1.296×10^2	2.225×10^1
a_3	X_3	1.098×10^3	2.673×10^2
a_4	X_4	1.815×10^3	6.646×10^2

It is seen that the coefficients a_0 and a_1 are not significant. Utilizing a refined model

$$T = a_2X_2 + a_3X_3 + a_4X_4 + E$$

it was found:

<u>Coefficient</u>	<u>Associated Variable</u>	<u>Coefficient Value (μs)</u>	<u>Standard Deviation</u>
a ₂	X ₂	1.271 x 10 ²	2.121 x 10 ¹
a ₃	X ₃	1.282 x 10 ³	2.215 x 10 ²
a ₄	X ₄	2.145 x 10 ³	2.174 x 10 ²

A comparison of these results with those of the initial model shows that the elimination of a₀ and a₁ improved the estimate ^{of the} ~~of~~ standard deviation of a₄ without materially changing the values of a₂, a₃, and a₄.

The refined linear model explains 94.77 percent of the variation in total execution time. However, the residuals displayed time dependency and non-normality. The model does, however, provide a good summary of the existing data.

As the total number of pairs for either forward (X₂) or backward search (X₁) is proportional to the square of the number of aircraft (X₄), a model involving X₄² was examined. That is, $T = a_0 + a_3X_3 + a_5X_4^2 + E$.

The resulting coefficient values were:

<u>Coefficient</u>	<u>Associated Variable</u>	<u>Coefficient Value (μs)</u>	<u>Standard Deviation</u>
a ₀	—	1.032 x 10 ⁵	1.055 x 10 ⁴
a ₃	X ₃	1.694 x 10 ³	1.838 x 10 ²
a ₅	X ₄ ²	1.446 x 10 ¹	1.429 x 10 ⁰

This model accounted for 95.048 percent of the variation in execution time and its residuals were close to being normally distributed.

Linear model involving X_2 is preferred because an analysis of the
structure shows that the coefficient a_5 would be dependent on both
densities and the proportion of controlled and uncontrolled aircraft.
The nonlinear model provides a good explanation for the ATARS 400
capacity scenario, it may be a poor choice for a different visual flight
instrument flight rules (IFR) mix.

were based on data bounded by

$$\underline{X}_1 \leq 3,286$$

$$\underline{X}_2 \leq 2,125$$

$$\underline{X}_3 \leq 267$$

$$\underline{X}_4 \leq 181$$

operation outside this region should be avoided.

EMPIRICAL MODEL OF DETECT.

Following variables were considered:

X_1 = Total number of potential pairs (approximately one-half the number of
initial pairs generated by coarse screen per epoch)

X_2 = Number of filtered controlled/uncontrolled (C/U) pairs

X_3 = Number of filtered uncontrolled/uncontrolled (U/U) pairs

X_4 = Number of filtered controlled/controlled (C/C) pairs

T = Total execution time for detect

The partial correlation between the number of filtered C/C pairs and total execution time for detect is -0.124, as opposed to a simple correlation of 0.542. This suggests that the linear association between total execution time for detect and the number of filtered C/C pairs is explainable in terms of the number of filtered C/U pairs.

For this reason the value T was estimated using only the variables X_1 , X_2 , and X_3 in the linear model $Y = a_0 + A_1X_1 + a_2X_2 + a_3X_3 + E$.

The results are summarized as follows:

<u>Coefficient</u>	<u>Associated Variable</u>	<u>Coefficient Value (μs)</u>	<u>Standard Deviation</u>
a_0	--	8.960×10^4	1.478×10^4
a_1	X_1	6.322×10^3	1.778×10^2
a_2	X_2	8.603×10^3	7.172×10^2
a_3	X_3	2.351×10^3	6.237×10^2

The correlation between observed and predicted values is 0.973; 94.67 percent of the variation is accounted for by the model.

Examination of the residuals revealed an almost perfect fit to a normal distribution. The run test provided no reason to reject the hypothesis of randomness. The plot of residuals revealed no pattern of dependency. The plot of total execution time versus epoch did show a time-dependent pattern. In later epochs an odd/even pattern manifested itself. The visual effect was of two sets of points converging to one constant as epoch 200 was approached. This distinctly nonrandom pattern has not been accounted for in the model. Data for this study were collected in the following region:

$$8 \leq X_1 \leq 147$$

$$0 \leq X_2 \leq 36$$

$$0 \leq X_3 \leq 44$$

$$0 \leq X_4 \leq 21$$

Application of the model beyond this region should be avoided.

ANALYTICAL MODEL OF RESOLVE POTENTIAL PAIRS.

The following variables were considered in the model:

X_1 = Number of pairs resolved ✓

X_2 = Number of proximity warning indications (PSI's) accumulated ✓

TX = Total execution time for resolve potential pairs

The linear model examined was $TX = a_0 + a_1X_1 + a_2X_2 + E$ and is summarized as follows:

<u>Coefficient</u>	<u>Associated Variable</u>	<u>Coefficient Value</u> (μs)	<u>Standard Deviation</u>
a_0	--	8.637×10^3	7.573×10^3
a_1	X_1	8.765×10^2	1.106×10^1
a_2	X_2	7.945×10^3	3.819×10^2

Examination of the standard deviations provide no reason to drop any terms from the model.

The correlation between predicted and observed values is 0.989, and 97.91 percent of variation in total execution time is accounted for by the model. Examination of the residuals revealed some, but not drastic, departures from normality. The time-dependency plot and the runs test did not indicate any reason to reject the assumption that the residuals were randomly distributed.

Data for this study were collected in the following region:

$$122 \leq X_1 \leq 877$$

$$11 \leq X_2 \leq 31$$

Application of the model beyond this region should be avoided.

of
ANALYTICAL MODEL FOR RESOLUTION COMMAND LOGIC.

The following variables were included in the model:

X_1 = Number of calls to command selection logic

X_2 = Number of calls to command transition logic

T_X = Total execution time for resolution command logic

$$T = a_0 + a_1 X_1 + a_2 X_2 + E$$

The results of fitting the model ~~$T = a_1 X_1 + a_2 X_2 + E$~~ are summarized as:

<u>Coefficient</u>	<u>Associated Variable</u>	<u>Coefficient Value (us)</u>	<u>Standard Deviation</u>
a_0	-	2.662×10^5 1.356×10^5	1.474×10^4
a_1	X_1	2.713×10^5 2.662×10^5	9.942×10^3 8.511×10^3
a_2	X_2	2.715×10^5 2.225×10^4	1.458×10^3 1.355×10^3

Of the total variation in execution time, 91.86 percent was accounted for by this model. The correlation between predicted and observed values was 0.958.

Although the residuals do not fit the appropriate normal distribution perfectly and show a definite pattern of time-dependency, this model provides a good summarization of the data.

Data for this study were collected in the following region:

$$0 \leq X_1 \leq 17$$

$$0 \leq X_2 \leq 52$$

Application of the model beyond this region should be avoided.

ANALYTICAL MODEL OF DATA LINK MESSAGE CONSTRUCTION.

The following variables were considered:

X_1 = Number of own messages

X_2 = Number of proximity warnings and threats

X_3 = Number of active slots

τY = Total execution time for Data Link Message Construction

The value of τY was estimated using the variables X_1 , X_2 , and X_3 in the linear model $\tau Y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + E$. The results are summarized below:

<u>Coefficient</u>	<u>Associated Variable</u>	<u>Coefficient Value (μs)</u>	<u>Standard Deviation</u>
a_0	—	1.076×10^5	1.053×10^4
a_1	X_1	1.989×10^3	5.190×10^1
a_2	X_2	9.524×10^2	5.337×10^1
a_3	X_3	6.054×10^2	3.264×10^1

The standard deviations of these estimates of the coefficients are at least one order of magnitude less than the estimated values, so all terms appear to be significant.

The correlation between predicted and observed values in the model is 0.997, and 99.4 percent of total variation in execution time for data link message construction is accounted for by this model. Examination of the residuals showed no marked departures from normality. The plot of the residuals against the order of occurrence did not yield any specific pattern and the run test provided no reason to reject the assumption of randomness of the residuals.

The time dependency plot of total execution time for data link message construction did reveal a strong dependency on time. The model provides an excellent summary of the data.

Data for this study were collected in the following region:

$$53 \leq X_1 \leq 394$$

$$0 \leq X_2 \leq 172$$

$$238 \leq X_3 \leq 680$$

Application of the model outside this region should be avoided.

ANALYTICAL MODEL ^{OF} STATE VECTOR DELETE.

The following variables were considered in modeling this task:

X = Number of aircraft deleted

X^2 = Number of aircraft deleted, squared

TX = Total execution time of state vector delete

Initially, a linear regression with TX as the dependent variable and X as the independent variable was examined. This yielded a distinctly nonnormal, asymmetric pattern of residuals and a negative intercept. The addition of the quadratic term improved the fit and yielded a pattern of residuals which was almost normal.

was estimated using the variables X and X^2 . When the coefficients $\hat{Y} = a_0 + a_1 X + a_2 X^2$ were calculated the linear term obtained was \hat{Y} and its standard deviation was 6.896×10^2 , which suggests that the \hat{Y} be eliminated. When the linear term was eliminated the following results were obtained:

<u>Coefficient</u>	<u>Associated</u>	<u>Value</u>	<u>Standard</u>
<u>Variable</u>		<u>(μs)</u>	<u>Deviation</u>
	—	2.647×10^3	4.629×10^2
	X^2	4.6117×10^2	2.845×10^1

Correlation between predicted and observed value is 0.856; the model accounted 3.24 percent of the total variation. Examination of the time-dependency plot of residuals and the results of the run test provided no reason to assume that the residuals are nonrandom.

for this study were collected in the region $1 \leq X \leq 10$. Application of the model outside this region should be avoided.

OF
EMPIRICAL MODEL OF OUTGOING CONFLICT TABLES.

following variables were considered:

- X_1 = Number of calls to conflict table delete subtask
- X_2 = Number of calls to conflict table update subtask
- T_X = Total execution time for outgoing conflict tables

The value of \bar{Y} was estimated using the model $\bar{Y} = a_0 + a_1X_1 + a_2X_2 + E$.

<u>Coefficient</u>	<u>Associated Variable</u>	<u>Coefficient Value (μs)</u>	<u>Standard Deviation</u>
a_0	--	4.307×10^3	2.300×10^1
a_1	X_1	5.440×10^2	1.334×10^1
a_2	X_2	9.528×10^2	6.897×10^1

Examination of the standard deviation column does not provide any reason for dropping terms from the model. This model accounts for 99.99 percent of all observed variation in execution time.

The residuals were not normally distributed. The runstest provided justification for rejecting the assumption that the residuals are randomly distributed.

The time dependency plot of the residuals also supported the results of the runstest. The plot of execution times against the order of their occurrence also reveals a marked dependency on epoch number. Although the model summarize the data almost perfectly, the residuals were not well behaved.

Data for this study were collected in the following region:

$$0 \leq X_1 \leq 28$$

$$0 \leq X_2 \leq 58$$

Application of the model beyond this region should be avoided.

SUMMARY OF RESULTS

ATARS performance data were collected using the CPMS and the 400 aircraft ATARS capacity scenario. A model was then developed for each of the major ATARS tasks using multiple regression analysis (MRA) techniques. The results of these analyses are summarized in table 1.

The analytical models helped identify critical subtasks in the ATARS and provided valuable insight into the performance of the system. For instance, the analysis of the aircraft update task indicated that there was a quadratic component to the model due to a sorting algorithm which became dominant at high loads.

CONCLUSIONS

It is concluded that:

1. Multiple regression analysis provides excellent models of execution time and provides the information necessary to identify critical subtasks.
2. The performance of an Automatic Traffic Advisory and Resolution Service (ATARS) task is not always easily understood by examination of code or system design flow charts. For example, the execution time of the aircraft update task displays a linear relationship with the number of aircraft updated for a small number of aircraft, but the quadratic character of the sorting algorithm within this task became dominant for a large number of aircraft.

TABLE 1a. SUMMARY OF ANALYTICAL MODELS

<u>Task Name</u>	<u>Aircraft Update</u>	<u>Add New Aircraft</u>	<u>Coarse Screen</u>
<u>Type of Model</u>	Linear for $X < 250$ Quadratic for $X > 250$	<u>Linear</u>	<u>Linear</u>
Independent variables	X = Number of aircraft updated	X = Number of new aircraft	X_1 = Number of pairs in backward search X_2 - Number of pairs in forward search X_3 - Number of potential pairs generated X_4 - Number of aircraft in coarse screen (approximately 1/2 the total number of aircraft)
Data bounds	$36 \leq X \leq 344$	$1 \leq X \leq 61$	$135 \leq X_1 \leq 3286$ $71 \leq X_2 \leq 2125$ $10 \leq X_3 \leq 267$ $34 \leq X_4 \leq 181$
Critical subtasks	None for $X < 250$ Sort for $X < 250$	None	Forward search potential pair generation
Percent of variation accounted for by the model	Linear model = 99.60 Quadratic model = 86.25	96.00	94.77

subscripts
 X_1

X_2

X_3

X_4

subs

TABLE 1b. SUMMARY OF ANALYTICAL MODELS

<u>Task Name</u>	<u>Detect</u>	<u>Resolve Potential Pairs</u>	<u>Resolution Command Logic</u>	<u>Data Link Message Construction</u>	<u>State Vector Delete</u>
<u>Type of Model</u>	<u>Linear</u>	<u>Linear</u>	<u>Linear</u>	<u>Linear</u>	<u>Quadratic</u>
Model variables	<p>X_1 = Number of potential pairs (approximately one-half Number of potential pairs generated by course screen per epoch)</p> <p>X_2 = Number of filtered C/U-pairs</p> <p>X_3 = Number of filtered U/U pairs</p> <p>X_4 = Number of filtered C/C pairs</p>	<p>X_1 = Number of pairs resolved</p> <p>X_2 = Number of PWI's accumulated</p>	<p>X_1 = Number of calls to command selection logic</p> <p>X_2 = Number of calls to command transition logic</p>	<p>X_1 = Number of own</p> <p>X_2 = Number of proximity warnings and threats</p> <p>X_3 = Number of active slots</p>	<p>X = Number of aircraft deleted</p>
Data bounds	<p>$8 \leq X_1 \leq 147$</p> <p>$0 \leq X_2 \leq 36$</p> <p>$0 \leq X_3 \leq 44$</p>	<p>$122 \leq X_1 \leq 877$</p> <p>$11 \leq X_2 \leq 31$</p>	<p>$0 \leq X_1 \leq 17$</p> <p>$0 \leq X_2 \leq 52$</p>	<p>$53 \leq X_1 \leq 394$</p> <p>$0 \leq X_2 \leq 172$</p> <p>$238 \leq X_3 \leq 680$</p>	<p>$1 \leq X \leq 10$</p>
Critical subtasks	C/U processing U/U processing	None	None	None	None
Percent of variation accounted for by the model	94.67	97.91	91.86	99.4	73.24

TABLE 1c. SUMMARY OF ANALYTICAL MODELS

<u>Task Name</u>	<u>Outgoing Conflict Tables</u>
<u>Type of Model</u>	<u>Linear</u>
Model variables	$X_1 =$ Number of conflict tables deleted $X_2 =$ Number of conflict tables updated
Data bounds	$0 \leq X_1 \leq 28$ $0 \leq X_2 \leq 58$
Critical subtasks	None
Percent of variation accounted for by the model	99.99

RECOMMENDATION

The execution time of Automatic Traffic Advisory and Resolution Service (ATARS) tasks, in general not be characterized by a single factor (e.g., average execution time).

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PERFORMANCE MEASUREMENT SYSTEM (CPMS).

Consists of a Digital Equipment Corporation PDP-11/55 minicomputer and a software probes to interface with the Discrete Address Beacon System (DABS)

This interface consists of 12 probes monitoring the DABS address lines and 12 probes monitoring the global memory bus lines. CPMS data are recorded on an analog magnetic tape unit.

Requires as input a start address and stop address for each probe and a cycle period for the entire system: During each of the cycle periods the CPMS will output the following information for each address probe:

1. Elapsed time sample — this is the amount of time between the execution of the start address and stop address for the first occurrence of the pair only.

2. Elapsed time accumulator — this is the total time spent between the start and stop times for all occurrences of the pair during the cycle period.

3. Address iteration count — this is a count of the number of times the start address was executed, the number of times the stop address was executed, or the number of times the start/stop pair was executed.

4. Address sample — this is the first valid address to appear in the address bus lines during the cycle period.

For each bus line probe the CPMS provides the elapsed time sample, the iteration count, and elapsed time accumulator.

A description of the CPMS data formats is in figure A-1.

SIX BUSLINE PROBES

KEY (5)

E.T.S. (11)

ITERATIONS (16)

E.T.A. (24) LSB

A B C D

E.T.A. MSB

- A - Lead Edge But No Trail Edge (E.T.S.)
- B - Overflow On One Time Sample (E.T.S.)
- C - 100% High (E.T.S. and E.T.A.)
- D - E.T.A. in Progress at End of Cycle

	<u>LSB</u>	<u>Maximum</u>
E.T.S. - Elapsed Time Sample	25 ns	51 s
- Iterations	16 bits	64K
E.T.A. - Elapsed Time Accumulator	25 ns	400 ms

TWELVE ADDRESS PROBES

KEY (5)

C.T.S. (11)

E.T.A. (16)

ADDRESS SAMPLE (16)

B C A

A.I.C. (13)

- A - Lead Edge But No Trail Edge (E.T.S.)
- B - Overflow On One Time Sample (E.T.S.)
- C - 100% High (E.T.S. and E.T.A.)

	<u>LSB</u>	<u>Maximum</u>
E.T.S. - Elapsed Time Sample	1 s	2 ms
- Address Sample	16 bits	64K
A.I.C. - Address Iteration Count	13 bits	8K
E.T.A. - Elapsed Time Accumulator	1 s	64 ms

A.I.C. Modes

- 1. Start Address 10
- 2. Stop Address 11
- 3. Start/Stop Address Pairs 00 or 01

FIGURE A-1. CPMS DATA FORMAT

Major



AIRCRAFT REPLY AND INTERFERENCE ENVIRONMENT SIMULATOR (ARIES).

The following is ^{based on} ~~extracted from~~ the Lincoln Laboratory Project Report, "The Aircraft Reply and Interference Environment Simulator (ARIES), Volume 1: Principles of Operation" (reference 15).

INTRODUCTION AND SYSTEM OVERVIEW.

Major

INTRODUCTION.

The Aircraft Reply and Interference Environment Simulator (ARIES) is designed to simulate a radar beacon environment of up to 400 transponders, plus high rates of interfering beacon replies ("fruit") for the purpose of testing the operation of beacon interrogators under heavy load.

The large target capacity of a DABS sensor and the existence of only a few DABS transponders make infeasible live tests which provide any significant loading of the DABS. The complexity of a DABS sensor precludes simply extrapolating performance from a less dense benchmark test. For these reasons, and the requirement to be able to repeat identical tests, an environment simulator was built which can appear to the sensor under test to be a dense beacon interference environment

typical of what might be encountered in the future. The ARIES also provides a capability to recreate various scenarios for purposes of continued sensor software development and debugging.

The ARIES equipment consists of interrogation receiving circuitry, reply generation circuitry, and a computer and associated peripheral equipment to control the system. This equipment is housed in two standard racks.

ARIES SYSTEM SUMMARY.

CAPABILITIES. The ARIES can simulate a beacon environment of up to 400 transponders. With any mix of ATCRBS and DABS transponders. Not all DABS interrogation and reply types are handled. Those that are handled and the special data bit protocols that are simulated are described later.

Along with simulated traffic, the ARIES can generate a simulated fruit environment. The arrival times of fruit replies are modeled as a random process with Poisson statistics. The operator can control the average fruit rate by setting parameters in a file on the system disk.

For both the simulated transponder (controlled) replies and fruit replies, the ARIES provides the necessary signals to accurately simulate the monopulse off-boresight angle. Also, an omnidirectional signal is provided that is specific to the ARIES. Inside the sensor ARIES side-lobes are summed with similar signals from the sensor's own antenna. This allows a simulated environment to be superimposed on a live environment, if desired.

In addition to the beacon data, the ARIES provides simulated digitized radar data in the output format of a production common digitizer (PCD). The radar targets correspond to the simulated beacon targets. The reported coordinates are those that would be seen by a primary radar whose antenna rotates with the beacon antenna about the same axis.

Finally, the ARIES is also capable of multisite operation, in order to exercise the multisite network aspects of DABS. This is accomplished by locating an ARIES at each sensor site. The traffic model at each site is coordinate adjusted so that each sensor sees a view of the environment consistent with that of the other sensors. The ARIES sites are linked by communication lines which allow them to maintain time synchronization and consistent transponder internal state data for DABS targets that can be seen by more than one site.

Each of the above mentioned features of the ARIES is described in more detail in the following sections.

SIMULATED TRANSPONDERS.

INTERROGATION/REPLY CYCLE. Interrogations are received by the ARIES from the DABS sensor at 1030 megahertz (MHz) and processed by the receiver circuitry. The receiver transfers a data block to the computer giving the type of interrogation, the time of arrival, the boresight azimuth of the antenna, whether the interrogation was a front antenna or back antenna interrogation (for the en route "back-to-back" antenna) and any data content. Azimuth data are provided by the azimuth decoder/simulator which can operate in either of two modes. In the decoder mode, azimuth change pulses (ACP's) and azimuth reference pulses (ARP's) are received

from the sensor's antenna system and used to increment and reset and azimuth register, respectively. The ACP's and ARP's are then "daisy-chained" back to the sensor. In effect, the ARIES is inserted into these lines between the antenna and the sensor. In the simulator mode, ACP's and ARP's are produced by the ARIES and sent to the sensor. ACP's and ARP's from the antenna, if an antenna is connected, are ignored. Thus, the ARIES can be run with a sensor that is not connected to an antenna system. The decoder mode is needed for the case where live data from the sensor's own antenna and simulated data from the ARIES are to be superimposed.

INTERROGATION AND REPLY TYPES HANDLED BY ARIES. The ARIES is capable of processing both mode A and mode C ATCRBS/All-Call interrogations. (The system software is not designed to process ATCRBS interrogations without the P4 pulse.) The reply modes are mode A or mode C (ATCRBS) replies from simulated ATCRBS transponders and All-Call replies from DABS transponders. ARIES is not capable of simulating military emergency codes, which consist of several sequential ATCRBS replies.

RADAR REPORT GENERATION. As targets in the ARIES track file enter the antenna beam, a simulated radar report is prepared for them by the computer. The range and azimuth coordinates are used to generate the beacon reports. These data are transferred to the radar report generator, which outputs the data to the sensor in a format identical to that of the output interface of a PCD. The data are transferred to the sensor just after the targets have left the beam.

A system-wide blip/scan ratio can be specified by the operator and, in conjunction with the random number generator, is used to determine whether a given target will have a radar report on a given scan. The interface is capable of transferring over 120 target reports per second.

FRUIT REPLY GENERATION. The ARIES is capable of generating ATCRBS fruit replies at rates up to about 50,000 replies per second. DABS fruit are not generated, although an independent fruit generator does exist. These high rates are required to test the performance of the DABS sensor's reply processing circuitry at the interference levels at which it is capable of operating. Because of the high rates required, the entire reply generation process is performed in hardware. The computer specifies to the fruit generator the average fruit rate desired, the fraction of the replies that are to appear in the main lobe as opposed to the side-lobes, a particular ATCRBS reply code, and the fraction of replies that are to have this code. The latter two items allow a particular code to be emphasized in the otherwise randomly generated stream of reply codes. One likely candidate for emphasis might be, for example, the nondiscrete visual flight rules (VFR) code 1200.

THE TRAFFIC MODEL. The traffic model is stored on the system disk. Each logical record specifies the position and velocity of one aircraft at a particular time, as well as such items as its altitude and identity codes. These records are sorted in increasing time order.

The data in the traffic model can be created in a variety of ways. However, for purposes of system tests of the DABS sensor, the method used in the Los Angeles Basin standard traffic model for 1982 will be used. A program has been written which will take any model in the format of the Los Angeles model and convert it to the appropriate format for input to the ARIES. This program also allows the user to control certain transponder state information (i.e., the downlink request bit, the pilot acknowledgement bits, etc.). Options are provided for generating these either randomly or under user control on a target-by-target basis.

MULTISITE OPERATION. In order to exercise a network of DABS sensors, an ARIES must be located at the Technical Center and Elwood DABS sensors. These ARIES sites are then connected together by means of telephone links. The links are required for two purposes. First, they are needed in order to start the simulations in synchronism at all sites and to verify that this synchronism is being maintained. Second, DABS transponders have certain states (i.e., lockout) that are controlled by interrogations from the sensor and cannot be precomputed as part of the traffic model. If a transponder is visible to more than one site, it is necessary to assure that this state information is consistent among all sites. Therefore, if a transponder is told to lockout All-Call interrogations at one site, the ARIES at that site will inform all other ARIES of this occurrence so that the transponder appears to be locked out at all sites.

DATA RECORDING. The ARIES records a limited amount of data in real time, primarily for debugging purposes. However, data are recorded indicating which targets replied to any ATRCBS/All-Call interrogation and whether or not a reply was generated for each discrete interrogation, (if not, why not). More extensive recording is available for a limited number of targets. This includes a record of all targets that were considered for an ATRCBS/All-Call reply, and if they did not reply, an indication of why. For DABS targets, all of the interrogation data block, except the unused message fields and the entire reply block, are recorded. Thus, a significant amount of information is available about the interrogations transmitted by the sensor and the replies that were generated by ARIES. This could potentially be used in analyzing the sensor's performance.

These data are normally recorded on magnetic tape. However, there is an option to record on the disk. Due to the limited size of the disk file allocated for this

purpose, only a few minutes of recording of a dense environment is possible. If the recording process reaches the end of the file it moves back to the beginning of the disk file and begins overwriting the old data.