GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

aLL

Date: 1/11/77

Project Title: "Stand-Off Target Acquisition System (SOTAS) Cost Analysis."

Project No: A-1931

Project Director: ~~Dr. R. A. Gagliano~~ Dr. R. D. Hayes

Sponsor: Office of Naval Research, Dept. of the Navy, Arlington, Va. 22217

Agreement Period: From 12/15/76 Until ~~5/15/77~~ 31 Mar 78

Type Agreement: Contract No. N00014-77-C-0119

Amount: $23,400

Reports Required: Progress Reports, (as required); Final Technical Report.

Sponsor Contact Person (s):

Technical Matters

Director, Fleet Analysis & Support
Office of Naval Research
800 N. Quincy Street
Arlington, Va. 22217

Contractual Matters
(thru OCA)

Office of Naval Research
Resident Representative
325 Hinman Research Building
Georgia Institute of Technology
Atlanta, Ga. 30332

Defense Priority Rating: DO-C9 under DMS Reg. 1

Assigned to: Systems and Techniques (School/Laboratory)

COPIES TO:

- Project Director
- Division Chief (EES)
- School/Laboratory Director
- Dean/Director—EES
- Accounting Office
- Procurement Office
- Security Coordinator (OCA)
- Reports Coordinator (OCA)
- Library, Technical Reports Section
- Office of Computing Services
- Director, Physical Plant
- EES Information Office
- Project File (OCA)
- Project Code (GTRI)
- Other ____________

CA–3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: October 13, 1980

Project Title: Stand-Off Target Acquisition System (SOTAS) Cost Analysis

Project No: A-1931

Project Director: Dr. R. A. Gagliano

Sponsor: Office of Naval Research; Dept. of the Navy; Arlington, Va. 22217

Effective Termination Date: 3/31/78 (Performance Period)

~~Clearance of Accounting Charges~~: 5/31/78 (Reporting Period)

Grant/Contract Closeout Actions Remaining:

X Final Invoice and Closing Documents
_ Final Fiscal Report
_ Final Report of Inventions
_ Govt. Property Inventory & Related Certificate
_ Classified Material Certificate
_ Other ______________

Assigned to: RAIL/ORB (School/Laboratory)

COPIES TO:

Project Director
Division Chief (EES)
School/Laboratory Director
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Library, Technical Reports Section
EES Information Office
Project File (OCA)
Project Code (GTRI)
Other ______________

CA-4 (1/79)

A-1931

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

24 February 1977

Office of Naval Research
Department of the Navy
800-North Quincy Street
Arlington, Virginia 22217

Reference: ONR Contract Number N00014-77-C-0119

Subject: Monthly Contract Technical Status Report No. 1
for the period 1 January 1977 to 1 February 1977

Gentlemen:

The results and current status of work performed under the referenced contract during the reporting period is summarized below.

Contractual Arrangements

The effective starting date for this contract is 1 January 1977. During this reporting period, contract negotiations were completed and formal contract documents were received. The effort under this contract has been designated as EES/GIT A-1931. Work under this contract will be performed by personnel of the Radar and Instrumentation Laboratory, which is now headed by Dr. E. K. Reedy. The project director is Dr. R. A. Gagliano with Dr. R. D. Hayes acting as principal radar consultant.

In addition to commencing work on Tasks I and II as outlined in GIT/EES's proposal, two significant accomplishments can be reported. The first is a mid-January meeting and the second is an agreement-in-principle to proceed into an additional work phase.

Trips/Conferences

On 24 January 1977, a meeting was held at the SOTAS Project Manager's office. This meeting wsa attended by W. Kenneally (PM), M. Shuhandler, W. Bryan, D. Usechek, and I. Roper of USAECOM, and R. Gagliano and E. Reedy of EES. Several technical issues were resolved at this meeting, and views were exchanged regarding the cost analysis and relationships to similar systems.

It was determined that all major radar signal processing will be done on board the H/C, and will include Doppler, CFAR, FFT, and sidelobe cancelling. Only narrow bandwidth data will be transmitted to the ground. The cost analysis will not be concerned with H/C stabilization, auxillary trackers, displays (none on H/C) nor the data link in the first phase. It is assumed that mil-standard components are to be used throughout, with full climatic and airborne specifications required. The first phase GIT/EES cost analysis will concentrate on the major radar subsystems.

Algorithm Development, Modification and Preliminary Cost Analysis

During this reporting period, GIT's major emphasis has been directed toward evaluation and comparison of the SOTAS radar design configuration with previous radar systems "costed" by EES using RECAP. A major radar parameter design comparison matrix is being developed so that the primary differences between the SOTAS radar and other radars investigated previously can be clearly delineated. This will, in turn, identify areas where modification of existing cost algorithms are required, and also where new cost estimating algorithms will be needed. One such area already identified as requiring new algorithms is ECCM features.

Contract Extension

The second major item is the approval by the PM to proceed into an additional work phase as proposed in our letter proposal dated 10 January 1977. This work effort will concern the ground-based display configurations, software cost analysis, and life cycle cost modeling. Approval to commit the additional funding is expected momentarily.

Plans for Next Reporting Period

Preparations were made in the latter part of January to attend the Study Advisory Group (SAG) meeting on SOTAS to be held at the Systems Planning Corporation (SPC) offices in Arlington, Virginia, on 2 February. Details from this meeting will be discussed in the next progress letter.

Plans are also being completed for a trip by R. Gagliano and R. Hayes to: the Intelligence Center at Fort Hauchuca to discuss SOTAS employment and integration; General Dynamics in San Diego for inspection of prototype development; and to Technology Services Corporation in Santa Monica for radar configuration discussions. These visits will probably be accomplished during 28 February to 3 March 1977.

Respectfully submitted,

Ross A. Gagliano
Project Director

RAG:sf

cc: SOTAS Office
A-1931 File

LIBRARY DOES NOT HAVE

Monthly Contract Technical Status Report, Nos. 2 and 3.

A-1931

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

20 May 1977

Office of Naval Research
Department of the Navy
840 North Quincy Street
Arlington, VA 22217

Reference: ONR Contract Number N00014-77-C-0119

Subject: Monthly Contract Technical Status Report No. 4 for the period 1 April 1977 through 30 April 1977

Gentlemen:

The current status of work performed under the referenced contract during the subject reporting period is summarized below.

Contractual Activities

Efforts under Tasks I and II have been largely completed and the results are scheduled to be presented to ECOM personnel the latter part of the month of May 1977. Costs have been generated for antenna, transmitter, receiver and signal processor subsystems. The impact of the cost of the ECM and ECCM on these subsystems is still being assessed. Besides the subsystem costs, per unit and total order costs have been determined which include specification of engineering development and advanced production engineering costs as well. Effort has been undertaken to validate the cost values with units purchased for airborne applications.

Work on Tasks I through V of the second phase could not commence since the additional funding was not received during April. A delay in the termination date of this extension is anticipated for 31 December 1977 (per telephone conversation with Ms. Walsh at ONR).

Trips/Conferences

The ECOM review has been rescheduled for 18 May (later rescheduled to 26 May), and is discussed in the next section.

Dr. Hayes visited with Mr. Al Jants at AVSCOM on 22 April to discuss airborne radar related topics.

Georgia Tech Meeting

Attached is the proposed agenda for the meeting now scheduled for Thursday, 26 May 1977 and which is to be held in the Electronics Research Building at the Engineering Experiment Station in Atlanta.

Plans for Next Reporting Period

The additional funding as stipulated in MIPR Number 77-095-22 (dated 7 March 1977) was received on 12 May 1977 to be effective on 16 May 1977. The results of the meeting of 26 May with respect to the direction of display configurations and software considerations will be discussed in the next progress letter.

Respectfully submitted,

Robert D. Hayes
Project Director

Attachment

Approved:

J. D. Echard, Chief
Radar Analysis Branch

PROPOSED AGENDA

SOTAS Cost Analysis Review

26 May 1977

Time	Tentative Topics
0830	INTRODUCTION - Reedy/Hayes - Agenda - Program Overview - EES Organization - Project Review
0900	SOTAS DESIGN PARAMETERS - Hayes - Requirements - Design Considerations - Matrix of Parameters - Performance Features - Alternatives
1000	COST ANALYSIS - Gagliano - Background - Data Bases - Cost Estimating Relationships (CER's) - RECAP - Conversion to SOTAS
1100	PRELIMINARY COST RESULTS - Gagliano - Radar Estimates - Display Systems Estimates - Comparisons with Known Systems
1200	LUNCH
1300	DISPLAY DESIGN CONSIDERATIONS - Divine - Related Experiences - Plasmas and CRT's - CPU Control/Interface
1400	SOFTWARE CONSIDERATIONS - Martin - Related Experiences - Measures of Performance/Cost - Hardware/Software Tradeoffs
1500	PROGRAM SUMMARY - Eaves/Hayes - Project Status - Future Plans - Schedule

MOST PROBABLE ATTENDEES

Wayne Bryan - SOTAS Office
Martin Shuhandler - ECOM CSTA Lab
Dave Usechek - CENTACS
Bob Hughes and/or Chuck Lowman - SPC

Bob Hayes - EES
Ross Gagliano - EES
Ed Reedy - EES
Jerry Eaves - EES
J. Echard - EES
Fred Dyer - EES
Edie Martin - EES
Tom Divine - EES
Jim Cofer - EES

A-1431

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

20 June 1977

Office of Naval Research
Department of the Navy
840 North Quincy Street
Arlington, VA 22217

Reference: ONR Contract Number N00014-77-C-0119

Subject: Monthly Contract Technical Status Report No. 5 for the period 1 May 1977 through 31 May 1977

Gentlemen:

The current status of work performed under the referenced contract during the subject reporting period is summarized below.

Contractual Activities

Preliminary cost estimates have been made under Task I and II. The system design parameters used in establishing the CER's were previously provided on an attachment to the March progress letters. Many of the cost estimates have been verified by using cost values of units purchased for airborne applications. Modifications to the CER's for ECM and ECCM subsystems are progressing and are expected to be completed next month.

Efforts on Task III are underway and will continue until the end of the project period.

Funding for Phase II has been received and the contracting Sponsor's office(ONR) has verified that the project termination date has been extended to 31 December 1977 because of delays in initating this portion of the program. A revised Time and Task Schedule is included for your information.

Trips/Conferences

The ECOM review meeting scheduled for 26 May 1977 was rescheduled for 3 June 1977 at the request of the SOTAS office. The same agenda, as presented last month, will be used and it is anticipated that representatives from Systems Planning Corporation and USAECOM-CENTACS will also be in attendance.

Personnel from Harris Systems, Melbourne, Florida, visited Georgia Tech on 26 May 1977 to discuss the Data Link system requirements and radar system concepts for the airborne equipment.

Plans for Next Reporting Period

The meeting planned for 3 June 1977 will propose a set of radar system parameters to be used in the CER effort. An interim technical report will be undertaken.

It is also anticipated that more definitive guidelines for the work proposed under Phase II and funded through MIPR Number 77-095-22 will be forthcoming from the ECOM 3 June 1977 meeting. In particular, display configurations and requirements and software considerations will be discussed.

Respectfully submitted,

Robert D. Hayes
Project Director

Attachment

Approved;

J. D. Echard, Chief
Radar Analysis Branch

Start: 15 December 1976
End: 31 December 1977

GIT/EES Project A-1931

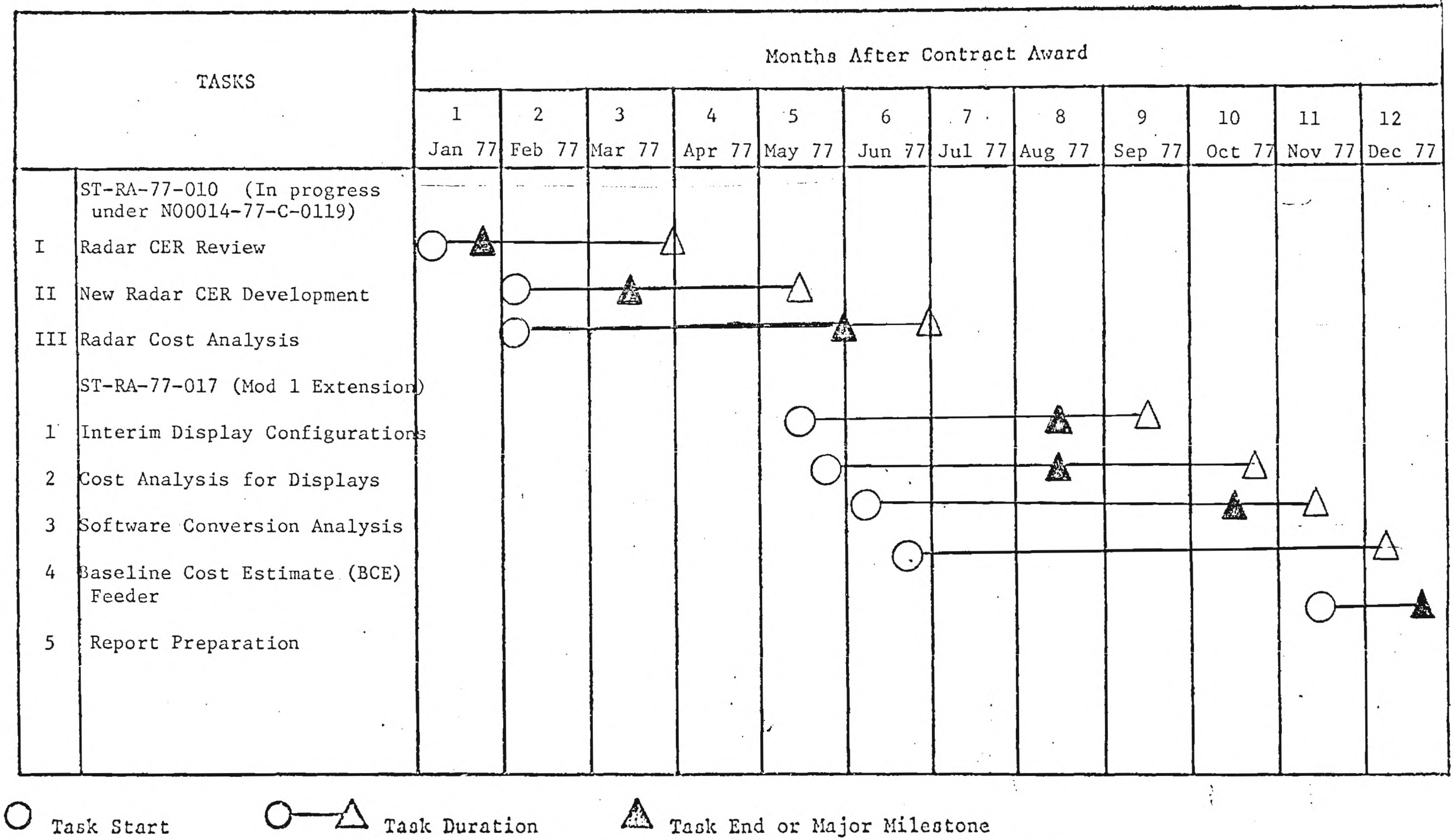

Figure 1. Time and Task Schedule for SOTAS Cost Study.

LIBRARY DOES NOT HAVE

Monthly Contract Technical Status Report, Nos. 6 and 7.

H-1931

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

29 September 1977

Office of Naval Research
Department of the Navy
800-North Quincy Street
Arlington, Virginia 22217

Reference: ONR Contract Number N00014-77-C-0119

Subject: Monthly Contract Technical Status Report No. 8
for the period 1 August 1977 through 31 August 1977

Gentlemen:

The results and current status of work performed under the referenced contract during the reporting period are summarized below.

Contractual Activities

An interim technical report entitled "SOTAS Radar Cost Analysis," (TM-1931-001) has been compiled in draft form. This report is to be delivered to, and discussed with, members of the SOTAS-PM Office at Fort Manmouth, New Jersey. It is also planned that a trip be made to Systems Planning Corporation (SPC) in Arlington, Virginia, for purposes of discussing the Baseline Cost Estimate (BCE) which is being compiled by SPC for submission in early October 1977.

The most significant effort remaining in the area of the radar cost analysis appears to be the validation of the cost estimating relationships (CER's) and completion of a radar data base. Cost estimates and actual contract expenditures on various comparable systems are now being assembled. Data on the following radar systems is being provided: AN/TPQ-36, AN/TPQ-37, HOWLS, the HWL System, CSTAR and various candidates in the MTAR/MTLR and HWL programs.

Considerable progress is being made in developing realistic cost predictions for the SOTAS software systems, which are to be employed in both the Master Ground Station and the Remote Ground Station. Cost "drivers" are being isolated and identified, and CER's are being assembled for possible use. It is anticipated that cost estimates can be available for the next program report.

Project Directorship

Effective 15 August 1977, Dr. Ross Gagliano has replaced Dr. Robert Hayes as Project Director. See attached RAIL memorandum.

Plans for the Next Reporting Period

A concerted effort is now being made to provide cost information on the display configurations and software development support of the ground stations. With the receipt of CENTACS Report #81, some additional insight into the Master Station has been provided through the discussion of the problems associated with the Remote Stations.

Respectfully submitted,

Ross A. Gagliano
Project Director

RAG:sf

cc: SOTAS Office
A-1931 File
R. D. Hayes

Approved:

Donald S. Sanford
Head, Simulation Group

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

MEMORANDUM

August 5, 1977

To: F. B. Dyer, J. L. Eaves
Branch/Group Heads
R. A. Gagliano, R. D. Hayes

From: E. K. Reedy

Subject: PROJECT A-1931 ADMINISTRATION AND MANAGEMENT

Phase I of Project A-1931 ("Standoff Target Acquisition System Cost Analysis") involving radar system analysis, definition, and costing, will be completed with the submission of our interim technical report within the next week. The second phase of the effort under this Project will involve software and display concepts analysis, definition, and costing. For this reason, effective August 15, 1977, Project A-1931 will be reassigned from the Radar Technology Area/Analysis Branch to the Technology Development Area/Simulation Group with Dr. Ross Gagliano reassuming duties as Project Director. Dr. Robert Hayes will continue to provide support to this Project in the radar systems area.

mar

c.c. D. J. Grace
H. G. Dean, Jr.
R. C. Johnson
GTRI
EES Accounting
Reports & Procedures
Security
Laboratory Directors
SED Chief
XM Office
C. E. Smith

A-1931

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

20 October 1977

Office of Naval Research
Department of the Navy
800 North Quincy Street
Arlington, VA. 22217

Reference: ONR Contract Number N00014-77-C-0119

Subject: Monthly Contract Technical Status Report No. 9, for the period 1 September 1977 through 30 September 1977.

Gentlemen:

The results and current status of work performed under the referenced contract during the subject reporting period are summarized below.

Contractual Activities

The Interim Technical Report (TM-1931-001) as described in the August Progress Letter was delivered to the SOTAS-PM Office on 15 September 1977. Contents of this report were discussed with Mr. Wayne Bryan at that time, and the report was to be reviewed by other SOTAS personnel shortly thereafter.

Two additional Interim Technical Memoranda are in preparation. One will address the software definition, analysis and costing. The other will discuss candidate display configurations, both from the costs and performance.

The most significant revelation resulting from the compilation of the Baseline Cost Estimate is that the overall software costs may become rather insignificant in terms of the total SOTAS life cycle costs. The same may not be true for the collective display systems. The radar BCE data effort has been completed.

Trips/Meetings

Besides the meeting at the SOTAS-PM Office (mentioned above) in which Mr. David Usechek (CENTACS) and Mr. Tom Divine of EES discussed the software/ display processes which were developed in the latest CENTACS Report, a meeting was also held at Systems Planning Corporation (SPC) on 15 September 1977. A copy of TM-1931-001 was delivered to SPC; and the cost data generated together with the CER's were discussed with Dr. Weiss, Mr. McDonald, Mr. Hughes, and Mr. E. Yates, all of SPC. Another trip to SPC was planned for early October 1977.

EES was visited by Mr. Alan Sherman of the ECOM Comptrollers Office. Information was provided to Mr. Sherman to assist in the preparation of the SOTAS life cycle cost estimate.

Plans for the Next Reporting Period

Specifically questioned at the 15 September meeting at the SOTAS-PM Office, were the needs for redirection of effort (subsequent to the material presented in the CENTACS Report #81), the extension of these efforts into evolving problem areas or the development of new work particularly addressing the SOTAS-TOS or SOTAS-TACFIRE interfacing. No decisions could be reached on these matters at that time. However, they shall again be discussed as it appears appropriate. Copies of the memoranda mentioned above will be forwarded as soon as they are available. A meeting may possibly be scheduled in the near future.

Respectfully submitted,

Ross A. Gagliano
Research Scientist
Project Director

cc: SOTAS Office
A-1931 File
R. D. Hayes

Approved:

Donald S. Sanford
Head, Simulation Group

A-1931

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

18 November 1977

Office of Naval Research
Department of the Navy
800 North Quincy Street
Arlington, VA. 22217

Reference: ONR Contract Number N00014-77-C-0119

Subject: Monthly Contract Technical Status Report No. 10, for the period 1 October 1977 through 31 October 1977.

Gentlemen:

The results and current status of work performed under the referenced contract during the subject reporting period are summarized below.

Contractual Activities

A second Interim Technical Report is in preparation (TM-1931-002) which is entitled "SOTAS Software Cost Analysis". A copy of this memorandum shall be forwarded under separate cover. The purpose of this report is to review software cost considerations. Certain software definitions and factors of the software development cycle are described. Appropriate methods are discussed and a few cost estimating relationships (CER) are illustrated. A cost rationale for SOTAS is proposed and representative cost estimates are developed.

Activity continues in producing a third interim report relating to costs associated with the various candidate display system. Additionally, some effort has still been extended to assist in the clarification of costs for the SOTAS radar as indicated in the Baseline Cost Estimate(BCE).

Trips/Meetings

On 4 October 1977, Systems Planning Corporation (SPC) was again visited for the purpose of discussing the BCE and explaining certain issues raised in TM-1931-001. Many telephone calls have also been conducted for the same purpose with SPC and the ECOM Comptrollers Office.

Plans for the Next Reporting Period

Work will continue on the above mentioned memoranda which shall constitute a major portion of the Final Technical Report to be written in January 1978. In the interim, it may be appropriate to schedule a meeting at Georgia Tech for the purpose of reviewing the material that has been assembled to date.

Respectfully submitted,

Ross A. Gagliano
Research Scientist
Project Director

Approved:

Donald S. Sanford
Head, Simulation Group

RAG/pat

cc: SOTAS Office
A-1931 File
R. D. Hayes

H-1931

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

20 December 1977

Office of Naval Research
Department of the Navy
800 North Quincy Street
Arlington, VA 22217

REFERENCE: ONR Contract Number N00014-77-C-0119

SUBJECT: Monthly Contract Technical Status Report No. 11, for the period 1 November 1977 through 30 November 1977.

Gentlemen:

The results and current status of work performed under the referenced contract during the subject reporting period are summarized below.

<u>Contractual Activities</u>

Our interim Technical Memorandum (7M-1931-002) is being completed and a copy is being sent to Mr. David Usechek of CENTACS. It is anticipated that some of the details of this report will be discussed with members of the PM office during a visit to Fort Monmouth contemplated for the second week of January 1978.

<u>Trips/Meetings</u>

The SAG meeting was attended by the Project Director (undersigned) and Dr. Robert Hayes who has had a large role in the program. This meeting was held at SPC in Arlington, Va. on 21 November 1977.

Several significant changes in the overall SOTAS program were announced at this meeting which involved schedule, type of equipment to be utilized and deployment aspects. Some of these changes will have serious cost implications and are now being assessed by EES.

<u>Plans for the Next Reporting Period</u>

A request for a no-cost extension of the contract is being processed. This matter has been brought to the attention of the PM office and will be explored further in early January 1978.

Respectfully submitted,

Ross A. Gagliano
Research Scientist
Project Director

cc: SOTAS Office
A-1931 File
R. D. Hayes

A-1931

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

20 January 1978

Office of Naval Research
Department of the Navy
800 North Quincy Street
Arlington, VA 22217

REFERENCE: ONR Contract Number N00014-77-C-0119

SUBJECT: Monthly Contract Technical Status Report No. 12, for the period 1 December 1977 through 31 December 1977.

Gentlemen:

The results and current status of work performed under the referenced contract during the subject reporting period are summarized below.

Contractual Activities

Work has begun on interim Technical Memorandum (TM-1931-003). It is anticipated that some of the details of this report will be discussed with members of the PM office during a program review contemplated for March 1978, or early April. This memo will deal with the display subsystems.

Trips/Meetings

During a visit to the Pentagon, several discussions were held on SOTAS-related activities. The overall cost impact of the program was reviewed with Maj. Hollander of DCSRDA in which the nature of the asset was discussed. The most obvious consideration for its deployment will be its role and density. Subsequently, several presentations were attended on a USAF near-real-time system, and the possible interaction with SOTAS was discussed with Mr. Bob Hughes of SPC.

Plans for the Next Reporting Period

A request for a no-cost extension of the contract is now being processed. See attached letter.

Respectfully submitted,

Ross A. Gagliano
Research Scientist
Project Director

1 attachment
cc: SOTAS Office
A-1931 file
R. D. Hayes

A-1931

GEORGIA TECH RESEARCH INSTITUTE
ADMINISTRATION BUILDING
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

January 19, 1978

Refer to: AAC/A-1931

Office of Naval Research
Resident Representative
325 Hinman Research Building
Georgia Institute of Technology
Atlanta, Georgia 30332

Attention: Mr. Henry S. Cassell, III

Subject: Contract No. N00014-77-C-0119; Request for no-cost time extension.

Dear Mr. Cassell:

We respectfully request that the subject contract be modified to extend the performance period (Schedule Section H) by three (3) months, or through March 31, 1978. The approved Final Report would be distributed by sixty days thereafter as specified. No additional funding is requested as a result of this time extension.

At a meeting on January 11, 1978 at Fort Monmouth the Army Program Manager, Col. A. M. Cianciolo, and our Project Director, Dr. R. A. Gagliano, determined that it would be mutually advantageous to take the additional time to assure the orderly completion of several tasks. The major factor in the schedule problem was the late (June 1, 1977) turn-on for the Mod. P00001 work, which was proposed as an eight (8) month effort.

We will appreciate your assistance in this matter, and will be happy to furnish additional information if necessary. The writer can be reached by telephone at (404)894-4819.

Very truly yours,

Alfred A. Camp
Sr. Contracting Officer

mas
Addressee: In duplicate.
bcc: Dr. Gagliano; Mr. Eaves; Dr. Reedy; Dr. Johnson; Mr. Atcheson; Mr. Becker; File A-1931; Diary.

LIBRARY DOES NOT HAVE
Monthly Contract Technical Status Report No. 13.

A-1931

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

22 March 1978

Office of Naval Research
Department of the Navy
800 North Quincy Street
Arlington, Virginia 22217

Reference: ONR Contract Number N00014-77-C-0119

Subject: Monthly Contract Technical Status Report No. 14
for the period 1 February 1978 through 28 February 1978

Gentlemen:

The results and current status of work performed under the referenced contract during the reporting period are summarized below.

Contractual Activities

The work during this reporting period has been concentrated on completing a third interim report (not initially specified in the contractual agreements) on the EES efforts at developing cost and technical parameters on SOTAS display systems and sub-systems.

Additionally, work continues on preparing for the final briefings to be held at Georgia Tech in April 1978.

Plans for Next Reporting Period

Progress continues to be made in completing the contractual efforts and writing the final technical report. It is envisioned that major discussions will focus on this report in March and April.

Respectfully submitted,

Ross A. Gagliano
Project Director

cc: SOTAS Office
A-1931 File

A-1931

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

April 21, 1978

Office of Naval Research
Department of the Navy
800 North Quincy Street
Arlington, VA 22217

Reference: ONR Contract Number N00014-77-C-0119

Subject: Monthly Contract Technical Status Report No. 15
for the period 1 March 1978 through 31 March 1978

Gentlemen:

Some specific results and the current status of the work performed under the referenced contract during the subject reporting period, and a sketch of the general activities performed are summarized below. Inasmuch as the program with the present extension was scheduled for completion on 31 March 1978, this is the final monthly progress letter. However, a final report is in preparation and should be completed by 15 May.

Contractual Activities

During the past several weeks, a concerted effort has been made to determine the widest spectrum of not only display devices, but also general peripherals, which would: meet a potentially expanding set of requirements; represent the most current technology; and be the most cost-effective for this class of problems. As a result, several recommendations are possible; several of which may impact a few of the decisions which have recently been made either with respect to the requirements or to the possible responses of the prospective bidders for the ED models. It is contemplated that these issues will constitute a major portion of the discussions in the final program review and the final report.

Trips/Meetings/Conferences

The following list has been compiled to indicate the various on-site briefings and information exchanges by EES personnel during the course of this contract. It has been the underlying motivation to not only attend as many SOTAS activities as possible, but also to contribute to the decision formulation process, particularly with regard to costs and cost related matters.

Dates	Place	Purpose
24 January 1977	Ft. Monmouth, NJ	Initial Contract Meeting
2 February 1977	Washington, DC	SAG Meeting
28 February 1977	Ft. Huachuca, AZ	Intel Briefings
1 March 1977	San Diego, CA	GD Tour
2 March 1977	Santa Monica, CA	Discussions with TSC
3 March 1977	Fort Sill, OK	FA Briefings
4 March 1977	Fort Levenworth, KS	Discussion with CACDA
15-17 March 1977	Ft. Monmouth, NJ	Technical Approach Meetings
22 April 1977	St. Louis, MO	AVSCOM Discussions
1 June 1977	Fort Sill, OK	Discussions at CD
3 June 1977	EES, Atlanta, GA	Program Review at Georgia Tech
15 September 1977	Ft. Monmouth, NJ	Presentation of Radar Costs
15 September 1977	Arlington, VA	Discussions on BCE (SPC)
4 October 1977	Arlington, VA	BCE Discussions at SPC
21 November 1977	Washington, DC	SAG Meeting
7-8 December 1977	Washington, DC	Discussions with DCSRDA, SPC and DUSA-OR
12 December 1977	Washington, DC	UPD Briefings
11 January 1978	Ft. Monmouth, NJ	Presentation of Software Costs

In addition to these visits, EES personnel were also contacted and were visited by personnel from: Harris Company; General Dynamics; Motorola; ECOM Comptrollers Office; and Systems Planning Corporation.

Reports

Several interim technical reports have been prepared and delivered to the Program Manager's Office. These include: TM-1931-001 entitled "SOTAS Radar Cost Analysis" and TM-1931-002 entitled "SOTAS Software Cost Analysis". A third interim report is in preparation which covers the cost analyses of the display systems and subsystems. Lastly, a final technical report is in preparation which will cover the entire scope of work covering December 1976 through March 1978.

Respectfully submitted,

Ross A. Gagliano
Research Scientist
Project Director

RAG/pat

cc: SOTAS Office
A-1931 File
R. D. Hayes

TECHNICAL REPORT

STAND-OFF TARGET ACQUISITION SYSTEM (SOTAS) COST ANALYSIS

EES/GIT PROJECT A-1931

BY:

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Prepared for:

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May 1978

Unclassified when Appendix A is removed.

Final Technical Report

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Radar and Instrumentation Laboratory

Engineering Experiment Station

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DISCLAIMER

The view, opinions, findings and recommendations in this report are those of the authors and should not be construed as an official Department of the Army position, policy or decision unless so indicated by other official documentation.

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I. INTRODUCTION

Inasmuch as the development of sophisticated military computer-embedded sensor systems require comprehensive cost analysis and technical assistance to the procurement programs, the US Army Electronics R&D Command (ERADCOM) at Fort Monmouth, NJ, contracting through the Office of Naval Research (ONR), tasked the Radar and Instrumentation Laboratory (RAIL), of the Engineering Experiment Station (EES) at Georgia Tech to conduct an investigation into the various cost aspects of the Stand-Off Target Acquisition System (SOTAS). SOTAS is being developed for long-range general surveillance and moving target acquisition capabilities. The system will involve a helicopter-borne radar which is data linked to a set of ground display stations.

This program of research was carried out under ONR Contract N00014-77-C-0119, and Modifications P-00001 and A-00001, after initiation on 15 December 1976 with the Phase I completed on or about 3 June 1977. Phase II commenced thereafter, and was concluded on 31 March 1978, as extended in the second modification.

The major technical efforts were devoted towards: conducting a parametric analysis of the costs associated with the SOTAS radar system; providing feeder cost data on the Baseline Cost Estimate (BCE); developing a technical background for the SOTAS software cost characterization; analyzing various display/peripheral devices and configurations which appear compatible with the SOTAS requirements; and specifying certain display system/subsystem costs inherent in the requirements (e.g., MIL-spec, data rate, etc.). Nonetheless, this study was directed neither towards detailed performance analysis nor specific hardware design or fabrication. Suffice it to say that the problem of relating performance to cost for any class of state-of-the-art military sensor systems is indeed challenging. To perform such a study while the technology is undergoing such dynamic changes, and when neither the requirements nor performance aspects are final, poses some additional difficult and demanding constraints. This study represents a sincere and continuing attempt to gain valuable and hopefully transferable insight into the costing of the SOTAS program.

This study has been divided into several phases, as was mentioned earlier. This was done primarily to address and complete in a timely fashion the specific efforts listed above. The tasks in Phase I were as follows:

Task I. RECAP Modification

Using a Radar Equipment Cost Analysis Program (RECAP) which was developed by EES to use on the Moving Target Acquisition Radar (MTAR) Program, a SOTAS Radar Cost Program was developed. This task involved contrasting the SOTAS radar with the ground-based MTAR system and modifying the Cost Estimating Relationships (CER's) to handle the SOTAS parameters. This entailed accounting for the: airborne radar system (microwave pressurization, for example); narrow versus wideband mode of operation; data links only as it would impact the signal and data processors; various antenna configurations and the aerodynamical structural requirements; and the inclusion of ECCM.

Task II. CER Development

Where it was required, several new CER's were developed to account for: the ground station; the data link; antenna design changes; new operator presentation and control devices; and certain ECCM cost features. Other options were developed in the costing sequence which proved to be useful not only in the radar cost analysis, but also for the BCE feeder data. This latter effort, performed in conjunction with the Systems Planning Corporation (SPC) of Arlington, VA continued for a period of approximately five months.

Task III. Radar Cost Tradeoffs

This final task of Phase I involved the computation, comparison and analysis of the cost predictions for many different parameters. Principally, the analysis concerned the allocation of numbers of units in the development (R&D) versus production (investment) portions of the SOTAS genesis. Many variations of the radar parameters were used to compile an extensive set of costs which could be compared to or projected against either actual expenditures or values generated by other sources, using perhaps different cost algorithms and strategies. Many comparisons were provided to the ERADCOM Comptrollers Office and the Comptroller of the Army.

It became apparent early in the radar efforts that SOTAS would not only require extensive (front-end) signal and data processing as part of the radar system, but also that the operator positions (back-end) involved the most sophisticated, state-of-the-art, yet MIL-qualified, graphic display systems and other peripherals. Inherent in this approach would be software cost analysis and a few of the more significant factors in the Design to Cost (DTC) and Life-Cycle Cost (LCC) modeling. Therefore, in Phase II, the following additional tasks were performed:

Task 1. Display Systems Analysis

As mentioned above, since the previous tasks did not address the processors or peripheral devices, nor the associated software, this task attempted to identify and analyze certain physical configurations. This was done by presenting some available alternatives relative to the evolving set of requirements. Central to this task was the incorporation of certain proposed equipment configurations and the analysis of the postulated set of requirements. The basic thrust was in comparing the various subsystems in order to assess their mutual compatibility and the degree to which the functions could be performed.

Task 2. MIL-Spec Display Candidates

This task amounted to the continuation of an earlier and continuing effort to develop a data base for MIL-spec display and peripheral systems and subsystems. This includes graphics devices, plotters, digitizers, printers, and input media. The manner in which this task has been accomplished is to continually assess the milieu of graphics capabilities since the technology has been changing so very rapidly. From such a background of possibilities, various vendors who, in fact, had met military specifications were then asked for specific data on certain particular end items. In this manner, it was possible to determine: what was available; what was being developed; what the real and anticipated costs would be; and what the future trends are.

Task 3. Software Cost Analysis

This necessary and important, albeit exceedingly difficult task, was the description of the software conversion and/or development for any interim SOTAS display system in order that costs could be ascribed to the software. Moreover, it appeared that a significant portion of the total cost might be attributed to software activities. Thus, software analysis in the command and control environment was investigated in an attempt to isolate and identify realistic cost predictions for a variety of levels of software development and conversion.

Task 4. BCE Feeder Reports

The original intent of this task was to provide an early indication of the Life Cycle Costs(LCC). However, this task was modified slightly by verbal agreement to allow for the necessary and timely completion of the BCE. This implied extending some of the activities mentioned previously (Task II) from radar costs to other costs; viz., software and display systems. However, it should be acknowledged that this cost prediction is a necessary part of the initial phases of LCC development. The operational and support (O&S) costs can be inferred from this and other historical cost data.

Task 5. Final Report

The final task is the preparation, production and distribution of this report. This entails the generation and publication of the necessary documentation and supporting results of this study which would reflect all the aspects of the SOTAS Cost Analysis.

This report summarizes the work involved in all of the above described tasks. However, as might be expected in any major investigative program, one of the more efficient forms of communication is the process of direct discussions, presentation and reviews. Throughout this program, EES has attended many formal briefings and technical conferences at which the key participants in the SOTAS development were present, and exchanges of information could be made. Table 1 summarizes these activities.

In addition to these visits, EES personnel were also contacted and visited by personnel from: Harris Company; General Dynamics; Motorola; ECOM Comptrollers Office; and Systems Planning Corporation.

Table 1. EES/SOTAS Agenda

Date	Place	Purpose
24 January 1977	Ft. Monmouth, NJ	Initial Contract Meeting
2 February 1977	Washington, DC	SAG Meetings
28 February 1977	Ft. Huachuca, AZ	MI Briefings
1 March 1977	San Diego, CA	GD Tour and Briefings
2 March 1977	Santa Monica, CA	Discussions with TSC
3 March 1977	Ft. Sill, OK	USAFAS Briefings
4 March 1977	Ft. Leavenworth, KS	Discussion with CACDA
15-17 March 1977	Ft. Monmouth, NJ	Technical Approach Meetings
22 April 1977	St. Louis, MO	AVSCOM Discussions
1 June 1977	Ft. Sill, OK	Discussions at CD, USAFAS
3 June 1977	EES, Atlanta, GA	Program Review at Georgia Tech
15 September 1977	Ft. Monmouth, NJ	Presentation of Radar Costs
15 September 1977	Arlington, VA	BCE Discussions (SPC)
4 October 1977	Arlington, VA	BCE Discussions (SPC)
21 November 1977	Washington, DC	SAG Meeting
7-8 December 1977	Washington, DC	Discussions with DCSRDA, SPC and DUSA-OR
12 December 1977	Washington, DC	UPD Briefings
11 January 1978	Ft. Monmouth, NJ	Presentation of Software Costs
10-11 May 1978	EES, Atlanta, GA	Program Review

In addition, EES has already provided to the SOTAS PMO two interim technical memoranda (EES TM-1931-001 and TM-1931-002) on the SOTAS Radar Cost Analysis and the SOTAS Software Cost Analysis, respectively. Major portions of these memoranda are contained in the main body of this report, or in the appendices.

The final Time and Task Schedule for this program is shown in Figure 1. There were several modifications, as was previously indicated. It is anticipated that EES will continue to provide support to the Army through the interim system (I^2) development and the engineering development (ED) programs.

The remainder of this report summarizes some of the more important aspects of the work performed under this contract. As was previously indicated, an important yet unstated objective was to relate cost to a specified level of performance. Further, without attempting to specify any particular system configuration or individual hardware devices, a spectrum of cost predictions are presented with the intention of providing benchmarks or indications of "cost-drivers."

Section II of this report discusses the parametric cost analysis of the SOTAS radar. In Section III, various aspects of the SOTAS Software analysis and costing are described. The SOTAS display and peripheral environment, to include the implications for the various processors, is identified in Section IV, and comparisons are made for some of the more viable alternatives. Section V summarizes the results of this study and reviews the major efforts of the program.

Start: 15 December 1976

End: 31 March 1978

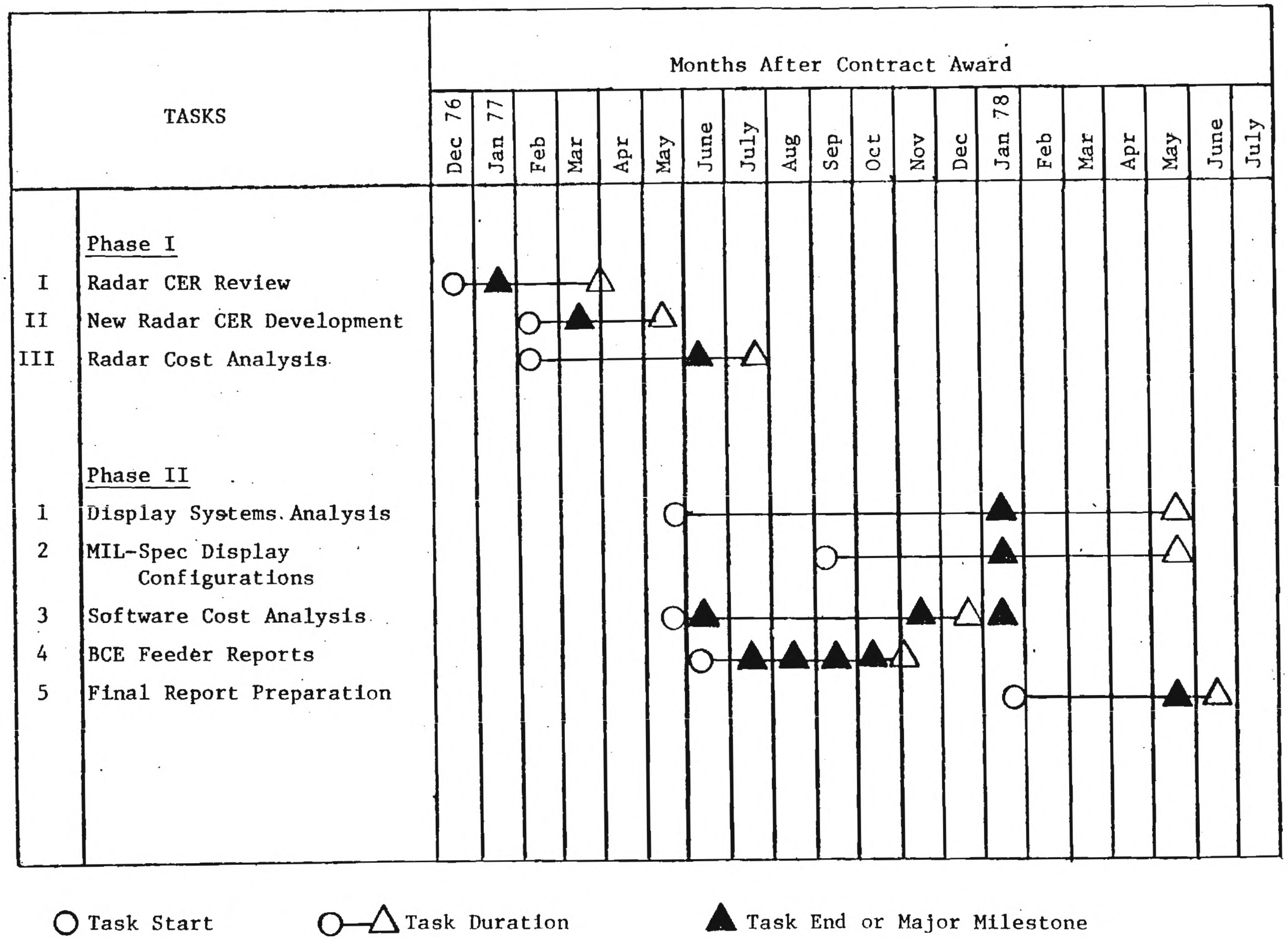

Figure 1. Time and Task Schedule for SOTAS Cost Study

II. RADAR COSTS

Design Parameters

In this chapter, an attempt will be made to describe costs for the most current sets of expected capabilities, system characteristics, and specific hardware parameters for the SOTAS advanced radar. It is assumed that these specifications will satisfy the requirements in the Required Operational Capability (ROC) [1] being formulated for this system. A detailed list of parameters (names and values) is provided in Appendix A, which reflects not only the concerns mentioned above, but also the evolving set of design parameters as indicated in: the work of Technology Service Corporation (TSC); the emulator radar; and comparisons with known capabilities and requirements of the various prototypes (viz; the R-76, R-77 and I^2 systems). There are perhaps some unintentional assumptions by EES in the assessment of the advanced radar which should in no way be construed as criticism of previous or current design thinking. The intent is to insure a broad conceptual coverage within the particular ranges of pertinent parametric analysis.

The advanced SOTAS radar, which was initially described by TSC [2], has undergone several changes during the past two years. This is a natural research and development evolution process, needless to say, with resulting technical differences in design, implementation and configuration of the radar. At the request of personnel from the SOTAS-PM Office and Laboratory personnel at ERADCOM, a review of: (1) the PROC; (2) the advanced SOTAS concepts; and (3) the technical data base have been compared to determine if there are any areas which could cause system design changes. The following comments are presented to highlight only a few changes which have occurred and to relate how these changes could impact the system performance. These in turn may require additional study.

Several different antenna configurations, to include a mechanical scan, mixed mode and an electronically scanned antenna, have been proposed; and the type of antenna will impact system performance in several areas. The calculated signal-to-noise ratio must include the degraded gain of the E-scan antenna far-field pattern as a function of the angle scanned off the "dead-ahead" mechanical orientation. The far-field peak gain follows a cosine envelope as the beam is steering off the center. Thus, at a 60 degree offset angle, the gain is reduced to one-half value (one-way), and reduced to one-fourth value (two-way). This clearly results in less radar power directed to the target.

When the beam is caused to scan off the center broadside alignment, the side lobes increase. The counterpart in optical systems is referred to as coma lobes. Recent work at ERADCOM [3] indicates that the side lobe levels will exceed the ECM requirements for SOTAS by as much as 10-15 dB. Consideration thus needs to be given to side lobe reduction, and the resulting cost.

When employing a frequency hopping or frequency agile transmission to reduce ground clutter and enhance target detection, the beam location in the far-field is also affected. This beam location can then affect the steering and "target-reporting" accuracy. Some compensation of the true pointing accuracy is required, and compensation with frequency changes should be noted and implemented in the design.

There is a non-coherent doppler spectrum in both ground clutter and in rain clutter. This will limit the minimum speed of moving targets which can be detected. The requirement to detect two (2) mph targets should perhaps be reviewed again in light of the limitations imposed by non-Gaussian ground and rain clutter.

From the sources previously mentioned, it appears that operating ranges in excess of 50 Km beyond the FEBA to locate vehicles may be expected. For such sensor-to-target ranges, several requirements are in order: the number of range bins has to be increased; more power is required for the same S/N; display resolution requirements may need revision; and clutter models must be reexamined. In general, larger and more sophisticated systems are more expensive, thus, the entire radar system should be reviewed for both signal processor and software limitations.

Radar Cost Estimates

This section contains a summary of the radar cost estimates which have been developed by EES and were provided to SPC for inclusion in the BCE. These cost estimates are differentiated into cost category by sub-system and also by BCE element [10].

The sub-systems costs are costs associated with the four major radar sub-systems (antenna, receiver, transmitter and signal processor). Also shown is the final assembly and test (FAT) or system integration cost. The BCE divisions include: R&D versus production; In-house versus contractual; and various other element categories.

From the chart (see Figure 2) on the next page, it can be seen that the cost per pre-production (both ED and APE are used here) model is relatively insensitive to the number of pre-production models developed. The cost per ED copy tends to run as high as $4M, and the cost per APE copy subsequently runs around $2M. All costs shown here have been adjusted to FY 1979, although the CER's reflect FY 1974 data.

From the ED and APE CER's (described in Appendix B), it should be noted that these pre-production costs are a function of the total production values. This technique for costing is not uncommon for many equipment manufacturers [6].

The production costs are, however, indeed sensitive to the number of production units. In the next figure (see Figure 3), the costs for both individual and total production order are given along with the sub-system costs. The costs were generated by a model developed at EES [4].

It should be noted, nevertheless, that the per unit cost, in this case for production, is relatively insensitive to production level. For example, a change in production by 39% (115 to 160 units) only causes the unit production cost to be reduced by about 10% ($1.33M to $1.19M in FY 1979 $M).

The last two figures (4 and 5) are abstracted from the standard BCE format as modified by SPC for the SOTAS radar. In the R&D phase, it has been assumed from historical data that approximately 30% of total R&D costs will be utilized "in house." In the production phase, on the contrary, the percentage can be as low as only 3%. The results agree with generally accepted values.

Category \ Number of Units	8* = (3 + 5)					5 = (2 + 3)
	80**	115	118	127	160	115
ED	14.8	13.9	13.8	13.7	13.1	10.5
APE	12.3	12.6	12.7	12.8	13.2	10.5
TOTAL	27.1	26.5	26.5	26.5	26.3	21.0

* Pre-production with sum of ED and APE units shown

** Production units

Figure 2. Pre-production costs (contractual FY79 M$)

Components \ Production Units	80	115	118	127	160
Ant	198	187	186	184	178
Xmtr	166	156	156	155	149
Rcvr	127	120	120	118	114
Sig Proc	383	363	362	358	345
FAT	621	505	497	476	413
Total Per Unit	1495	1332	1321	1291	1199
GRAND TOTAL	119580	153186	155902	163921	191909

Figure 3. Radar costs (production FY79 K$).

	ROW	PRIME APPRO	DEFN REF	COST ELEMENT / SYSTEM STRUCTURE	(1) 5=(2,3) Preprod RADAR s	(2) 8=(3,5) Preprod RADAR s	%
	1	--	1.0	RESEARCH AND DEVELOPMENT	29456	37877	
CONTRACT	2	RDTE	1.01C	Development Engineering	1262	1623	6
CONTRACT	3	RDTE	1.02C	Producibility Engineering and Planning	3156	4058	15
CONTRACT	4	RDTE	1.03C	Tooling	1473	1894	7
CONTRACT	5	RDTE	1.04C	Prototype Manufacturing	7364	9469	35
CONTRACT	6	RDTE	1.05C	Data	842	1082	4
CONTRACT	7	RDTE	1.06C	System Test and Evaluation	1052	1352	5
CONTRACT	8	RD/OM	1.07C	System/Project Management	3156	4058	15
CONTRACT	9	RD/OM	1.08C	Training			
CONTRACT	10	RD/MC	1.09C	Facilities	1056	1353	5
CONTRACT	11	RDTE	1.10C	Other (Fees)	1683	2164	8
	12	CONTRACT TOTAL			21040	27055	100
IN-HOUSE	13	RDTE	1.01I	Development Engineering	3787	4870	45
IN-HOUSE	14	RDTE	1.02I	Producibility Engineering			
IN-HOUSE	15	RDTE	1.03I	Tooling			
IN-HOUSE	16	RDTE	1.04I	Prototype Manufacturing			
IN-HOUSE	17	RDTE	1.05I	Data			
IN-HOUSE	18	RDTE	1.06I	System Test and Evaluation			
IN-HOUSE	19	RD/OM	1.07I	System/Project Management	4629	5952	55
IN-HOUSE	20	RD/OM	1.08I	Training			
IN-HOUSE	21	RD/MC	1.09I	Facilities			
IN-HOUSE	22	RDTE	1.10I	Other			
IN-HOUSE	23	IN-HOUSE TOTAL			8416	10822	100

Figure 4. BCE Inputs for SOTAS R & D Costs (FY79 K$).

	ROW	PRIME APPRO	DEFN REF	SYSTEM STRUCTURE / COST ELEMENT	(1) 80 prod RADAR s	(2) 115 prod RADAR s	(3) 118 prod RADARs
	1	--	2.01	INVESTMENT	123765	158547	161359
CONTRACTS	2	PR/MC	2.01C	Non-recurring Investment	13154	16850	17149
CONTRACTS	3	PROC	2.02C	Production	59790	76593	77951
CONTRACTS	4	PROC	2.03C	Engineering Changes	17937	22978	23385
CONTRACTS	5	PR/OM	2.04C	System Test & Evaluation	14350	18382	18708
CONTRACTS	6	PR/OM	2.05C	Data	4783	6127	6557
CONTRACTS	7	PR/OM	2.06C	System/Project Management	9566	12255	12472
CONTRACTS	8	PR/MC	2.07C	Operational/Site Activation			
CONTRACTS	9	PR/OM	2.08C	Training			
CONTRACTS	10	PR/OM	2.09C	Initial Spares and Repair Parts			
CONTRACTS	11	PR/OM	2.10C	Transportation			
CONTRACTS	12	CONTRACT TOTAL			119580	153186	155902
IN-HOUSE	13	PR/MC	2.01I	Non-recurring Investment			
IN-HOUSE	14	PROC	2.02I	Production			
IN-HOUSE	15	PROC	2.03I	Engineering Changes	1464	1877	1910
IN-HOUSE	16	PR/OM	2.04I	System Test & Evaluation	1046	1340	1364
IN-HOUSE	17	PR/OM	2.05I	Data	419	536	546
IN-HOUSE	18	PR/OM	2.06I	System/Project Management	1256	1608	1637
IN-HOUSE	19	PR/MC	2.07I	Operational/Site Activation			
IN-HOUSE	20	PR/OM	2.08I	Training			
IN-HOUSE	21	PR/OM	2.09I	Initial Spares and Repair Parts			
IN-HOUSE	22	PR/OM	2.10I	Transportation			
IN-HOUSE	23	PR/OM	2.11I	Other			
IN-HOUSE	24	IN-HOUSE TOTAL			4185	5361	5457

Figure 5. BCE Inputs for SOTAS production costs (FY79 K$).

	ROW	PRIME APPRO	DEFN REF	SYSTEM STRUCTURE / COST ELEMENT	(4) 127 prod RADARs	(5) 160 prod RADARs	% prod
	1	--	2.01	INVESTMENT	170638	198626	
CONTRACTS	2	PR/MC	2.01C	Non-recurring Investment	18031	21110	11
	3	PROC	2.02C	Production	81961	95954	50
	4	PROC	2.03C	Engineering Changes	24588	28786	15
	5	PR/OM	2.04C	System Test & Evaluation	19671	23029	12
	6	PR/OM	2.05C	Data	6557	7676	4
	7	PR/OM	2.06C	System/Project Management	13114	15353	8
	8	PR/MC	2.07C	Operational/Site Activation			
	9	PR/OM	2.08C	Training			
	10	PR/OM	2.09C	Initial Spares and Repair Parts			
	11	PR/OM	2.10C	Transportation			
	12	CONTRACT TOTAL			163921	191909	100
IN-HOUSE	13	PR/MC	2.01I	Non-recurring Investment			
	14	PROC	2.02I	Production			
	15	PROC	2.03I	Engineering Changes	2008	2351	35
	16	PR/OM	2.04I	System Test & Evaluation	1434	1679	25
	17	PR/OM	2.05I	Data	574	672	10
	18	PR/OM	2.06I	System/Project Management	1721	2015	30
	19	PR/MC	2.07I	Operational/Site Activation			
	20	PR/OM	2.08I	Training			
	21	PR/OM	2.09I	Initial Spares and Repair Parts			
	22	PR/OM	2.10I	Transportation			
	23	PR/OM	2.11I	Other			
	24	IN-HOUSE TOTAL			5737	6717	100

Figure 5 (continued). BCE Inputs for SOTAS production costs (FY79 K$)

III. SOFTWARE COSTING

Background

In accordance with Task 3 (Phase II), this section basically represents an attempt to isolate and identify cost parameters and develop realistic cost predictions for various levels of software development and conversion.

Since EES has not been directly involved in the hardware design, performance analysis, or the software conversion and development, this study concentrated on the general aspects of software cost estimation and compiled guidelines for broad software investigations. Hopefully, the tools and techniques which have been compiled will be useful in developing realistic cost estimates for monitoring the actual costs of the advanced SOTAS software.

A brief review of some of the more current literature on software specifications and costing is presented. Particular attention is paid to the software costs of the command and control environment.

Software Cost Considerations

Prior to suggesting techniques and making recommendations for estimating SOTAS software development costs, EES found it necessary to conduct a rather thorough literature search. It appeared that since no single comprehensive study on the subject was available, this approach was justified. Topics such as software definitions, software engineering, and software physics were explored to assess the current state-of-the-art in software cost estimation. This section presents highlights of the literature surveyed.

First, a particularly useful definition of software [13] is as follows:

> A set of computer programs, data bases, procedure rules, and associated documentation concerned with the operation of a data processing system: e.g., compilers, library routines, manuals, and perhaps circuit diagrams, and data bases.

Note that this definition extends beyond the actual programs that we usually think of as software, to encompass much of the environment of programs.

From the literature, there was evidence of an increasing awareness among information systems managers that there is much more to software development than programming. This realization has brought on a need for a more complete and encompassing definition of software development. It is not only beneficial for accounting purposes, but also necessary for cost estimation algorithms, to express this definition in terms of the life-cycle cost of a system. A comprehensive definition of software life-cycle cost is thus proposed here:

> Software life-cycle cost is the total of all costs, in constant dollars, which accrue to the development and use of software throughout its useful life.

These costs include such things as personnel, materials, computer time and/or maintenance, and overhead. The life-cycle of the software begins with the initial proposal, and continues through the specification of requirements, the design, coding and debugging, verification and validation, reliability testing, and documentation phases.

Debugging refers to the overall process of getting a program to perform as desired, although the term often has the mundane connotation of syntax error removal, etc. Validation is the process of ascertaining that what is performed is appropriate to the real-world environment. Alternatively, the process of insuring that the program does what is expected of it is called verification. Reliability is a measure of the unlikelihood of failure. All of these processes fall into the general category of testing.

The following paragraphs review various sources from the literature which present schemes for allocating costs over the life cycle of software development.

Khtaran [14] divided the computer life cycle into three phases. The first, the proposal phase, includes: the preliminary analysis, proposal and approval, and usually a definition of user requirements and the required data base. Phase II consists of detailed Design Development for each subsystem, which is further broken down into three activities. The first, the System Design, includes all the steps needed to transfer the package to the programming group and requires about 60% of the total time allocated to Phase II. Follow-up Design, requiring approximately 30% of the effort, consists of any further design activity from initial acceptance of the program to the point of conversion or implementation. Post-conversion Follow-up is basically a cleanup process and requires about 10% of the effort.

Phase III, the Programming Phase, consists of Coding, Testing, and Implementation. Khtaran assumes that these three functions require approximately 60%, 35%, and 5%, respectively, of the effort, with the documentation effort spread throughout, and not treated separately.

Alberts [15] presents four phases of the project life-cycle. While the functions are similar to those given above, the delineation is slightly different. In the Conceptual phase, a feasibility study is performed and order of magnitude cost figures are assigned. The second phase parallels Khtaran's System Design Phase (II) in which hardware - software interfaces are refined and decisions are made which place constraints on the subsequent development. The Development Phase is made up of coding, testing, validation, and documentation. The fourth and final phase (Operations) is actually an extension of the development phase in which refinements are made to render the system operational.

Alberts presents two separate concepts of the software development life cycle. The first histogram shows an idealized breakdown of expenditures and comes from several sources in the literature. The second is drawn from five government projects and is considered to be representative of the cycle over a broad range of development projects. The percentages of effort involved are given in Table 2 below for the four phases and the graphs of the life-cycle, time vs. expenditure percentages, are shown in Figure 6.

TABLE 2. Software Development Phase Effort

	Idealized	Actual
Conceptual	15%	30%
Requirements	8%	8%
Development	40%	12%
Operations	37%	50%

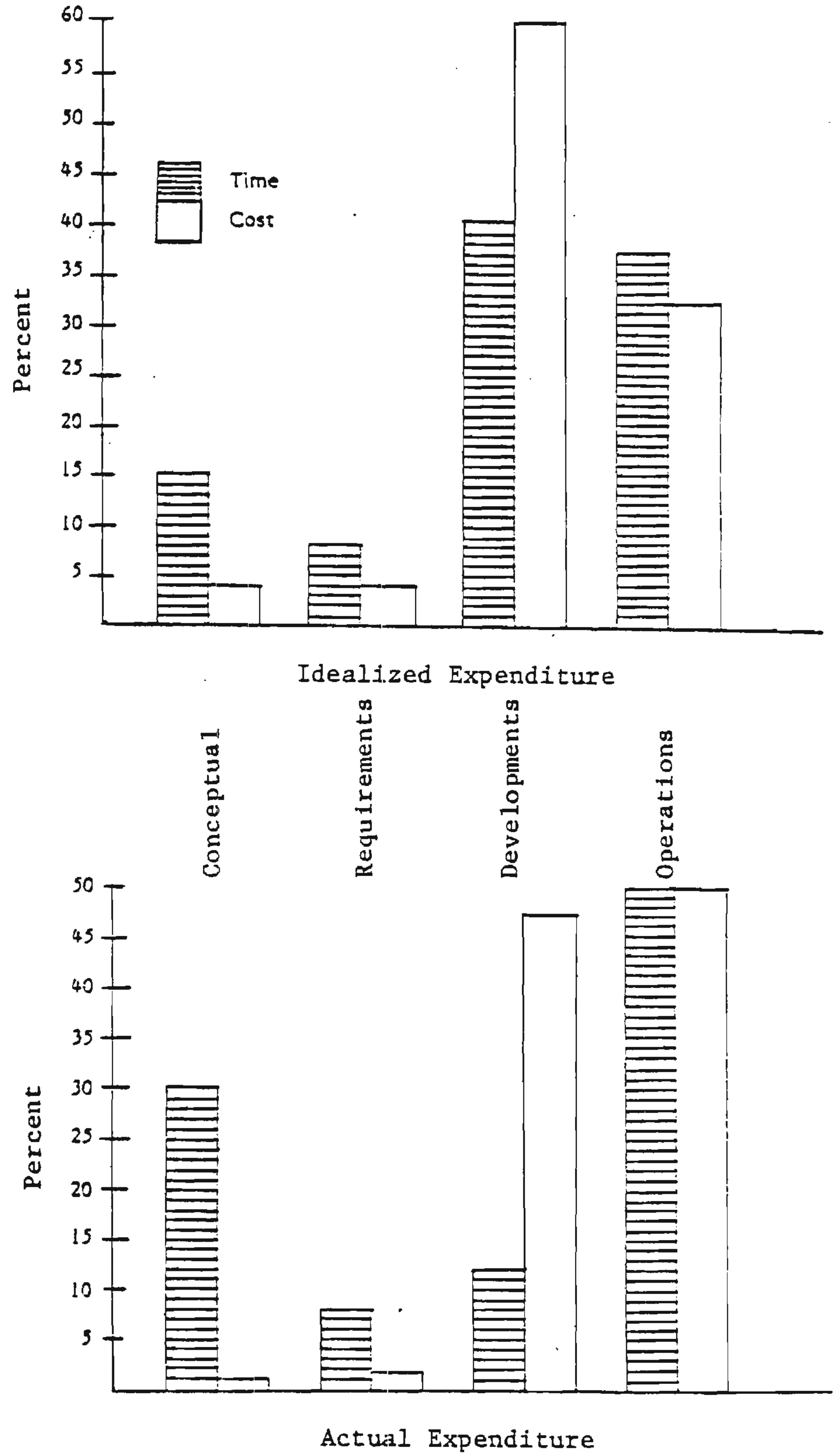

Figure 6. Relative Software Expenditures [15]

From the data available, a breakdown in percentages of time was also made for the same phase of the software life cycle. Preparation of specifications consumed about 50% of the requirements phase or 3-1/2% of the total life-cycle time. The other elements of this phase and associated percentages are the specification and proposal writing (2-1/2% of total), and review, evaluation and selection (2%).

Alberts' Development phase is conceptually equivalent to Khtaran's, but the percentages of time differ considerably. Based on the same five projects, analysis and design requires about 34% of the effort while coding/debugging and validation require 18% and 48%, respectively.

Other sources in the literature [16,17,18] give approximately the same breakdown structure for the Development phase of the software life-cycle. One "rule-of-thumb" presented the percentages for this phase as: 40%, analysis and design; 20% coding and debugging; and 40% testing. Brooks [19] divided the Development phase into four functions with the associated fractions: 1/3, planning, 1/6, coding, 1/4, component and early system test, and 1/4, system test with all components on hand. If the two portions of testing are grouped together, this breakdown is consistent with previous results.

Appendix C contains further discussions on factors involved in software cost estimation.

Software Cost Estimation

Without a single proven method to accurately estimate software development costs, various relationships among the factors thought to contribute to costs have been proposed. The recommendations (or rules-of-thumb) currently appearing throughout the literature give a great deal of insight into software development costs, which further lead to more accurate CER's. This section reviews recommendations from a variety of sources which may be used a priori in the development of CER's in a SOTAS-like environment.

Factors contributing to costs appear in Appendix C, but no specific relationships are given among the variables. If the proper data base were available, however, it would be relatively easy to derive a CER through simple linear regression or nonlinear estimation using these factors as independent variables and cost as the dependent variable. Although results from experiments of this type have appeared in the literature, an overall data base has not been completed. Thus, the CER's obtained may not be very accurate in predicting costs for developing software. The inadequacy of CER's previously developed can be attributed in part to a lack of quantitative means to measure certain variables properly; for example, a measure of programmer productivity, which takes into account such elements as experience level and differences in capabilities among programmers. Any quantification scheme would thus depend on subjective judgments made by an estimator.

RCA has recently developed a computer program [21] for software cost estimation using a parametric approach. It is not known how well the model works in terms of estimating costs, but the variables which were used seem to agree with what has been published elsewhere in the literature. Inputs to the model include the number of peripheral devices used and a measure of the uniqueness (or newness) of the project. Several other variables are required for the model which heretofore have received very little attention. These are state-of-the-art of overall software technology, and the percent of available hardware speed and memory capacity utilized by the program. Since no results from this modeling scheme have apparently been published, the accuracy of the procedure is unknown.

The parametric method has significant merit in developing CER's, but a fairly large data base is required to develop a model (such as the RCA model). Therefore, most software personnel use "rules-of-thumb" based on experience from past projects.

Programmer productivity often presents the most difficult problem in estimating software costs. Programming is, by its nature, a creative and individualistic process. It has been noted that as much as a 26:1 productivity ratio between individuals exists, and the difference in production among programmers can be 100 to 1000 machine instructions per man-month.

Because of such large disparities in programming productivity, there is some question as to whether productivity should really be measured in terms of number of lines of code or number of instructions. A suggestion is to assign weights to certain variables and to measure the effectiveness of the programmer. Object run time, elapsed time for the software development, and storage used might be of varying importance from one application to another so that effectiveness (E) may be measured by:

$$E = W_1 \times \text{elapsed time} + W_2 \times \text{storage used} + W_3 \times \text{object time},$$

where W_1, W_2, and W_3 are various weighting factors.

It has also been suggested that programming effectiveness may also be determined by evaluating factors such as the total dollar cost vs. the profit for the organization, the quality of the developed system, the effect on employee satisfaction and career growth.

Programmer performance may also be evaluated by measuring:

1. the number of efficient steps per hour;
2. the number of "bugs" left in the program;
3. the severity of those "bugs";
4. the customer acceptance of the program;
5. the efficiency of computer time used; and
6. the analytic ability shown by the programmer.

However, suffice it to say that even if it is possible to rate programmers in some way, there is no guarantee that the higher rated programmer will perform better on a particular task. There is probably some point where the background of the coder has adverse effects; e.g., an efficient and creative programmer may become bored with routine tasks.

In the literature survey conducted by the Air Force Systems Command [22] in 1975, five different techniques for estimating software development costs were identified: (1) Similar Experience; (2) Quantitative; (3) Statistical; (4) Constraint; and (5) Unit of Work. The following discussion describes these five techniques and, in the case of the quantitative method, presents several examples of documented applications. The five methods listed are in order of preference according to the survey.

The Similar Experience Technique, though widely applied, should only be used when the estimator is very familiar with the project and has experience with other projects which are comparable in size and content. Complete specifications are necessary before an estimate can be made. Even with complete specifications, an estimate made based on similar experience can easily be incorrect. If it is incorrect, there is little or no possibility for assessing where the problem could exist. If it is correct, it is difficult to sell to management because there is no way to justify the estimated costs.

Quantitative Techniques are preferable to other methods if they can yield better estimates than the current literature suggests are typical. Efforts are being made to quantify factors contributing to costs, but as yet none have been very successful. The Quantitative Technique actually may not be much better than the Similar Experience Technique, but suggestions usually are made for structuring the cost estimating procedure so that the process is more externally valid. This technique is usually based on programmer productivity (number of deliverable instructions per unit time by the average programmer) and the size of the system (number of source statements or object instructions). Two examples are presented of applications of the Quantitative Technique.

The first method, attributed to Wolverton [23], proceeds as follows:

1. Categorize the software into
   a) control routines;
   b) algorithms to manipulate data;
   c) I/O routines;
   d) algorithms to perform logical or math operations; and
   e) data management routines.
2. Estimate the size and complexity by routine or subprogram. Six complexity levels were suggested: old/easy, old/medium, old/hard, new/easy, new/medium, new/hard.
3. Identify development and test phases and allocate a fraction of the total amount to each.

4. Define activities for each phase by an activity array and associated cost matrix (Wolverton had 25 activities for each of seven phases).

5. Provide schedule data based on management considerations.

A more precise technique is recommended by Aron [24]. The technique is for rather large projects; i.e., ones for which there are more than 25 programmers, more than 30,000 deliverable instructions and require more than six months development time with more than one level of management. Other assumptions and qualifications are:

1. 30% of total time is devoted to system design;
2. 40% is devoted to implementation;
3. 30% is devoted to system test;
4. 40-50% of total resources are management and support resources;
5. System design resources are negligible compared to total resources;
6. The duration of the project is determined by management; i.e., it is not a function of the algorithm; and
7. Formulas do not normally include overhead.

Seven steps are then defined for obtaining an estimate of development duration. Aron suggests that the following procedure be used once each month to adjust the estimate as the project proceeds:

1. Calculate: Number of deliverable instructions =(Number of programs) X(average program size).
2. Determine the difficulty of programs and the duration of the project. Three levels of difficulty are suggested with an accompanying table (see Table 3.) for establishing the number of instructions which can be produced. The three levels and a description of each are:

   a. Easy - there are very few interactions with other system elements. These programs are usually problem solving or application programs.
   b. Medium - there is some interaction with problem programs, monitor and other "medium" programs. More than one device is used for Input/Output.
   c. Hard - there are many interactions involved. This category includes all monitors and operating systems.

3. Calculate man-months for programming during implementation from information in Table 3 and from Step 1.

$$\text{man-months} = \frac{\text{deliverable instructions}}{\text{instructions per man-month}}$$

Table 3. Software Productivity Table [24]

Duration / Difficulty	6 - 12 mos.	12 - 24 mos.	> 24 mos.
Easy	20	500	10000
Medium	10	250	5000
Hard	5	125	1500
units	Instructions per man day	Instructions per man-month	Instructions per man-year

4. Adjust for use of a higher level language - the ratio is 2:1 improvement over assembly language.
5. Extrapolate system man-months for the project to include management of support manpower, using the following:
   a. ignore system design phase - this is assumed to require less than 1% of total resources
   b. system test makes up 15-20% of the total schedule
   c. management and support are 1/2 of the total system resources
   d. system man-months = $\frac{2(\text{man-months})}{.8}$

      $= 2.5 \times \text{man-months}$
6. Adjust the number obtained in Step 5 in the following way:
   a. -25% if all factors are favorable
   b. +100% if all factors are unfavorable
7. Schedule the effort over the calculated duration.

The other three techniques reviewed in [24] will be discussed only briefly. The third technique is Statistical and there are two ways suggested for its use. The first is to have several knowledgeable people in the organization make an estimate of either cost or duration, and then take a simple average of the estimates. The other method is to obtain an optimistic (O), a most likely (M), and a pessimistic (P) estimate of duration (D). To obtain the final estimate, calculate:

$$D = \frac{O + 2M + P}{4} .$$

The fourth technique is the constraint technique in which the levels of manpower and resources are fixed, and then the amount of work which can be done under these constraints is estimated. The Unit of Work Technique could be used in conjunction with one of the other techniques. In this method, the total programming effort is defined and segmented so that each task may be completed by one programmer in a short, but specifiable, amount of time. Aron also recommended three rules-of-thumb for the average computer resource requirement:

1. 6 hours/programmer/month for familiar projects
2. 8 hours/programmer/month for unfamiliar projects
3. 12 hours/programmer/month for real time projects

The dependency of software on hardware and vice versa has been mentioned previously. J. L. Butler [25] proposed a method for comparing computer systems which takes into account both software and hardware capabilities. Here a price/performance ratio for each is computed separately, and then the total price/performance is found by averaging. Note that this method attributes equal importance to the price/performance of software (P_s) and that of hardware (P_h).

Thus,

$$P_s = \frac{\text{Basic System Cost}}{500 \quad (D+B+L) + 1000A + 2000C + 50\ S}$$

where

- D = off-line diagnostic routines
- B = debugging routines
- L = loader routines
- A = number of assemblers
- C = number of compilers
- S = power of on-line operating system ($0 \leq S \leq 10$)

$$P_h = \frac{\text{Basic System Cost}}{\{.1 \times M \quad \{1 - \{(W-F)/2W\}\} + (20/T)(A_H + L_H + I_H) + 1000N + 50R\}}$$

where

- M = total number of bytes
- F = total number of bits in address field
- W = word length in bits
- R = number of general purpose registers
- T = memory read/write cycle time
- N = options included
- A_H = arithmetic capability {0, 25, 50, 75, 100}
- L_H = logic capability ($0 \leq L_H \leq 100$)
- I_H = I/O capability ($0 \leq I_H \leq 100$)

Once P_s and P_h are obtained, a total system price/performance ratio (P_t) is computed by:

$$P_t = \frac{P_h + P_s}{2} .$$

A new field [26] has emerged in the software area known as <u>software physics</u>. Instead of trying to derive a heuristic estimate of software development costs via the estimation of system hardware and software capability, software physics attempts to develop time (cost) estimates based on the properties inherent in the calculations. One hypothesis relates the number of elementary mental discriminations required to implement an algorithm to measurable properties of that algorithm in order to calculate programming time. The equation used is:

$$T = \frac{n_1 N_2 N \log_2 n}{2 S n_2}$$

where T is time in minutes

and n_1 = number of distinct operators

n_2 = number of distinct operands

$n = n_1 + n_2$

N_1 = number of uses of operators

N_2 = number of uses of operands

$N = N_1 + N_2$

S = psychological discriminations per second ($5 < S \leq 20$)

See [26] for derivation.

Data from eleven different experiments, when compared to programming time, produced a correlation coefficient for the observed vs. the calculated time of .934. Obviously, there is strong indication that this method is useful in predicting programming time, but the problem remains of being able to count the operands and operators in a program prior to the actual coding. Yet, software physics has shown great promise in terms of quantifying relationships among the many variables involved in software development.

The Comptrollers Office of the U.S. Army Electronics Command has developed a model [27] to estimate costs for software development. The form is:

$$C = 0.013\,(RT)^{1.19} + 0.308(SI)^{0.63}$$

where C = FY73 K \$

RT = number of real-time instructions

SI = number of support instructions

To use this model, the instruction count must be in assembly language instructions. Higher-order language instructions are converted to assembly by multiplying by two. All costs are included, such as overhead and profit. However, a ±30% deviation around the estimate is required to give an adequate confidence range.

The simplicity of the model is appealing, but it has not been shown that such a model is effective for cost estimation in an area (such as in Command and Control) where there are many variables, some of them unquantifiable, which may contribute to cost.

SOTAS Software Cost Rationale

In this section, a sketch of the advanced SOTAS operational system will be given in order to more fully develop a useful software cost criterion. Obviously, since the hardware has not been fully specified, and several problems associated with integrating the generic class of tactical information and acquisition systems remain unresolved, this is a formidable task.

The approach that will be employed is to outline the capabilities that were first envisioned for SOTAS [28], and relate these to specific functions as later developed for the Remote Stations and contrasted with the emergent Tactical Computer System (TCS). The point of departure for this latter effort will be the most recent CENTACS report [29] with one attachment and three Appendices, particularly emphasizing the TCS. The other systems, which will not be specifically addressed, but frequently referred to, are those such as in the Army Tactical Data System (ARTADS), the Tactical Operating System (TOS), the Artillery Fire Control System (TACFIRE), and others.

SOTAS has been visualized [28] as having eight basic capabilities. In aggregate form, these capabilities concern the radar data, the graphics manipulation and output format. Let us examine each of the original eight capabilities separately.

The first capability is the processing of the "raw" radar data. This data falls into two general categories: the returns from moving targets and those from fixed objects. Presumably, since the primary SOTAS objective is to discern moving objects (targets), the fixed objects may be difficult, if not impossible, to identify. Additionally, much of the total signal and data processing will be done in the aircraft, perhaps denying the ground-based operator the flexibility that is presently available in the prototype system. Nonetheless, it appears that some steps can be taken to make the necessary discriminations in conjunction with the proposed and sophisticated constant false alarm rate (CFAR) device and other processing techniques. The moving target (MTI) categories which would require further identification are: the friendly versus enemy "movers"; the old versus new "movers"; and the type of moving object (if possible). The fixed targets (FTI) which would be beneficial to identify are: the boundaries and obstacles; the major and minor routes of travel; and certain significant landmarks for map coordinates.

The second capability deals with the graphics generation which should be largely accomplished automatically. The graphics could be employed for a wide range of activities, but the major items include the map symbols for both geographic and military identification. There would undoubtedly be a further need for more general symbology. For example, communications, message and status reports would be a few.

The third capability involves the total spectrum of the graphics manipulation. This would encompass the addition, deletion or change (move, repeat of symbols, etc.) of certain portions of the display presentation.

Transferring the entire graphics display comprises the task for the fourth capability. This implies moving the display features, possibly in their entirety, to and from certain files and the ability to plot them either directly or from a file.

This latter task leads to the fifth capability, that of performing both printouts or plots of either the radar data, the system status, or the graphics display. In essence, this requires that the operator have the facility to select the mode of outputting; e.g., from the CRT to an X-Y plotter or a line printer, etc.

The sixth capability entails the various tasks that the operator might employ in the process of target acquisition. The operator could: "freeze" the display; place a cursor for input over a given location; interrogate the UTM coordinates; or step through the "frames" of the graphics display upon command.

Once the target has been acquired, the identification process might determine the target speed and future location. The operator could call upon a routine to compute the radial velocity ($\dot{R}$) and acceleration ($\ddot{R}$). Thus, if the future time (location) is given, then the future location (time) can be estimated. This prediction process is the seventh capability.

The eighth and final capability is that of time compression or the ability to select several display frames and step through them rapidly enough so as to give the appearance of movement of certain target collections. Later, these eight capabilities were modified somewhat [29] when the remote ground station was further defined and examined against the Master Station relative to the TCS employment. It was then established that the need for remote/master commonality required a modular approach to the SOTAS software, and the allowance for specific tailoring. In addition, the structure should be "extendable to accept new technical developments as modifications without major redesign [29]."

The functional performance areas were also expanded in order that: status data could be transceived; encryption could be employed; and the dissemination of information could occur in more timely and efficient manner. As a result of the various man-machine interface experiences, it was felt that a very critical role was that of the analyst who must: interpret the MTI data; generate the target information; and disseminate combat information, which becomes meaningful intelligence to the appropriate users.

It has become increasingly clear, furthermore, that the success of the analyst depends in no small fashion on the type and amount of visual cues that can be automatically or manually inserted into the display menu. These cues will assist the analyst in controlling and interpreting the imagery. It is questionable at this time whether the entire clutter map is necessary to the smooth, precise functioning of the ground display station. However, the availability of the clutter map is a definite advantage to the interpretive operation.

Another important feature, as it appears at this time, is the combination of capabilities that the analyst might possess relative to the airborne platform. First, along with the status information, it would be extremely useful to have the current aircraft location and disposition. Secondly, the ability to "steer" the platform may ultimately prove indespensable both for platform protection and enhanced target detection.

Probably one of the more difficult tasks for the SOTAS software is the proposed "zoom" capability in which a particular region (either circular or rectangular) would be expanded such that either additional relational detail or an increased amount of information can be reviewed by the analyst. Whereas the calculations shown in CENTACS Report #81 (see page 3-26) do not seem unreasonable, the "zoom" scheme, when applied to the clutter map (question on page 3-27) or to the problems associated with the target/clutter comparison, may prove insurmountable. The chief reason for such a conclusion is that the clutter at any particular time will be determined by the range (R) and the platform height (h). As the platform negotiates its course, both R and h will tend to change more rapidly than the analyst can either call for or utilize the particular clutter map.

The SOTAS software itself, at least as it pertains to the remote station, must be secure (limited field modification), yet interrupt driven. And, as mentioned earlier, the remote and master stations should be compatible in software. While this fact alone would yield some additional savings, it dictates commonality of software design.

Nine functional areas were subsequently identified [29] within the software for allocation and assignment functions at the remote station. These may be grouped into the general areas of executive, input, processing, output, and maintenance routines.

These, of course, are the usual functional areas for dedicated, military computer application systems. In fact, there is a strong correspondence to the TCS software. Moreover, the TCS might be employed in the initial SOTAS conversion for the remote. However, there are several distinct differences that should be anticipated between a radar-driven system, such as SOTAS, and tactical information systems, such as the TCS.

First, the SOTAS software development will require a tremendous amount of "test" programs. These and other short programs will essentially be written for thorough understanding of the different hardware and software components and the interaction between the various routines. Secondly, since in all probability there will be more than one processor involved (at least at the master station), then there will be additional coding, especially for the different functions that each processor is to perform and for the intermediate control, etc.

There is normally a significant amount of code involved in trying to converse efficiently with an operating system in an effort to minimize its inherent constraints. Thirdly, however, the SOTAS software environment will require additional code for this communication and interprocessor control.

Therefore, in the opinion of the EES software research group and software applications personnel, the projected number of lines of code will exceed 50K. More specifically, the number of deliverable lines or product code will, in all probability, exceed this number, with the grand total of all lines in a HOL necessary in the conversion and development most likely in the 200-250K area.

Using these values for the number of lines of code, and the Tecolote Model [27] mentioned in the previous section, cost values were calculated which are presented in Table 4. In an effort to gain some understanding of the sensitivity of this function of each of the two variables separately, Figure 7 was prepared.

Another consideration will be the required documentation to include the publications for start-up, check-out, trouble shooting, facilities arrangement, operational instructions, standard system formats, and listings. Typically, this can increase the overall costs for the total software development by a few percent up to two or three times the total cost. This will be especially true to insure the overall reliability [30] and maintainability required for SOTAS.

Table 4. Development Costs vs. Lines of Code (FY73 M$)

SUPPORT (K LINES) \ REALTIME (K LINES)	20	40	60	80	100	120
280	2.539	4.726	7.141	9.716	12.418	15.226
260	2.501	4.688	7.103	9.678	12.380	15.188
240	2.462	4.649	7.064	9.639	12.341	15.149
220	2.422	4.609	7.024	9.599	12.301	15.108
200	2.380	4.567	6.982	9.557	12.259	15.067
180	2.337	4.524	6.939	9.514	12.216	15.024
160	2.292	4.479	6.894	9.469	12.171	14.978
140	2.245	4.432	6.847	9.422	12.124	14.931
120	2.195	4.382	6.797	9.372	12.074	14.882
100	2.142	4.329	6.744	9.319	12.021	14.829
80	2.085	4.272	6.687	9.262	11.964	14.772
60	2.022	4.209	6.624	9.200	11.902	14.709
40	1.951	4.138	6.553	9.128	11.830	14.638
20	1.865	4.052	6.467	9.042	11.744	14.551

REALTIME (K LINES)

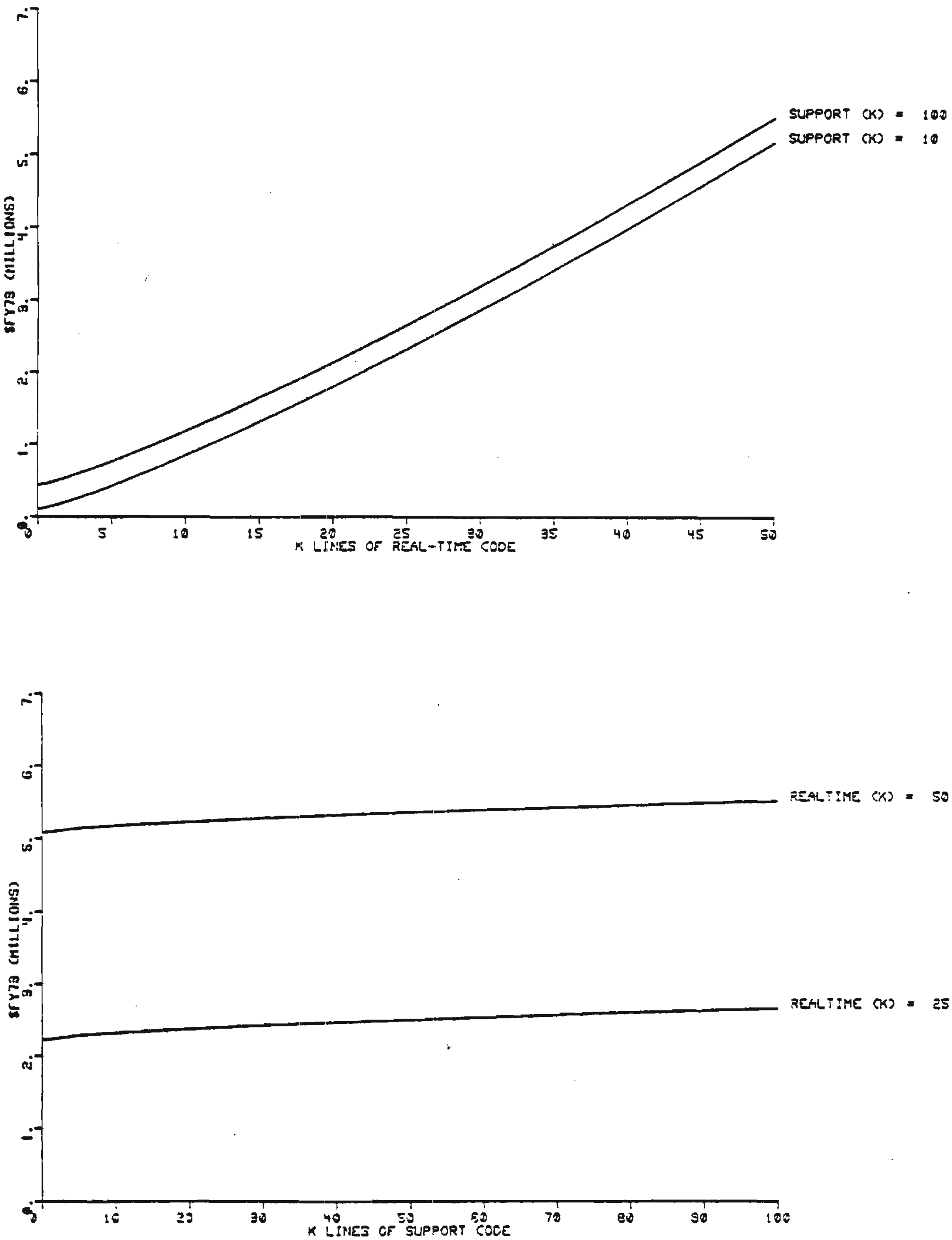

Figure 7. Software Development Cost vs. Lines of Code

A realistic estimate of the number of lines of code needed for the SOTAS conversion and development has been established to be between 200 and 250K. Since using the approach of pricing at a fixed cost per line can sometimes yield unreasonable results, a range of costs were developed which seemed to agree with currently acceptable expenditures for software development.

The two most promising avenues for possible cost reduction appear to be the minimization of the complexity of each individual system component and/or the decrease in the ultimate deployment density. Whereas the latter approach may assure significant savings in hardware, it may not be so promising for the SOTAS development. Therefore, it is the conclusion of EES that the SOTAS operational concept should continue to be refined and monitored with the expectation of reduced complexity. This may be accomplished by more intensive research and greater technological innovation.

IV. DISPLAY SYSTEM COSTS

Background

As has been clearly stated in the several CENTACS reports on the interim SOTAS Display System, this is indeed the most critical item in the entire SOTAS Program, at least from the point of view of the ultimate user, the operator/analyst. It is at this level that the so-called "man-machine" interface takes place. Accordingly, certain amounts and forms of outputs (graphical, etc.) from the various peripherals are sensed, interpreted, and acted upon. Thereafter, new inputs are entered into the various devices either for processing, storage, and/or communication to either other SOTAS elements or other components in the battlefield information network (TOS, TACFIRE, etc.).

The analysis that is to be presented here, in light of the exceedingly large topical boundaries that could be envisioned, will include a cursory review of display systems in general, the evolving field of MIL-qualified devices, and a comparison with some of the more significant issues proposed or inferred by appropriate vendors. It is well to again remember that the central thrust of this discussion is cost; however, as is most usually the case, it is almost impossible to discuss costs without some discussion of performance or operational aspects.

It appears without question that the computer display industry has been successful in recent years in reducing the overall size and cost of the equipment while generally increasing the total performance. The more universal measures of performance are taken to be: throughput, turn around time, and availability. However, while processors (because of the evolution of reliable yet cheaper microprocessors) and commercial quality peripherals have become less and less expensive, certain restraining factors for militarized, computer-embedded real-time graphics systems have remained relatively expensive. The reasons for this conclusion are that: interfacing is more complex and usually one-of-a-kind; peripheral interfacing is particularly expensive; and

MIL-specification for peripherals adds at times one order of magnitude more in costs. These latter reasons are driven by higher development and engineering costs associated with the nature of special-purpose device, stringent environmental requirements, and low densities particularly in the production phases.

A standard rule-of-thumb that is often applied to gain insight into computing costs was developed in the late forties and is known as Grosch's Law. Although it was never published, it suggested that system costs were proportional to the square root of the computing power*. However, only very few took it seriously (it does have some empirical validity), and more often it was used effectively in a humorous way in the computer industry.

This rule-of-thumb might not be adequate for military, command and control systems, especially ones, like SOTAS, which have an inordinate amount of peripherals. Some of these peripherals are: keyboards, touch panels, joysticks, digitizers, light pens, tape (paper and magnetic) devices; card devices; printers, plotters, displays (CRT, plasmas) and others.

General Display Aspects

The first important aspect of any computer system design is the man/machine interface that allows fast and accurate computer devices to communicate with relatively slow and more error-prone users. Before decisions can be made concerning how this interface should occur, an analysis of the user's informational requirements is most often performed. An information requirements analysis determines the relevant information to be presented, including both its timeliness and the most appropriate form for the user. Based upon these results, the devices which create the man-machine information exchange may be selected.

* It was actually expressed as $P = KC^2$ where P = computing power, C = system cost and K = a constant.

Using the two information characteristics of timeliness and form, Table 5 illustrates a range of computer output devices.

Table 5. Computer Input/Output Devices

Form / Timeliness	Non-Graphical Output	Graphical Output
Batch Mode	Line Printers	Plotters electromechanical electrostatic
Interactive	Alphanumeric Terminals and CRTs	Graphics Terminals

Batch environments usually refer to situations where the timeliness of the information is not critical, and the amount of time to process a task is indeterminable. The interactive on-line environment users expect a response within a small but predictable amount of time.

The information forms have been divided into non-graphic and graphic. Non-graphic implies alphanumeric or character output, such as the standard ASCII set. The graphic form represents information using points and lines, perhaps in addition to alphanumeric notations. Examples of graphic compositions are two and three dimensional plots, symbolic diagrams, and colored pictures.

Referring to Table 5, the most common computer output device for batch, non-graphic situations is the line printer. Interactive on-line, non-graphic output devices are alphanumeric hardcopy terminals, such as the TTY, and CRTs, or video displays. The graphical form of output for batch environments is the digital plotter. Electromechanical plotters drive a pen along a paper surface to create the lines of a graph, while electrostatic plotters selectively darken dots within a fixed matrix on specially coated paper. The actual graph production time of an electrostatic plotter can be much less than an electromechanical plotter since the computer's computational speed is utilized to convert line segments into the appropriate series of dots to darken. The electro-mechanical plotter, however, must rely on fast pen speeds across the paper to produce its graphic output.

The remaining types are interactive on-line graphics, and this environment relies on the class of computer output devices collectively called graphics terminals. A graphics terminal is similar to a video display, but having both a display screen and an alphanumeric keyboard. The difference is the graphics terminal's ability to display points, lines, and curves, in addition to characters. To achieve this broad range of graphical capability, the number of addressable points on the terminal's screen must be much greater than the limited addressability of elements in an alphanumeric CRT. For instance, a standard video display is able to put a dot or character within a 24 line by 80 elements per line matrix, while a graphics terminal may have a point addressability of 1024 horizontal by 780 vertical elements. This greater addressability, and corresponding screen resolution, allows graphics terminals to represent straight lines as a series of dots and smooth curves as a series of straight lines. Graphics terminals may be catagorized into four types: Storage CRTs, Refresh Random-Positioning CRT's, Refresh Raster Scan CRT's, and Matrix Panels.

Storage cathode-ray tubes constitute the highest percentage of graphics terminals currently in use. The display mechanism "stores" the image on the screen rather than in computer memory. It requires a non-conventional CRT that has two types of electron guns, a special long-persistance phosphor, and a fine grid of electrodes behind the screen. Once the writing gun is activated, to draw characters of graphics, the image is retained by the combined action of grid electrode discharge and phosphor illuminance until the flood gun is activated to erase the entire display. Information to generate graphic images is transmitted from a host computer in ASCII (character) code. This code is converted by the hardware digital logic into analog CRT signals that drive the display.

Refresh random-positioning cathode-ray tubes have been the traditional output devices for interactive computer graphics. They are also known as vectoring CRTs, stroke-writing CRTs, directed-beam CRTs, and beam-steering CRTs. As these names imply, the device draws an image on the screen in the same manner a pen draws an image on paper. For a CRT, an electron beam does the drawing on a screen with short-persistance phosphor. Electromagnetic or electrostatic deflection fields position the electron beam on the screen. With the beam on, a bright dot appears and, as the beam moves, a line is traced. If the beam is off it can be invisibly moved or repositioned to any point on the screen. Since the screen phosphor only illuminates for a split second, the entire image must be "refreshed," or retraced before the image fades. If the image cannot be refreshed quickly, a flickering effect will occur. The display processor performs the image refreshing and determines the total vector size, or data content, that can be displayed without flickering. It contains logic to decode image definition data from a display file and activate corresponding functions to generate the CRT signal.

The refresh raster-scan cathode-ray tube is operationally similar to a home television receiver. The image is displayed by a TV video format of horizontal sweeps proceeding down the screen. The CRT beam is deflected, or scanned, in this fixed pattern, or raster, with one complete "raster-scan" being a frame of information. To prevent flicker, the screen is refreshed at a fixed rate, usually 30 frames per second. This is above the flicker detection threshold of the human eye (about 24 frames per second). To generate the appropriate video signal for the image to be displayed, a display controller must access a matrix of computer memory corresponding to each picture element, or "pixel," on the screen. The state of each pixel's memory bit is mapped into an "on or off" signal to intensify the electron beam (no grey scale). This matrix of memory, or bit map, may also be expanded to provide grey scale or color information for each pixel in a color raster-scan CRT system.

Matrix panels are the only conventional graphics terminals that do not use a cathode-ray tube. Instead, they have a matrix of discrete illumination points that can be selectively turned on or off, such as the light-bulbs in a stadium scoreboard. There are different types of matrix displays, but plasma panels are the most widely used for interactive computer graphics. The plasma panel consists of two panes of glass sandwiching a layer of bistable plasma gas cells. Each glass panel contains a set of transparent wire conductors running horizontally in one panel and vertically in the other. The intersection of these conductors defines a point (or cell) in the plasma layer that can be excited by an electric current pulsed through the conductors. When this occurs, the gas near the intersection illuminates to display a dot on the panel screen. The bistable gas will remain in its current state until another activation current changes it. This allows the image to be retained without refreshing. Hardware logic is required to select the conductors that discretely address each point of the display.

Each graphics terminal category has a particular display mechanism to achieve the graphical requirements of high resolution and point addressability. However, the performance of each display can be measured against how well it meets these and other attributes of graphics systems. Table 6 shows a list of these capability attributes and a general performance rating for each graphics terminal catagory. The quantitative ratings represent average values, maximum values, or a range of possible values. The feasibility of an attribute is represented by a qualitative "yes-no" answer, or the availability of special equipment.

Table 6. Comparative Graphics Terminal Attributes

CAPABILITY ATTRIBUTE	STORAGE TUBE CRT	REFRESH RANDOM-POSITIONING CRT	REFRESH RASTER-SCAN CRT	PLASMA MATRIX PANEL
Screen Size	8" x 6" 15" x 11"	16" x 12 " max.	17" x 13" max.	10" x 10"
Displayable Addressability	1024 x 780 4096 x 3120	4096 x 4096 max.	320 x 240 512 x 256 512 x 512 640 x 480	512 x 512
Resolution	70	50 - 300	15 - 100	25 - 60
Data Content	full	33,000 vector-inches max.	full	full
Selective Erasure	no	yes	yes	yes
Grey Scale	no	yes	yes	no
Colors	no	3 or 4 with special CRT	yes	not yet
Brightness	10 ft-L	20 ft-L	20 ft-L	60 ft-L
Contrast	5:1	8:1	8:1	25:1
Image Mixing	no	rear projection by special CRT	video mixing	rear projections
Monitors	no	no	yes	no
Projector	no	yes	yes	no
Hardcopy	thermal copy	no direct	video plotter	no direct

This list of attributes contains the most important features of a graphics terminal from the user's point of view. More detailed performance information can be obtained from terminal specifications for a particular device. However, the information of Table 6 is useful in comparing the advantages and disadvantages among the different terminal catagories. Each interactive computer graphics application has a set of information display requirements that can be matched against the list of capability attributes.

Some capabilities have been presented in the catagory descriptions, but others may still require definition. Screen size is the width by height (in inches) of the viewable screen area. Display addressability is the number of x-axis by y-axis points that can be individually seen and controlled by the user. Higher non-displayable addressabilities may be available that extend the addressable points beyond the physical screen boundaries. Resolution is a point or data density measure that is calculated by dividing displayable addressability by screen size for each screen dimension. Data content represents the amount of data points able to be displayed at one time. If every point on the screen can be turned on, without flicker effects, the display has full data content. Selective erasure is the ability to turn off or erase an individual point without affecting any other points of the display. Grey scale allows an individual point to attain intermediate brightness intensities between totally dark and light. Colors, other than black and white, may be available in some display terminals, also. Brightness and contrast are self-explanatory.

To superimpose computer graphic generated data with non-computer generated data, a terminal requires image mixing capability. Computer controlled image mixing is accomplished internal to the display screen, rather than placing a transparency in front of the screen. Photographic images, such as slides, movies, and microfiche and film projections are possible, in addition to video signal mixing. Some terminals allow monitor connections directly to the display without using another computer interface. Large screen projection is another means of duplicating the display screen for viewing by a group of users. Finally, hardcopy units, other than digital plotters, are available to reproduce the screen's softcopy information onto a more permanent and portable medium.

Some typical costs of available display systems and subsystems are shown in Table 7.

Display Systems in Severe Environments

Since the military normally operates in rather severe environments, at least in terms of the computer systems which are part of the command and control display systems, it is necessary to "militarize" these devices; i.e., insure that they meet military specification (or MIL-spec). The main design goal for MIL-spec computers is to optimize reliability. Such MIL-spec or "MIL-qualified" devices are either developed for specific tasks by various manufacturers, or are ruggedized commercial equipment which have been repackaged to meet more stringent environmental requirements than their commercial counterparts.

The commercial devices which have been ruggedized usually have more extensive software available; new software can usually be developed in a non-military, support facility environment, usually at reduced cost.

Ruggedizing can be achieved by various methods. The ROLM 1602, compatible with the Data General NOVA (hence, Ruggednova) employs the following methods:

1. Circuit boards attached to a thermally conducting metal frame;
2. IC's straddle the metal frame to stiffen the board and conduct heat away from the IC's to the edge of the board;
3. Fork-type connectors are used instead of friction-type metal pads for better contact under vibration;

Table 7. Display Subsystems Costs (Commercial and MIL-Spec)

	FY79 K$
Peripherals	
CRT's	30-100
Plasma Displays	5-35
Printers	5-35
Plotters	35-150
Magnetic Tape	75-150
Digitizers	2-5
Processors	
Main Frame (CPU)	75-275
Auxillary (CPU)	25-150
Special Purpose	10-35
Ancillary Equipment	
Discs	
Fixed Head	75-150
Moving Head	100-200

4. An alignment block is inserted between connectors which provides additional support and prevents the wrong card from being plugged in;

5. Circuit boards are covered with a plate that prevents flexing during vibration;

6. Each card is clamped inside the computer chasis with a wedge that serves as a thermal connection between the board and chasis;

7. The entire device is enclosed without a fan or coolant which allows it to meet specifications on electromagnetic interference, dust, sand and other contaminants;

8. Power supply and all cards are coated with a material which protects them from humidity and condensation; and

9. Ceramic circuits are used in lieu of plastic IC's for maximum reliability in a wider range of temperature.

The costs associated with such modifications can be quite large; in fact, MIL-spec equipment can cost several times more than their commercial counterparts. It is obvious that the display system with its often fragile components poses an enormous problem for the above types of ruggedizing.

SOTAS Display Requirements

It has become increasingly certain that a significant portion of the SOTAS display functions will be provided by CRT. It is implicit that this CRT will be MIL-qualified, hence it should have an EMI-tested case, and a high quality refresh stroke writer. The resolution should be at least 1024 x 1024. Common features of these CRT's which make them appropriate to the SOTAS, in addition to the above mentioned features, are: the compactness; the stand-alone capability which includes microprogrammable microprocessors, local editing, hardware vectors, symbols and conic generators; and BITE.

The original capabilities statement suggested that approximately 4000 symbols, up to 1500 vectors and color might also be required. Further, the display functions were listed in the following eight categories. No distinction is made here to discriminate between processing on-board the aircraft and that done on the ground; nor is there a distinction made for data versus signal processing, as might be done.

The graphics functions are:

1. Process "raw" radar data for
   a. moving targets
   b. fixed targets
2. Graphics generation
   a. map symbols for geographic and
   b. military identification
3. Graphics manipulation to
   a. add, delete, or change symbols
4. Graphics Transfer
   a. move to and from files
   b. plot directly to or from file
5. Printing and Plotting
   a. radar data, system status, graphics display
   b. mode of output
6. Operator tasks
   a. freeze display
   b. cursor for input over a given location
   c. interrogate UTM coordinates
   d. step through the "frame" of the graphics display upon command
7. Prediction
   a. speed, location
   b. radial velocity, acceleration
8. Time Compression

Military Computer and Peripheral Data Base

During this program, EES began to compile a comprehensive data base on attributes and prices of currently available MIL-qualified computers and peripherals. As a result, it provides EES with a unique position to assess current availability and costs of general purpose computers and graphical input-output devices for command and control functions.

Preliminary conclusions thereto and recommendations for continuing the data base acquisition/updating system process vis-a-vis specific SOTAS system requirements are in order.

The first task was to develop a list of attributes of particular devices under study. These attributes should be well defined so that inquiries (e.g., vendor data via phone conversations) can yield comparable information on various vendor devices. More specifically, various vendors utilize sales brochure and advertising literature terminology in describing their products; and descriptive terms which apply to the same attribute may appear to be completely unrelated. An example in the area of CRT's is "deflection bandwidth" vs. "positioning time" or "writing speed." It is possible, however, to convert any of these measures into the others.

In general, it is often difficult and time consuming to arrive at the most parsimonious (minimum) set of clearly defined attributes for any device. If such a set can be compiled which gives a complete characterization of the device, obtaining the information from vendor representatives can still be a formidable task.

Although EES has considerable historical information and the expertise necessary to build a truly useful data base of MIL-qualified computers and peripherals, the integration of more recent developments requires additional effort (perhaps at least nine (9) months). The proposed data base system would be accessible as an on-line interactive computer program. Any arbitrarily chosen set of attributes could be used as keywords in a search; and graphical output comparing attributes of candidate systems would be presented. A complete printout of all attributes as well as sources of information would be available on demand.

Table 8 shows a pro-forma comparison between several standard MIL-spec stroke-writing CRT's. Some of the more important attributes are listed only to indicate a range of comparison.

CPU Considerations

Considerable attention was paid in earlier CENTACS reports on the use of dual IOC's. The advantage of the dual IOC as opposed to the single I/O concept, is the more rapid access time to or from the disc, due to the fact that dual read/write I/O paths operate independently. Apparently, few machines have dual IOC capability. The UYK-7, for instance, does have this capability whereas the UYK-28 does not. Therefore, an analysis of the UYK-7 was made.

Table 8. A COMPARISON OF MIL-SPEC STROKE-WRITING CRTS

ATTRIBUTE	MOTOROLA TOTALSCOPE	HUGHES HMD-22	LORAL TDS
COST	about $70K minimal	about $100K	-----
JS DESIGNATION	AN/UYQ 29 (V)		AN/ASA-82
DISPLAY			
Size: W x H x D-in.	17-1/2 x 20-1/2 x 19		18 x 14-1/2 x 22
Weight: Lbs.	121		65.7
Power: Watts	625		625
KEYSET			
Size	18 x 4-1/2 x 9		
Weight	included		
Power	included		
# CHARACTERS	64/128	64/118	
Write Time		3μsec	3.2μsec
SPECIAL SYMBOLS		30μsec	
Write Time			
BRIGHTNESS (FOOT-LAMBERTS)	20	0 - 10	
CONTRAST	10:1	11:1	
COLORS	20K$/color		3(ryg)
WRITING CAPACITY			
# "Long" Vectors			
# .5" Vectors			5000 @ 57Hz
# Small Characters	4000		3300 @ 40Hz
SPOT SIZE (MAX)	15 mil	15 mil	18 mil
WRITING SPEED (mm/μsec)		14.2	12.7

ATTRIBUTE	MOTOROLA TOTALSCOPE	HUGHES HMD-22	LORAL TDS
# CHARACTER SIZES	4	4	
# CURSORS	1 or 2		2
CURSOR CONTROL	Stiff Stick	Trackball	
LOCAL EDITING	30 Commands	Yes	
VIEWING AREA	12" x 10" (16" diagonal)	22" dia. 20" useful	9" x 12.7"
RESOLUTION	1024^2	1024^2	1024^2
PHOSPHOR	P-31 (green, close to bluish green)	P-39 (yellow-green)	P-28 (yellow-green)
# INTENSITIES	8 levels	5-9 Channels Continuous	
# PROCESSORS	1	2	1
µp WORD SIZE	16 bit	16 bit	36 bit
MEMORY			
RAM	4-32K x 16	32K x 16	
ROM		2 x 4K x 32	
BITE	X	X	X
HDW CONICS	X		X
REFRESH RATE	50hz	30hz	40-57hz
LIGHT PEN	X	X	

The following is intended as a review of the arguments for and against the use of the Univac UYK-7 as the SOTAS "mainframe" computer. In the #73 report, the labels given to the computers in the Master Ground Station are "PCU" (peripheral control unit) and "mainframe" CPU. The implication of the naming convention is that the capabilities of the machines differ as much as their intended functions. It should be pointed out at the outset that all of the computers under consideration for use in the Master Ground Station are in fact general purpose computers. They should be evaluated on the basis of functional attributes, cost effectiveness, and estimated system development and integration costs.

It is a worthwhile preliminary to reviewing specific machines for SOTAS to review the roles intended for those machines. In particular, the concept of "unbundling" the functions allocated to the PRIME 300 in the commercial test bed system means that several machines will take over those (and additional) functions. However, it does not follow that those several machines must be locked in to particular functions. Indeed, in the interests of maximum retained capability of the system in degraded modes of operation, a design criterion should be to build in the systemic redundancy by allowing for example, the flexible allocation of functions.

There are several ways to retain this flexibility; one is to use bus switches to allow switch-selectable combinations of computers, peripherals, and communication lines. It is apparent that this could most easily be accomplished if several identical or near-identical computers are used.

The primary arguments against the use of the UYK-28 (ROLM 1664) in the capacity of system executive and "number cruncher" are the following:

1. It had insufficient time in the field to instill confidence, at least as of 1976;

2. It was felt that it could not run with only 64K of memory under RDOS (Rev. 4). Since then, Revisions 5 and 6 of RDOS have become available and have been extensively field tested.

3. Although the 1664 is not expandable beyond 64K of memory, the ROLM 1666 is now available with up to 576K (16 bit) words of memory, and is fully compatible with ROLM 1602 and 1664 software, the UYK-19 architecture.

In general, most all of the limitations of the UYK-19 family of computers have apparently been overcome since the CENTACS report #73 was published. The major argument in favor of the Univac UYK-7 is that it can be configured with dual I/O controllers. This is deemed a nearly indispensible feature in report #73 since it allows a single computer access to two discs at the same time. It can be shown that: (a) this capability is not required to perform the function of SOTAS, based on the total informational requirements of the system, even as the system block diagrams are drawn in reports #73 or #79; and that (b) the apparent need for this capability is a result of over-doing the unbundling, of locking-in to machine/function combinations, and of drawing the system block diagram in only one particular way when considering alternatives. Finally, it is becoming clear that the costs of hardware, software development, and system integration can be decreased while perhaps enhancing overall performance, particularly in degraded modes of operation, if the SOTAS ground station is configured with a compatible set of computers; e.g., the ROLM group.

It is the opinion of Georgia Tech that the Rolm 1666 should be the primary or central processor for the SOTAS ground stations, and could also be utilized as a peripheral controller; e.g., for the printer and plotter. This would allow the system a facility to reorganize and thus remain operational should one processor go down.

The 1666 is an improvement over the 1664 in that it has an expanded and enhanced memory management capability. Thus, along with the larger memory, it has improved memory allocation and protection features.

SOTAS-LARIAT Comparison

It has occurred to us that the SOTAS display capabilities are strikingly similar to the LARIAT (Long Range Area Radar for Intrusion, Detection, and Tracking) system currently under development at EES for the Air Force with ERADCOM sponsorship. Many of the same problems in the selection of display terminals, interfacing, and processor design have been addressed. Appendix D discusses the LARIAT program in greater detail. The intention here is to review four major areas of comparison (LARIAT to SOTAS) and outline the basic LARIAT display system and subsystem costs. More discussion on LARIAT can be found in [31].

The four areas of comparison will be: the use of a clutter map; the track prediction technique; the preprocessors; and the displays.

For the LARIAT program, it was determined that the clutter map would be of little utility for the operator unless it was of lower intensity than the target tracks. There were several ways to solve this problem. Firstly, by time-sharing, it was possible to obtain a clutter map by the realization of a proportionate amount of radar sweeps; one out of 50 or one out of 100, for example. Secondly, the use of a two-color presentation would allow clutter to be presented in a different hue. The third solution is to call the clutter map separately. To use a low intensity background, a fourth solution was finally chosen in which the gain threshold was set such that most of the clutter could be rejected. The considerations which weighted against obtaining and using a clutter map, in the LARIAT application were: (1) the serious storage problems that it would cause; and (2) the human engineering problem associated with the clutter (radar) versus clutter (human eye to brain) combination.

To perform target track predictions, the LARIAT system takes the track history of a declared target and performs a filter operation involving a 4-stage Kalman process. An algorithm then makes a prediction based on the output of these filters. A measurement is also made on how closely the track predicted point is from a point calculated on a straight line in order to add some discrimination between "random" tracks (animal, other) and more systematic tracks (vehicles, human, etc). Lastly, a simple prediction is also made by an extrapolation based on the last two points of the target track.

There are three microprocessors performing the pre-processing on the LARIAT front-end, which play a similar role to the anticipated SOTAS airborne processor. Each of these microprocessors performs routine functions to reduce the quantity of, while increasing the quality of the data. With the exception of the processing associated with one of the clutter map techniques previously discussed, the data rates to the primary computers of SOTAS and LARIAT are probably comparable.

In the display subsystem area, the greatest differences between LARIAT and SOTAS appears to exist. Again, the graphics related load on the main LARIAT computer is analogous to that which is expected for the advanced SOTAS display CPU. Although a NOVA-3 does all the graphics processing for the main LARIAT display console (AG-60), which includes hardware character and vector generation, it is not anticipated that as much dynamic information is handled as will be in the SOTAS case. However, the CRT's envisioned for SOTAS will have independent display processors with extensive stand-alone capability; e.g., curve generators, local editing, user-definable functions and communications capability.

Table 9 indicates the acquisition costs of the LARIAT display equipment. Other substantial additional costs in the program accounted for the radar (sub-contract with AIL) and personal services cost. A significant portion of the latter was involved in software conversion and development costs.

Table 9. LARIAT DISPLAY EQUIPMENT COSTS

	FY78K$
Power Supply	2
NOVA-3	12
Disc	8
Mag Tape	8
Terminet Line Printer	5
Plasma Display	5
Touch Panel	2
Interfacing	4
Miscellaneous Supplies	10
TOTAL	56

Display System Considerations

In this section, an attempt has been made to sketch a few of the more significant aspects of the rapidly advancing field of military computer-embedded command and control display devices. These technical aspects are considered useful for the cost analysis of the SOTAS development. The performance to cost linkage was briefly presented for peripherals and processors. The specific issues in military-specification were addressed; and the SOTAS display requirements reevaluated, as they particularly compared to an emergent system being built by EES known as LARIAT.

A comparison between standard commercial-grade display system equipment, existing MIL-spec components and special systems that could be developed is presented in Table 10. The intent is to capture some of the more important advantages and disadvantages of these various alternatives.

As was mentioned earlier, the costs of most display hardware appear to be decreasing during a period of time in which performance is generally increasing. However, for our purposes, this generalization may not continue to hold. Figure 8 indicates ranges of costs (FY75$) a function of performance; i.e., throughput or speed in characters/ second.

Figure 9 illustrates one of the reasons that hardware costs are declining; the introduction of newer semiconductor technology. Shown here is the speed-power product decrease as it has been seen in the last few years. The speed-power product is in joules (energy units) and is derived from bits/second (speed) times watts (power). The assumption here, of course, is that cost is directly related (or proportioned) to energy consumed. Thus, it is anticipated that the Integrated Injection Logic (IIL or I^2L) will be several orders of magnitude smaller in costs than the Diode Transistor Logic (DTL) of only a decade ago. The intervening technologies have included the Transistor-Transistor Logic (TTL) and the Emitter Coupled Logic (ECL), among others.

Table 10. Display System Comparisons

	Commercial	Existing MIL-Spec	Special Systems
Satisfy Operational Capabilities	Marginal	Good	Best
Development Risk	Very Little	Some	Some
Development Costs: HW	Low	Fair	High
SW	Low	Fair	High
Capabilities Provided to Capabilities Required	Good	Poor	Best
Compact Packaging	Best	Good	Good
Training Applications	Marginal	Fair	Best
O & M Costs	Low	Fair	High
Growth Potential	Good	Fair	Best

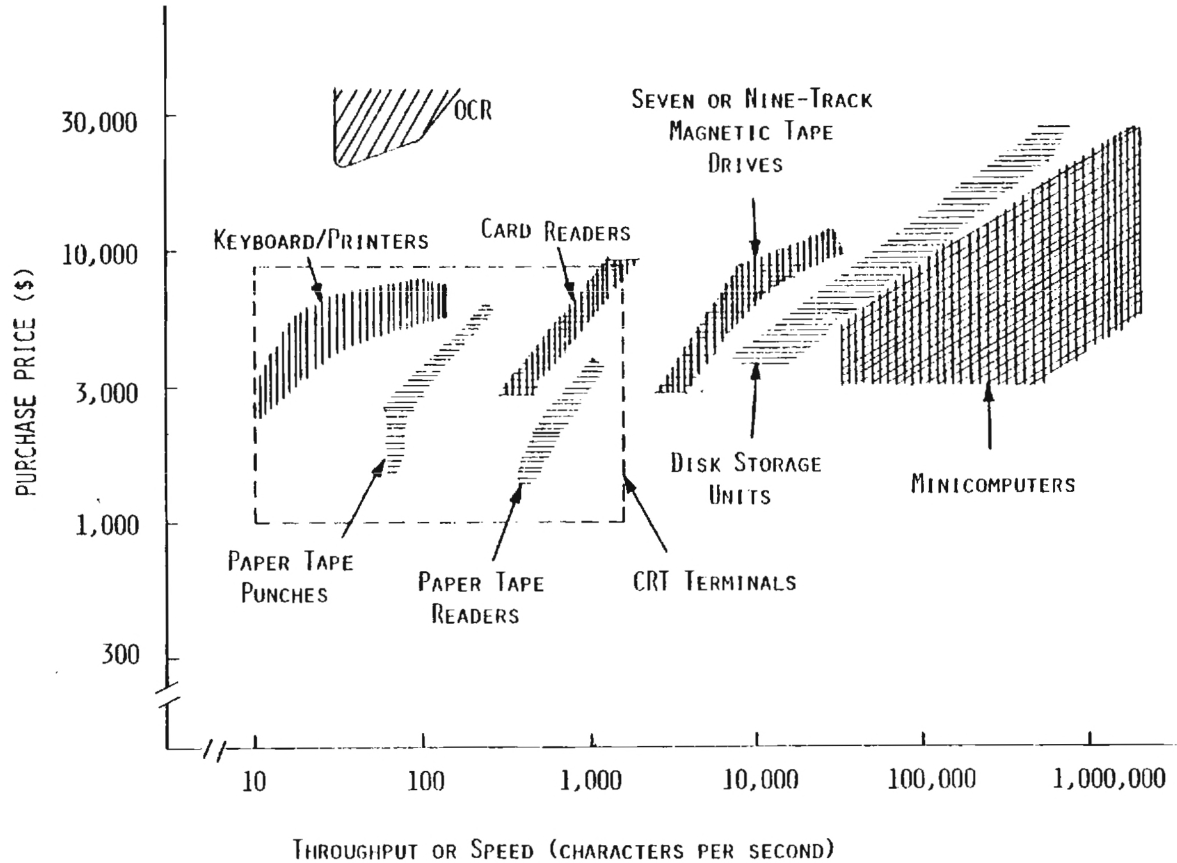

Figure 8. Cost versus Performance for Typical Devices [20]

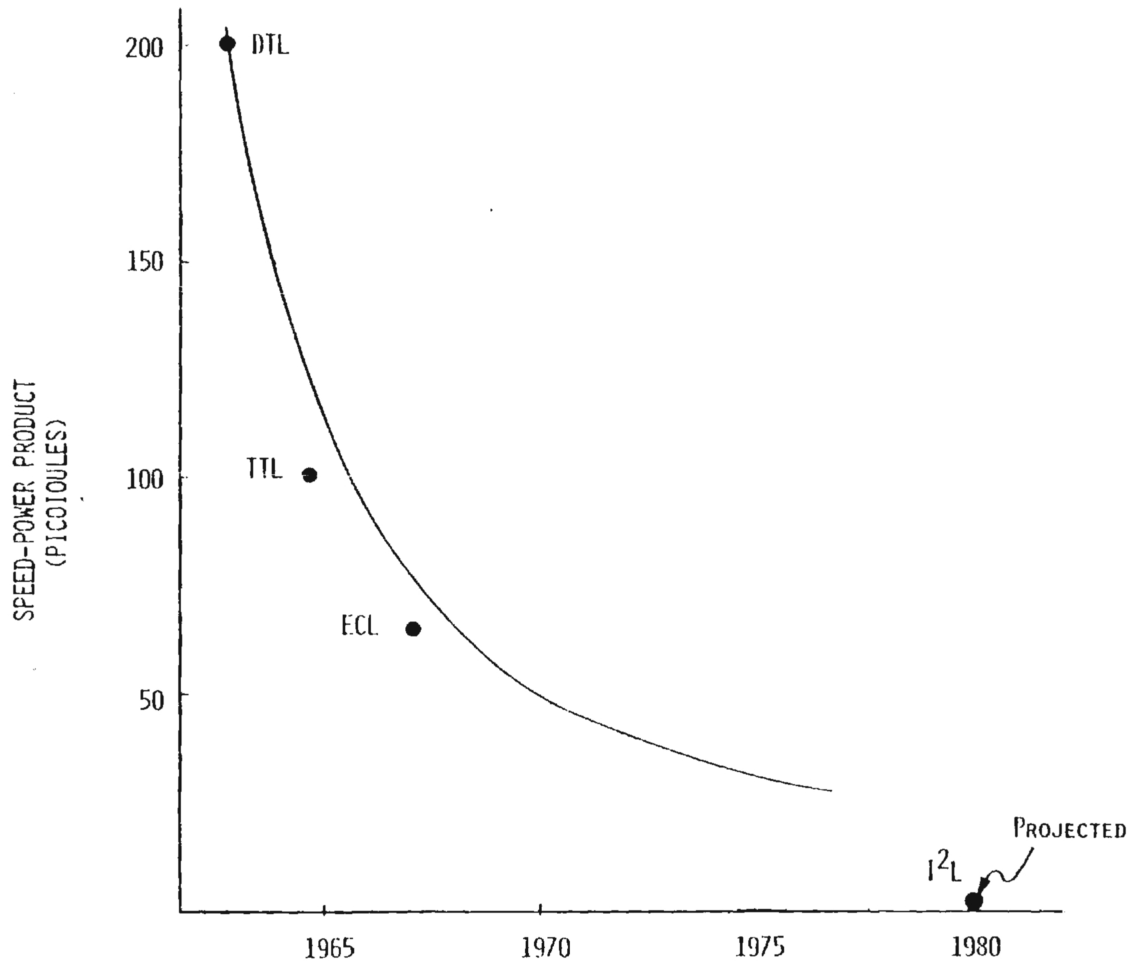

Figure 9. Trends in Semi-conductor Speed-Power Product [31].

However, as is graphically portrayed in Figure 10, the reliability goes down rather severely as a function of the number of components in the system, almost independently of the specific type of advanced electronics system. This observation provides the other side of the argument for the SOTAS development against the more complex; i.e., increased numbers of systems components involved, the less reliable (and the more expensive will be its total life-cycle costs). This additional burden that the SOTAS display system must bear is the diversity of sub-systems and components, and undeniable necessity for this type of target acquisition system. What this entails, however, for the development as well as the operational programs, is that if very different devices are intermixed; e.g., plasma and CRT's, the logistic support (spares, etc). requirements increase substantially.

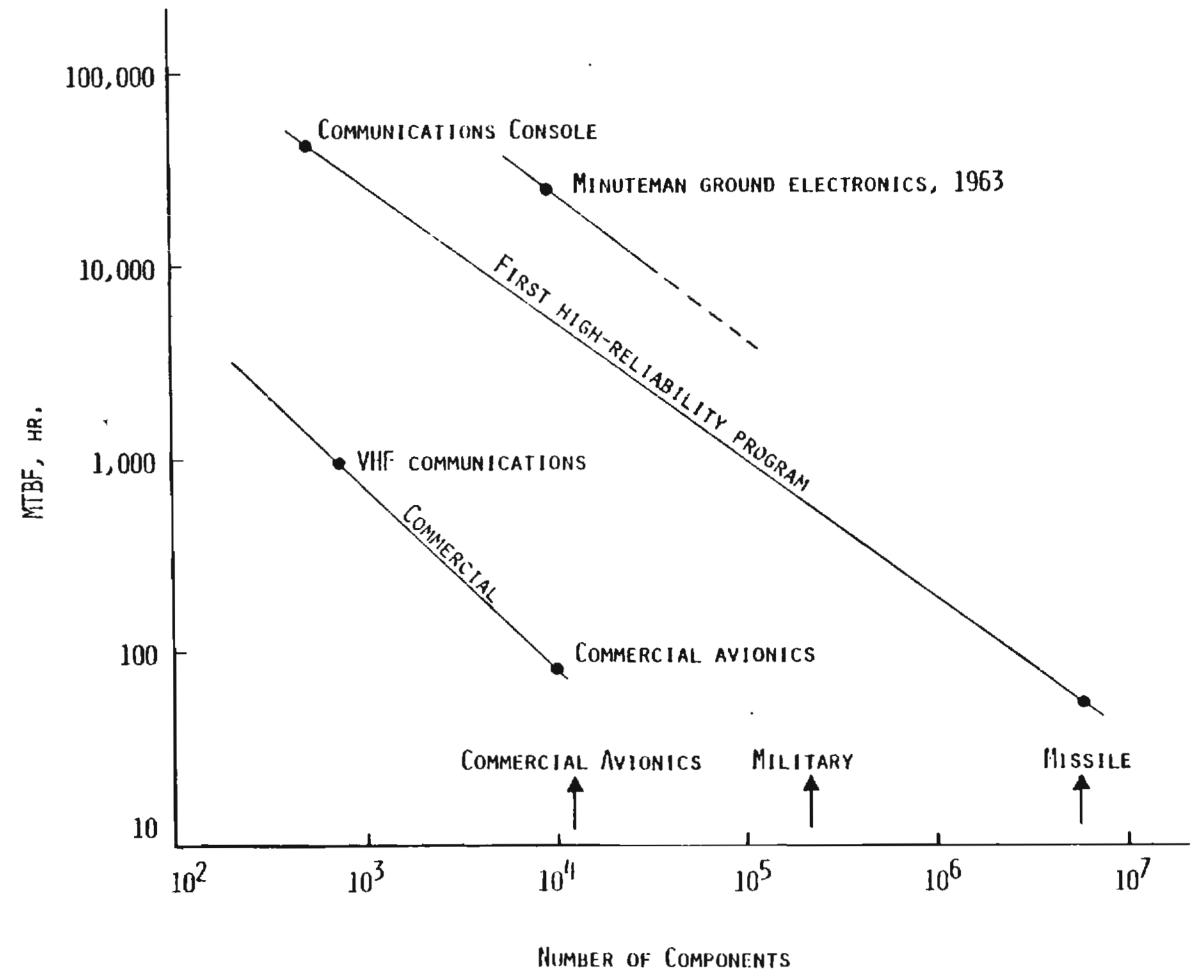

Figure 10. Reliability (MTBF in hrs.) versus Systems Component Count. [33].

V. SUMMARY

Results of this Study

This research program, as is described in this report, has been dedicated to the problem of ascertaining costs for several of the major technical functions and systems of the SOTAS or Standoff Target Acquisition System. Since SOTAS is a helicopter-mounted MTI radar which is data-linked via a tracker to mobile display units, the chief cost analysis centered on: the radar itself; the display system and subsystems; and the software development and conversion.

The radar costs were computed for four components: antenna, transmitter, receiver, and signal processor. These costs were appropriated for R&D and production. It was determined that the development radars would cost from two to four million dollars (FY 79) each, and these same radars in production could be manufactured for approximately one million dollars each.

The next major area of cost analysis was the software development, and, in particular, the cost implications in the conversion from the present test-bed system which utilizes a PRIME-300 mainframe computer and nonMIL-spec peripheral devices mounted in a commercial van. An early review of the display requirements and the operator functions indicated that the software conversion costs (one time basis) could run as much as one to two million dollars with little modification in present routines. However, for the advanced system, new software must be developed; and very little, if any, of the currently used code, logic diagnosis or flow charts would be particularly useful. The justification for this conclusion is that the change from wide band to narrow band data linking; i.e., the introduction of on-board processing, will cause considerable changes. It is also anticipated that the introduction of different processors, display devices and generally ruggedized equipment will cause severe deviations in the present software. Thus, EES estimates the total SW development costs (unbundled) will most likey be in the area of five million dollars.

The final SOTAS cost estimates were for the advanced system display configurations. Here, the variations in total display system cost becomes rather significant due to the extremely large number of variations of sub-systems that could be assembled. Additionally, the cost for MIL-spec equipment could increase the overall cost from three to five (with up to ten times not unusual) the cost for the commercial grade equivalent. While it can be safely assumed that the display sub-systems costs shown in the CONTACS Reports (#73 and #81) are not unrealistic for the various ground station configurations, it should also be remembered that substantial progress has been made in the past two years (1976-1978) in: developing improved graphics determination devices; producing smaller (in physical size), faster, larger (in memory size), and more efficient processors and interfacing, as well as printers, plotters, etc.; and marked improvements in ruggedizing and containerizing which is proving extremely useful for real-time, computer-embedded command and control systems.

Recommendations

These recommendations fall into two categories: the first applies to specific hardware for the SOTAS advanced system; and the second is for areas where it is felt, at this time, that more in-depth study and evaluation is needed which should continue to provide the most cost-effective solutions to problems as they are encountered in this complex program.

Particularly suggested at this time, because of overall cost/performance aspects, would be: the Motorola Totalscope, the ruggedized plasma panels (MIL-spec AG-60) and the ROLM group of processors (the 1666 and the modular 1650 avionics group). Specifically rejected by EES for use in the SOTAS program would include the following equipment: the AN/UYK-7 and the Hughes HMD-22. Although both have considerable field testing and modifications, neither has the advantages of recent technological changes, and do not appear to outperform newer, ruggedized equipment. No specific recommendations can be made on the radar equipment, since there does not appear to be a system, either commercial or militarized, which could be adapted for this task.

A general assesment of the costs involved in the radar and display (hardware) areas would indicate that: the overall costs appear to have remained fairly constant over the past few years, and may continue to do so in the near term. This conclusion is due partially to the fact that there has been a counterbalancing effect by technology, particularly in digital semiconductor products, vis à vis the recent inflationary trends. More sharply rising costs in the past few years, which may be sufficient grounds to predict a continuance, are the personnel services costs, which will have the greatest impact on the software conversion, development, and general testing. However, in the overall life cycle costs, the SOTAS software related costs may not be very significant.

Thus, it is strongly suggested that a SOTAS LCC program be initiated as soon as practicable; and, that DTC data be maintained on the various hardware components of the commercial testbed, the I^2 systems, and the ED units. Similarly, the costs of software design, production of code, and the testing of separate modules and complete routines should be assembled with some emphasis on corroborating cost data that might be supplied from other command and control system developments.

The last area of recommendation for additional study, besides the earlier described MIL-spec data base, entails the general review of the aggregation of battlefield information systems, coupled with specific analysis of the employment of the SOTAS in the role of an intelligence asset. The connection of these topics to the total Army investment in these programs is obvious. Yet, the nature of the information accumulation, processing and dissemination has not been fully investigated, in particular for moving target acquisition systems. The manner in which such systems, as SOTAS, is developed, integrated into ongoing training programs and deployed into the current force structure will, without question, be critical issues in the coming years.

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APPENDIX A

SOTAS Radar Parameters

(Detached)

Appendix B

SOTAS RADAR CER'S

The SOTAS Radar Cost Model retains a similarity to RECAP [4] in that it employs various CER's which are executed on a computer in realtime. RECAP was developed earlier as an interactive program written in FORTRAN for a CDC CYBER-74 computer. The main program handled input/output operations and controlled the calls to ten subroutines, each of which produced cost estimates for particular component/feature groups. The computations for component group costs were accomplished in various subroutines.

The SOTAS variant of this program obviously deals with a different class of sensor. As such, the cost model takes on a somewhat different character. It is still executed in FORTRAN, but on a NOVA-2 Minicomputer. The major sub-systems are priced in separate subroutines; most of these sub-system CER's are explained below. It should be noted that all costs are in constant FY 74 K$, as was obtained from data base sources, whereas costs that appear in matrices in the text are in FY 79 K$.

A. Transmitter Group Cost

The transmitter group cost is computed in two steps. First, a basic cost is derived from pertinent radar parameters which is then adjusted upward to account for certain system options.

Since the transmitter must be considered as a MIL-spec airborne device, the following cost function is thus used.

$$TC = [0.65\ PW^{.614} + 0.013\ PW^{.86}]\ 1000$$

Where TC = the transmitter cost, PW = power in watts, and XMTRGP = the transmitter group cost [5].

Thus, XMTRGP = TC + CMC,

Where $CMC = 10^{POLY}$, in which

$$POLY = 3.03 + .108(PLOG) - .128(PLOG)^2 + .072\ (PLOG)^3,$$

for freq. 10 GHz; and PLOG = $\log_{10}$ (PP) where PP = peak power in KW.

And, $MTC = 1300(PET^{.33})$, where

PET = PP(100/TE), with TE expressed in percent efficiency.

Finally, the basic transmitter group cost is adjusted for the following options to produce the final transmitter group cost. Since a staggered waveform is used, XMTRGP is increased by 10%. Pulse compression accounts for an additional 10%. Frequency agility causes a final escalation of 10%.

B. Receiver Group Cost

The basic receiver group cost (RCVRGP) is estimated at a fixed value per channel, which is altered for certain options. Since the receiver is also an airborne device, the following function is used:

$$RCVRGP = 40000 + 7500\ (PATHS)$$

and since pulse compression is used, the number of channels (PATHS) is increased by one [7].

C. Antenna Group Cost

The initial decision in determining antenna group cost (ANTGP) is whether the system used mechanical (M) or electronic (E) scanning since different pricing algorithms are used for the two types (which has been modified for the combination M-E antennas).

1. Mechanical Scan

For mechanical scanning antennas, a basic price is derived as the sum of the costs of the antenna itself, the scanhead, and the mechanical structure. The basic price is later increased for certain options [6].

Thus,

$$ANTGP = SHC + TRIC + AC$$

where

SHC = scanhead cost,

TRIC = structural cost, and

AC = antenna cost.

The component costs are derived as follows. For the scanhead:

$$SHC = 2967.16\ (AA)^{0.288}$$

where AA is the cross-sectional area in square feet. SHC is used as defined for manual tracking, and is increased by 50% for automatic tracking.

The support structure cost is

TRIC = 780 + 12(AE)

where AE is the length of the extendible support member. For automatic tracking, TRIC is increased by 100% to account for the heavier and more sophisticated construction needed to support the tracking mechanism.

The antenna cost (AC) depends on several parameters including type of material, carrier frequency, and number of feeds, etc. The base cost is again subject to upgrading for options. If the antenna material is fiberglass, then

AC = 870 + 7.5 (AA).

If the material is aluminum, then a partial cost factor depending on frequency is

AC1 = 132.36 EXP (0.0217 AA)

following which

AC = AC1 + 170 (FDHRN) + 5 (EN)

where

FDHRN = Number of feedhorns, and

EN = Number of elements.

2. Electronic Scan

For electronically scanned antennas, the pricing algorithm that determines the base price is:

ANTGP = 40000 + CE(EN) + 170 (PSNUM)

where CE = Cost of a simple radiating element (5 for slotted elements or 10 for dipoles), and EN = Number of radiating elements with PSNUM = Number of phase shifters.

The large constant (40000) accounts for the antenna radiating and reflecting structure and the beam steering processor.

3. Final Cost

For both scan types, an additional 15% is used for track-while-scan capability. The total ANTGP is the sum of ANTGP-M and ANTGP-E, for combination (M-E) systems.

D. Signal Processor Group Cost

The signal processor cost (PROCGP) is first derived as a basic cost for digital processors which depends on the number of range gates and the number of pulses used in the Fast Fourier Transform (FFT). For this processor type, the basic cost is increased for: CFAR, the use of a second computer, and multiple target tracking capability.

1. Range Gate Filtering

Range gate filtering is costed as follows. The range gate cost, GTCST, is a function of the number of range gates, RGTS. Thus:

GTCST = 61800 + 10(RGTS - 500), since RGTS > 500.

2. Digital Processing

For digital processors, the processor cost depends on the number of pulses (PULNO) processed in the FFT algorithm, as well as the number of range gates. The cost is

PCT = 10000 + GTCST + PULCST

where GTCST is defined above. The pulse cost is

PULCST = 11200 +250(PULNO - 32), 32 < PULNO $\leq$ 64,

Or 19200 +200(PULNO - 64), 64 < PULNO $\leq$ 128.

3. Options Adjustment - Final Cost

For either type of processor, costs of options are added to provide the group cost, PROCGP. Thus

PROCGP = PCT + CFC + CPC + CMT

where CFC = Cost of CFAR

CPC = Cost of a separate computer

CMT = Cost of multiple target tracking.

Options are priced as follows:

CFC = 20000, Moderate complexity CFAR

Or 40000, Advanced CFAR.

The separate computer cost (CPC) is fixed presently at 30000. The multiple target tracking cost (CMT) is

$$\text{CMT} = \begin{cases} 0, & \text{TARNO} = 1 \\ 7500\,(\text{TARNO} - 1), & \text{TARNO} > 1 \end{cases}$$

where TARNO is the number of targets tracked.

A covariance matrix processor would increase the processor cost throughout by 25%.

Countermeasure capabilities (ECM and ECCM) have been incorporated in each basic component unit. The multielement antenna, for example, includes the cross-polarized-dispersed receiving array. Additional receiver channels (PATHS) have been included in the receiver costs. Frequency agility and PRF-hopping have been included in the other cost estimates.

However, the amount of automation to control various radar system parameters has not been included. The basic impact will result in the software. This will, at most, increase the signal processor cost by about 10% above the stated cost which includes the covariance matrix processor. The final system configuration has apparently not been established at this time, and thus final provisions have not been made in these cost estimate areas.

E. Sub-System Learning

Each of the sub-systems costs (XMTRGP, ANTGP, RCVRGP and PROCGP) are adjusted according to accepted learning curve techniques. For example, a 90% (slope) learning curve is assumed throughout, and the following algorithm is used. See [8].

The appropriate group cost is multiplied by a constant (CK), where

$CK = 10^z$ and

$z = 0.301 - 0.1505\ Q.$

Q is the $\log_{10}$ of the number of production units.

F. Final Assembly and Test Cost

This cost is determined after the total cumulative sub-system cost has been calculated. It is a per unit cost that is based both on the complexity of the total system integration and the cost of the total sub-systems. The sum of the various sub-systems previously discussed is then subtracted and the result is the FAT cost, indicated below.

The total sub-system cost (CSS) is the sum of the listed component group costs.

$$CSS = ANTGP + XMTRGP + RCVRGP + PROCGP.$$

The radar set cost (CRS) is then computed as follows;

$$CRS = 0.35\ (CSS)^{1.11}.$$

The total production hardware cost (CHP) depends on CRS, and a learning curve factor (CK1). Thus,

$$CHP = CRS\ (CK1)$$

where $CK1 = 10^{(.301\ -\ .1505\ QUAN)}$

$QUAN = \log_{10}\ (N3)$, and N3 is the total number of production units. The total per unit cost (C) is then:

$C = 1.05\ (CHP)$ and C is the average per unit cost.

from which the final assembly and test cost (FATC) is:

$FATC = C - CSS$. See [9].

G. Engineering Development Cost

The engineering development costs are those associated with designing and producing a certain number of engineering prototypes. Usually there are only a very few such engineering models constructed, but the expense derives from the tedious design and planning, and often wasteful experimentation.

The engineering development cost (CD) is computed from the number of prototypes (N1) and the total production hardware cost (CHP) in the following manner. Another learning curve factor (CK2) is computed:

$$CK2 = 10^{UCK2};$$

where $UCK2 = .23 + .68\ \log_{10}(N1)$.

Then, $CD = (1.15)\ (2.6)\ (CHP/CK1)\ CK2$. See [6].

H. Advanced Production Engineering Cost

In a similar fashion as the engineering development cost, the advanced production engineering cost is computed for a certain limited number (usually about 10) of the early production models. This cost involves the tooling, drawings, specifications and layouts for production. The advanced production engineering cost (CAPE) depends on both the number of advanced production models (N2), the ultimate production quantity (N3), and the unit cost (C) and lot cost (CP).

The cost of the drawings (DNGS) is based on C:

$$DNGS = 31.9\ (C/1000)^{.35}.$$

The cost of tooling (PMODS) depends on C and N2:

$$PMODS = 4.62\ (C/1000)^{.848}(N2)^{.68}.$$

The cost of engineering design (PE) is derived solely from CP:

$$PE = .0273\ (CP/1000) + 55.54.$$

Then,

$$CAPE = 1000\ \{1.1705\ (DNGS + PMODS + PE) - 17\}.$$ See [6].

It has been assumed that the number of pre-production models would equal the sum of the ED and APE models. Hence, the R&D costs are a summation of ED and APE costs.

Appendix C

SOFTWARE COST FACTORS

Background

Estimating software costs for the Development phase is usually done by knowledgeable persons based on past experience with similar projects. In the light of frequent cost and schedule overruns experienced in software development in the past, this estimating procedure has not always been adequate. In general, a sufficiently knowledgeable person may not be available. In a move toward more exact methods of estimation, recent efforts have been aimed at identifying various factors which contribute to software development costs. Once the proper factors are identified, it is often possible to specify scales on which to quantify them. Then a statistical procedure, such as regression analysis, may be used to investigate the degree to which these factors contribute to costs. It was found that there are literally hundreds of factors which analysts suggest influence software costs. Obviously, these are not all mutually independent. Many of them are application dependent, but there are others which are present across a broad range of applications. The sources reviewed (see Bibliography) often grouped factors into categories, but these categories differed in scope from author to author. A variety of factors are discussed in the following context. First, it is beneficial to separate application dependent factors from more general ones. Secondly, general factors which apply to almost all applicants are further categorized into three groups: Requirements, Development Environment, and Data Processing equipment. These groups are discussed in the following four sections.

Requirements

As discussed in an earlier section, the Design phase of the computer life-cycle may consume as much as 40% of the time for the software development project. During this phase, requirements should be specified for the software itself, as well as for the documentation and all reliability, verification, and validation tests. Further, the desired input or data and the desired output content and format requirements are specified. Such factors as the size of the data base and the form of presentation may affect programming costs, since memory must be managed and input/output (I/O) formats must be developed to accommodate the data.

Documentation costs, have become an integral part of the total system cost. The degree to which documentation is required is therefore an important cost factor. For very large systems, especially those developed for military command and control systems, a large amount of external documentation is required so that personnel can be continually trained to operate the system. Also, for very large systems, much internal documentation is required which allows new programmers to debut, to implement subsequent modifications, and to carry out routine program maintenance.

For embedded software systems; i.e., those whose primary function is not data processing, but yet are integral parts of larger systems, there are usually strict reliability requirements. For example, in modern aircraft or spacecraft systems, the software is usually required to run with back-up hardware, should the primary hardware fail. Such requirements increase software costs since conditional branches must be incorporated into the software to permit shifting loads from one hardware device to another as the need arises.

If necessary, software can be tested in such a way that, with high probability, it will perform its functions correctly. Again, in the instance of embedded software systems, verification and validation must be accomplished to some degree. The requirements set for testing the software are thus an important factor in development costs.

<u>Development Environment</u>

The development environment includes the developer's interaction with the customer, the characteristics of the programming team, and the internal task environment.

The communication between the developer and the customer is important in that open communication helps insure that the software will satisfy the user's final requirements. It is essential for the developer to understand thoroughly the user requirements. It is beneficial to have senior programmers on the design team (with the customer) since they can directly transfer the information to the programmers involved with the acutal coding. The customer's prior experience with data processing applications has a great effect on the quality of communication, and hence, on how well the developer perceives what the software is required to do.

The number of programmers working on the project also affects costs directly. There is an indication too that as the percent of senior programmers increases, costs for the programming task decrease. Lack of experience with the programming language and the target computer also tend to drive the cost of software development up. If the programming team has experience with an application similar to the development project, the learning curve phenomenon appears to be present. Thus, there is less need for an intensive study of the system before actual coding begins. Another important cost factor is the personnel turnover rate, especially within the programming team. It is difficult to bring new personnel into a project that is well along, since the new employee must familiarize himself with the project with the help of those already on the project. This means that valuable resources will be used in training the new personnel with possibly no tangible immediate benefit to the project.

The environment internal to the programming shop and surrounding the programming team depends, to a certain extent, on the standards set by the organization. Internal documentation standards can be very effective means for communication among members of the programming team.

If programmers are required to document their programs in some standard form, other team members may easily familiarize themselves with those portions of the program, should the need arise. The availability of software support tools, such as flowcharts or "debuggers," can greatly enhance the development process. Also, a comprehensive support program library has beneficial results for the programming project.

As mentioned before, programmer experience with the language used has an impact on cost. More important may be the programming language chosen, whether a higher-order language (HOL) or machine assembly code. If possible, the language chosen should be one which is familiar to all programmers involved, and one which is compatible with the user's capabilities. For example, if the customer's experience is with FORTRAN, it would be much easier for him to maintain the system, once development is complete, if all programs were also writtin in FORTRAN.

The general work environment is also important for the programmers to perform well. Programmer interface with the operating system may have a large impact on costs. The ideal situation would be to have the software development done on the same computer as the customer's. However, since this is often not feasible (e.g., when the software is developed for a system in which the hardware is not specified prior to the development), the computer used for development should be as close as possible to the target computer.

It is further cost effective for all the development to take place in one central location. If this is not possible, severe communication problems may occur among programmers. Also, the code must be easily transportable. This usually requires an investment of time (computer and personnel) over and above the usual development time. Also, travel expenses between location may contribute heavily to cost in this type of situation.

Data Processing Equipment

It is obvious that the data processing equipment used in the development project is an important factor in determining costs. The hardware imposes certain design constraints on the software, and thus indirectly affects programming costs. The cost of the hardware and peripherals is a direct cost which must be taken into account. The efficiency of the assembler and/or compiler can affect turnaround or processing time, which, in turn, affect costs. Of course, any special devices such as fast mass-storage devices, speical displays, or read-only memory have both a direct and indirect effect on development costs. In general, a mature operating system with standard peripherals should be used whenever possible.

Figure C-1 indicates the hypothesized expotential relationship which exists between cost and the relative hardware utilization. Specifically, the speed and capacity of the processor memory are used, as developed by Boehm [16].

Application-Dependent Factors

Most of the factors discussed in the preceding paragraphs may be seen to impact costs regardless of the specific application or job type. Once a design has been decided upon, cost factors associated with the software itself may be analyzed. The characteristics of the software should be the major input to any algorithm to estimate software costs. If, for example, the number of lines of code (or the number of subroutines or subprograms) required to accomplish the development tasks can be estimated, a ball park cost estimate may usually be obtained.

Any or all of the following items may be used to input into a cost algorithm:

1) number of object instructions delivered
2) number of source instructions written
3) number of conditional branches
4) number of subprograms
5) number of subroutines
6) number of characters in the data base
7) number of input transactions per time period
8) number of characters/time period of output
9) percentage of program that is clerical or housekeeping
10) percentage of program which is transformation or reformatting
11) percentage of program which is real-time.

The eomplexity of the program is an important cost factor which indirectly affects other aspects of the development project. Complex applications, especially those which are unique to the developer or customer, require extensive design consideration, a certain amoung of programmer ingenuity and certainly well laid-out test and validation procedures.

The cost factors discussed here aré not all quantifiable. Measurement is often not possible, so that determining the cost impact must be done arbitrarily or by assigning weights based on experience in similar software development projects. However, the lack of means to measure variables does not imply that they lack utility in determining costs. Their impact should be considered even if the procedure for doing so appears somewhat esoteric.

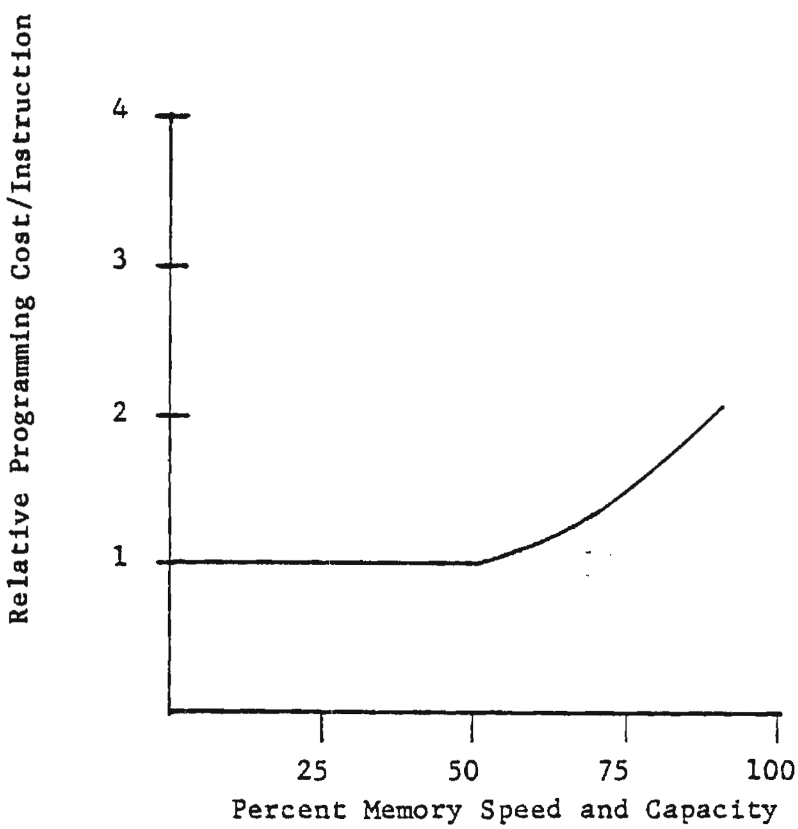

Figure C-1Relative Software Cost/Hardware Utilization

Although most software cost estimation is concentrated on programming costs, there is some increasing awareness that maintenance, validation, and testing contribute significantly to the total life cycle cost of software. Maintenance can encompass as much as 50% of the total effort and thus cost for large systems. In particular, maintenance costs consistently exceed development costs. Figure C-2 depicts relative hardware and software maintenance costs [20] over the somewhat typical life cycle of a computer system.

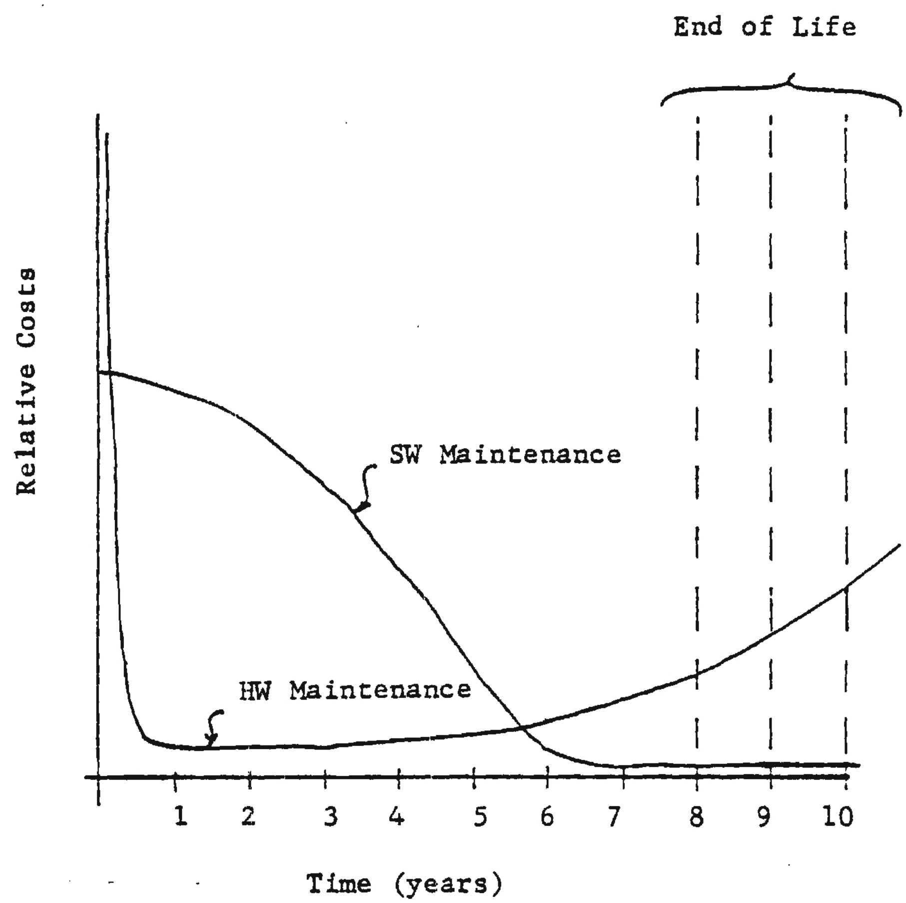

Figure C-2 Hardware vs. Software Maintenance Costs

Appendix D

LARIAT

Background

Begun in January 1977, the LARIAT (Long Range Area Radar for Intrusion, Detection, and Tracking) system's basic purpose is to detect intruders into a secure test facility. Presently, the system consists of a fixed ground station and two fixed scan MTI radars. However, it is envisioned that up to ten MTI radars will eventually be employed simultaneously. The primary targets to be detected from the MTI radar scan are moving personnel; the cross section of a person ranges from about 0.1 to 0.5 square meters at K_u band. The LARIAT radars have 200 range bins and a 0.7° beam width, implying approximately 102K bits per 360° scan.

The LARIAT radars have the capability of providing either a clutter map or moving target information. However, the limitations imposed by the size of the processor (a NOVA III with 96K of memory) prevents the processing and storing of clutter map data. This constraint was accepted in order to speed the development of LARIAT and to provide a cost-effective prototype system which was intended solely to demonstrate the feasibility of the LARIAT system.

There are two basic algorithms used by LARIAT in processing the raw radar data: (1) target detection and (2) verification. The target detection algorithm works in the following way: the radar system with MTI processing and integration over a period of about 20 ms (set by the frame rate of the multiplexer between the two radars) receives the data as it enters the processing system. A CFAR algorithm employing range-only averaging receives a set of range cells, which are utilized in the following way.

The algorithm locates the candidate cell (read candidate target) and performs an operation analogous to automatic gain control. A weighted average of range cells on either side of the candidate cell is computed and a threshold is compared to this result. The threshold is based on the amount of clutter expected in the environment.

The verification process uses an M/N algorithm (basically a binary integrator in time) to determine whether a particular signal return is to be considered a target; i.e., a human intruder. As the target beam scans the target area and encounters a moving object, the system receives information at 20 ms intervals. Sixteen readouts per target is common at the slower scan speed. The verification algorithm searches to see if in any N consecutive intervals of time, the candidate target is there M of them. The ratio M/N might be set (within the software) as 3/5, 7/10, etc. If a candidate target does not pass the M/N criterion, it will not be passed on as a target.

Each of these algorithms is performed in one of three preprocessors. One RAIL microprocessor (a fast 16-bit microprocessor employing 2900-series bit-slice architecture) receives the raw radar data from the two radars and splits the multiplexed signal into two portions. The data is then received by one of two other RAIL microprocessors (one per radar). These three preprocessors function as data reducers to perform detection, verification, and coordinate conversion (polar to rectangular) and all three are interfaced with the main NOVA III computer.

A "target" in this system is defined as a signal return which has passed the CFAR and verification algorithms. Thus, only those returns which seem to indicate possible intruders are sent to the NOVA.

Once a target has been identified, it is placed in a circular file which can hold approximately 1000 targets. The NOVA performs two functions, threat analysis and track identification, to attempt target description based on the radar history that is recorded. Track identification works as follows: position and time of detection are used to correlate targets and estimate their speed and direction. If a "track" is identified, it is presented on the screen and threat analysis begins. Yellow and red alaerts may be declared based on the penetration of specified boundaries.

LARIAT Display Options

There are six basic capabilities of the LARIAT display system and these are described below:

(1) Real-time target display - This capability is the typical mode of operation. The screen presents targets which are encountered by the radar scan against a background of the monitored area, i.e., buildings, streets, boundaries, etc. The operator does not have to continuously monitor the screen because of the automatic alarming capability. If a target meets certain criteria, established in the software, there is either a red or yellow alert. When this occurs, the operator may wish to utilize either or both capabilities, (2) and (3), described below.

(2) Time compressed display - Because human targets move so slowly, targets may be "missed" by the operator or processor in real-time. Therefore a repetitive time compressed display of information that is on the target file can be called on demand by the operator.

(3) Recent-history option - This capability allows the operator to call for display of all information stored on disk for approximately a prior 30 minute period. The circular file disk is 10 times the size of the circular file retained in the core.

(4) Visual tracking - This capability allows the operator to call for a graphical presentation of the linkages that are made in the identification of a given track.

(5) Zoom - Using the two available input media, keyboard and touch panel, the operator can "zoom" in on a particular area. The operator first keys in the zoom command, and then touches the screen at the lower left and upper right corner. After a pause to show the area that will be enlarged, the enclosed area is drawn on the screen.

(6) Target coordinates - The operator uses the touch panel to indicate a target on the screen. Within the limits of the resolution of the (16 x 16) touch panel, the coordinates of the target are presented at the bottom of the screen. By zooming in on a target and repeating this process, the coordinates for a particular location become more and more precise.