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RAMCAD FINAL REPORT

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13. ABSTRACT *(Maximum 200 words)*
The Reliability, Availability and Maintainability in Computer-Aided Design (RAMCAD) Program was established by the Air Force Armstrong Laboratory (AL/HRGA) in 1987 as a direct result of the Computer-Aided Acquisition and Logistics Support (CALS) Initiatives. The purpose of RAMCAD was to solicit "new and creative solutions" to the problem of integrating Reliability, Maintainability and Supportability into Computer-Aided Design. To provide a near-term RAMCAD capability, a principle task, funded by Armstrong Laboratory and the Army Armament, Munitions and Chemical Command (AMCCOM) was contracted to General Dynamics to integrate stand-alone commercially available or public domain reliability, maintainability and supportability analysis software with a computer-aided design workstation for electronic, mechanical and structural design as a RAMCAD Prototype system. RAMCAD provides a common user interface and shared database for reliability, maintainability and supportability of electronic, mechanical and structural designs. Execution of analysis programs is transparent to the user through the common user interface. Additionally, RAMCAD provides a significant process improvement in the quality and "robustness" of reliability predictions for new designs. This is accomplished by analysis of the environmental stresses experienced by each component in the system, rather than relying on default values or average values for the unit under analysis. This report documents the development of the RAMCAD Prototype System and Lessons Learned.

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TABLE OF CONTENTS

Page

LIST OF FIGURES vi

LIST OF TABLES viii

LIST OF ACRONYMS ix

SUMMARY xii

PREFACE xiii

I. INTRODUCTION 1

Statement of the Problem 1
Computer-Aided Acquisition and Logistics Support Initiatives 2
Army-Air Force Contracts 4
Technical Interchange Meetings 5
Institute for Defense Analyses RAMCAD Technical Interchange Meetings 7
Joint Logistics Commanders' Joint Policy Coordinating Group RAMCAD Sub-Panel Technical Interchange Meetings 8
Institute of Electrical and Electronics Engineers (IEEE) R&M~CAE Workshops 8
RAMCAD Task 2 and Task 3 Technical Interchange Meetings 9

II. RAMCAD SYSTEM CAPABILITIES 10

Overview 10
Reliability, Maintainability, and Supportability Requirements Presentation 13

System-Level Reliability, Maintainability, and Supportability Predictions. 13
Parts List Verification 13
Design Rule Checking 15
Electronic Workstation 16
Mechanical Workstation 22
Structural Workstation 26

III. RAMCAD DEVELOPMENT 32

RAMCAD Requirements Analysis 32
Design Process Analysis and Simulation 32
Electronic Design 33
Mechanical Design 36
Structural Design 39
Software Survey 42
RAMCAD System Development 43
Testbed Development 46
Prototype System 46
Advanced Prototype 48
Additional Mechanical Testbeds 49
Workstation Architecture 49
Software Architecture 51
Computer-Aided Design (CAD)/Computer-Aided Engineering (CAE) Software 55
RM&S Software 57
Common User Interface 61
Database Management System 62
Approved Parts List 63
RAMCAD Software Development and Test 64
Development and Documentation 64
RAMCAD Software Testing 65
RAMCAD Implementation 67

IV. RAMCAD CONTRACT HISTORY 69

V. RAMCAD LESSONS LEARNED 73

RAMCAD Portability 73
Common User Interface 73
RAMCAD Database 74
Workstation/Application Software Color Standards 74
"Upward Compatibility" of Software 75
DOS-Based RM&S Analysis Software 76
Design Process Changes 76
CAD Workstation Requirements 77
Workstation Functionality 77
Workstation Process Architectures 78
Workstation Communications 79
User Interface Color Considerations 80
Vendor Part Models 81
Software Documentation 82

VI. RAMCAD FUTURE DEVELOPMENT 84

Follow-On Technical Challenges 84
Implementation Plans 84
Enhancements to RAMCAD 85
Manpower Requirements Analysis 86
Reliability-to-Cost Analysis 86
Failure Modes and Effects Analysis 86
Producibility/Tolerance Checking 86
RAMCAD/Logistics Support Analysis Interface 87
External RAMCAD Interfaces 87

APPENDIX A: RAMCAD DATABASE MANAGEMENT SYSTEM TABLES A-1
Approved Parts List Tables A-3
Electrical Tables A-4
Mechanical Tables A-5
Structural Tables A-6
Network Repair Level Analysis Tables A-7
Sample Data Formats A-8

LIST OF FIGURES

		Page
Figure 1.	RAMCAD Program Schedule	6
Figure 2.	RAMCAD Functionality	10
Figure 3.	RAMCAD Common User Interface	11
Figure 4.	RAMCAD System Architecture	12
Figure 5.	Weapon System Life-Cycle Overview	14
Figure 6.	RAMCAD Analysis	15
Figure 7.	CUI Requirements Menu	17
Figure 8.	Mentor Graphics Network Editor Schematic Capture	18
Figure 9.	Accurate Simulation Analysis	19
Figure 10.	Printed Circuit Board Thermal Analysis	20
Figure 11.	Failure Rates	21
Figure 12.	Maintainability Menu	22
Figure 13.	Supportability Menu	23
Figure 14.	Mechanical Design Menu	24
Figure 15.	Mechanical Advantage Sketch Note	25

Figure 16. Mechanical Advantage Sketch Note and Mathsolve 26

Figure 17. Failure Rates 27

Figure 18. Solid Model 28

Figure 19. Finite-Element Model 29

Figure 20. Stress Analysis Results 30

Figure 21. Structural Reliability Analysis Results 31

Figure 22. Electronics Design Process 34

Figure 23. Mechanical Design Process 37

Figure 24. Structural Design Process 40

Figure 25. Initial RAMCAD Architecture 50

Figure 26. RAMCAD Preliminary Design System Architecture 52

Figure 27. Top-Level RAMCAD Software Architecture 53

Figure 28. RAMCAD Communication/Common User Interface/ Translation/Artificial Intelligence Architecture 54

LIST OF TABLES

Page

Table 1. Evolution of RAMCAD 44

Table 2. Code Impacted by RM&S Package Changes 55

Table 3. RAMCAD Design Documentation 65

LIST OF ACRONYMS

ACCUSIM	Accurate Simulation
AFALC	Air Force Acquisition Logistics Center
AFHRL	Air Force Human Resources Laboratory
AI	Artificial Intelligence
AL/HRGA	Armstrong Labs, Human Resources Directorate, Logistics Research Division
AMCCOM	Army Armament Munitions and Chemical Command
APL	Approved Parts List
ARDEC	Army Research and Development Center
ATE	Automated Test Equipment
BIT	Built-In Test
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CALS	Computer-Aided Acquisition and Logistics Support
CASE	Computer-Aided Software Engineering
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CITA	Communication/Common User Interface/Translation/Artificial Intelligence
CSC	Computer Software Component
CSCI	Computer Software Configuration Item
CUI	Common User Interface
DARPA	Defense Advanced Research Projects Agency
DBIII	Database III (Database Management System Software)
DBMS	Database Management System
DCA	Defense Communications Agency
DCAP	Data Capture in Presentation
DEC	Digital Equipment Corporation
DEREX	Derating Expert
DID	Data Item Description
DLA	Defense Logistics Agency
DoD	Department of Defense
DOS	Disk Operating System

ECP	Equipment Change Proposal
EM&S	Electrical, Mechanical, and Structural
EMI	Electromagnetic Interference
FQT	Formal Qualification Testing
GD	General Dynamics
GDC	General Dynamics Convair Division
I-DEAS	Integrated Design Engineering Analysis Software
IC	Integrated Circuit
IDA	Institute for Defense Analyses
IMS	Integrated Manufacturing Systems
LAN	Local Area Network
LCC	Life-Cycle Cost
LSACN	Logistics Support Analysis Control Number
LSAR	Logistics Support Analysis Record
MAC II	Apple Macintosh II Computer
MDP	Mechanical Data Interchange Program
MECHREL	Mechanical Reliability Program
MIL-HDBK	Military Handbook
MIL-STD	Military Standard
MOTIF	Windowing Software
MPP	Maintainability Prediction Program
MRP	Mechanical Reliability Prediction program
MSPICE Plus	Mentor Special Integrated Circuit Evaluation
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
NETED	Network Editor
NFS	Network File System
NRLA	Network Repair Level Analysis
OC/ALC	Oklahoma City Air Logistics Center
OSF	Open Software Foundation
PC	Personal Computer
PCB	Printed Circuit Board
PDR	Preliminary Design Review
PDT	Pre-Demonstration Testing
PHIGS	Programmers Hierarchical Interactive Graphics System

PRDA	Program Research and Development Announcement
PSA	Power Switching Amplifier
R&M	Reliability and Maintainability
RADC	Rome Air Development Center
RAM	Reliability, Availability, and Maintainability
RAMCAD	Reliability, Availability, and Maintainability in Computer-Aided Design
REL PLUS	Electrical Reliability Software Program
RISC	Reduced Instruction Set Computing
RM&S	Reliability, Maintainability, and Supportability
S/W	Software
SDR	System Design Review
SDRC	Structural Dynamics Research Corporation
SI	Suggested Improvement
SOFT PC	DOS Software Emulation Program
SOLE	Society of Logistics Engineers
SPCR	Software Problem/Change Request
SQL	Structured Query Language
SQL*NET	Structured Query Language Network
SRB	Software Review Board
SRR	System Requirements Review
STP	Software Test Plan
STPR	Software Test Procedure
TAR	Test Anomaly Report
TCP/IP	Transmission Control Protocol/Internet Protocol
TDAS	Test Data Analysis System
TIM	Technical Interchange Meeting
VMS	Virtual Memory System
W/S	Workstation
XWINDOWS	Standardized Windowing Software

SUMMARY

The Reliability, Availability, and Maintainability in Computer-Aided Design (RAMCAD) Program was conceived to bring Reliability, Maintainability, and Supportability (RM&S) issues to the heart of the design process by bringing RM&S analysis to the designer. RAMCAD connects and integrates software packages performing RM&S analysis with computer-aided design (CAD) and computer-aided engineering workstations and software for electronic, mechanical, and structural design. These capabilities enable the designer to review RM&S requirements, predict RM&S characteristics for each of the evolving candidate designs, and compare the results with the requirements.

General Dynamics' task under the RAMCAD Program was to develop a prototype RAMCAD system that would integrate commercially available or public domain RM&S analysis software packages with CAD workstations for electronic, mechanical, and structural design.

The RAMCAD prototype provides a common user interface, shared database, and software and communications interfaces to enable an electronic, mechanical, or structural designer to perform RM&S analyses from a CAD workstation. All analysis results and design requirements are available to the designer through queries of the database which may be initiated at any workstation in the RAMCAD prototype. These capabilities provide designers with visibility of RM&S design requirements and timely feedback of the designers' success in meeting these requirements. Direct linkage of the RM&S analyses to the CAD design software provides the designer with an RM&S assessment that is as current as the latest iteration of the design itself.

PREFACE

This report documents the Reliability, Availability, and Maintainability in Computer-Aided Design (RAMCAD) Software Development Program which was started in July 1986 by General Dynamics Convair Division under a Program Research and Development Announcement (PRDA 86-16-PMRS). This PRDA was issued on May 15, 1986, by the Air Force Human Resources Laboratory, at Wright Patterson Air Force Base. It was subsequently co-sponsored by the Army Armament Munitions and Chemical Command, at Picatinny Arsenal. The objective of the program is to integrate reliability, maintainability, and supportability (RM&S) software into a computer-aided design (CAD) workstation for three different types of designs: electrical, mechanical, and structural.

The PRDA divides the research effort into three Tasks. Task One is to develop a RAMCAD prototype which demonstrates the feasibility of the RAMCAD concept. Task Two is to conduct long-range research into how the concept could make use of emerging technologies. Task Three is to develop a college-level curriculum to instruct and motivate future engineers using a RAMCAD design tool. General Dynamics was selected to perform Task One. This report addresses the performance of Task One, development of a RAMCAD prototype System.

I. INTRODUCTION

Statement of the Problem

Reliability, maintainability, and supportability (RM&S) characteristics drive the operations and support costs of a weapon system. Unreliable and unsupportable weapon systems have poor utility in their operational environment.

Theoretically, RM&S considerations should be an integral part of the design process to enhance weapon system operational availability and to minimize system life-cycle costs (LCCs). In practice, RM&S design considerations are usually addressed during the later stages of the design process--often after prototype hardware fabrication and testing--when it is too late to have a meaningful impact on the design. The factors that contribute to this problem include the following.

- Emphasis is placed on weapon system performance and acquisition cost (vs. life-cycle cost) during the design process. RM&S issues are often not addressed until after many of the design trade-off analyses have been completed and an engineering "commitment" has been made to the proposed design.

- Design engineer access to and understanding of RM&S analysis techniques and tools is often limited. Little of the available RM&S analysis software (S/W) is integrated into the designer's computer aids. Much of the RM&S software cannot be used by the design engineer with only cursory RM&S knowledge.

- A methodology for design that incorporates RM&S design problems has not been developed. The trade-offs involved in designing to meet specific RM&S requirements are not widely documented or understood in the design community.

- The availability of computer-aided design (CAD) and computer-aided engineering (CAE) analysis software tools has provided the designer with a means to rapidly iterate the design to achieve desired levels of performance. Consequently, RM&S analysis results using manual input from drawings and engineering data may be several iterations behind the current level of design.

- Many of the software tools used to assess the RM&S features of a design require a level of design definition that is available only in the later stages of the design process.

Thus, there is a need for automated design tools that integrate CAE, CAD, and RM&S analysis software into a design system that will provide the engineer with the capabilities to conduct prudent design analyses (considering RM&S requirements and characteristics coequal with performance), acquisition cost, and delivery schedules. RAMCAD was conceived to provide that required linkage between engineering design workstations and RM&S analysis software.

Computer-Aided Acquisition and Logistics Support Initiatives

In recognition of the foregoing problem, the Deputy Secretary of Defense placed a high priority on the accelerated integration of automated RM&S design capability into the CAD and CAE processes. This integration effort is part of the Computer-Aided Acquisition and Logistics Support (CALS) initiative. The CALS Program was initiated by the Department of Defense (DoD) to achieve major improvements in supportable weapon system designs and improve the accuracy, timeliness, and use of logistic technical information.

In September, 1985, Deputy Secretary of Defense, William H. Taft, IV, issued a memorandum to all Service Secretaries and the Defense Logistics Agency (DLA), Defense Communications Agency (DCA), and Defense Advanced Research Projects Agency (DARPA)

Directors directing them to implement the CALS initiative under the auspices of an Office of an Undersecretary of Defense chaired Steering Group. A goal of this program is to improve all elements of the acquisition process by facilitating the acquisition of the highest quality weapon systems possible at a reasonable price. In this context, a quality product is one that not only performs as expected, but also meets expectations in use, durability, and conformance. Increased RM&S is a critical element of the quality emphasis, with approximately 30 percent of a system's LCC attributed to R&M alone.[1]

With the implementation of the CALS initiatives, the DoD demonstrated its commitment to applying existing and emerging communication and computer-aided technologies to increasing the RM&S features of defense systems. The intent of this effort is to maximize the benefits afforded by automation to provide timely design decision support for those aspects of the engineering/design process that determine a product's R&M characteristics.

Two associated government/industry RAMCAD efforts had a significant influence on the implementation of RAMCAD and development of the RAMCAD prototype System:

- the CALS R&M Summer Study on Complex Electronics, and
- the CALS R&M Mechanical System Study.

The CALS R&M Summer Study on Complex Electronics was conducted by the Joint DoD and CALS Industry Steering Committee, Reliability and Maintainability Integration Task Group. This study was a series of five meetings held during the summer of 1987 by a team assembled from industry and supported by DoD personnel. It was sponsored by the Office of the Assistant Secretary for Defense

[1] Joint DoD and CALS Industry Steering Committee Reliability and Maintainability Integration Task Group. (1988). Integration of R&M into the Automated Design Process, Report of the CALS R&M Summer Study on Complex Electronics.

for Production and Logistics. The purpose of this study was to develop recommendations for the successful integration of R&M design capability into the automated design and engineering environment, and to identify those R&M processes for which RAMCAD could provide the most immediate and significant improvements. The results of the Summer Study were reported in Integration of R&M Into The Automated Design Process, published March 17, 1988.

The CALS R&M Mechanical Systems Study, initiated by the CALS Industry Steering Group, was convened early in 1988 as an industry working group. This group consisted of senior personnel from more than 40 major system and subsystem vendors from the shipbuilding, ground vehicle, and rotary and fixed wing aircraft industries, and one representative each from OSD, USAF Armstrong Labs, and US Army Picatinny Arsenal. These individuals represented all major mechanical design disciplines involved with weapon systems development for DoD systems. The purpose of this group was to develop recommendations for DoD and industry concerning technical approaches and implementation options for applying CALS R&M to the design of complex mechanical systems. The results of this effort were reported in CALS Technical Report 002, Application of Concurrent Engineering to Mechanical Systems Design, published June 16, 1989.

Army-Air Force Contracts

In response to CALS initiatives, a Reliability, Availability, and Maintainability in Computer-Aided Design (RAMCAD) Program Research and Development Announcement (PRDA 86-16-PMRS) was issued on May 15, 1986, by the Air Force Human Resources Laboratory (AFHRL, changed to Armstrong Laboratory, Human Resources Directorate, Logistics Research Division, (AL/HRGA)), at Wright Patterson Air Force Base. This PRDA was subsequently co-sponsored by the Army Armament Munitions and Chemical Command (AMCCOM) at Picatinny Arsenal. The objective of the program was to integrate RM&S software into a CAD workstation for three different types of designs: electrical, mechanical, and structural (EM&S).

The PRDA divided the research effort into three tasks. Task One was to develop a RAMCAD prototype which demonstrated the feasibility of the RAMCAD concept. Task Two was to conduct long-range research into how the concept could make use of emerging technologies. Task Three was to develop a college-level curriculum to instruct and motivate future engineers using a RAMCAD design tool. General Dynamics (GD) was selected to perform Task One.

Task One was structured as a three-phase, 48-month program (Figure 1). During Phase I, Requirements Definition, the design process and requirements for the prototype RAMCAD system were defined. During Phase II, Systems Integration, the system architecture was developed and a "proof-of-concept" advanced prototype was developed and demonstrated. Phase III, Systems Development and Test, involved software coding and test, demonstration, and delivery of the final reports and software for the prototype RAMCAD system.

Technical Interchange Meetings

In addition to the RAMCAD tasks contracted by the Air Force and Army, a series of government/industry Technical Interchange Meetings (TIMs) has been conducted over the years. These meetings have been actively supported by GD in providing status of the RAMCAD contract and related technology development efforts. While RAMCAD technology has also been discussed at nearly every major logistics or systems engineering symposium and workshop over the past five years, the following TIMs were dedicated to addressing the issues involved in implementing RAMCAD techniques:

- Institute for Defense Analyses (IDA) RAMCAD TIMs,
- Joint Logistics Commanders' Joint Policy Coordinating Group,
- RAMCAD Subpanel TIMs,

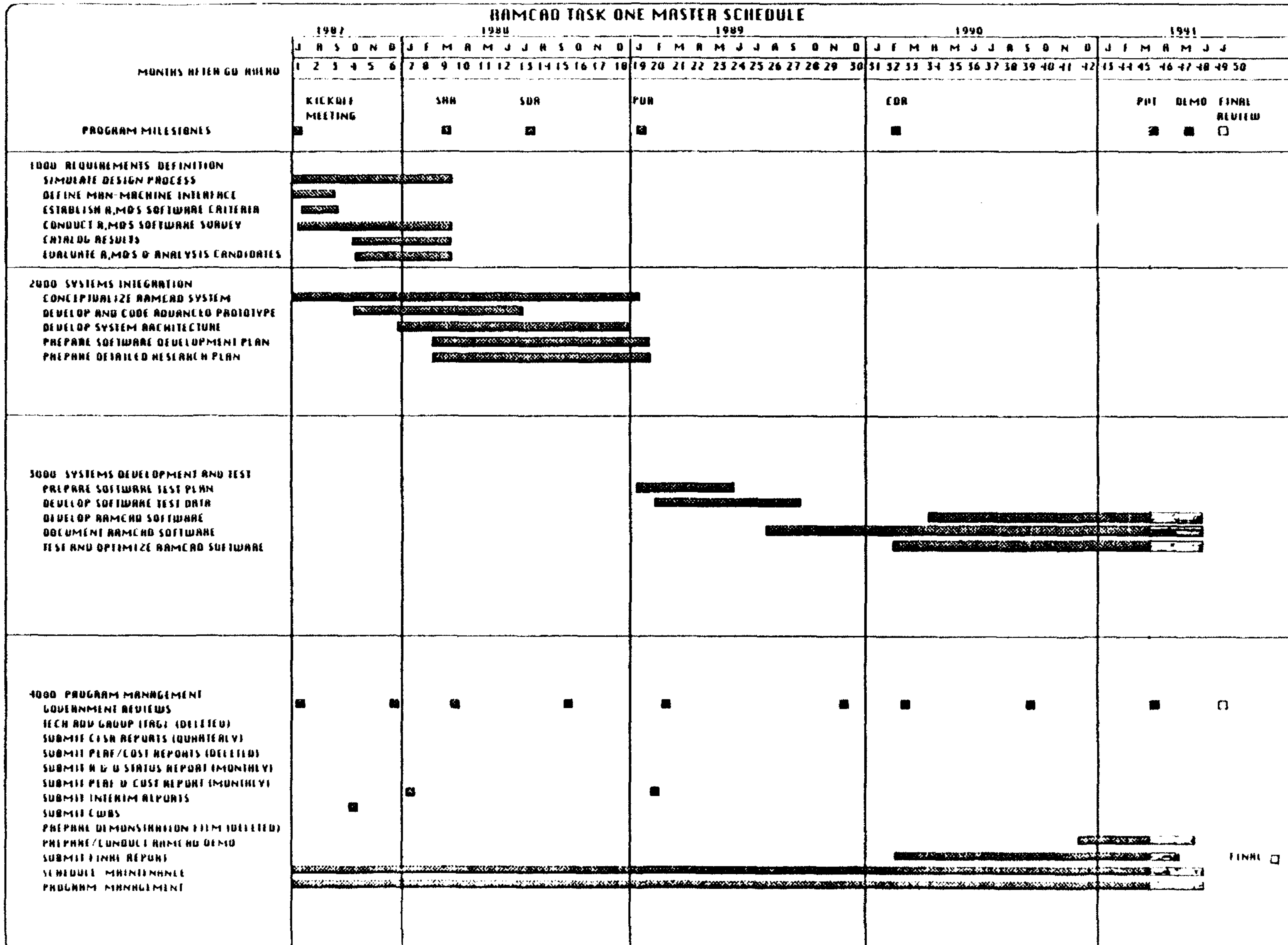

Figure 1. RAMCAD Program Schedule

- Institute of Electrical and Electronics Engineers Reliability and Maintainability/Computer-Aided Engineering workshops, and
- RAMCAD Task 2 and 3 TIMs.

Institute for Defense Analyses RAMCAD Technical Interchange Meetings

This series of meetings was a continuing study by the Institute for Defense Analyses (IDA) under Office of the Secretary of Defense sponsorship to address the issues involved in implementing RAMCAD techniques It involved managers, design engineers, specialist engineers, and the computer and software scientists in addressing solutions to the application and implementation problems of RAMCAD/Unified Life Cycle Engineering as perceived by the target users.

The first meeting, which predated the RAMCAD Contract, identified technical problems involved with developing RAMCAD capabilities, and identified the business benefits and advantages of investing in RAMCAD development.

The second meeting identified integration issues in the design process; showed the results of some preliminary studies; and provided evidence of the Government's commitment to change the contractual focus and discuss the future design-engineering environment.

The third meeting focused on conveying the concerns of potential users (e.g., the design engineers, supportability specialty engineers, manufacturing and quality engineers, etc.) to the computer hardware/software developers. It also presented the concerns of the computer scientists/software developers to the target users. This meeting included a presentation by the RAMCAD Program Office on the status of the RAMCAD Contract and solicitation of feedback on RAMCAD system requirements from potential users.

Joint Logistics Commanders' Joint Policy Coordinating Group RAMCAD Sub-Panel Technical Interchange Meetings

This series of TIMs was conducted at various locations across the country. Its objective was to communicate, educate, and institutionalize in Government, industry, and academia the ideas and applications of RAMCAD. The first five meetings were co-sponsored by local chapters of professional engineering societies within the RM&S disciplines. The sixth and subsequent meetings were co-sponsored through the national level of the Society of Logistics Engineers (SOLE).

Government and GD personnel actively supported these meetings. They provided evidence of RAMCAD's feasibility through presentations on the evolving RAMCAD prototype. A significant program decision resulted from these TIMs: to host the RAMCAD advanced prototype at the Air Force Human Factors Laboratory at Wright Patterson Air Force Base and thereby provide a site for RAMCAD demonstrations to Government and industry personnel.

Institute of Electrical and Electronics Engineers (IEEE) R&M~CAE Workshops

This series of annual workshops was aimed at assuring that R&M needs are addressed when the engineering workstation capabilities are being defined. An important feature of the IEEE workshops has been the high level of computer hardware and software developer/vendor participation. This provided an opportunity for RAMCAD users to directly communicate platform and software capability requirements to the vendor community. Each workshop sought to bring its participants up to date on the automation of R&M processes, identify remaining automation technical roadblocks/barriers, and discuss possible solutions and plans of action to remove these barriers. The RAMCAD program provided presentations on the status of the RAMCAD prototype System development, barrier removal issues, and RAMCAD/CAE integration issues. A demonstration of the RAMCAD mechanical workstation was also provided at these meetings.

RAMCAD Task 2 and Task 3 Technical Interchange Meetings

In addition to technical interchange with the Government and industry at large, meetings were conducted with the RAMCAD Task 2 and Task 3 contractors to assure the definition and achievement of common goals for RM&S integration into the design process. During the course of these meetings, GD provided insight to the Boeing Company (the Task 2 contractor) on the current status of the design process and state-of-the-art computing capabilities for their consideration in developing future RAMCAD processes and architectures. GD also co-hosted and supported Task 3 Workshops to integrate and implement RAMCAD as part of the college and university curriculum for future engineers.

II. RAMCAD SYSTEM CAPABILITIES

Overview

The RAMCAD Prototype System brings Reliability, Maintainability, and Supportability analysis (RM&S) issues to the forefront of the design trade-off process by bringing RM&S analysis to the designer (Figure 2). The system connects and integrates commercially available or public domain RM&S analysis software packages with CAD workstations and CAD/CAE software for electronic, mechanical, and structural design. These capabilities enable the designer to review RM&S requirements, predict RM&S characteristics for a candidate design, and compare the results with the requirements.

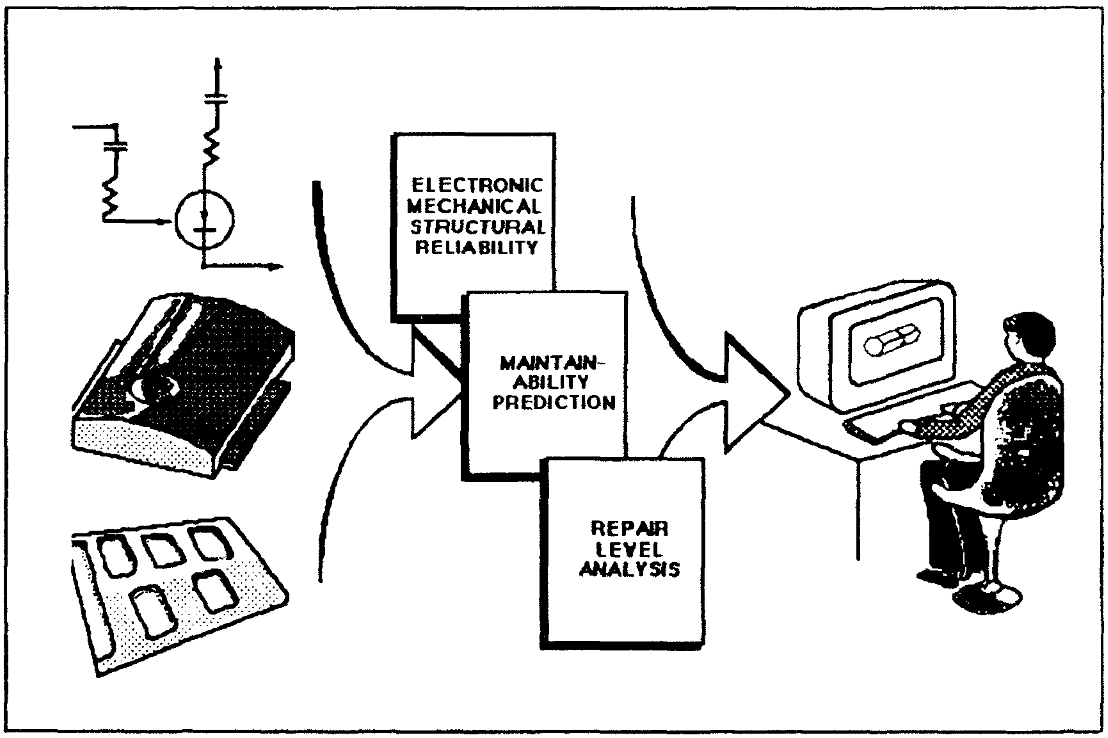

Figure 2. RAMCAD Functionality. RAMCAD brings RM&S analysis to the designer.

RAMCAD is accessible to the designer through a common user interface (CUI) that provides a standard menu format at each workstation for executing CAD, CAE, data storage and retrieval, and RM&S analysis programs (Figure 3). Through its translators and communications interfaces, RAMCAD captures design attributes from CAD functional and physical models that are created using CAD design packages--Mentor Graphics for electronic design, Mechanical Advantage for mechanical design, and Structural Dynamics Research Corporation (SDRC) I-DEAS for structural design. These attributes are saved to a common RAMCAD database from which they may be retrieved for input to RM&S analyses or displayed to designers at any RAMCAD workstation through the "Query" function.

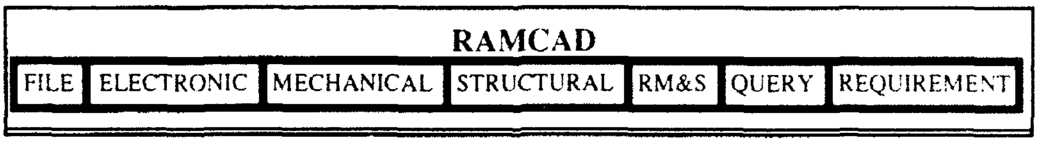

Figure 3. RAMCAD Common User Interface. The RAMCAD CUI provides a standard menu format at each workstation for executing CAD, CAE, data storage and retrieval, and RM&S analysis programs.

The RAMCAD prototype architecture is shown in Figure 4. It consists of electronic, mechanical, and structural workstations with a communications network and ORACLE database. Coprocessors or disk operating system (DOS) emulation enables DOS-based RM&S software packages to be run at each workstation.

RAMCAD is applicable to all phases of a product development effort. Figure 5 provides an overview of a weapon system life cycle, and major engineering and RAMCAD activities during each phase. Specific capabilities of the RAMCAD system are applicable to weapon system development phases, as described in the following paragraphs.

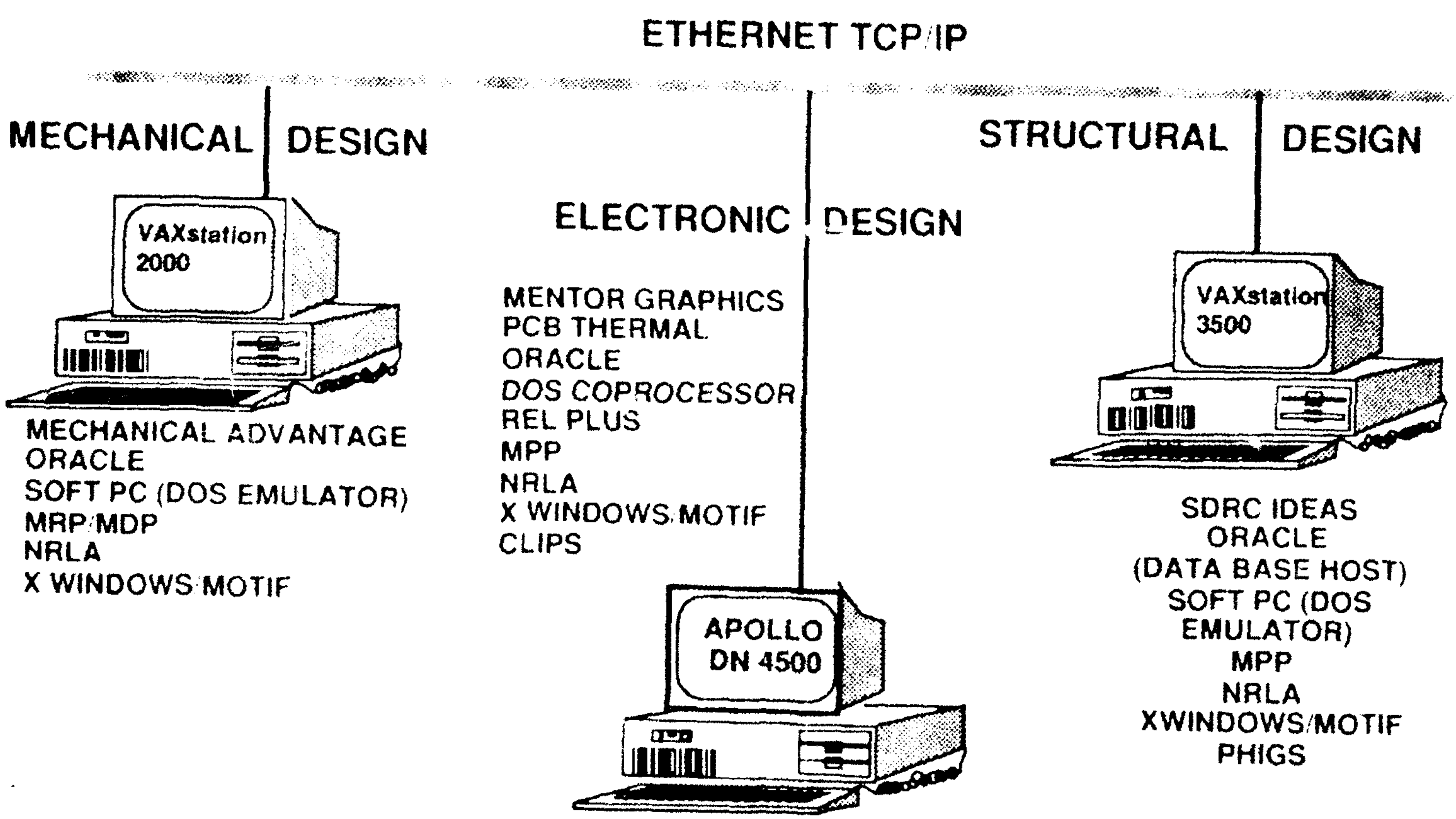

Figure 4. RAMCAD System Architecture

Reliability, Maintainability, and Supportability (RM&S) Requirements Presentation

The RAMCAD database includes a library of RM&S requirements (such as specified mean time between failures (MTBF), specified mean time to repair (MTTR), useful life, system service life, and system environmental requirements) that are applicable to subsystems and components of the weapon system under development. This requirements library contains specified, derived, and allocated requirements at the applicable indenture level which provide a basis for determining whether the proposed design will meet RM&S requirements. This capability is applicable to all development phases--particularly, the conceptual stage.

System Level Reliability, Maintainability, and Supportability Predictions

RM&S predictions for new systems can be performed prior to detailed design using RM&S analysis packages and data for similar components or analysis program default values. Substitution of known parameters, such as component junction temperatures, for default values as the design and analysis evolve will provide an orderly transition from system-level RM&S characteristics to predicted values for detailed designs. This capability is applicable to conceptual and detailed design.

Parts List Verification

The RAMCAD Approved Parts List (APL) provides the designer with those parts approved for the specific weapon system development program. If non-approved parts are required, they would be flagged and incorporated in a program parts exception lists. This capability is applicable to conceptual and detailed design.

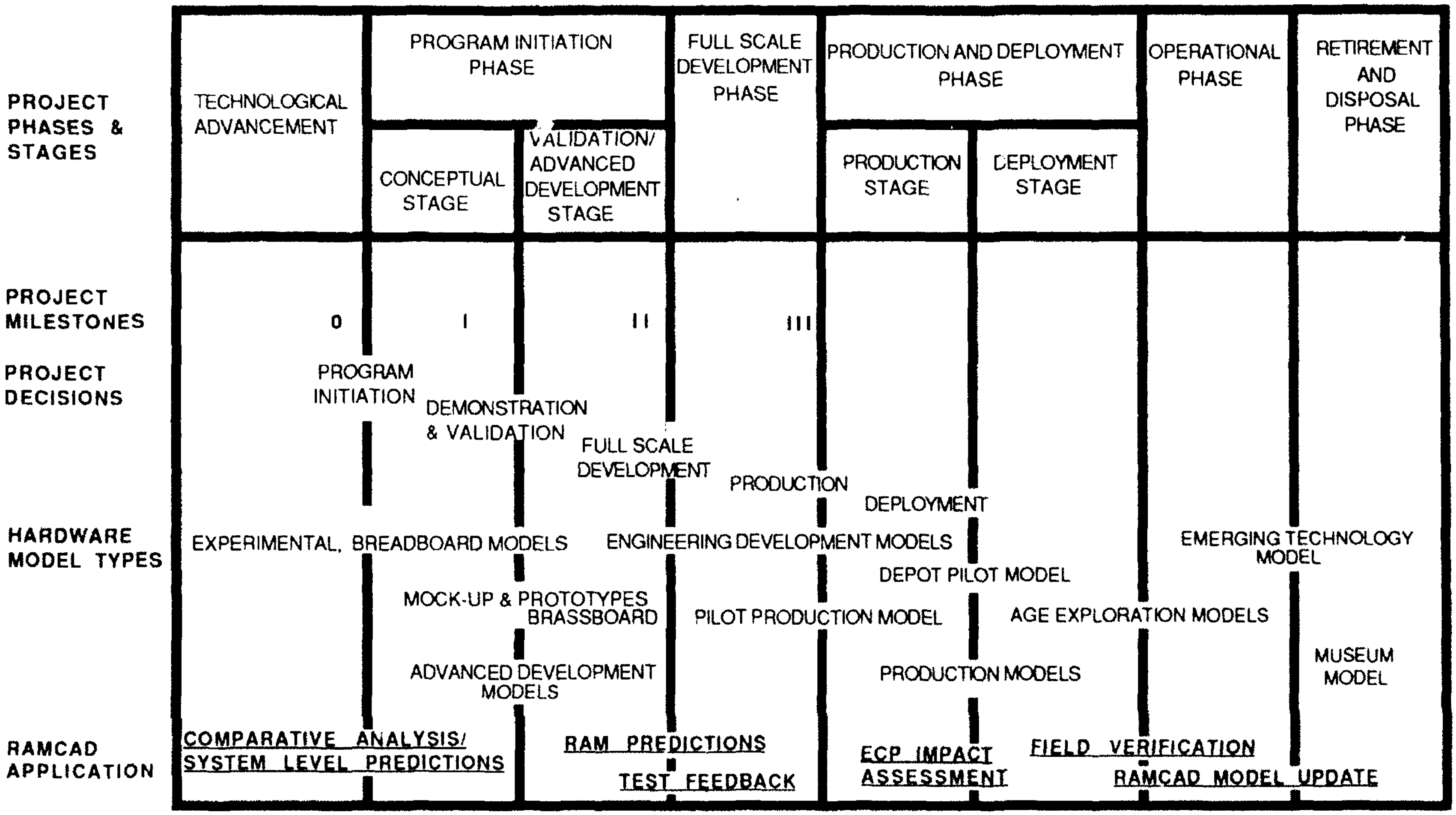

Figure 5 Weapon System Life-Cycle Overview.

Design Rule Checking

RAMCAD provides analysis of a proposed design for conformance with company design rules, "best practices," and contractually imposed design requirements. The RAMCAD prototype system addresses part-derating requirements and guidelines as well as maximum allowable temperatures for electronic components. This capability is applicable to conceptual and detailed design.

RAMCAD employs a natural and logical sequence of designer tasks, as shown in Figure 6. First, the designer develops a preliminary design using the RAMCAD electronic, mechanical, or structural CAD software. Then she/he performs engineering analyses of the design using RAMCAD CAE packages such as Mentor Graphics Accurate Simulation (ACCUSIM) for electrical simulation or SDRC's finite element analysis for structural components.

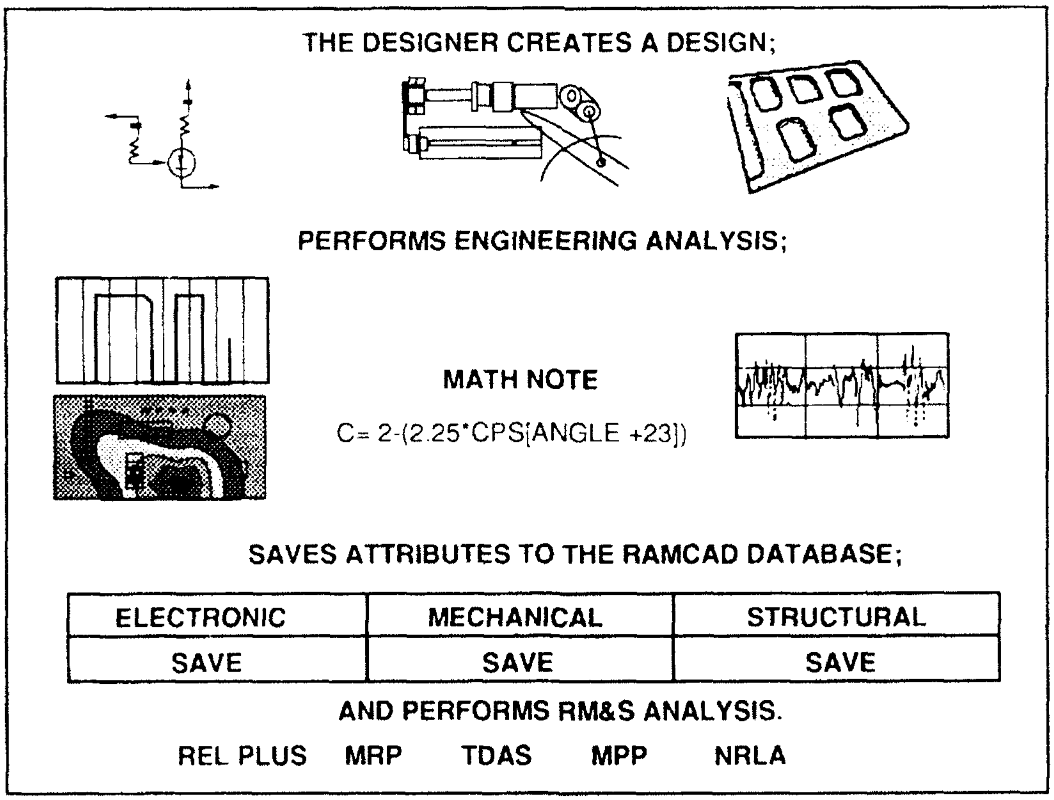

Figure 6. RAMCAD Analysis. RAMCAD employs a natural and logical sequence of designer tasks.

As these analyses are performed, attributes that impact RM&S design characteristics are captured and saved to the RAMCAD database. Upon completion of preliminary design and analysis, RM&S analyses are performed. RAMCAD selects and formats design attributes saved to the database for input to the RM&S packages. Results of the RM&S analyses may then be displayed and compared with requirements for the design and with results for other candidate design alternatives. This provides the ability to characterize RM&S design attributes before committing a proposed design to hardware.

Specific capabilities for each RAMCAD workstation are described in the following paragraphs.

Electronic Workstation

The designer selects or designates a design name for the electronic subsystem or assembly to be developed through the File Menu of the CUI. Requirements for the unit under development may be displayed through the CUI Requirements Menu (Figure 7). The designer uses the RAMCAD CUI to access the electrical CAD/CAE module, Mentor Graphics, to create the functional block diagram of the proposed electronic subsystem or unit. Schematic design and schematic capture are performed using the Mentor Graphics network editor (NETED) (Figure 8).

When the schematic design is saved, parts are matched to the APL. The APL contains all the part attributes that are required for downstream analyses and the part attributes required by Mentor Graphics for schematic design. These attributes are added to the data in the RAMCAD database for the usage of each part in the schematic design.

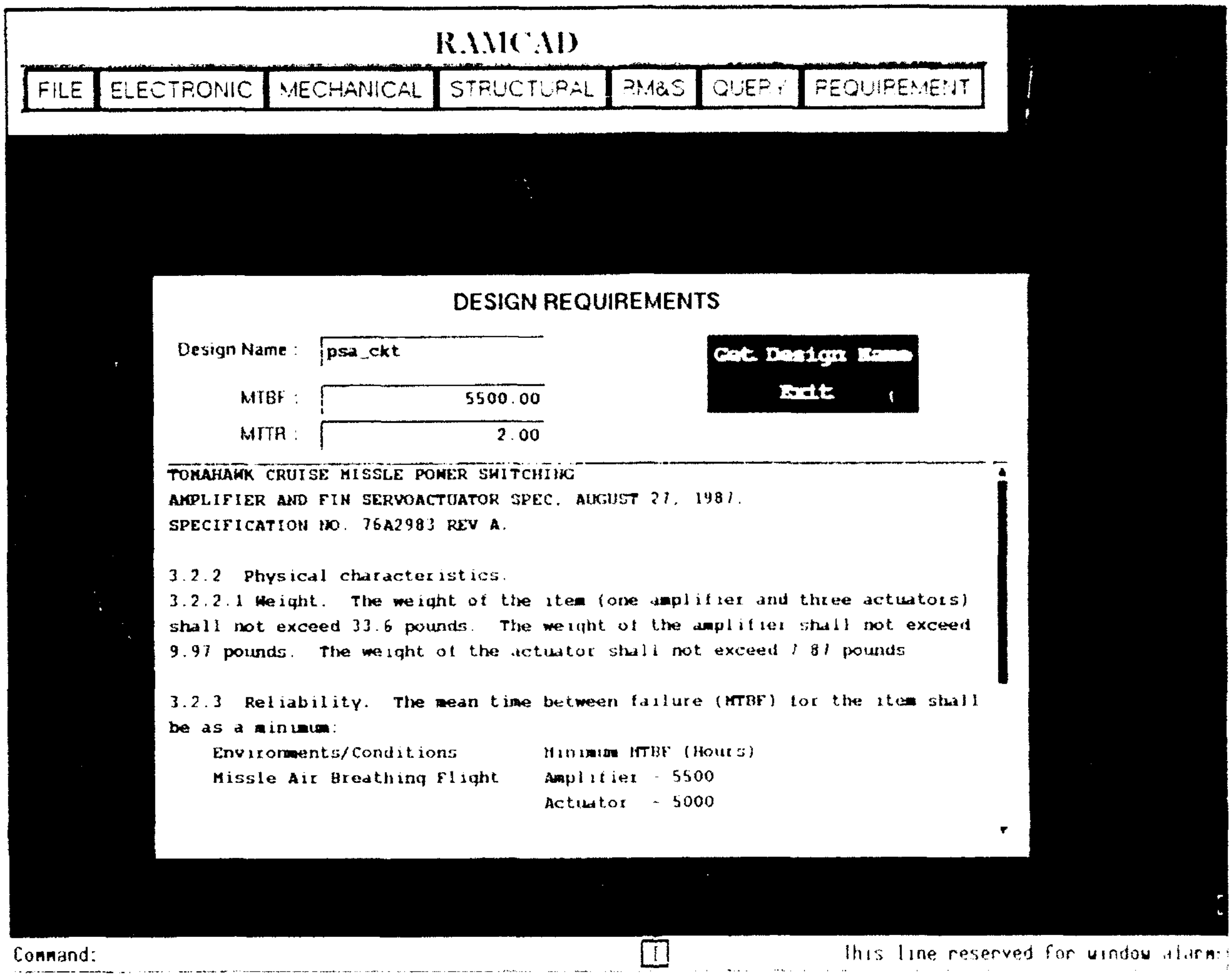

Figure 7. CUI Requirements Menu. Requirements for the unit under development are displayed through the CUI Requirements Menu.

An electrical simulation analysis is then performed using Mentor Graphics ACCUSIM. This analysis package provides a view of the circuit performance at a designated test point and computes the electrical performance of all components (Figure 9). Thus, the designer has access to circuit performance and expected waveforms and timing. The simulation is also used by RAMCAD to calculate power dissipation and electrical stress. This data is saved to the RAMCAD database.

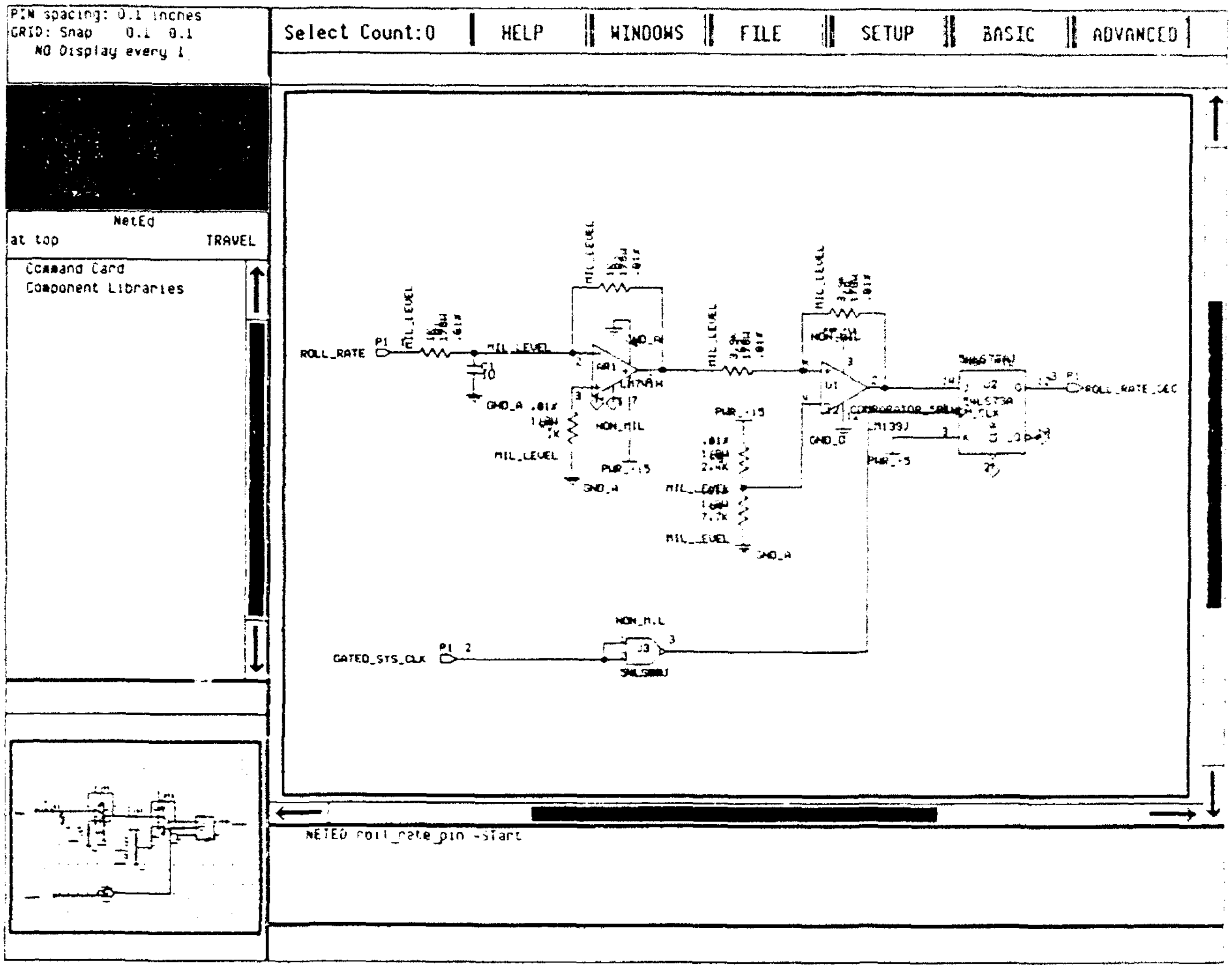

Figure 8. Mentor Graphics Network Editor Schematic Capture.

The circuit board design is then laid out, and a thermal analysis is performed using printed circuit board (PCB) thermal analysis software (Figure 10). The derating expert (DEREX) module compares the electrical and thermal stress of the part, calculated during the electronic simulation and PCB thermal analyses, with requirements of applicable derating specifications. Those components that exceed stress parameters are flagged. The designer corrects the design and iteratively performs the analyses until derating requirements have been met.

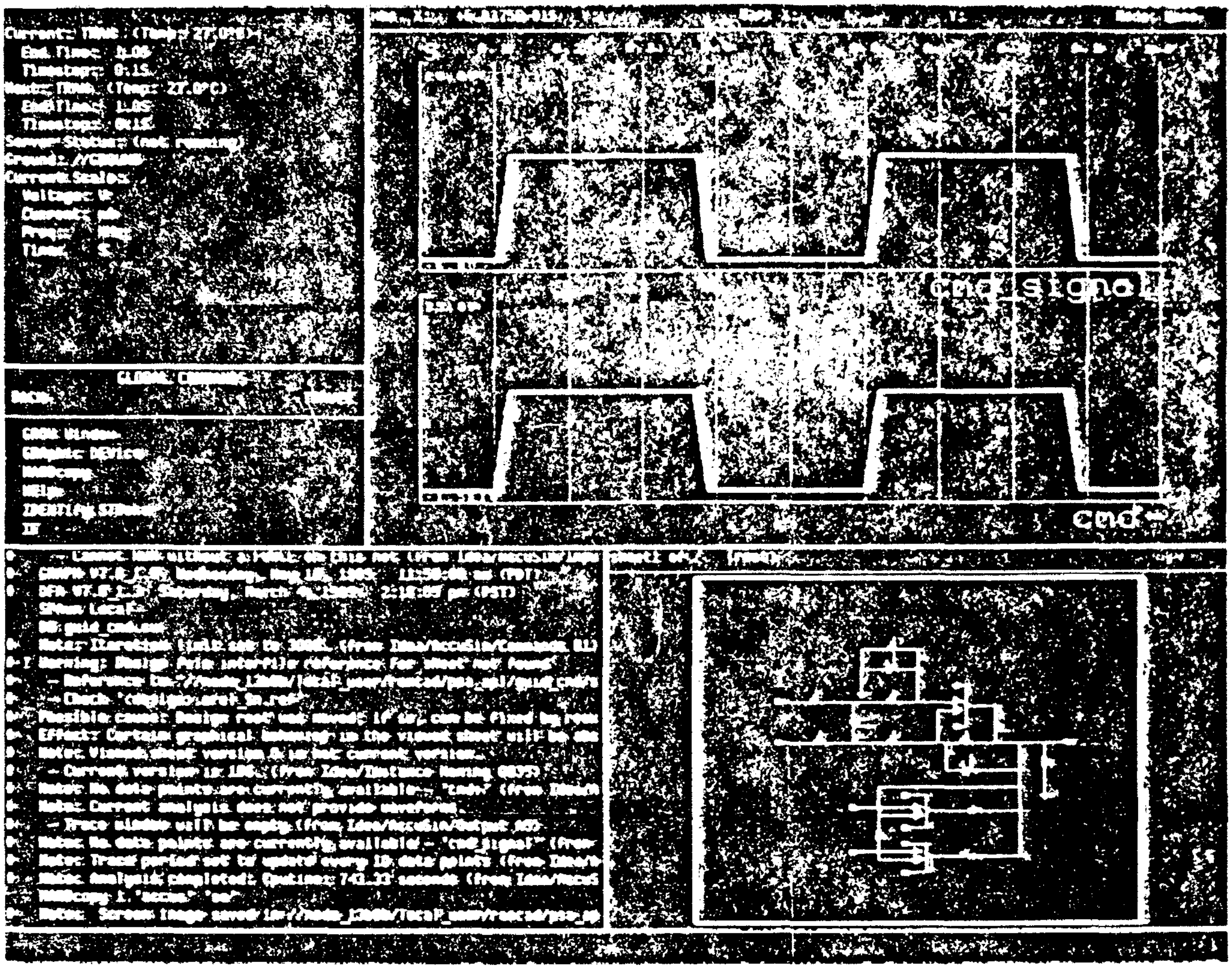

Figure 9. Accurate Simulation Analysis.

The designer may perform a reliability analysis under the RMS&S menu of the GUI. Input data is formatted and submitted to RELEX [illegible] on the [illegible] of the Mentor Graphics workstation. RELEX PLUS computes the MTBF for each PCB and the assembly. The reliability results with the MTBF requirement for the design can be displayed using the [illegible] Query Menu. The designer can review these results to determine whether the proposed design meets or exceeds requirements (Figure 11). Should the proposed design not meet requirements, the design is changed (e.g., through component relocation to reduce thermal stress or substitution of more [illegible] or higher quality parts) and electrical and thermal stress analyses are reiterated. REL PLUS is rerun until the proposed design meets or exceeds requirements.

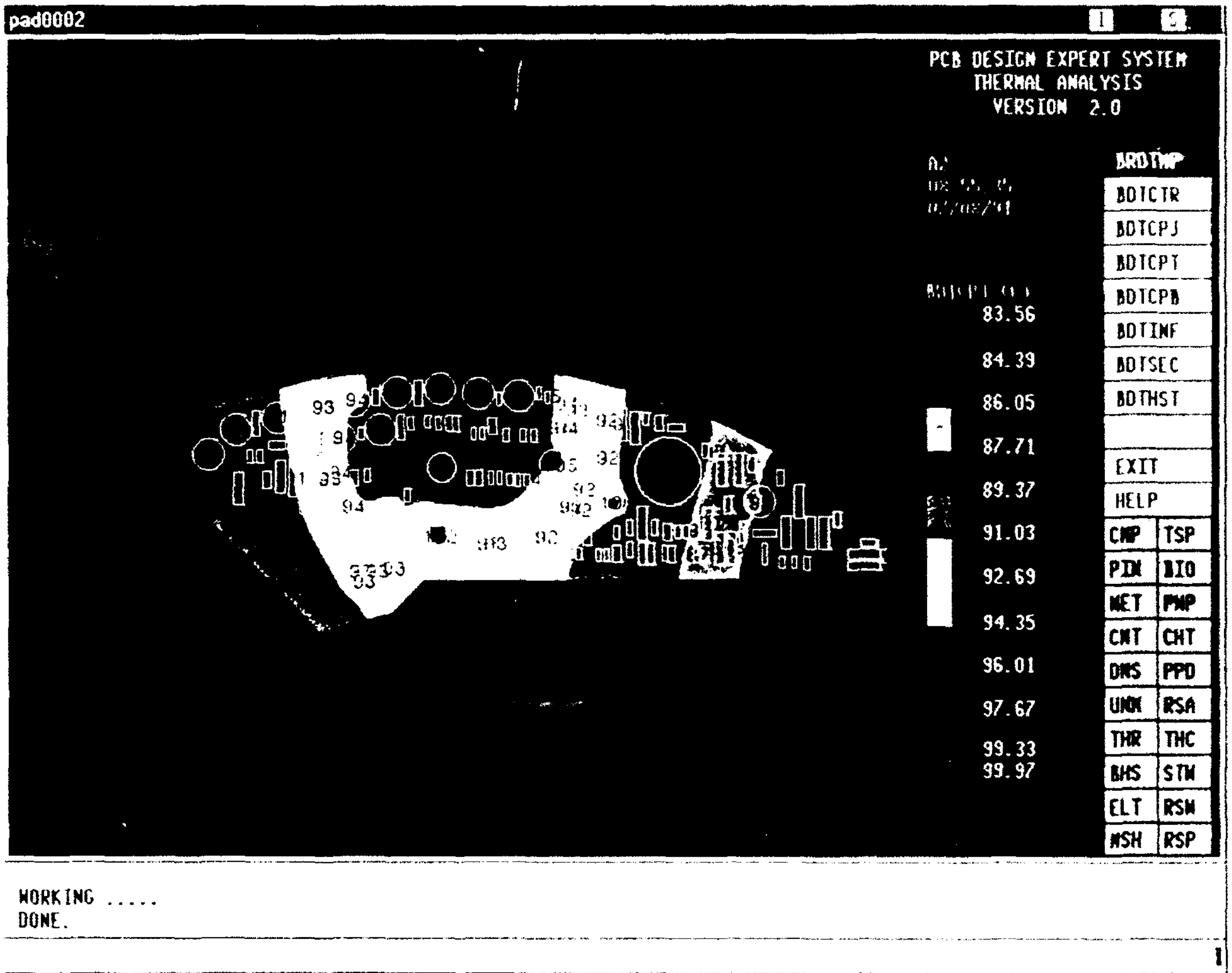

Figure 10. Printed Circuit Board Thermal Analysis. PCB thermal analysis provides board layout capability and identifies regions of thermal stress.

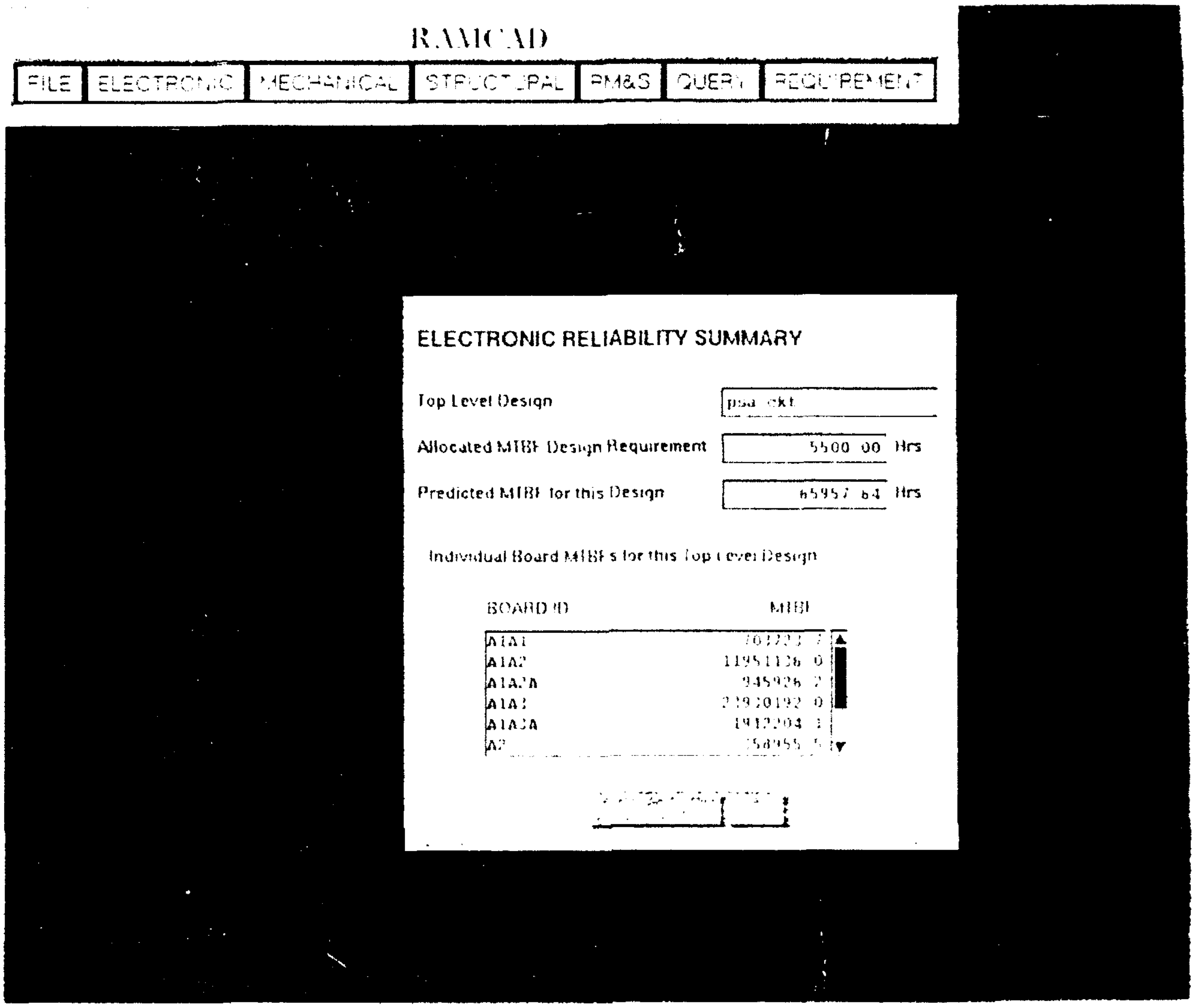

Figure 11. Failure Rates. Failure rates are predicted for each circuit board and the top-level design, then compared to the required failure rate.

Repair tasks are identified and input to the Maintainability Prediction Program (MPP). Repair times and REL PLUS failure rates are input to the MPP, and an equipment MTTR is determined. This MTTR is compared to the MTTR requirement (Figure 12). The MTTR and failure rates are input to the supportability analysis package--Network Repair Level Analysis (NRLA)--to determine the optimum maintenance location or if the item is designed for discard at failure (Figure 13).

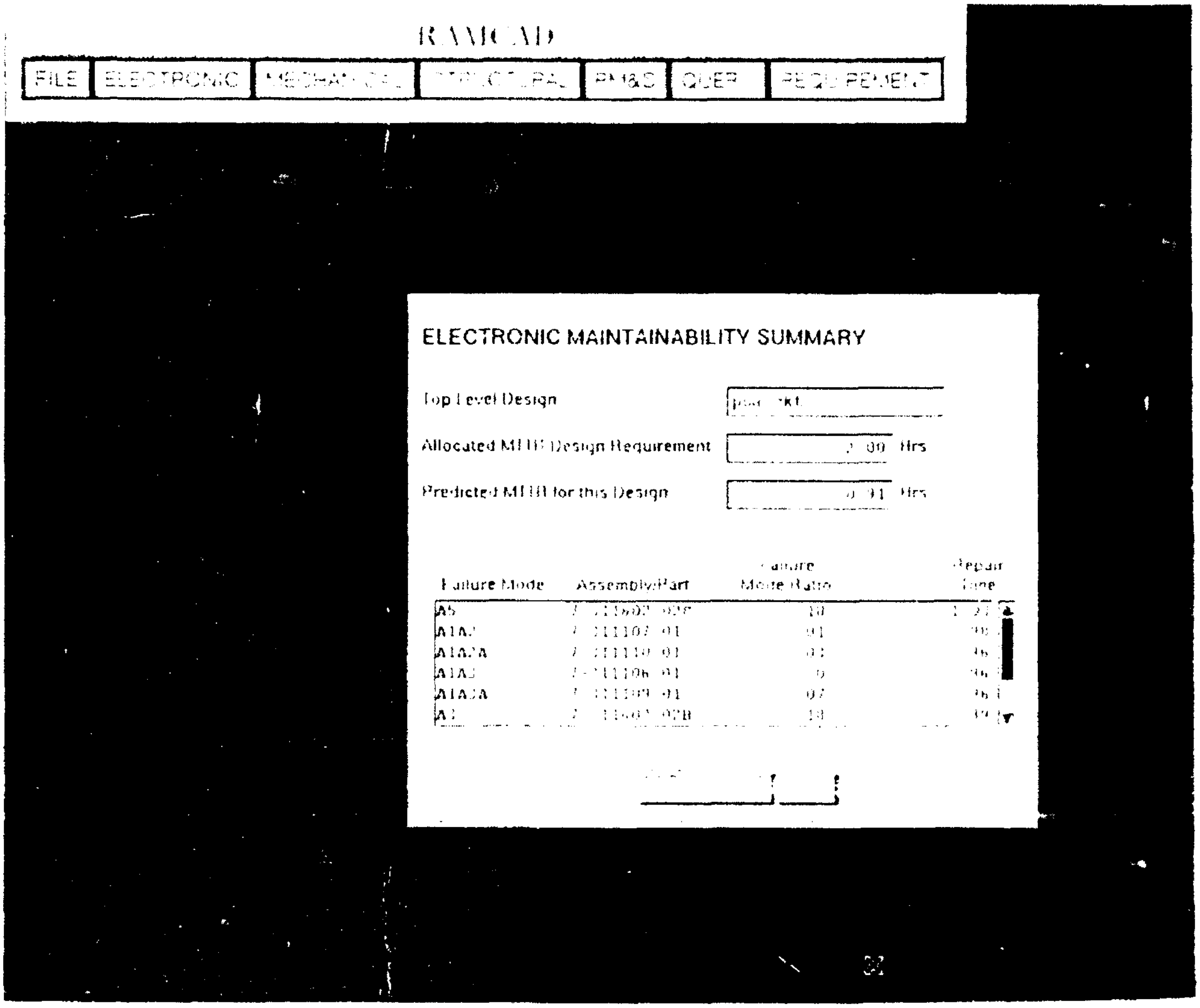

Figure 12. Maintainability Menu. Component repair times and an assembly MTTR are displayed through the maintainability menu.

Mechanical Workstation

The designer selects or designates a design name for the mechanical subsystem or assembly to be developed through the File Menu of the CUI (Figure 14). He or she then selects the Mechanical Advantage CAD software package on which to perform initial subsystem layout or component design through the Mechanical Menu.

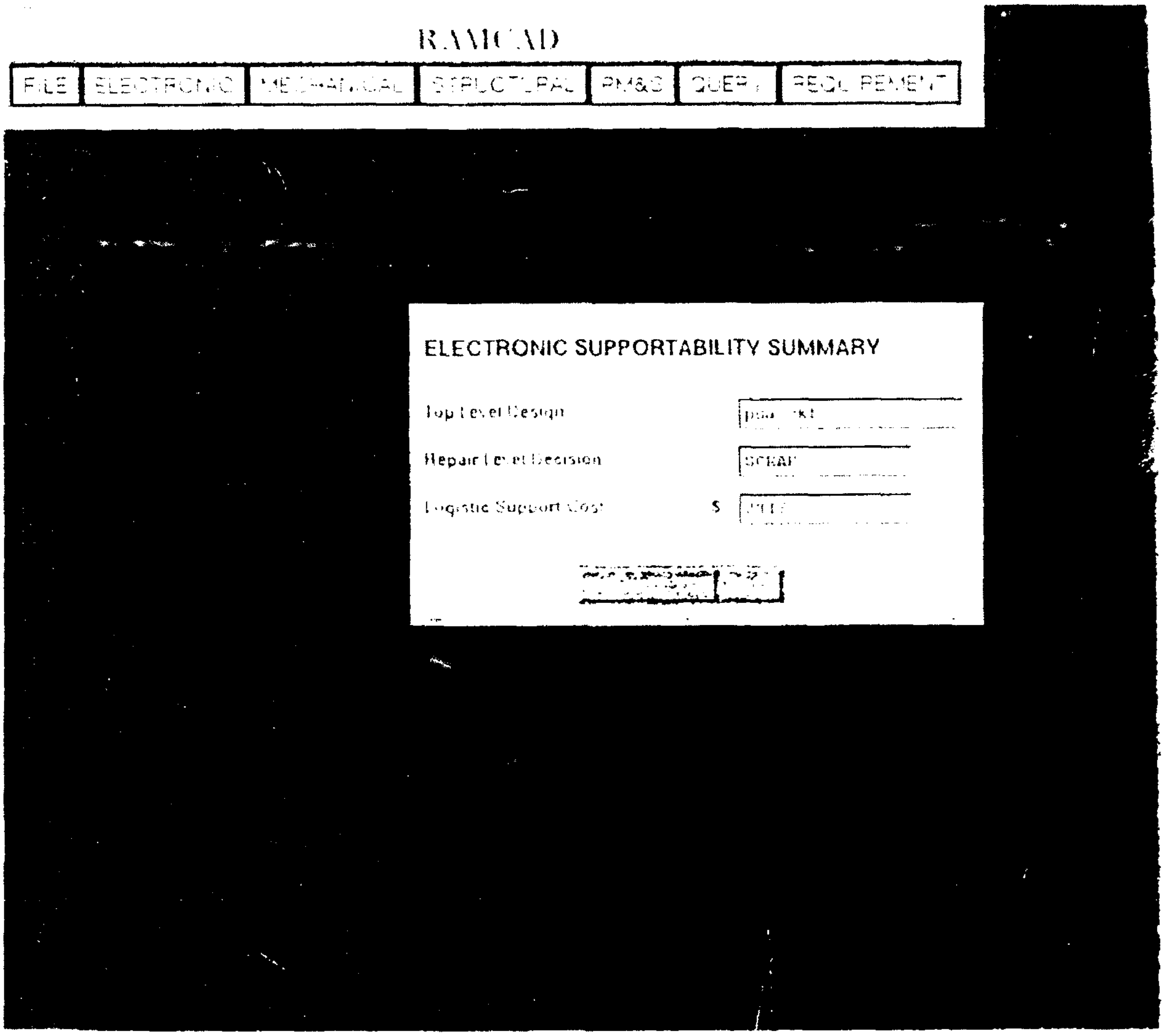

Figure 13 Supportability Menu. An optimum level of repair is displayed through the Supportability Menu.

The Sketch Note capability of the Cognition Mechanical Advantage software package provides the capability to do initial two-dimensional layouts (Figure 15). The preliminary design is then analyzed for performance and mass properties characteristics and component stress using Mathsolve. This software applies standard engineering handbook equations to the component geometry. As the design is modified those parameter values in the engineering formulas which are impacted by geometry changes are updated respectively. When the design is complete, the designer executes a "save results" command to save the design attributes to the RAMCAD database (Figure 16).

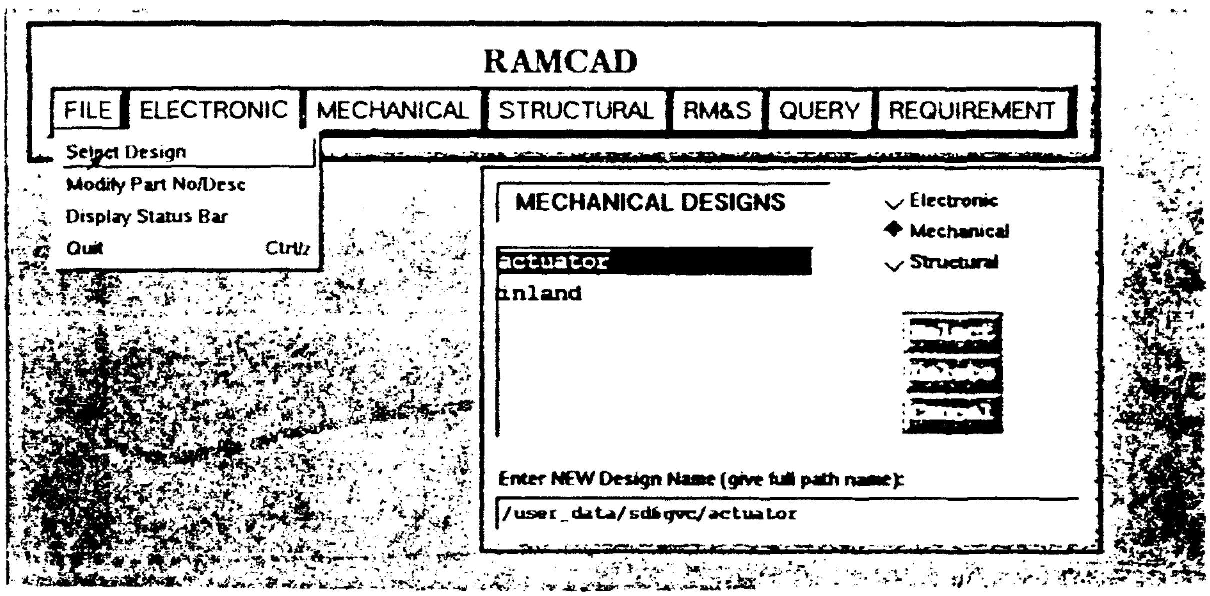

Figure 14. Mechanical Design Menu. Before performing mechanical design and analysis, the user must select an existing design file or create a new one.

The designer may then select the Reliability option under the RM&S menu. Execution of this option prompts the database to format design and analysis data for input to the Mechanical Reliability Prediction Program (MRP) through its batch interface--the Mechanical Data Interchange Program (MDP)--to determine an equipment failure rate. Mechanical stress factors are calculated using algorithms from the Mechanical Reliability Handbook developed for DoD by Scientific Management Associates, Inc., and the David Taylor Research Center. MRP applies these factors to base failure rates contained in the handbook.

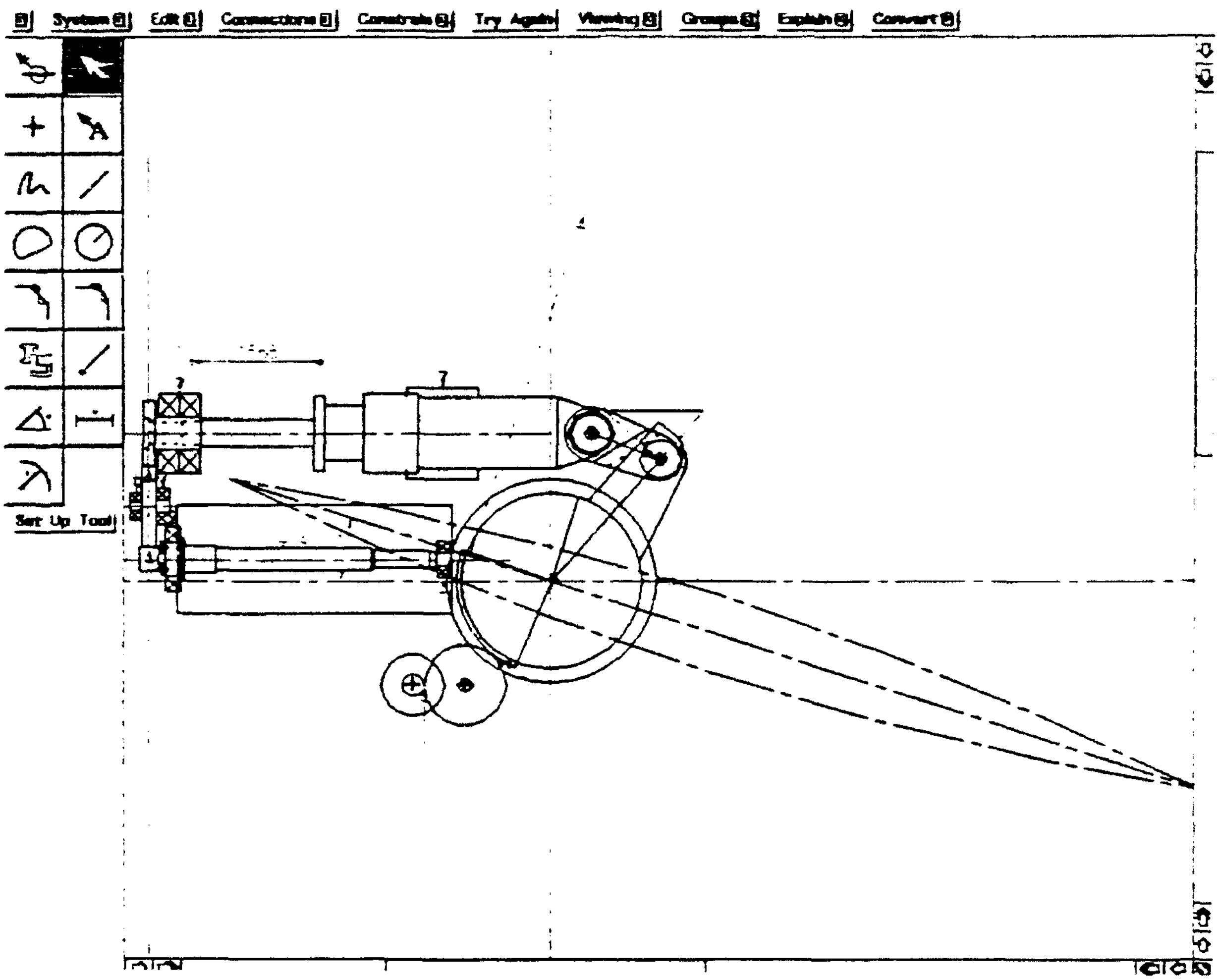

Figure 15. Mechanical Advantage Sketch Note. The Mechanical Advantage Sketch Note provides a capability for initial design layout and analysis.

Mechanical failure rates from MRP and component replacement and repair times are input to MPP to determine MTTR. Supportability analysis is conducted using NRLA as described for electrical subsystem design.

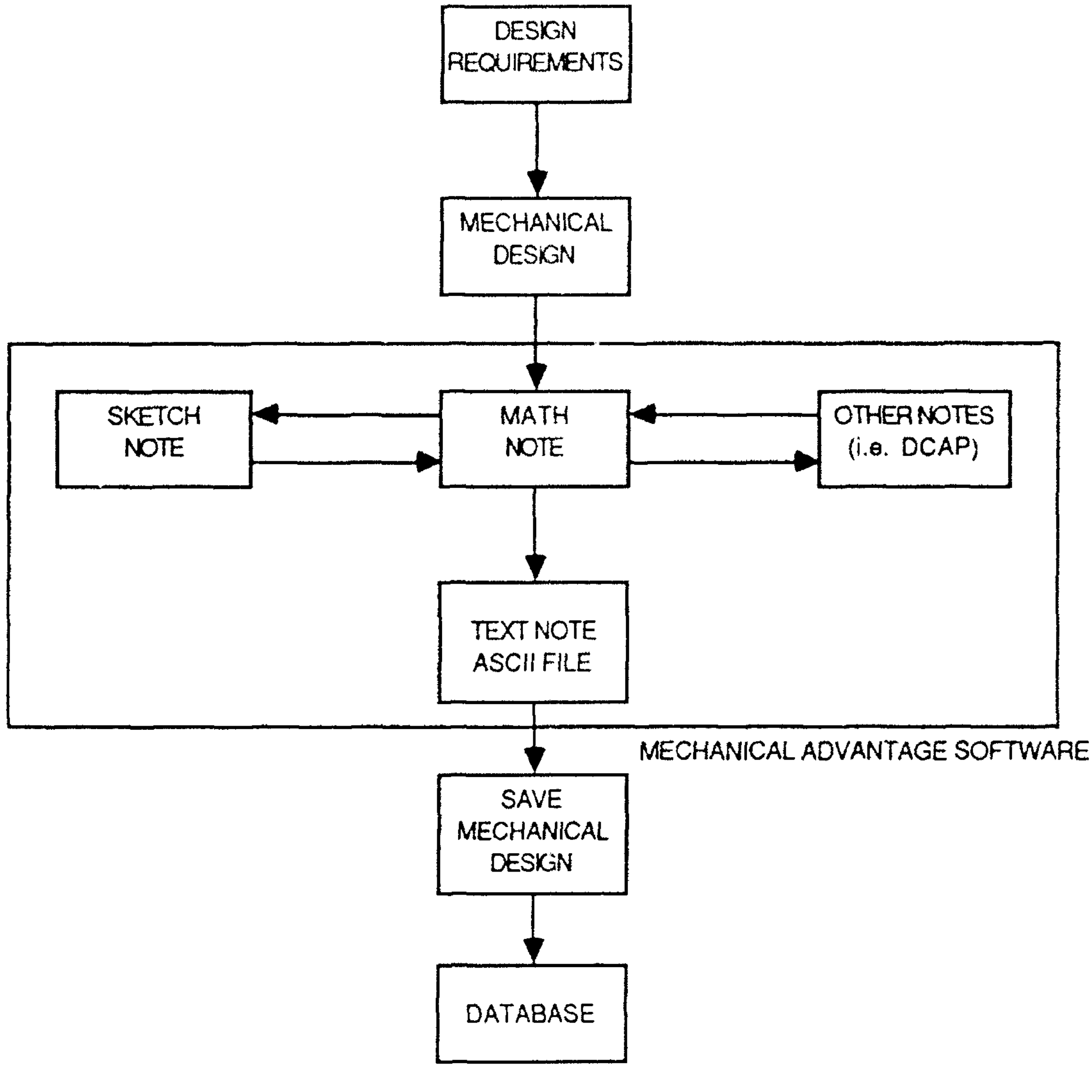

Figure 16. Mechanical Advantage Sketch Note and Mathsolve. They are used to create a design and solve for part attributes that are used to calculate part and assembly failure rates.

Structural Workstation

The designer selects or designates a design name for the structural assembly or component to be developed through the File Menu of the CUI. He or she then selects the structural CAD/CAE package, SDRC I-DEAS (consisting of Geomod, Supertab, Model Solution, and Systan) through the Structural Menu (Figure 17) of theRAMCAD user interface. A solid model of the structural component is created using Geomod (Figure 18).

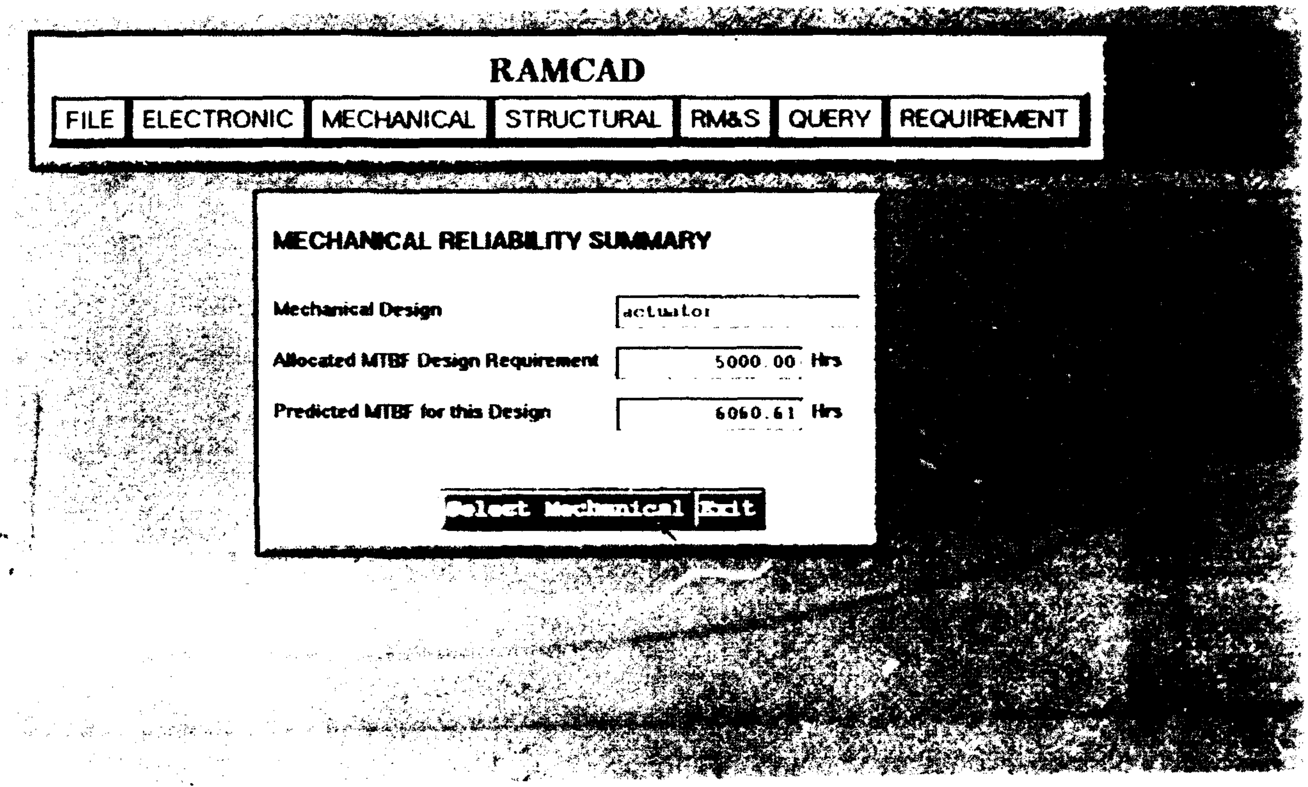

Figure 17. Failure Rates. Failure rates are displayed for components and the top level design against the required failure rate.

A finite element mesh is generated onto the solid representation and boundary conditions (load, support) are defined by using the preprocessor capabilities of Supertab (Figure 19). The Supertab enhanced representation is processed (solved) by Model Solution. The results (e.g., strain distributions) are displayed by using the postprocessor capabilities of Supertab (Figure 20). If the engineering model comprises of more than one constituent part, it can be assembled and dynamically enhanced by using Systan.

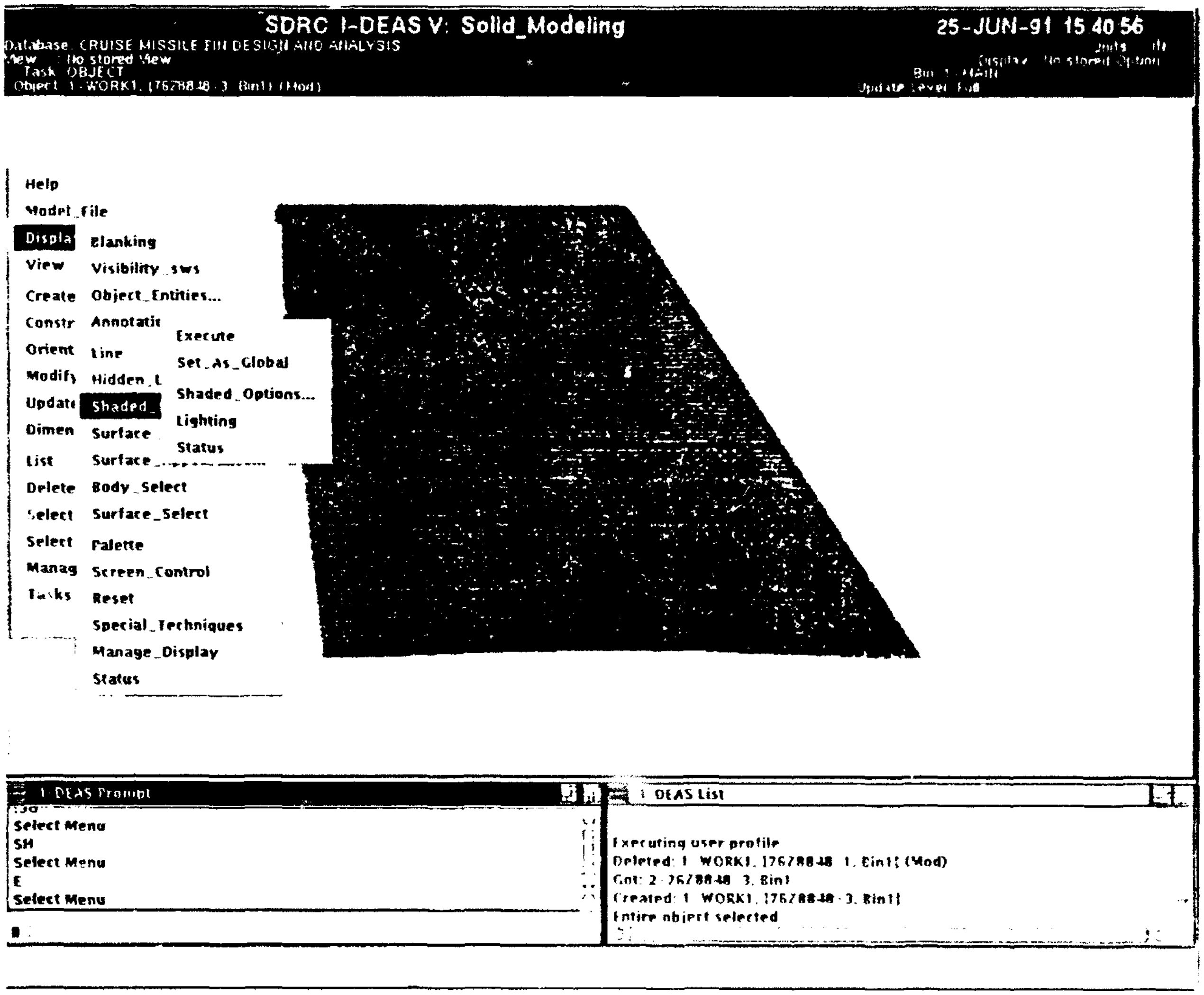

Figure 18. Solid Model. A solid model of the structural component is created using Geomod.

Output data from the CAD/CAE module (such as strain distributions) are passed to the Test Data Analysis System (TDAS) structural reliability analysis module (Figure 21). The data are then represented as a histogram (such as cycles versus strain ranges) and merged with data from the TDAS material characterization library (such as fatigue cyclic properties) via a failure criterion from the TDAS life criterion selection file. The result is the life of the component or assembly in hours or events. This information is passed back to the designer.

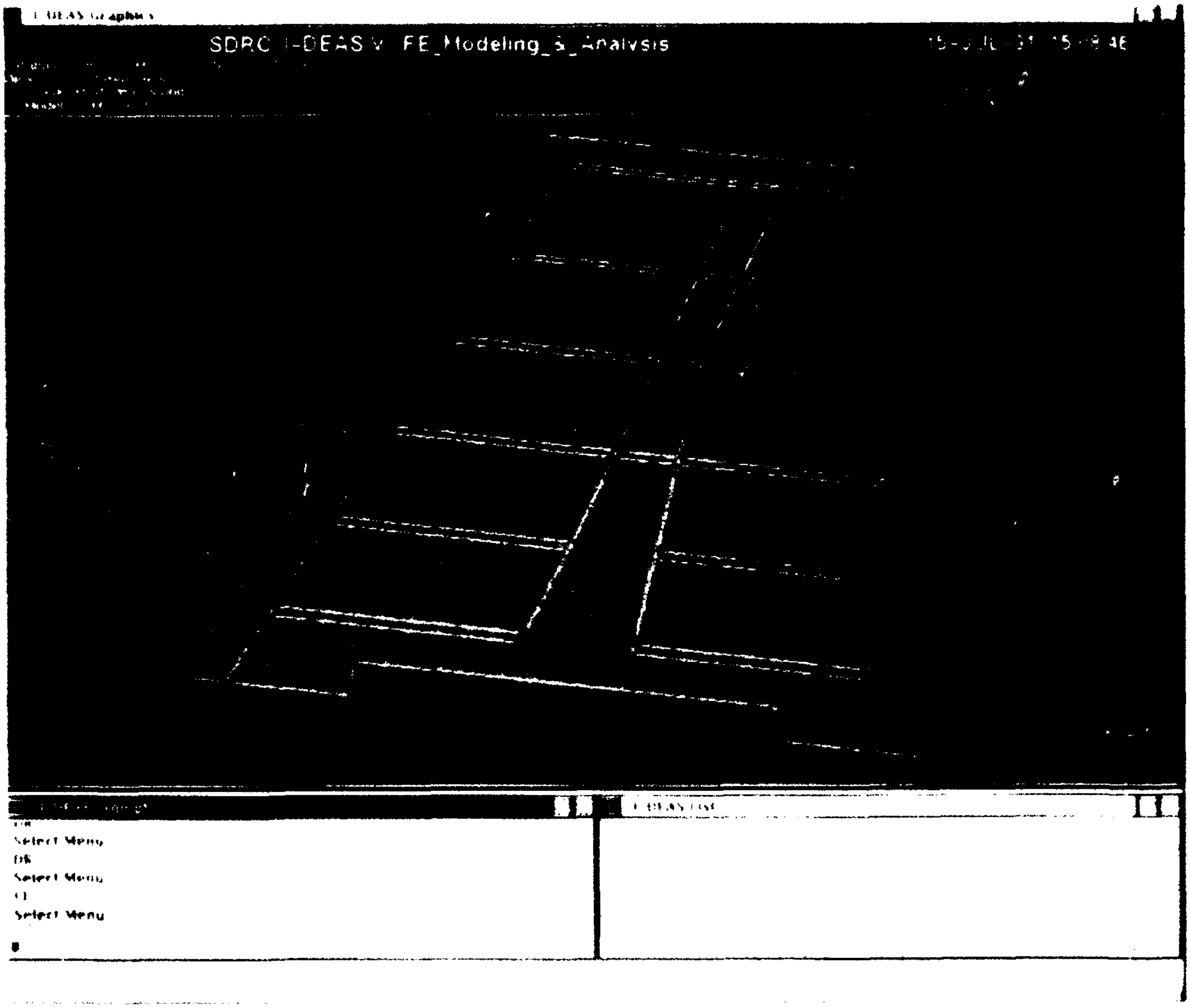

Figure 19. Finite-Element Model. A finite-element model is developed from the solid structural model using Supertab.

Structural component expected damage and maintenance demand rates from analysis of field data and component replacement and repair times are input to the MPP to determine MTTR. Supportability analysis is conducted using NRLA as described for electrical subsystem design.

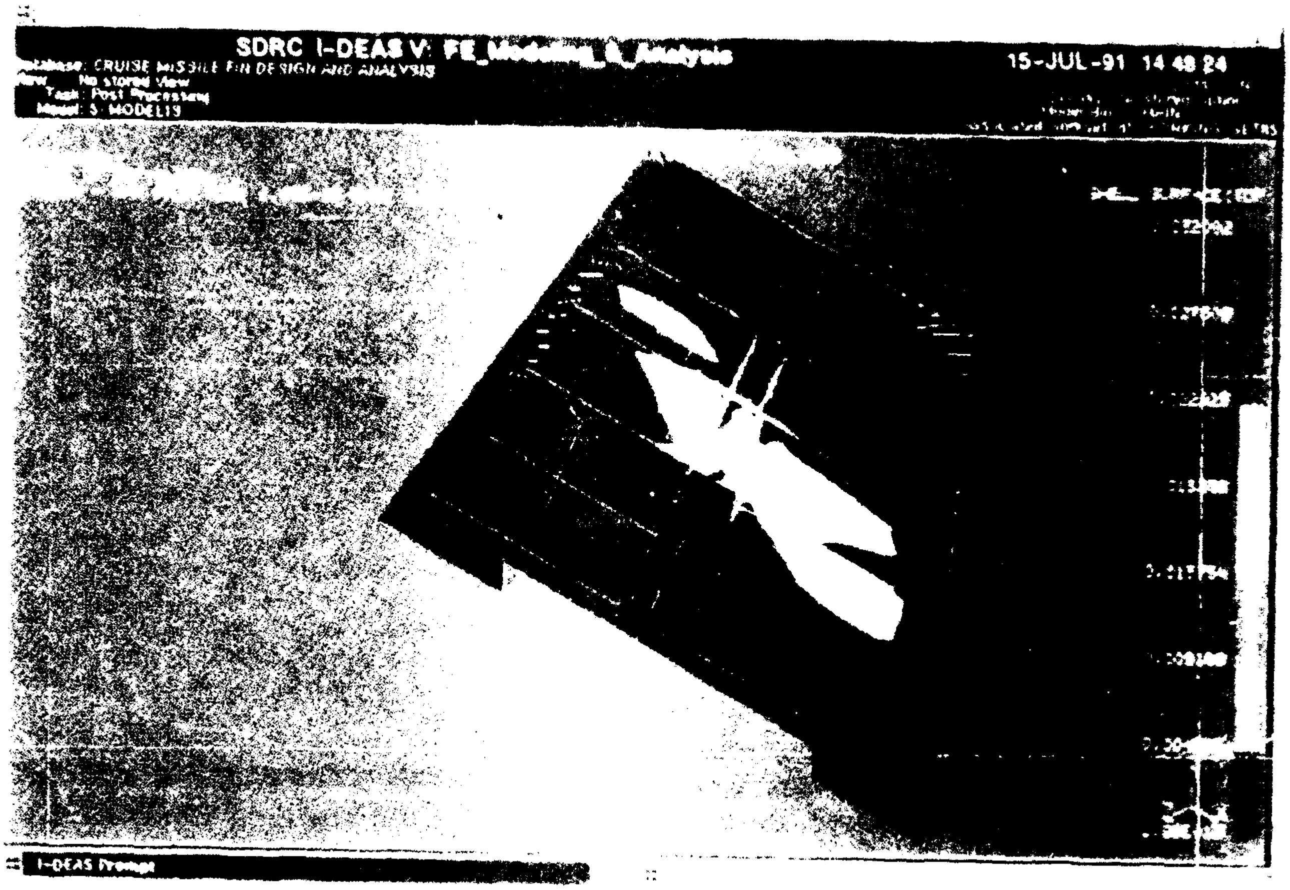

Figure 20. Stress Analysis Results. The results of stress analysis (e.g. strain distributions) are displayed by using the postprocessor capabilities of Supertab.

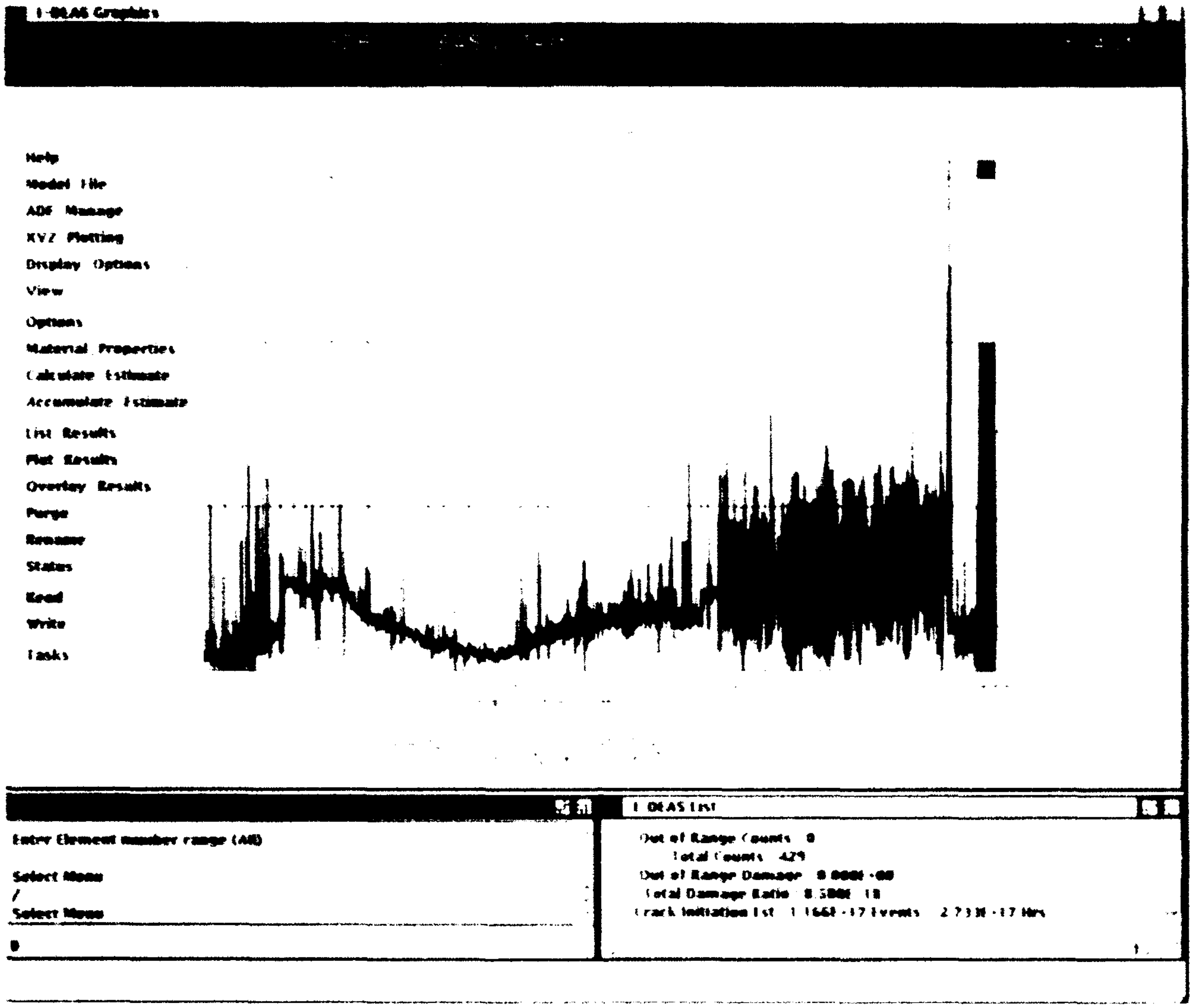

Figure 21. Structural Reliability Analysis Results. The result of structural reliability analysis is the life of the component or assembly in hours or events.

III. RAMCAD DEVELOPMENT

RAMCAD Requirements Analysis

To ensure the functionality and designer acceptance required for development and integration of a prototype RAMCAD system into the design process, target users were identified for early and continued involvement in system development. Design team personnel at various levels of engineering management were surveyed to identify key decision points, required information, and preferred user/system interface requirements necessary to develop an analysis tool adapted to the needs of the design process.

Additionally, surveys were conducted to assess the state of the art and growth potential for RM&S and CAD/CAE software. These surveys identified those packages best-suited for development and capture of design attributes that influence RM&S, and for performance and integration of RM&S analysis.

The capabilities and growth potential of CAD workstations were also assessed to assure hosting and interconnection of the RAMCAD prototype on platforms that would keep pace with the evolution of RAMCAD software. This would ensure development of a RAMCAD prototype that would keep pace with the evolution of concurrent engineering; total quality management; integrated product development; and computer-aided logistics acquisition and support concepts, methodologies, and processes.

Design Process Analysis and Simulation

Analysis and simulation of the design process was a key task in identifying data requirements and interfaces, and user interface requirements for the RAMCAD system. By investigating the basic tasks performed by various engineering disciplines involved in hardware design and segregating their activities in terms of competing design attributes, GD determined the interrelationships between RM&S and other design requirements. GD was also able to assess the degree of automation of various activities for electronic, mechanical, and structural design, and identify those activities for which automation would provide the greatest benefit.

Design engineers were surveyed to determine their assessment of the relative importance of design attributes and characteristics to the overall design. Engineers were selected for the survey based on their abilities as designers rather than their knowledge of RM&S or computer experience. Surveys were conducted with 29 electronics design engineers from seven avionics departments, 40 mechanical design engineers from seven departments, and 18 structural design engineers from four departments.

The basic design tasks and activities performed by individual designers were determined. Interactions between design groups were identified and documented as data flow diagrams. These diagrams identified existing media for exchange of data and sources, types, and users of the data. The flow diagrams were beneficial in developing data input and flow requirements for the RAMCAD prototype.

RM&S standards and practices for the electronic, mechanical, and structural design processes were also evaluated to determine CAD/CAE data that must be "captured" by RAMCAD to provide inputs to RM&S analyses. During the course of this evaluation, differences in the methodologies and figures of merit for the design disciplines were identified, as discussed for each of the design areas.

Electronic Design. The electronics design process is shown in Figure 22. Designers surveyed from the avionics departments had an average of 15.2 years of experience in electronics design. Thirty eight percent of the engineers were workstation literate;

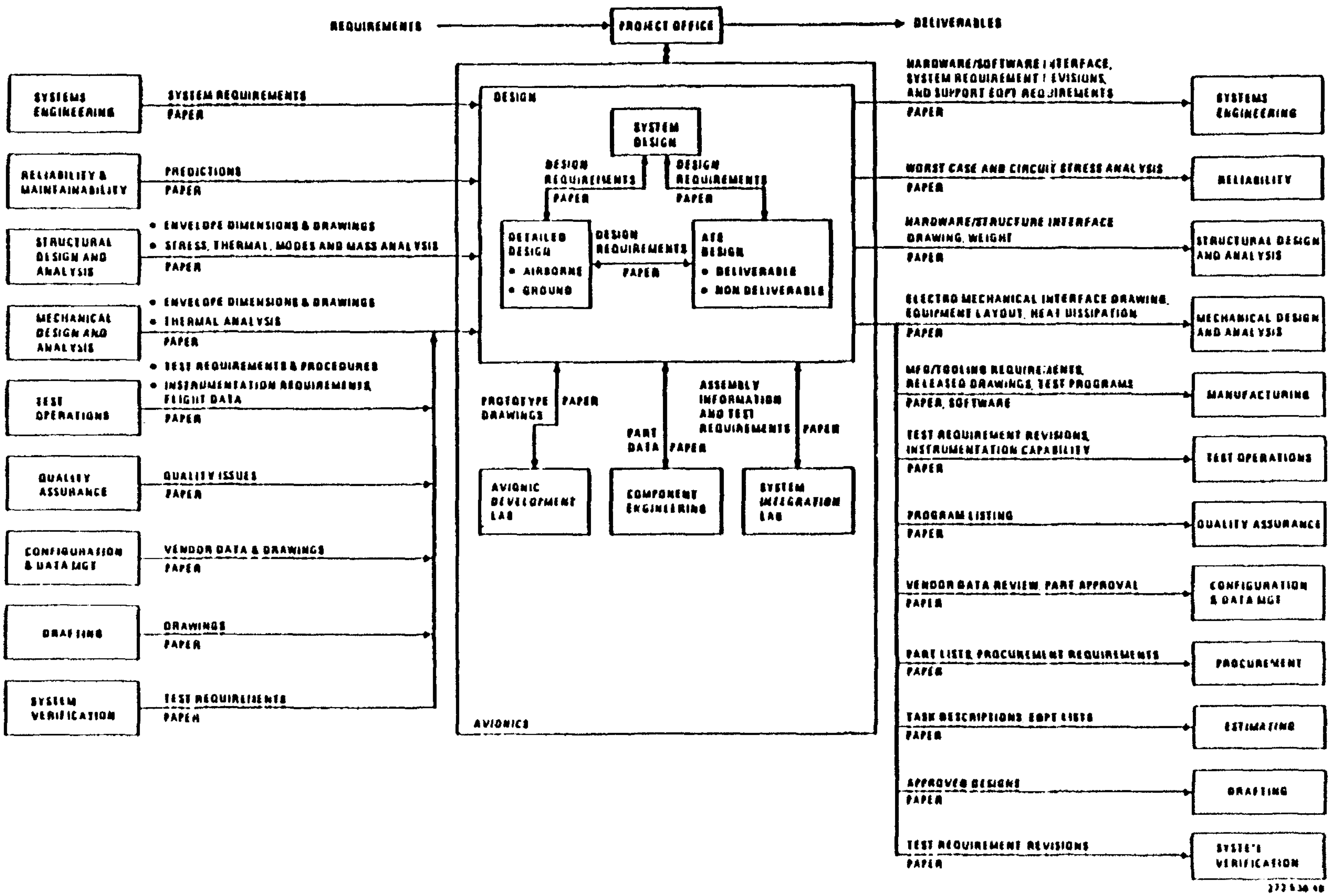

Figure 22. Electronics Design Process.

additional 14 percent were personal computer (PC) literate. Apollo-hosted Mentor Graphics electronics design software was the electronic CAD system in use, as identified in our RAMCAD proposal.

In assessing the relative importance of competing design requirements, reliability was ranked immediately behind performance and ahead of cost, schedule, maintainability, and supportability. The perceived lesser importance of maintainability and supportability is not surprising. The avionics groups develop electronics systems for cruise missiles with three- to five-year ready storage requirements between scheduled maintenance periods, and all maintenance or repair (other than built in test (BIT)) are performed at the depot level.

Electronic designers ranked heat dissipation, unit temperature, and parts availability in the top five most important attributes. These attributes all contribute directly to reliability and supportability. Although the engineers do not directly use MTBF as a design metric, a great deal of attention is focused on temperature and thermal stress reduction which contribute directly to increased MTBF. Any RAMCAD process for incorporating reliability modeling into early design analysis would have to include thermal modeling and analysis to gain acceptance from the designers. For this reason, and to be consistent with NAVSO P-6071 "Best Practices" for electronic design, a decision was made to include board layout and thermal modeling software in the electronic CAE software. This would ensure input of individual part temperature and thermal data to the reliability analysis rather than a single default temperature or average unit temperature.

Reliability modeling and prediction were contractually required to comply with the parts stress analysis and parts count methods of Military Handbook 217D/E (MIL-HDBK-217D/E). This, in turn, requires incorporation of an electronic reliability software package which meets the requirements of MIL-HDBK-217D/E. There is growing interest in developing reliability predictions for electronics systems by analyzing the physics of individual component and assembly failures due to thermal stress, shock, and vibration. However, the field is not mature enough with sufficient data on electronic components to be implemented .

Maintainability prediction for electronic components, using MTTR as the key parameter, is the primary maintainability task recognized by electronics designers. The principal design attributes of concern to the various design groups are fault isolation strategy and allocation of fault detection to BIT or automated test equipment. Maintainability analysis software as part of an acceptable RAMCAD architecture would have to meet the maintainability prediction requirements of Military Standard 470A (MIL-STD-470A). It should be capable of accepting automated failure rate inputs from the reliability analysis to minimize manual data entry.

In conjunction with the maintainability analysis, the supportability concerns which most influence electronic component design is the repair concept. Units that have a high MTBF and that may be discarded at failure can be designed for hermetic sealing, conformal coatings, limited access panels, and test points. This would reduce design complexity and contribute to high reliability. An assembly planned for test and repair should have test points, access requirements, and modularity requirements identified early in the development of the packaging design. Therefore, repair level analysis was considered to be a beneficial capability for a RAMCAD system.

Additional identified capabilities that were manually intensive but important to electronics design with a high payoff if incorporated in RAMCAD were parts standardization and parts derating analysis.

Mechanical Design. The mechanical design process is shown in Figure 23. Designers surveyed from the mechanical design

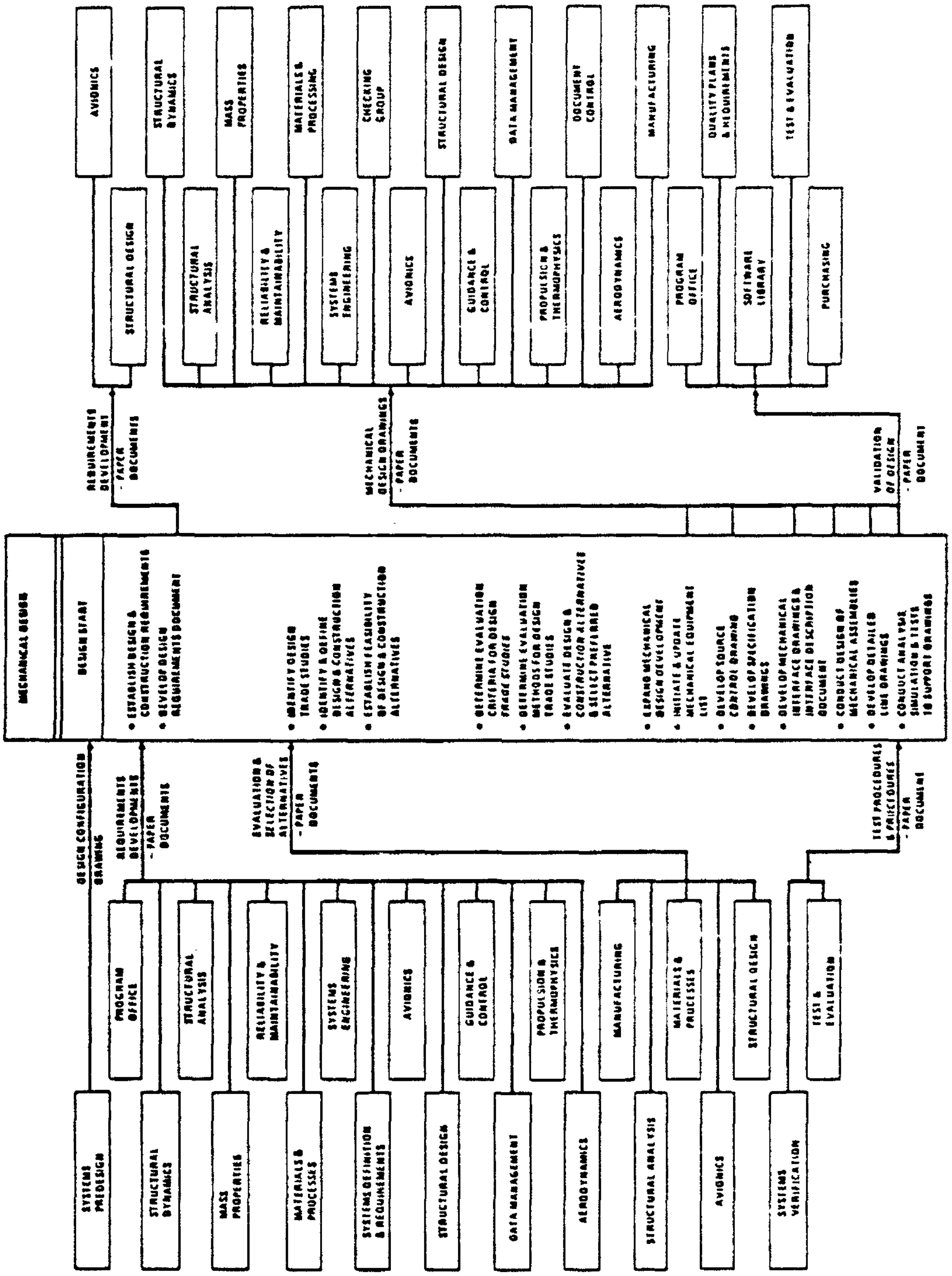

Figure 23. Mechanical Design Process. Information is input from the left analyses, conducted, and results are output to the right.

departments had an average of 15.7 years of experience in mechanical design. Fifty percent of the engineers were workstation or mainframe literate; an additional 29 percent were PC-literate. Those with design workstation experience had some familiarity with the development of three-dimensional computer models of proposed designs. However, most preliminary layouts, even if only in the designer's notebook, are done in two dimensions as a three-view drawing. Three-dimensional models are primarily used for visualization, space allocation, and engineering analysis rather than original design.

In assessing the relative importance of competing design requirements, reliability was ranked immediately behind performance and ahead of cost, schedule, maintainability, and supportability. The perceived lesser importance of maintainability and supportability occurred because the mechanical designers are not directly involved in maintainability and supportability analyses. These analyses are performed by maintainability and logistics engineers.

Although reliability ranked very highly, the mechanical designers' concept of mechanical reliability is not in terms of an MTBF or failure rate. Rather, it is measured by whether the design is overstressed during operation, thereby resulting in failure. In contrast to the well-defined and accepted methods for predicting electronic reliability, an equivalent method for predicting mechanical reliability was not available. Factors which contribute to the difficulty of determining mechanical failure rates include the wide dispersion of failure-rate data in the Non-Electronic Reliability Notebook, the multiplicity of functions performed by single mechanical components, and failure mechanisms caused by wear and fatigue rather than the constant failure rates assumed for electronic components. Additionally, mechanical reliability is more sensitive than electronic reliability to equipment loading, operating mode, and utilization rate. Failure predictions based on operating time alone may be inadequate for mechanical equipment.

The primary source of information for developing mechanical reliability predictions was the Handbook of Reliability Prediction Procedures for Mechanical Equipment being developed by Scientific Management Associates, Inc. Therefore, mechanical reliability prediction software in a RAMCAD system should incorporate the methods and algorithms being developed for the Handbook.

Maintainability prediction for mechanical components using MTTR as the key parameter is the primary maintainability task recognized by the designers. The principal design attributes of concern to the various design groups are the provisions for accessibility for removal and replacement, disassembly, and repair. Maintainability analysis software, as part of an acceptable RAMCAD architecture, would have to meet the maintainability prediction requirements of MIL-STD-470A. It must also be capable of accepting automated failure-rate inputs from the reliability analysis to minimize manual data entry.

In conjunction with the maintainability analysis, the supportability concern that most influences mechanical design is the repair concept. Units that have a high MTBF may be discarded at failure; thus they can be designed with limited access panels and test points, thereby reducing design complexity. An assembly planned for test and repair should have test points, access requirements, and modularity requirements identified early in the development of the packaging design. Therefore, repair level analysis is considered beneficial for a RAMCAD system.

Structural Design. The structural design process is shown in Figure 24. Designers surveyed from the structural design departments had an average of 22 years of experience in structural design. All the engineers were workstation-, mainframe-, or PC-literate in applications for mass properties analysis, stress analysis, or dynamic analysis.

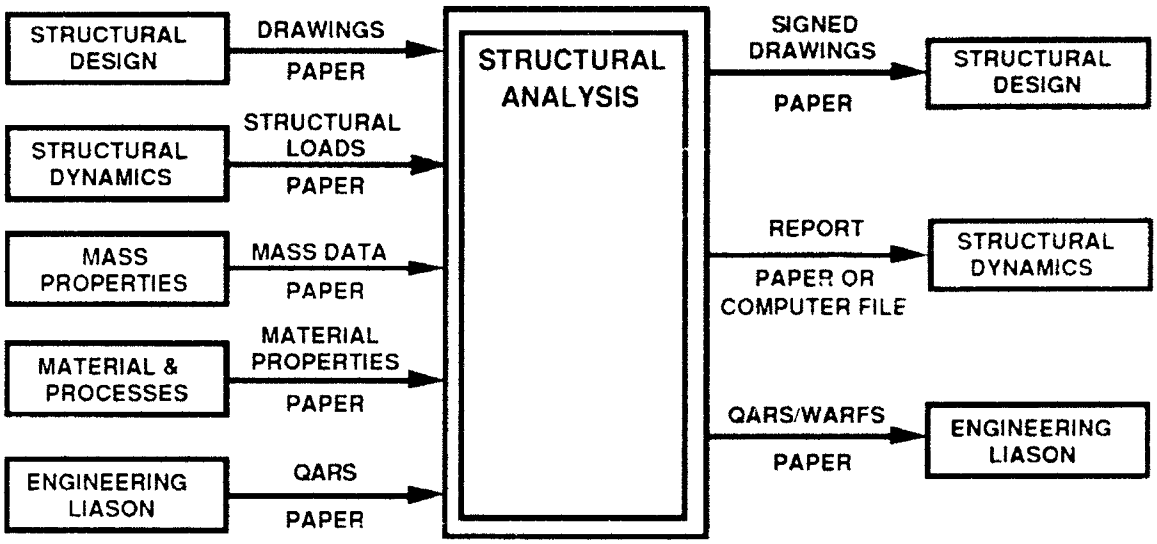

Figure 24. Structural Design Process.

In assessing the relative importance of competing design requirements, reliability ranked immediately behind performance and ahead of cost, schedule, maintainability, and supportability. Maintainability and supportability were perceived as less important because the mechanical designers are not directly involved in maintainability and supportability analyses. These analyses are performed by maintainability and logistics engineers. Additionally, structural components of cruise missile systems are generally designed to provide access for maintenance of mechanical or electronic equipment, not for maintenance of the structure itself.

Although reliability ranked very highly, the structural designers' concept of reliability is not in terms of an MTBF or failure rate. Rather, it is measured by whether the design is overstressed during operation, thereby resulting in structural failure. Structural components are typically assigned a reliability of "1.00" in the development of cruise missile system reliability predictions because they are designed for no failures within the mission envelope of the missile. Therefore, rather than failure rate, the significant measure of merit for structural reliability is a life estimate, or time until crack initiation under the expected loading conditions.

Maintainability prediction for structural components using MTTR as the key parameter is the primary maintainability task recognized by the designers. The principal design attributes of concern to the various design groups are the provisions for accessibility for removal and replacement, disassembly, and repair. However, these tasks are driven by the failure rates of the failed equipment being repaired and not by the life estimate for the structure. Maintenance tasks which would be driven by the structural life estimate would be analytical condition inspections and phased airframe inspections of systems with long operating lives as contrasted with expendable missile systems. Other structural maintenance tasks would be driven by damage rather than the structural life estimate. Maintainability analysis software, as part of an acceptable RAMCAD architecture, would have to meet the maintainability prediction requirements of MIL-STD-470A. Additionally, it should be capable of accepting a maintenance demand rate developed from the frequency of scheduled maintenance or from field data on the frequency of structural damage.

In conjunction with the maintainability analysis, the supportability concern that most influences structural design is the repair concept. Most missile structural components are designed to be discarded at failure. An assembly that is planned for repair should have disassembly requirements identified early in design development. Therefore, repair level analysis is considered beneficial for a RAMCAD system.

Software Survey

An industry-wide survey of software houses and DoD agencies that offer RM&S software to the public was conducted to identify those candidates for incorporation in the RAMCAD system. A total of 74 software packages (48 RM&S packages and 16 CAD/CAE packages) were evaluated and catalogued in the RAMCAD Software Survey, GDC-RAMCAD-88-001, and in a DBIII digital database. Twelve additional packages were subsequently added to the RAMCAD software database.

Candidate packages were evaluated and cataloged based on the following criteria: (1) ability to fulfill the RM&S engineering design requirements; (2) integratable into the CAD/CAE process; (3) user-friendly to the design engineer (who may not be fully knowledgeable of RM&S engineering analysis); and (4) allow for an evolving model design--from conceptual design to preliminary and detailed designs. Selection of those packages for incorporation into the RAMCAD system is discussed in RAMCAD System Development.

Based on the design process analysis and simulation, it was determined that a RAMCAD system providing a high level of user acceptance must provide a "single-seat" operation for the user, provide access to CAD/CAE and RM&S packages through a single-user interface, access and save data to a shared database, and eliminate multiple input of the same data to different design or analysis programs. This would require a "smart interface" with CAD and analysis packages, translators for extracting and reformatting design and analysis data as required for each analysis package, and a relational database management system. CAD software would have to meet requirements for original design and/or import of existing digital design data through graphics translators and existing CAD networks. Design figures of merit to be provided to the designer through RAMCAD analysis would be MTBF for electronic and design, a structural life estimate for reliability analysis, MTTR for maintainability analysis, and an optimum repair level for supportability analysis.

RAMCAD System Development.

To validate the applicability of the prototype RAMCAD system to a wide range of product lines, it would have to be exercised for designs of sufficient complexity in the electronic, mechanical. and structural design areas. However, an advanced prototype incorporating a manageable testbed was also determined necessary to verify the feasibility of the development approach, and to evaluate and demonstrate the connectivity achievable between diverse computer platforms and operating systems.

In addition to using an advanced prototype in the development approach, software functionality was phased into two builds to reduce development risk. Build One, following a successful demonstration of the advanced prototype and Government approval of the preliminary RAMCAD system design, would provide connectivity between electronic, mechanical, and structural design and reliability analysis. Build Two would provide maintainability and supportability analysis connectivity.

This phased approach to software development and integration proved to be effective for RAMCAD prototype development. It provided an opportunity to assess the feasibility of design concepts and obtain user and Government feedback from demonstration of the advanced prototype and subsequent builds. It also provided an opportunity to take advantage of advances in development of computer platforms, operating systems, and commercial software. Table 1 illustrates the evolution of the RAMCAD system from advanced prototype through the final prototype system. The remainder of this section will address the major design areas for the RAMCAD system and their development.

Table 1. Evolution of RAMCAD

Feature	Advanced Prototype	Prototype System
Electronic Workstation (W/S)	Apollo DN 580 with SR 9.7 Operating System	Mentor Graphics DN4500 Ideas Station with SR 10 Operating System
Electronic CAD S/W	Mentor Graphics 6.0	Mentor Graphics 7.0
Electronic CAE S/W	MSPICE Plus PCB Thermal	ACCUSIM PCB Thermal APL
Reliability S/W	REL PLUS on an IBM PC	REL PLUS on a coprocessor on the Electronic W/S
CUI	Apollo Domain Dialog	X Windows/Motif 2.0
Database Management S/W	Informix	ORACLE
Electronic Derating S/W	None	DEREX/CLIPS
Electronic Testbed	Tomahawk Cruise Missile Power Supply--2 PCBs, 129 components of seven types	Tomahawk Cruise Missile Power Switching Amplifier--seven PCBs, 600 components

Feature	Mechanical/Structural Preliminary Design Review (PDR)	Prototype System
Mechanical W/S	VAXstation 2000, UNIX 2.0	VAXstation 2000, UNIX 3.0; DECstation 3100, RISC Ultrix
Mechanical CAD S/W	Cognition Mechanical Advantage 2.2	Cognition Mechanical Advantage 3.0
Mechanical CAE S/W	Cognition Mechanical Advantage 2.2 Mathsolve	Cognition Mechanical Advantage 3.0 Mathsolve
Mechanical Reliability S/W	Eagle Technology's MECHREL on an IBM PC	Powertronics MRP/MDP with DOS Emulation on Mechanical W/S
Structural W/S	VAXstation 3500, VMS	VAXstation 3500, VMS
Structural CAD S/W	SDRC I-DEAS 4.0 (GEOMOD)	SDRC I-DEAS 5.0 (GEOMOD)
Structural CAE S/W	SDRC I-DEAS 4.0 (SUPERTAB, SYSTAN)	SDRC I-DEAS 5.0 (SUPERTAB, SYSTAN)
Structural Reliability S/W	SDRC I-DEAS 4.0 (TDAS)	SDRC I-DEAS 5.0 (TDAS)

Feature	RAMCAD PDR (All Workstations)	Prototype System
Maintain-ability S/W	Powertronics MPP on an IBM PC	Powertronics MPP on a DOS Coprocessor or DOS Emulation at W/S (SoftPC)
Support-ability S/W	NRLA on an IBM PC	NRLA on a DOS Coprocessor or DOS Emulation at W/S (SoftPC)
CUI	Xwindows	Xwindows/Motif 2.0
DBMS	Informix	ORACLE
Queries	SQL Forms	Motif/SQL Forms (Ad hoc)
Queries	SQL Forms	Motif/SQL Forms (Ad hoc)

Testbed Development

RAMCAD Program requirements dictated that the complexity of equipment design for each discipline (whether electronic, mechanical, or structural) be equivalent to that of an electronic device with a minimum of 25 components representing at least four component types.

Prototype System. Considerations for selection of an engineering testbed for the RAMCAD prototype system included the identification of a system/subsystem which contains each of the electrical, mechanical, and structural design areas to be addressed by RAMCAD. The selected testbed was required to allow RAMCAD to evaluate interaction between the electrical, mechanical, and structural components. A level of complexity was required to sufficiently exercise the capability of the RAMCAD prototype. However, this level must be within a scope which would make testbed development manageable and achievable for near-term exercise of RAMCAD software modules. Additionally, the availability of sufficient engineering data was required to provide representative and accurate input to the analysis packages. Therefore, the Tomahawk cruise missile (BGM-109) fin control system was selected as the engineering testbed for the RAMCAD prototype system.

The Tomahawk cruise missile fin control system is located in the missile tailcone. It consists of the following components:

- a power switching amplifier (PSA) which receives digital missile attitude control signals from the missile guidance control set and converts them to analog signals to the fin control actuators;

- three rotary electromechanical actuators with an output *shaft position feedback transducer* which provides fin position feedback to the PSA; and

- two horizontal fins and one vertical fin which control missile pitch and yaw and react to aerodynamic loads.

Requirements for the design of the fin control system are as follows.

The MTBF of the fin control system shall be as a minimum:

Amplifier	5500 hours
Actuator	5000 hours

The MTTR shall be as follows:

Amplifier	2.0 hours
Actuator	4.0 hours

The system shall require no preventative maintenance during its useful life.

Electrical Subsystem. The fin control system electrical subsystem consists of the PSA and connecting harnesses. The PSA consists of three major subassemblies: the shell, which contains two PCBs; the baseplate, containing four PCBs; and the EMI output assembly, which contains one PCB.

Mechanical Subsystem. The fin control system mechanical subsystem consists of the fin control actuator assembly. The actuator assembly consists of 21 mechanical components comprising eight major subassemblies: the motor, two spur gears and bearings, the energy absorbing shaft assembly, the bell crank assembly, the housing assembly, the antibacklash gear assembly, and the fin position feedback potentiometer assembly.

Structural Subsystem. The structural subsystem of the fin control system is the missile fin assembly. The fin structure is comprised of the following major elements: left and right skins, fold footing, and adhesive bondline.

Advanced Prototype. The advanced prototype engineering testbed is the cruise missile modular power supply (P/N 76Z8964-4). This testbed consists of two circuit boards comprised of 129 components of seven different types (resistors, capacitors, diodes, transistors, integrated circuits, inductors, and transformers) contained in a 2.5" x 4"x 6" enclosure. The power supply provides + 5 volts DC, +15 volts DC, and -15 volts DC to logic and relay circuits in the cruise missile avionics system. Design requirements for the power supply which were input to the advanced prototype requirements library are as follows.

The power supply shall have a maximum weight of two pounds. Useful life of the power supply shall be ten years. The power supply shall be designed for a MTBF of 21,409 hours (airborne, uninhabited environment).

Additional Mechanical Testbeds. In December of 1988, a contract modification authorized mechanical design and reliability analysis of a hydraulically operated travel lock for a self-propelled howitzer as an additional mechanical testbed.

In May of 1990, the Government issued a contract modification which authorized an additional testbed for mechanical design and reliability analysis. This testbed was an electrically operated travel lock assembly for the self-propelled howitzer.

Workstation Architecture

One of the greatest areas of change during the development of the RAMCAD prototype system was the workstation architecture. Table 1 indicates upgrades to the workstation operating systems and a change from a networked PC hosting RM&S software. However, the most significant changes occurred in transitioning from the initial RAMCAD concept to the preliminary design.

As shown in Figure 25, the initial concept for RAMCAD was an Apollo CAD workstation connected via a mainframe computer to a PC hosting the RM&S analysis software. The IBM mainframe would also host the database. The PC and mainframe were to be connected via an RS 232 bus. However, once the PC was networked with the workstation by Ethernet, using Transmission Control Protocol/Internet Protocol (TCP/IP), the IBM mainframe was deleted from the architecture.

During the design process simulation and software survey, it was determined that the lack of Apollo-hosted mechanical design software meeting RAMCAD requirements would require adding a second workstation to the architecture. A Hewlett Packard 350 SRX workstation was considered for mechanical design with an Apple Macintosh II as a possible addition as a predesign CAD workstation.

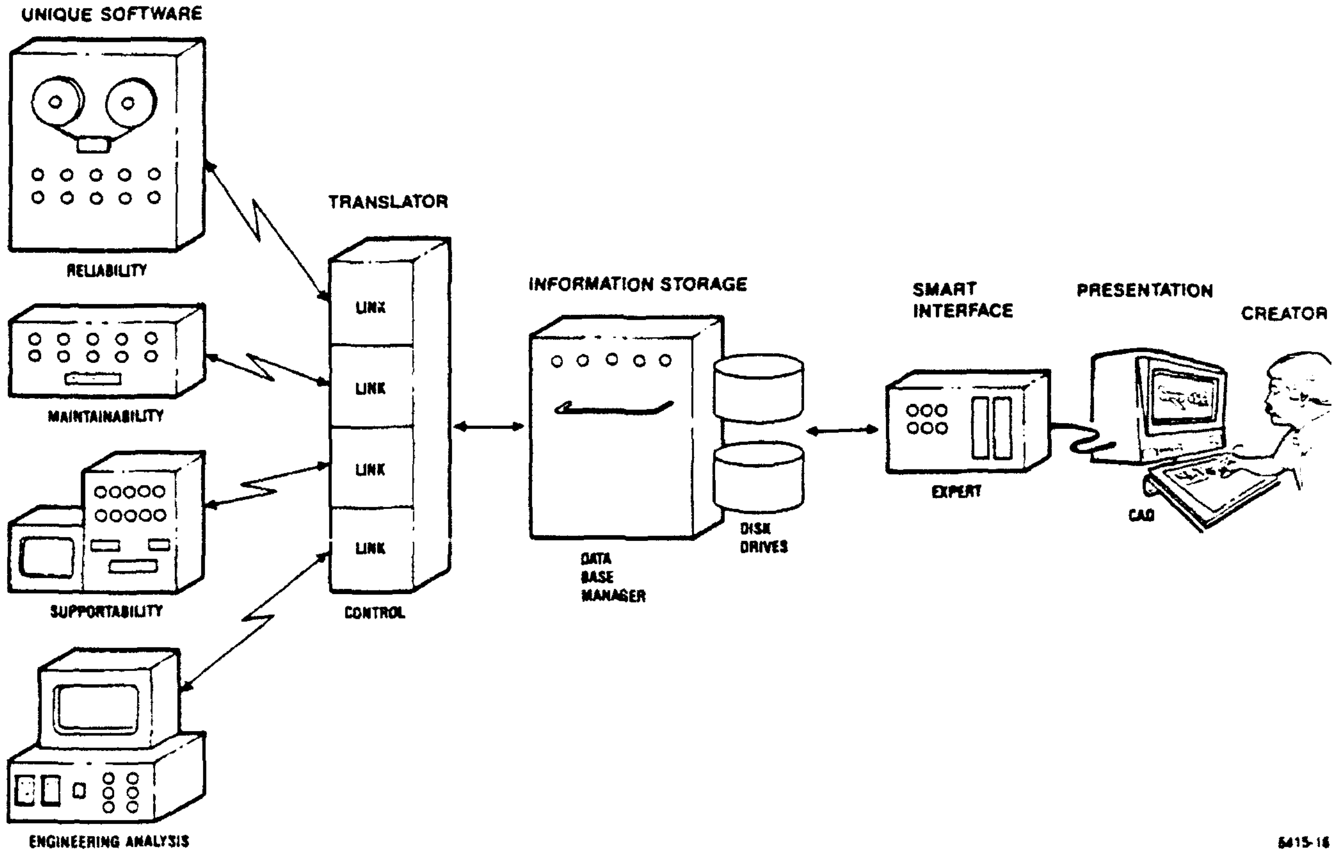

Figure 25. Initial RAMCAD Architecture. The initial RAMCAD Architecture employed a PC linked to the CAD workstation via an IBM mainframe.

The preliminary design workstation architecture, shown in Figure 26, was driven by the CAD/CAE and RM&S software selection. Cognition's Mechanical Advantage required the UNIX Operating System; this led to selection of the VAXstation 2000 as the mechanical workstation. SDRC I-DEAS TDAS module, used for development of the structural life estimate, would only run on a VMS platform; thus the VAXstation 3500 was selected.

The IBM PC was replaced by a coprocessor on the electronic design workstation when it was determined that the DOS-based

RM&S packages could not be executed without some user interaction. For example, REL PLUS requires the design name and operating environment. Although the vendors provided a batch data entry capability to eliminate user input of all required data, the requirement for minimal user interaction with the DOS programs led to co-hosting the RM&S packages at the workstations to maintain a single-seat capability.

Software Architecture

The RAMCAD prototype software interlinks commercially available RM&S software packages with CAE and CAD software to integrate RM&S analysis into EM&S designs. The software architecture is shown in Figures 27 and 28.

The RAMCAD system consists of two major Computer Software Configuration Items (CSCIs): the Communication/Common User Interface/Translation/Artificial Intelligence (CITA) CSCI and DBMS CSCI. RM&S, CAE, and CAD software packages, which are to be interlinked by the prototype RAMCAD system, were not part of the developmental software of the RAMCAD prototype. Therefore, they are not included in Figures 27 and 28.

Because workstation technology and CAD/CAE and RM&S software are continually evolving, RAMCAD was designed to maximize modularity and facilitate swapping-out or upgrading a software package or workstation. The Conceptual Schema, the "heart of RAMCAD," consists of the translators and DBMS that solve the problem of facilitating the interchange of information in a heterogeneous computer environment. If new CAD/CAE or RM&S packages were added to the system, the "heart of RAMCAD" basic structure would remain essentially the same. For CAD/CAE packages, additional translators would be written as required to read additional or differently formatted CAD/CAE data into the database.

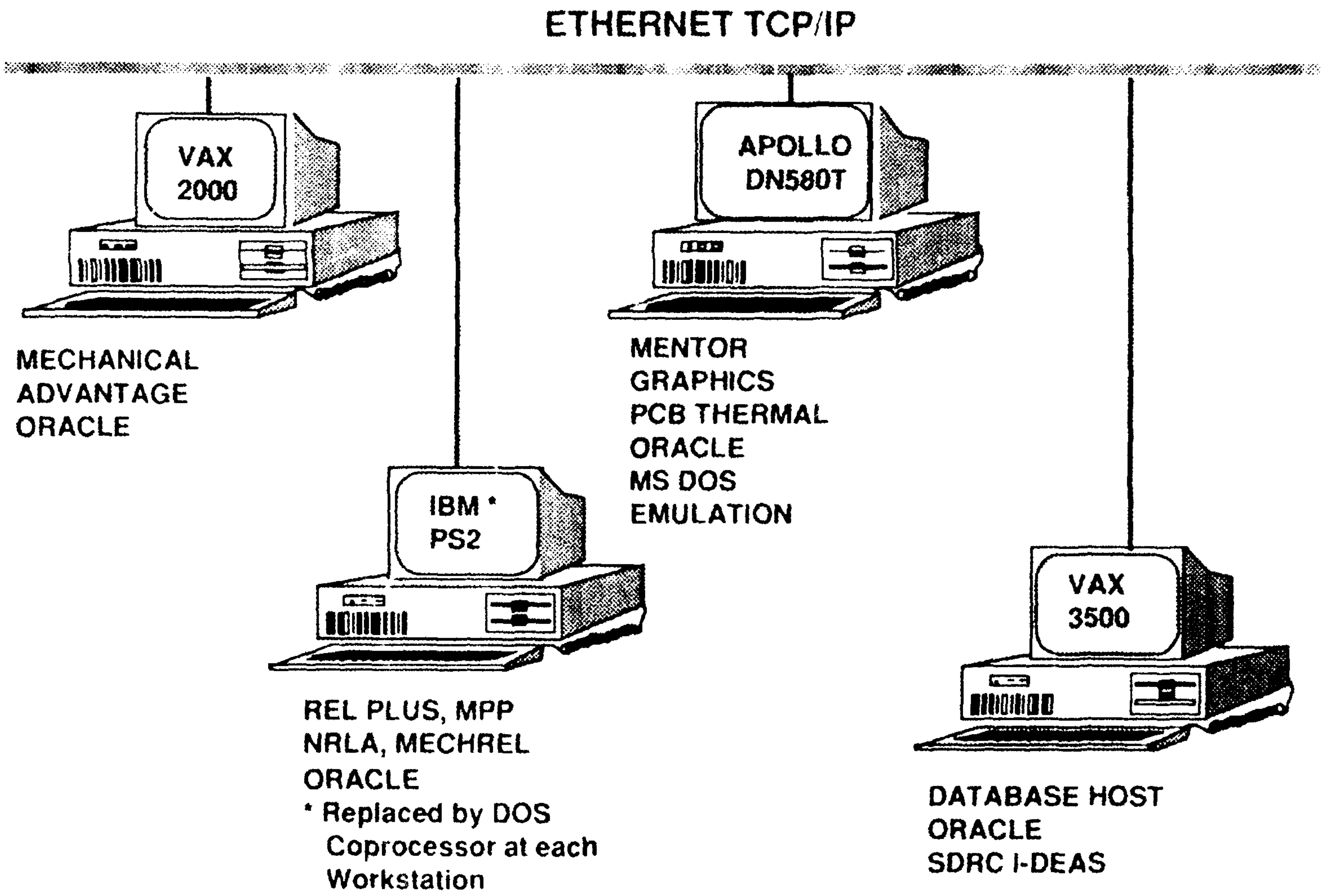

Figure 26 . RAMCAD Preliminary Design System Architecture.

If new RM&S packages were added, the DBMS would be modified to accept any new required input data, provide the capability to retrieve input data from the database, and execute the new package(s) on command from the CUI.

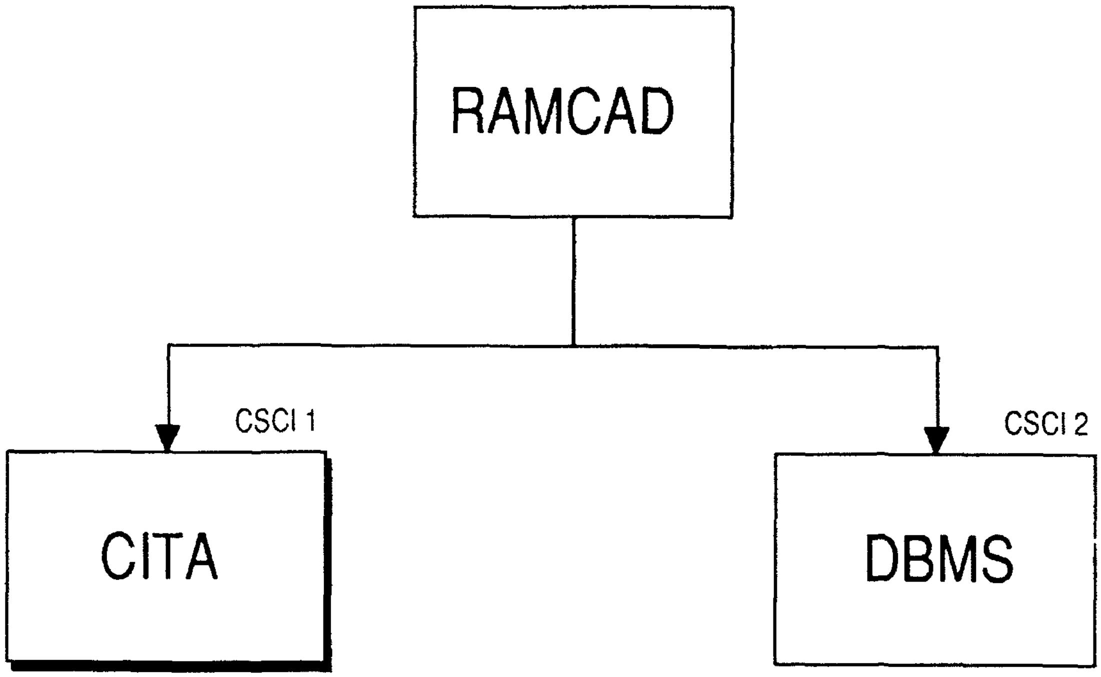

Figure 27. Top-Level RAMCAD Software Architecture.

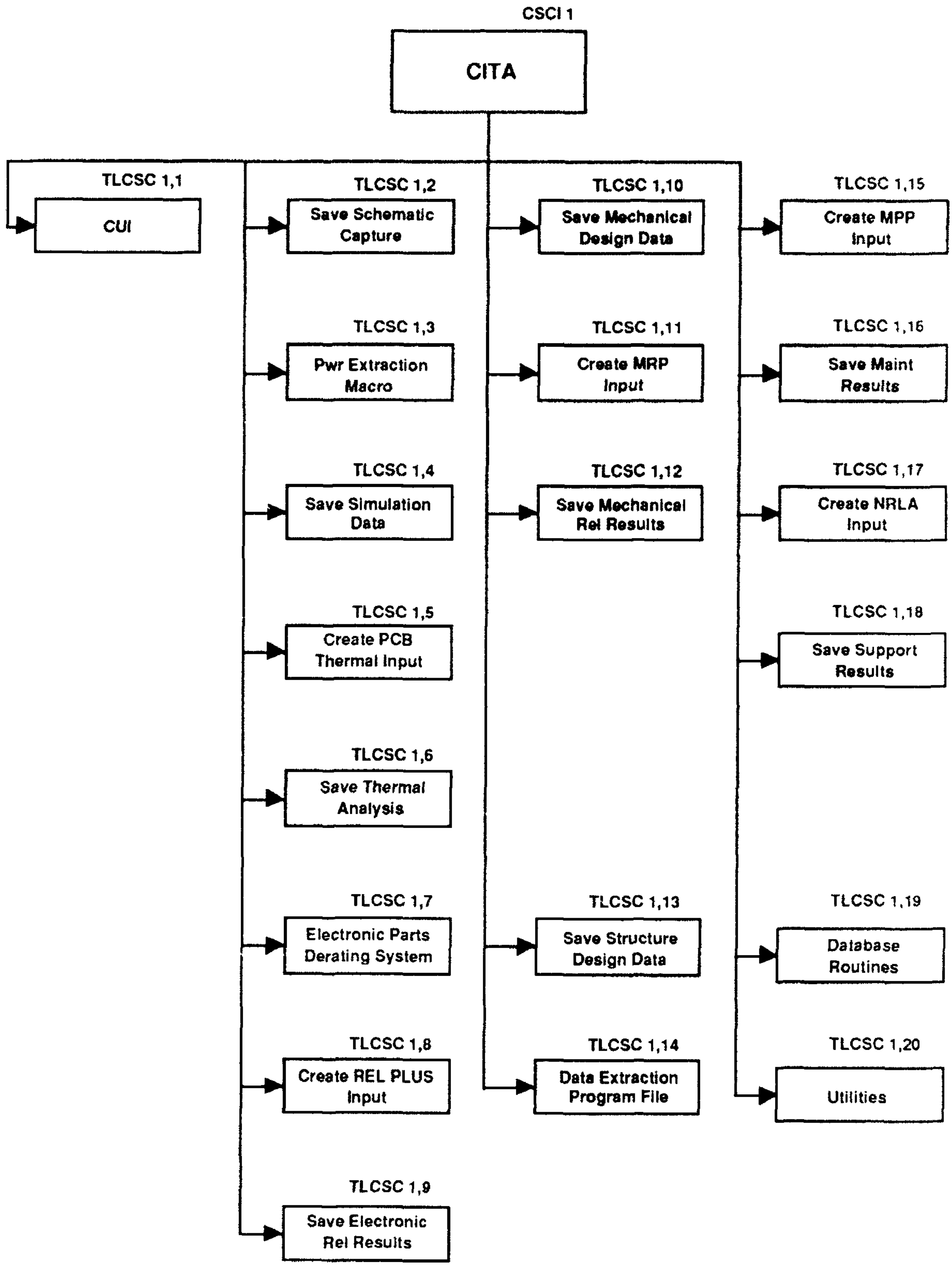

Figure 28. RAMCAD Communication/Common User Interface/ Translation/Artificial Intelligence Architecture.

Table 2 presents developmental code that would have to change as a result of swapping out one of the RM&S packages.

Table 2. Code Impacted by RM&S Package Changes

RM&S	Developmental Code Requiring Change			
REL PLUS	frontend_relplus.pc	extract_relplus.pc	cui_routines.c	dos.h
MRP	frontend_mrp.pc	extract_mrp.pc	cui_routines.c	dos.h
MPP	frontend_mpp.pc	extract_mpp.pc	cui_routines.c	dos.h
NRLA	frontend_nrla.pc	extract_nrla.pc	cui_routines.c	dos.h

This matrix is included in the System Administrator's Manual.

Computer-Aided Design (CAD)/Computer-Aided Engineering (CAE) Software. Mentor Graphics electrical design software was recommended and selected at the System Design Review (SDR) for several reasons: it is in use in the Convair Advanced Avionics Group, GD has purchased over 100 Mentor Graphics Apollo workstations, and it has the ability to perform design and analysis tasks required for input to REL PLUS during development and demonstration of the advanced prototype. Design of electronic systems is performed using Mentor Graphics schematic capture, parts libraries, and board layout software on the Apollo workstation. To support the Xwindows/Motif CUI, Mentor Graphics was upgraded from Version 6.0 to Version 7.0, requiring an Apollo operating system upgrade from SR 9.0 to SR 10.

An electronic simulation, ACCUSIM, engineering analysis program is used to analyze electronics design to determine voltages and currents of electronic components and calculate power dissipation and electronic stress. The advanced prototype was developed using the MSPICE Plus simulation program. However, Mentor Graphics announced in April of 1989 that they would no longer support

MSPICE Plus; therefore, a shift was made to ACCUSIM, Mentor's simulation program. This required reconfiguring the parts database for compatibility with the ACCUSIM libraries and modifying the power extraction macros to provide component current and voltage data to the thermal analysis program.

In addition to ACCUSIM, the electronics RM&S software interfaces with a thermal analysis package, PCB Thermal by Pacific Numerix. This software provides the MIL-HDBK-217 prediction with more accurate thermal stress information.

Mechanical RM&S software, in the RAMCAD prototype system, links with Mechanical Advantage by Cognition, Inc. Mechanical Advantage was recommended as a result of the RM&S software survey for its support of mechanical reliability prediction. It provides RAMCAD with a parametric modeling capability that associates preliminary design characteristics with engineering equations and relationships. Mechanical Advantage will assist the mechanical designer in determining the reliability of the design by determining mechanical stress characteristics which are input to the MRP reliability analysis software. To support the Xwindows/Motif-based CUI, the UNIX operating system on the mechanical workstation had to be upgraded to Version 3.0. This, in turn, required upgrading Mechanical Advantage to Version 3.0.

SDRC I-DEAS software was selected for structural design and analysis based on its use by the structural design group at GD. It will be used to perform three specific structural design functions in RAMCAD. These include "finite element analysis" as a representative Engineering Analysis tool and the I-DEAS Geomod Module for CAD solid modeling. (It will also be used for solid modeling of mechanical components.) In addition, structural design will use the I-DEAS TDAS Module for reliability analysis. SDRC I-DEAS was upgraded from Version 6.0 to Version 7.0 to support the Xwindows/Motif-based CUI.

RM&S Software. Selection of RM&S Software Programs for integration into the prototype RAMCAD System was based on utility, functionality, transportability, risk, and cost. Utility was judged as those user features which enhance the ease of software use by the weapon system designer. Functionality concerned how well the software fulfilled the requirements of the design process, complied with applicable MIL-STDs and MIL-HDBKs, and evolved with the design process. Transportability concerned the ability to integrate the software into the CAD process through workstation compatibility and communication of output/input files to/from other CAE and analysis software. Risk considerations addressed the availability of the software as a released demonstrable package and the availability of continued software support.

Reliability Analysis Software. Our original intention was to select a single, commercially available software package for reliability analysis of EM&S design. However, since no commercially available package could meet the requirements for all three design areas, three different packages were selected, based on the differing requirements for analysis of EM&S reliability (as documented in RAMCAD Requirements Definition, GDC-RAMCAD-88-02).

Electronic Reliability. Evaluation Software, Inc. (formerly Prophet Software, Inc.) REL PLUS was selected for electronic reliability analysis. REL PLUS performs reliability analysis in accordance with MIL-HDBK-217D and MIL-STD-756. It models systems from parts lists up to subsystem level and can read ASCII formats as data inputs from CAD/CAE systems. It uses a menu-driven interface and a built-in editor for editing macro-command files for batch runs. REL PLUS uses MS-DOS batch files to run its sub-applications (such as mission reliability) making it highly feasible for integration with other systems.

Mechanical Reliability. At the time of the software survey, Eagle Technology's MECHREL demonstration program for their mechanical reliability handbook was the only package available for reliability analysis of mechanical systems. It had not yet been replaced by a commercially available or public domain mechanical reliability analysis program by PDR. MECHREL can calculate failure rates for valves, gearboxes, pumps, bearings, and filters. MECHREL applies mechanical stress factors that are calculated using algorithms in the mechanical reliability handbook and applies them to base failure rates contained in the Rome Air Development Center (RADC) handbook for reliability prediction of non-electronic components.

Powertronics' MRP program automated the algorithms in the mechanical reliability handbook and became available for analysis of the Army travel lock mechanical reliability testbed. A comparison of failure rates using MECHREL and MRP indicated that the two packages have equivalent capability. MRP, which was intended as a commercial product and would continue to be maintained, was substituted for mechanical reliability analysis.

MRP can receive batch input through the MDP. During the course of the travel lock analysis, it was determined that six equations in the handbook were in error and had been incorporated in the MRP package. This information was provided to Scientific Management Associates and Powertronics, resulting in the orrection of three equations and a complete revision of one algorithm. We continue to maintain contact with MRP and the David Taylor Research Center regarding the status of the two remaining equations.

MRP Version 1.0 calculates failure rates for the following part types:

Static Seals	Pump Shafts
Dynamic Seals	Pump Casings
Springs	Pump Fluid Drivers
Solenoids	Filters
Poppet Assemblies	Brake Friction Materials
Spool Assemblies	Clutch Friction Materials
Housing Assemblies	Actuators
Bearings	Miscellaneous
Gears	Splines

A beta version of MRP 2.0 has been received from Powertronics and is presently being evaluated.

Structural Reliability. SDRC I-DEAS was selected for analysis of structural reliability. SDRC I-DEAS is a CAD/CAE, three-dimensional, solid-modeling finite-element-analysis package. Its capabilities include fatigue and stress analysis, statistical and spectral analysis, and structural optimization. Thermoplastics and laminates can be modeled as well as other more common hard structures.

Maintainability Analysis Software. Powertronics Systems, Inc., MPP was selected for maintainability analysis in all three design areas. MPP performs maintainability MTTR prediction of electronic and mechanical equipment in accordance with MIL-HDBK-472. It can be used for the analysis of systems of up to 32,000 assemblies and subassemblies. The program provides the capability for user-defined libraries of maintenance tasks and associated times.

Supportability Analysis Software. NRLA, provided through the Air Force Acquisition Logistics Center (AFALC), is used to establish equipment and component repair-level analysis on an economical basis that integrates design, operations, and logistics support characteristics. This program is capable of supporting a design process that considers the economics of support alternatives and chooses from those alternatives to select design characteristics which result in an economical life-cycle-cost profile. It provides a number of outputs of value to the designer and logistics analyst including repair/discard information, sensitivity analysis, and logistics costs. NRLA is easily implemented using macros and ASCII data files.

Derating Expert System. Electronic part derating poses a major problem for design engineers. Designing circuits to perform up to maximum ratings is considered poor design practice under most circumstances. Conservative designers usually derate a device to fractions of the data book maximum values. If derating is desired, all values are multiplied by their associated derating factors, obtained from a derating specification. Each contractor creates and maintains a separate derating policy since derating specifications are developed for a specific program and agreed to by the Government. The problem is that program specific derating guidelines do not always cover the full spectrum of electronic components. In these cases, judgment calls are made to create a best fit match to the specification. This knowledge is typically the intellectual property of isolated experts making it a perfect candidate for a rule-based expert system.

The objective for an artificial intelligence (AI) application for parts derating was to create a DEREX module that can handle the full breadth of components within hardware as complicated as the PSA-30. Using the CLIPS expert system shell (a NASA-developed expert system shell available in the public domain), rules used by the experts and transferred from specifications were coded into a rule base. Outputs from CAD/CAE software packages are used as input to the DEREX system and to send the derated parameters derived by the expert system to the central database (ORACLE).

The derating requirements and the derating process were reviewed and approved by the Avionics Design Group. Interviews with those engineers expert at derating have begun. A "proof-of-concept" derating system using derating rules for resistors was developed and successfully demonstrated to validate the RAMCAD DEREX module.

Additionally, DEREX was initially developed using CLIPS on a MAC II. This provided the capability to modify test data to ensure proper firing of all rules without perversion of the RAMCAD database. DEREX warning messages were reviewed by electronic design and parts engineering personnel on the MAC II prior to porting DEREX to the electronic workstation.

Common User Interface. The CITA CSCI serves as the designer's "window" into the RAMCAD environment. It provides a common set of procedures for conducting RAMCAD analyses at each of the three types of workstations. The designer uses the CUI to execute and save data from the CAD package to bring the electrical, mechanical, or structural concept into visual existence. It also allows the designer to view RM&S requirements and other data from the RAMCAD database, and to perform RM&S analyses (such as electrical MTBF prediction, mechanical failure-rate prediction, structural useful-life prediction, MTTR prediction, and optimum repair-level analysis).

To achieve the required functionality of the CUI, the original RAMCAD concept proposed a "smart interface." This interface would use AI techniques to execute CAD/CAE and RM&S programs, and save and retrieve data to and from the RAMCAD database. It was determined that a relational database system and translators could be designed to provide the required functionality without using AI.

The user interface for the advanced prototype consisted of nine windows or "buttons" for EM&S design with submenus for requirements, CAD, and analysis. The advanced prototype user interface was programmed using the Apollo workstation's Domain Dialog, but the prototype CUI was to be programmed in Xwindows to be common for all workstations.

Designer and Government feedback indicated a preference for a "Macintosh-like" pull-down menu system. Open Software Foundation (OSF)/Motif provided the capability to reprogram the CUI for all workstations with fewer lines of code in less time than would have been possible with Xwindows alone. The OSF/Motif widget set provides a set of functions and procedures to access lower levels of the Xwindows system. This facilitates rapid response to designer feedback and rapid prototyping of the user interface. The Motif User Interface Language does type checking. This feature, not available with X tool kits, allows for earlier error detection and fewer errors in a specified interface.

The use of Motif also enabled standard user queries to be programmed through the CUI without the use of SQL FORMS. SQL FORMS will be available for the user to create custom or ad hoc queries of design and analysis data from the RAMCAD database.

Database Management System. The DBMS is a repository for RAMCAD data, an interface medium with the RAMCAD user's global computing system for requirements allocation and tracking, and an information broker for RAMCAD and engineering analysis programs. SQL is standard for database management programs. This standard is generally supported throughout Government and industry. SQL basically standardizes the query language used to access information in the database. Diverse SQL-compatible databases should be accessible with the same set of SQL commands. A relational database was used for this function so that more diverse and programmatic query capabilities would be possible.

The drivers for selection of the DBMS were the use of SQL, a relational structure, and a wide customer base. During the development of the advanced prototype, Informix had the largest percentage of the installed UNIX base. Thus, it was selected for the advanced prototype DBMS. Subsequent to system design review, ORACLE was selected for the RAMCAD prototype system based on Government feedback and potential for compatibility with other Government data and analysis systems.

The DBMS comprises of five master sets of relational tables. These tables are listed in the Appendix. Sample extracts from these tables are also included, providing the definition, format, units of measure (if applicable), and other characteristics for data elements in the RAMCAD database tables.

Approved Parts List. During the design process analysis and simulation, a need was identified to provide the designer with a tailored list of parts that have been approved for the weapon system under development. Custom program-specific parts libraries can be programmed within Mentor Graphics. However, input to the Pacific Numerix PCB Thermal Analysis Program and other downstream analyses requires many additional component attributes which are not contained in the Mentor Graphics component library (such as dimensions, thermal conductivity of contact layer and board, and board mass density and specific heat).

To meet this requirement, an APL for electronic parts was added to the RAMCAD architecture. The APL is a database table that contains static parameters of electronic components from the manufacturer's handbooks. Examples are rated power, value (ohms, microfarads, etc.), tolerance, quality, and physical dimensions. Because these parameters are not application-dependent, all RAMCAD designs need only to point to the APL for static component data.

There are several benefits to this methodology. One benefit is simplification of the RAMCAD Mentor libraries. The only attributes needed in Mentor Graphics for RAMCAD components are those necessary to uniquely identify the part in the APL. This speeds up

Mentor processing. Another major benefit is the reduction of storage space consumed by a RAMCAD design. Because static parameters make up 60 percent of a component's attributes, the net reduction in space is 60 percent.

RAMCAD Software Development and Test

Development and Documentation. RAMCAD prototype System development was based on the requirements of DoD Standard 2167, Defense System Software Development, 4 June 1985. The prototype system was developed in three builds, following successful demonstration of the advanced prototype and Government approval of the software development plan, GDC-RAMCAD-89-003.

Build 1 consisted of the EM&S workstations connected to the RAMCAD database through the CUI for reliability analysis. The electronic workstation also had derating analysis capability for resistors and capacitors. Upon completion of Build 1 formal qualification testing (FQT), Build 1 software was installed at AL/HRGA, Wright Patterson Air Force Base, in November 1990, to replace the advanced prototype. This software provided additional opportunities for Government demonstration of RAMCAD and provision of feedback to the RAMCAD development team.

Build 2 included connecting the EM&S workstations to the maintainability and supportability analysis software through the CUI. The parts DEREX system was also completed for all remaining types of electronic components.

Following formal qualification (FQT) of Build 2 and the preliminary demonstration and test of the RAMCAD prototype for the Government, Build 3 incorporated required changes to close out test anomalies and incorporate Government feedback.

The RAMCAD software configuration is detailed in the design documents listed in Table 3.

Table 3. RAMCAD Design Documentation

Document	Data Item Description (DID)
Software Product Specification	(DI-MCCR-80029) Tailored
Software Top Level Design Document	(DI-MCCR-80012) Tailored
Interface Design Document	(DI-MCCR-80027) Tailored
Database Design Document	(DI-MCCR-80028) Tailored
Software Detailed Design Document	(DI-MCCR-80031) Tailored
Software User's Manual (Includes System Administrator's Manual)	(DI-MCCR-80019) Tailored

RAMCAD Software Testing. The RAMCAD Software Test Plan (STP) was developed from July 1989 to November 1989, reviewed, updated, and presented to the Government at the RAMCAD Critical Design Review (CDR) conducted on 14-15 February 1990. Government review comments were incorporated and the final plan was delivered in April 1990.

Build 1 Testing. Development, validation, dry-running, and performance of Build 1 formal test procedures followed standard formal testing methodology. The FQT Descriptions provided in the approved STP were converted to test steps of the Software Test Procedures (STPRs). During development of the basic test steps, procedures for executing each step were identified through evaluation of the requirements, discussion with the software developers, experience gained during advanced prototype testing, and hands-on examination of the evolving RAMCAD prototype.

After development of the STPRs, a validation was performed to resolve concerns that may have arisen from differences between expected and actual operation of the software, and a "first look" of the test team to identify possible errors in the developing software. Build 1 STPR validation was performed concurrently with software development and informal Computer Software Component (CSC) integration and test. This allowed direct interaction between the test team and and software developers to resolve any areas of confusion, and facilitated rapid correction of identified software errors. During validation, 120 Build 1 Test Anomaly Reports (TARs) were generated and resolved.

Upon completion of the Build 1 STPR Validation, a testing baseline was established. A Build 1 STPR dry run was conducted to perform a sequential test of all Build 1 functionality in preparation for FQT. Seventeen TARs were generated and resolved during the dry run. Build 1 was then baselined and a Test Readiness Review was conducted to verify readiness for FQT.

Build 1 FQT consisted of performing all Build 1 STPRs in sequential order. During two weeks of FQT, a Government representative was present to observe testing. Build 1 FQT was conducted from 29 October to 28 November 1990. The Build 1 FQT encompassed 1305 pages of Software Test Procedures. Eight Software Problem/Change Requests (SPCRs) were generated, reviewed by the Software Review Board (SRB), and resolved as a result of Build 1 FQT. Following the SRB and implementation of approved changes, Build 1 was re-baselined on 19 December 1990 as Build 1A. Build 1A was retested and all SPCRs were closed out.

Build 2 Testing. Build 2 testing followed the same methodology as Build 1 FQT. Build 2 FQT, conducted 18 February to 22 March 1991, generated 22 SPCRs and 52 Suggested Improvements (SIs). An SRB was conducted on 25 March 1991 to review proposed software changes for resolution of SPCRs and implementation of SIs. Build 2 was re-baselined as Build 2A. The SRB-approved SPCRs/SIs were retested and closed.

Build 3 Testing. Build 3 testing followed the same methodology as Build 1 and 2 FQT. Build 3 FQT was conducted from 3 June to 13 June 1991 to test RAMCAD functionality changes resulting from Government feedback during pre-demonstration testing (PDT). Three SPCRs were generated during this FQT. An SRB was conducted on 20 June 1991 to review proposed software changes for resolution of Build 3 SPCRs. Build 3 was re-baselined as Build 3A. The Build 3 SPCRs were retested and closed.

RAMCAD Implementation

In addition to formal validation and test of the RAMCAD prototype software, RAMCAD has been implemented on actual cruise missile system design efforts to verify attainment of required functionality, and obtain designer feedback and designer assessment of RAMCAD technology. RAMCAD implementation was achieved by having RAMCAD program personnel participate on process action teams to define procedures and identify methods and tools for performance of concurrent engineering at General Dynamics Convair Division (GDC).

The RAMCAD electronic design engineer, through membership on the concurrent engineering implementation team, used RAMCAD software to assess redesign and repackaging of the cruise missile PSA for installation in the long-range stand-off weapon. This design required consolidation of the seven PSA circuit board components onto two new design boards shaped to fit in a "wafer" in the nose section of the vehicle. The original placement of components would have dramatically increased the PSA failure rate because of a concentration of heat-emitting components within the highly constrained packaging of the unit. Rearranging components based on the RAMCAD analysis achieved the required reliability without actively cooling the unit.

The RAMCAD advanced prototype software was also installed in the lab for the Convair Integrated Manufacturing Systems (IMS) development team for integration in the IMS architecture. IMS is an enterprise-shared design and data system for achievement of integrated product development from conceptual design through production and support.

IV. RAMCAD CONTRACT HISTORY

The RAMCAD Software Development Program was started in July 1986 by GDC under PRDA 86-16-PMRS. This PRDA was issued on May 15, 1986, by AL/HRGA Wright Patterson Air Force Base, and subsequently funded by AMCCOM at Picatinny Arsenal.

The objective of the program is to integrate RM&S software into a CAD workstation for three different types of designs: electrical, mechanical, and structural. The PRDA divides the research effort into three tasks. Task One is to develop a RAMCAD prototype which demonstrates the feasibility of the RAMCAD concept. Task Two is to conduct long-range research into how the RAMCAD could make use of emerging technologies. Task Three is to develop a college-level curriculum to instruct and motivate future engineers using a RAMCAD design tool. GD was selected to perform Task One.

Using the systems integration approach, a three-phased, 48-month program was planned. In Phase I, Requirements Definition, the design process and requirements for the RAMCAD prototype were defined. A survey of both national and international companies was conducted to determine the state of the art for RM&S software. Seventy-seven surveys were sent to software vendors; 31 replies were received. From these replies, 48 RM&S and 16 CAE software programs were catalogued.

Phase I was completed and its results were documented in two reports, GDC-RAMCAD-88-001 and 002. The first report provides information obtained from the survey of RM&S software available as of March 1988. The second report gives the results and analysis of an internal survey of GDC design engineers. It documents the GDC design process as it is today and defines requirements for the RAMCAD prototype which was developed in Phase III. The results and findings of both reports were reviewed and approved by the

Government at the Systems Requirements Review (SRR) held at GDC in February 1988.

Phase II, Systems Integration Phase, began immediately after SRR approval. The Systems Integration Phase was structured for two Government reviews. The first, an SDR, was conducted in August 1988. This review demonstrated the results of the RAMCAD advanced prototype. This effort proved by demonstration the feasibility of linking electronic design tools so that the design engineer can perform schematic capture, PC board layout, and thermal and reliability analysis from a single CAD workstation. In addition to the advanced prototype demonstration, the system architecture and conceptual schema for the complete RAMCAD prototype were presented and approved by the Government during SDR.

Three plans were then prepared and submitted at the PDR, which was held at GDC in February 1989. These were the Systems Integration Plan, Contract Data Requirements List (CDRL) 6; the Detailed Research Plan, CDRL 7; and the Software Development Plan, CDRL 8.

After approval of these plans, Phase III, the Systems Development Phase and Test Phase, began. This third and final phase included coding and documenting the RAMCAD prototype software, linkages, translators, and database for the approved EM&S design testbeds. The approved test--bed was the tailcone section of the Tomahawk Cruise Missile which contained the PSA as the electrical testbed, the mechanical actuator as the mechanical testbed, and the fin as the structural testbed. The PSA receives signals from the guidance set and sends the signals to the mechanical actuator which then turns the fin.

CDR was conducted at GDC on 14-15 February 1990. At CDR the Software Test Plan, CDRL 9, was reviewed and delivered to the Government. The STP defined the process and procedures which would be used for formal testing of the software based on MIL-STD-2167.

RAMCAD software code was developed and tested in two Builds. Build 1 code consisted of the EM&S design workstations integrated with reliability software using the ORACLE database and the GD-designed CUI. Build 2 consisted of EM&S workstations integrated with maintainability and supportability software. Build 2 also included the GD-developed DEREX system, used for derating electronic components based on the Tomahawk military specification. At the end of each Build, a tape of the baselined build software configuration was made along with a Version Description Document. This tape was then loaded on the RAMCAD system where formal testing began.

On 26-27 March 1991, a PDT was held at GDC. This test showed the results of formal testing and demonstrated the completed RAMCAD system for EM&S design. Suggestions were made by the Government for additional functionality. These functions were incorporated in preparation for the RAMCAD demonstration review held at GDC on 7-8 May 1991. At the end of Phase III, the following CDRLs were delivered: CDRL 10, Software Requirements Specification; CDRL 11, Software Product Specification; CDRL 12, Users Manual; and CDRL 1 Attachment 2, Computer Software Product (including all software developed under the contract and software flow charts).

On 22 December 1988, a contract modification was received from the Government. This modification authorized the purchase, for the Government, of the EM&S design software and the reliability and maintainability software which was baselined at PDR. In addition, the Government authorized a testbed for mechanical design and reliability analysis of a hydraulically operated travel lock for a self-propelled howitzer. The software purchase and travel lock analysis were completed in August 1989.

On 14 May 1990, a contract modification was received from the Government. It authorized an additional testbed for mechanical design and reliability analysis. This testbed was an electrically operated travel lock assembly for the self-propelled howitzer. Software, a final report, and a users manual were delivered to the Government in December 1990.

V. RAMCAD LESSONS LEARNED

RAMCAD Portability

Portability of the RAMCAD prototype is a key Government requirement which has been addressed by implementing industry and Government standards in the prototype system architecture. Adherence to these standards maximizes the portability of RAMCAD. Computer standards for operating systems (UNIX where possible), programming language (C language), networking (TCP/IP), window management (Xwindows-based OSF/Motif), and database access with the SQL were design guidelines for RAMCAD development.

Common User Interface

Another requirement of RAMCAD is a CUI on each design workstation. Utilization of the Xwindows-based OSF/Motif window management software provides RAMCAD with a common look and feel on the heterogeneous design workstations.

"Portable" applications such as Xwindows and C language are highly dependent on the vendor's implementation. For example, porting the CUI to three implementations of UNIX (Mentor Graphics Ideas Station, ULTRIX (VAX UNIX), and DEC RISC ULTRIX) was much easier than porting between the UNIX workstations and the structural workstation (VAXstation 3500) VMS operating system. Methods of opening windows and initiating procedures are vastly different for VMS and ULTRIX, making commonality of the CUI very difficult. Of the four platforms, the Mentor Graphics workstation was the most forgiving. OSF/Motif greatly facilitated the development of the CUI. The lesson learned is that the OSF/Motif window management standard is a key concurrent engineering enabling technology.

RAMCAD Database

The choice of database software was also made to achieve portability and to adhere to industry standards. The ORACLE DBMS was chosen because it used the SQL access method and the DBMS was available on all major computer platforms. ORACLE also has off-the-shelf communications software that utilizes TCP/IP for networking. Therefore, it meets the RAMCAD communications requirements. The GD RAMCAD team has successfully developed shared database schemata via SQL on DB2, Informix, and ORACLE. Adherence to the SQL standard by commercial database products allows the concurrent engineering environment to interact with external databases within and outside the enterprise. The freedom to interact with a broad range of databases (the norm in the aerospace industry) through SQL is a key concurrent engineering enabler and lesson learned.

Workstation/Application Software Color Standards

Following execution of the PCB thermal program during electronic design analysis, the user interface would appear in different colors. This was caused by the PCB thermal program resetting the palette for color display on the workstation. There is no common industry standard for colors. Thus, a code for a particular palette setting for one application may differ from the basic default settings of a different application. This, caused difficulties in determining the code to restore the colors of the interface.

When porting an application between workstations, the palette settings may be different for each workstation. Consequently, a "shared" model being simultaneously viewed on two types of workstations may appear in completely different colors unless color settings are translated in addition to color values when transferring the model. Standardization of palette settings for workstations and application software will avoid a complex problem for future concurrent engineering architectures which will share product models among a variety of types of workstations.

"Upward Compatibility" of Software

Revisions of RAMCAD software application programs for improved capabilities had a significant impact on the development of the prototype system. This was caused by a lack of upward compatibility of the upgraded software. For example, Mentor Graphics was upgraded to Version 7.0 for Xwindows compatibility. This also required upgrading of the DN4500 operating system from SR 9.7 to SR 10. Changes in the operating system caused some anomalies in the operation of the RAMCAD software. Additionally, changes to electronic parts models in the ACCUSIM parts libraries caused the previously developed schematics to be incompatible with the simulation program. This required changes to the existing schematics to restore the required interface from electronic design to analysis.

The part model changes also impacted the power extraction macro developed by GD. This macro was designed to extract voltage and current data for each part from the electronic simulation for input to the thermal analysis program. The total impact of the change was nearly half a person-year to restore compatibility of the design files with the analysis software.

When upgrading application software for increased capability, developers must consider the impact to users. The upgraded software should be compatible with design files created with the "pre-upgrade" version, or should provide translators to upgrade the existing design data.

DOS-Based RM&S Analysis Software

The methodology for supplying the DOS-based RM&S analysis programs to the designer has evolved in the RAMCAD project. The original approach of performing RM&S analysis on a networked PC has become one of performing the analyses on the designer's workstation using DOS coprocessors or emulators. This RAMCAD design change was technically directed during the course of the RAMCAD Program because of the limitations of the input/output capabilities of networked PCs using DOS. This methodology also supports the basic requirement of not forcing the designer to leave the design workstation to perform RM&S analysis. The lesson learned on this subject is that as software vendors convert DOS-based RM&S analysis programs to UNIX and the C language. developing systems for "single seat" functionality will be greatly simplified.

Design Process Changes

The concurrent engineering requirement of providing multi-disciplinary analysis tools (such as RAMCAD RM&S analyses) to the designer on the design workstation causes changes to the design process. One aspect of these changes addressed by the RAMCAD prototype can be characterized as a level of control exerted on the design file life cycle. The design file life cycle covers the creation of new design names (i.e., a naming convention), the creation of a hierarchy for designs (e.g., requirement allocation), version control of existing designs, the analysis sequence for designs, and an adequate history of the design. RAMCAD development has incorporated, in prototype fashion, the concurrent engineering requirement of the design file life cycle. The implementation of the design file life cycle is a RAMCAD lesson learned.

The methodology for incorporating design file life cycle requirements into the design process is to administer design file control through the user interface and transparently provide a database structure to record the needed information. The user interface guides a designer through the design file creation process. This prevents the use of duplicate names and builds a design hierarchy. The design hierarchy identifies parent-child relationships so that requirement allocations can be rolled up to the system level.

The user interface also keeps the designer informed of the consequences of requested actions. For example, if analysis results have been stored for a design and the designer requests that RAMCAD store a new version of that design, the user interface informs the designer that all downstream analyses based on the original design version will be deleted. If the designer decides not to overwrite existing data, the requested action will be terminated. The designer may then elect to rename the design for trade study purposes and duplicate the activities using the design name.

CAD Workstation Requirements

Workstation Functionality

The primary tool of designers is the computer workstation. The workstation of today has been designed and tuned to accomplish specific CAE tasks in the shortest amount of time. The workstation performs optimally when a single user is working on a single application. RAMCAD and concurrent engineering require the workstation to take on functionality above and beyond this limited scope. The very basic premise of concurrent engineering is sharing design concepts during development. Sharing designs implies networking for the bits and bytes transfer, communications to comment and annotate design changes, read/write privileges, and engineering release--to name a few. These implications of "sharing designs" in a concurrent engineering environment cannot be accomplished by the workstation itself.

The additional design workstation functionalities required by RAMCAD and concurrent engineering can be accomplished by providing an underlying process--that is, software--to the workstation. The process software is necessary because the designer's workstation is expected to fulfill the non-traditional functions mentioned above; "non-traditional" in the sense of extending and controlling the design environment as prescribed by the enterprise. The concurrent engineering workstation must be able to "share" designs and serve other diverse purposes such as: design rule checking; provide standard parts libraries; design requirement performance checking; proper design practices checking; authorization and security control; labor recording; schedule and cost tracking; asset utilization tracking; et cetera. Workstations configured to meet all these diverse requirements of an enterprise's concurrent engineering environment cannot be purchased "off the shelf."

A lesson learned is that the enterprise and target users must define the concurrent engineering environment and then assemble a suite of CAD analysis and communications tools to accomplish the enterprise objectives. The software that provides the concurrent engineering process support to the design workstations has been the subject of some very large development budgets at this time, in both the user and software vendor communities.

Workstation Process Architectures

The concept of a process structure for engineering workstations has become a new product line for several computing industry vendors. These process structures are being referred to as frameworks. A typical scenario is to have a CAE vendor provide a framework with a primary application. The framework vendor "encapsulates" other software programs within the framework to enable the designer to move seamlessly from the CAD or CAE program to another application; for example, from design to analysis. Encapsulation means that the framework vendor provides the user interface, input/output services, and database storage requirements for the software being encapsulated.

At this time, frameworks are being developed by individual vendors. Therefore, it is imperative that the need for standardization be addressed. Without standardization, there is the potential for limiting computer user applications that have not been encapsulated into the framework. Computer users require that computers and software applications be commodities that the users can choose as best fits their requirements. Therefore, computers and applications should be "plug compatible" through standardization. Recent developments in standards have brought significant advances in these areas. UNIX workstations, for example, can be purchased for many applications in terms of price/performance instead of unique capability. The OSF/Motif user interface is also a standard that furthers this concept. SQL, TCP/IP, Network File System (NFS), and the IEEE computer standards all contribute to the benefit of computer users. An open architecture framework or a framework standard would solve a very large problem. With a framework standard in place, concurrent engineering implementors would be able to choose computer hardware based on price/performance and computer software based on functionality. This is the vision of the future for concurrent engineering.

Workstation Communications

Networking and workstation communications are RAMCAD and concurrent engineering requirements because designers typically use computer workstations that are individually licensed to perform a specific electronic, mechanical, or structural CAD function. Concurrent engineering environments must be able to communicate with all design workstations. The standard with the broadest industry acceptance for this purpose is TCP/IP. The U.S. Government developed and supports this standard. The RAMCAD prototype is using the ORACLE database communications feature, Structured Query Language Network (SQL*NET), using TCP/IP.

The advertised data rate of TCP/IP, ten megabits per second, is sufficient for ASCII information and meets the current RAMCAD requirements. However, it is not fast enough to satisfy the vision of concurrent engineering in which the ultimate functionality of workstation communications would be the "real time" transmission of three-dimensional graphics.

Sophisticated three-dimensional model transfers would require (at 30 refreshes per second, 24 bit planes, 1280 x 1024 resolution monitors) a transfer rate of approximately 960 megabits per second (30 x 24 x 1280 x 1024). This rate could be realistically rounded up to 1 gigabit per second when protocol overhead is considered, and even this number assumes only one transmission on the network. The communications scenario described above is a "worst case" example. The use of emerging standards for graphics primitives, smaller screen viewing windows, and slower refresh rates could ameliorate this requirement for the future vision of concurrent engineering.

User Interface Color Considerations

Following the pre-demonstration test of the RAMCAD prototype system, GD was requested to review human factors issues for the CUI relative to screen colors, fonts, font sizes, and consistency. The following factors, incorporated in the CUI as a result of this review, are recommended for consideration for general application to the development of user interfaces.

- Window titles should be in all capital letters.
- Red (danger color) and reddish colors such as pink should be avoided.
- Bright colors should be limited in area or brightness, as they strain the eyes with prolonged viewing.
- Related items on a screen should have the same or similar colors.
- The use of italics should be avoided except to draw attention to an item.
- Serif fonts should be avoided in long lists of data, such as main menu pull-down sub-menus.
- Colors that will be seen together should complement each other.
- Consistent colors should be used for features with the same function under multiple subwindows or message windows (e.g., push buttons should be turquoise or medium aquamarine, if possible).

Vendor Part Models

A key requirement for accuracy of reliability predictions, particularly for electronic reliability, is the availability of accurate part models for simulation. Five integrated circuits (ICs) required modeling of their internal components because models were not available in the Mentor libraries. While internal modeling met the requirement of electrical simulation, it also complicated configuration management because of the increased number of "synthetic parts" comprising a single IC.

As new components are introduced for application to electronic design, the vendors of design software will find it increasingly difficult to keep their libraries updated. Part manufacturers or third party vendors should consider creating "soft" specification sheets containing digital models of the parts for addition to design software libraries. This would facilitate inclusion of these parts in digitally created designs of new electronic products.

There is increasing interest in determining electronic component failure rates through analysis of "the physics of failure." (e.g., physical failures of electronic components caused by cracking of component leads and failure of solder due to shock and vibration). Analysis programs capable of stress and dynamic analysis of electronic assemblies are currently available. However, performing structural analysis on electronic components and assemblies requires information on component materials, packaging, and precise dimensioning, such as lead lengths. This would require considerable effort to develop additional characterization and libraries of part models.

Software Documentation

Unlike development of software for the operation of equipment (such as missile guidance software or radar system processing software for which functional requirements are well-defined), RAMCAD system software was developed as the concurrent engineering processes it supports and the workstations and application software programs it integrates were also evolving. Current methods and requirements for software documentation are oriented toward a more classical approach to a development program, with the establishment of firm requirements and traceability throughout the development process to those requirements.

Technology-driven changes to RAMCAD requirements have a major impact on software documentation. For example, a change to an analysis program requires that every software requirements document, detail design document, and flow diagram be modified. This is because every element of information to be processed and stored for the new analysis software to be incorporated in RAMCAD must be documented under current requirements.

Computer-aided software engineering (CASE) tools are being developed to assist software development by generating code based on inputs of required functionality. Such tools should also be oriented toward capturing and producing the software logic in formats that meet software documentation requirements. This will reduce the "overhead" associated with upgrading concurrent engineering and RAMCAD software systems.

VI. RAMCAD FUTURE DEVELOPMENTS

Follow-On Technical Challenges

RAMCAD has been developed, validated, and tested using data from existing designs to reduce development time for the engineering testbeds and provide standards for measuring the expected results of RAMCAD analyses. Analysis of the design process and target user feedback and limited application of evolving RAMCAD software to real design problems have demonstrated that the RAMCAD prototype will be an effective tool for facilitating concurrent engineering.

The next challenge for RAMCAD will be using the RAMCAD prototype as an integral part of the design process for new designs; either to modify existing systems or develop new system designs.

In developing the RAMCAD system, a primary objective has been to implement a modular architecture to facilitate differences in the workstation architecture, or the availability or choice of RM&S software for individual user organizations. Delivery of the RAMCAD system to the Government will provide an opportunity to measure the success in achieving that objective. Therefore, the immediate technical challenge for the RAMCAD Team is twofold: (1) to accomplish implementation of RAMCAD in Government design organizations for use in ongoing and future development efforts; and (2) to add RAMCAD functionality to enhance its utility in the concurrent engineering process.

Implementation Plans

As a follow-on to development of the RAMCAD prototype system, implementation is planned at both Air Force and Army facilities associated with design development and analysis. Initial sites for implementation, in addition to AL/HRGA at Wright Patterson Air Force Base, are the Oklahoma City Air Logistics Center (OC-ALC) at Tinker Air Force Base and the Army Research and Development Center (ARDEC) at Picatinny Arsenal.

The CAE facilities at OC/ALC should be evaluated to determine the preferred workstations for RAMCAD installation and any impacts of implementation on platform operating systems or versions of applications software. This analysis should be documented in a study identifying the recommended workstation architecture and all installation requirements.

Also, the RAMCAD software required to implement RAMCAD in an NFS-style Local Area Network (LAN) environment should be developed or modified to integrate and implement the RAMCAD at ARDEC. As part of the RAMCAD implementation at ARDEC, an alternate structural analysis capability should be added using PDA's PATRAN and P-Fatigue software hosted on a Silicon Graphics IRIS 4D series workstation. This workstation would be in addition to the SDRC-based structural workstation in the RAMCAD prototype system. It would be capable of performing an independent structural analysis in the absence of an SDRC-based structural workstation.

To support implementation of RAMCAD at Government facilities, the User's Manuals for the EM&S workstation should be augmented with materials for training the target users. Also training courses should be developed.

Enhancements to RAMCAD

Enhancements to RAMCAD to increase utility of the prototype in a concurrent engineering environment include the following.

Manpower Requirements Analysis. RAMCAD analyses identify many of the major drivers for maintenance manpower. These drivers include frequency of system/equipment failures, repair times for system hardware, types of hardware requiring maintenance (i.e., electronic, mechanical, structural), and types of support equipment to be operated by support personnel. Linkage of RAMCAD with manpower analysis models would provide direct input of these attributes to provide real-time assessment of the impacts of proposed design changes on required manpower and maintenance skills.

Reliability-to-Cost Analysis. As previously discussed, the RAMCAD APL contains static data for each component approved for use on the proposed design. The addition of cost data to the parts list would provide the capability to sum the cost of alterative design concepts. This would enable a designer not only to meet reliability requirements for a given design, but also to select alternate lower-cost components if the design requirement is greatly exceeded.

Failure Modes and Effects Analysis. RAMCAD simulation of hardware performance that provides input to the respective reliability analysis programs could also be used to determine downstream effects of simulated failures. Failures could be "inserted" and simulations performed to determine the effects and criticality of the failure of each component. Downstream analysis programs such as PCB thermal and DEREX would identify overstress conditions that would cause resulting secondary failures.

Producibility/Tolerance Checking. Currently there are programs that check the design geometry for compatibility with manufacturing processes, such as the use of standard cutter radiuses and hole sizes. These programs could be integrated with the structural and mechanical workstations to assure that the design meets producibility as well as RM&S requirements

RAMCAD/Logistics Support Analysis Interface. The system hierarchy for the design under analysis is captured in the RAMCAD database. The hierarchy could be associated with logistics support analysis control numbers (LSACNs) for interface with the logistics support analysis record (LSAR) because the hierarchy is structured to reflect a top-down subsystem breakdown of the hardware under analysis. RM&S data generated by RAMCAD analyses could then be provided to the relational tables comprising the LSAR. This would assure that impacts of design changes are reflected in logistics planning documentation.

External RAMCAD Interfaces. RAMCAD presently has an internal APL and requirements database for the engineering testbeds. The availability of parts libraries using a relational database structure would allow the RAMCAD DBMS to point to external databases for parts data. This would reduce memory requirements for the RAMCAD system. Similarly, the ability to point to external requirements data by design name would provide real-time access to requirements data without imposing massive storage requirements on RAMCAD.

A similar capability could be used to access lessons learned and best practices for the type of design being developed. This could be accomplished by matching the design name to an index for the lessons learned database or by providing a window for the designer to enter keywords.

An additional area for interface with existing data would be providing connectivity for field data on actual performance of the design. Comparison of achieved values for system RM&S performance with RAMCAD predictions will provide a means for assessing the effectiveness of the prediction methodologies.

APPENDIX A: RAMCAD DATABASE MANAGEMENT SYSTEM TABLES

This appendix contains the database structure for RAMCAD. It provides listings of subtables of the Five Master sets of tables as follows:

Approved Parts List Tables

Electrical Tables

Mechanical Tables

Structural Tables

Network Repair Level Analysis Tables

Sample definitions and formats are provided for data elements comprising the tables.

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Approved Parts List Tables

RAMCADA - APL TABLES

- APL_CAPACITOR
- APL_CKT_BRKR
- APL_CKT_CARD
- APL_CONNECTOR
- APL_CRYSTAL
- APL_DIODE
- APL_FUSE
- APL_IC
- APL_INDUCTOR
- APL_INTERCONNECTION
- APL_KLYSTRON
- APL_LAMP
- APL_MAGNETRON
- APL_METER
- APL_MOTOR
- APL_RELAY
- APL_RESISTOR
- APL_SWITCH
- APL_TRANSFORMER
- APL_TRANSISTOR
- APL_TUBE
- APL_TWT
- APL_ZENER_DIODE

Electrical Tables

RAMCADE - ELECTRICAL TABLES

- CAPACITOR
- CKT_BRKR
- CKT_CARD
- CONNECTOR
- CRYSTAL
- DIODE
- DSGN_FILE
- FUSE
- IC
- INDUCTOR
- INTERCONNECTION
- KLYSTRON
- LAMP
- MAGNETRON
- METER
- MOTOR
- RELAY
- RESISTOR
- RQMT
- SCHEMATIC_REF
- SWITCH
- TRANSFORMER
- TRANSISTOR
- TUBE
- TWT
- WARNINGS
- ZENER_DIODE

Mechanical Tables

RAMCADM - MECHANICAL TABLES

- ACTUATOR
- ASSEMBLY
- BEARING
- BRAKE
- CLUTCH
- DYN_SEAL
- FILTER
- GEAR
- HOUSING
- MISC
- POPPET
- PUMP_CASING
- PUMP_FLUID_DRIVER
- PUMP_SHAFT
- SOLENOID
- SPLINE
- SPOOLS
- SPRING
- STATIC_SEAL

Structural Tables

```
RAMCADS - STRUCTURAL TABLES
       FIELD_MAINT_DATA
       STRUCT_COMP_PART
       STRUCT_DSGN_FILE
       STRUCT_PART
```

Network Repair Level Analysis Tables

RAMCADN - NRLA TABLES

- END_ITEM
- FAILR_MODE_SE_XREF
- LRU_FAILR_MODE
- LRU_PART
- NRLA_GLOBAL_CONSTANTS
- SRU_DATA
- SUPPORT_EQUIP

Sample Data Formats

```
TABLE NAME:  APL_RESISTOR

   MIL_SPEC            CHAR           30
      ENTIRE MIL NUMBER INCLUDING DASH NUMBER. EX: MIL-C-39006/22-0640R

   SPICEPAR            FLOT
      SPICE PARAMENTER FOR COMPONENT. FOR IC, TRANSISTOR, DIODE IS PART NU
      FOR RESISTOR, UNIT OF MEASURE IS OHM (MILLI,MICRO,KILO)
      FOR CAPACITOR, UNIT OF MEASURE IS FARAD (MILLI,MICRO,KILO)
      FOR INDUCTOR, UNIT OF MEASURE IS HENRY (MILLI,MICRO,KILO)

   PART_GROUP          CHAR           20
      TYPE OF COMPONENT. EX: CAPACITOR

   TOLERANCE           NUM             4,2
      THE DEIVATION AROUND A RATED VALUE

   RATED_MAX_PWR       NUM            20,10
      MAXIMUM ALLOWABLE POWER DISSIPATION AS SEEN IN MIL SPEC
      UNIT OF MEASURE - MILLIWATT


   COMP_MASS           NUM            20,10
      MASS OF COMPONENT
      UNIT OF MEASURE - G

   PART_COST           NUM            10,3
      PART COST
      UNIT OF MEASURE - $


   EMISSIVITY          NUM            20,10
      VALUE REQUIRED FOR PCBLIB. DEFAULT OF .85 USED


   X_DIMEN             NUM            20,10
      HEIGHT OF COMPONENT TAKEN FROM THE MILITARY SPECIFICATION
      UNIT OF MEASURE - INCHES

   Y_DIMEN             NUM            20,10
      WIDTH OF COMPONENT TAKEN FROM THE MILITARY SPECIFICATION
      UNIT OF MEASURE - INCHES


   Z_DIMEN             NUM            20,10
      DEPTH OF COMPONENT TAKEN FROM THE MILITARY SPECIFICATION
      UNIT OF MEASURE - INCHES
```

TABLESPACE: RAMCADE - ELECTRICAL TABLES

TABLE NAME: CAPACITOR

DSGN_NAME CHAR 20
DESIGN NAME OR END ITEM NAME

DSGN_HIERARCHY CHAR 80
WHERE IS A DESIGN A PARTICULAR COMPONENT IS LOCATED

SCHEMATIC_PATH_NAME CHAR 100
HIERARCHICAL DIRECTORY TREE LEADING TO SCHEMATIC

BOARD_ID CHAR 10
IDENTIFIER OF THE BOARD

REF_DESIGNATOR CHAR 5
IDENTIFIES THE INSTANCE OF A COMPONENT WITHIN A SCHEMATIC

MIL_SPEC CHAR 30
ENTIRE MIL NUMBER INCLUDING DASH NUMBER. EX: MIL-C-39006/22-0640R

ACTL_MAX_V NUM 20,10
ACTUAL MAXIXMUM VOLTAGE APPLIED ACROSS A COMPONENT DURING SIMULATION
UNIT OF MEASURE - VOLT

DERATED_MAX_V NUM 20,10
DERATED MAXIMUM VOLTAGE FROM DEREX
UNIT OF MEASURE - VOLT

ACTL_MAX_I NUM 20,10
ACTUAL MAXIMUM CURRENT
UNIT OF MEASURE - MILLIAMP

DERATED_MAX_I NUM 20,10
DERATED MAXIMUM CURRENT FROM DEREX
UNIT OF MEASURE - MILLIAMP

HOT_SPOT_TEMP NUM 20,10
OUTPUT COMPONENT TEMPERATURE FROM PCB THERMAL.

FAILR_RATE NUM 20,10
RATE OF FAILURE FOR A PARTICULAR UNIT

TABLE NAME: CLUTCH

DSGN_NAME	CHAR	20
DESIGN NAME OR END ITEM NAME		
PART_NO	CHAR	19
PART NUMBER		
PART_QTY	NUM	10
THE NUMBER OF PARTS		
REF_NO	CHAR	10
REFERENCE NUMBER.		
ASSY_PART_NO	CHAR	19
PART NUMBER IN THE ASSEMBLY DESIGN		
MIL_SPEC	CHAR	30
ENTIRE MIL NUMBER INCLUDING DASH NUMBER. EX: MIL-C-39006/22-0640R		
FSCM	CHAR	5
FEDERAL MANUFACTURING CODE		
PART_DESC	CHAR	40
PART DESCRIPTION		
OP_TEMP	NUM	20,10
OPERATING TEMPERATURE UNIT OF MEASURE - DEGREES F		
CLUTCH_TYPE	CHAR	1
TYPE OF CLUTCH		
CLUTCH_DISC_QTY	NUM	20,10
NUMBER OF DISCS IN THE CLUTCH		
LINING_TYPE	CHAR	1
BRAKE OR CLUTCH LINING TYPE: SINTERED, RESIN-ASBESTOS (LIGHT), RESIN-ASBESTOS (HEAVY), CARBON-CARBON		
MTBF	NUM	20,10
MEAN TIME BETWEEN FAILURE IS A RELIABLILITY FIGURE OF MERIT UNIT OF MEASURE - HOURS		
FAILR_RATE	NUM	20,10
NUMBER OF EXPECTED FAILURES PER MILLION HOURS UNIT OF MEASURE - PER MILLION HOURS		

```
TABLE NAME:  STRUCT_DSGN_FILE

   DSGN_NAME          CHAR           20
      DESIGN NAME OR END ITEM NAME

   FILE_NAME          CHAR          132
      NAME OF THE FILE WHERE A PARTICULAR DESIGN IS KEPT


   FILE_TYPE          CHAR            2
      FILE TYPE. ET-TOP LEVEL, ES-SCHEMATIC, EB-BOARD
      FOR NRLA ET-ELECTRICAL, ST-STRUCTURAL, M-MECHANICAL

   REL_AMBNT_TEMP     NUM            15,10
      AMBIENT TEMPERATURE USED DURING RELIABILITY ANALYSIS
      UNIT OF MEASURE - DEGREE

   THRML_AMBNT_TEMP   NUM            15,10
      AMBIENT TEMPERATURE USED DURING THERMAL ANALYSIS
      UNIT OF MEASURE - DEGREE


   MTBF               FLOT
      MEAN TIME BETWEEN FAILURE IS A RELIABLILITY FIGURE OF MERIT
      UNIT OF MEASURE - HOURS

   LIFE_EST_HRS       FLOT
      ESTIMATED LIFE, I.E., THE TIME AT WHICH FAILURE IS FIRST INITIATED
      UNIT OF MEASURE - HOUR


   LIFE_EST_CYCLES    FLOT
      NUMBER OF CYCLES UNTIL FAILURE


   MEAN_TIME_BET_DMND FLOT
      FIELD MAINTENANCE DEMAND DATA -- FOR STRUCTURES, THIS IS FREQUENCY O
      MAINTENANCE REQUIRED IN THE FIELD, AND IS AN INDICATION OF MTBF
      UNIT OF MEASURE - HOUR

   DMND_RATE          FLOT
      SIMILAR TO FAILURE RATE, REPRESENTS THE FIELD FAILURE RATE. USED TO
      CALCULATE MEAN TIME BETWEEN DEMAND
      UNIT OF MEASURE - PER MILLION HR
```

TABLESPACE: RAMCADN - NRLA TABLES

TABLE NAME: END_ITEM

END_ITEM CHAR 20
END ITEM OR DESIGN NAME.

FILE_TYPE CHAR 2
FILE TYPE. ET-TOP LEVEL, ES-SCHEMATIC, EB-BOARD
FOR NRLA ET-ELECTRICAL, ST-STRUCTURAL, M-MECHANICAL

DSGN_NAME CHAR 20
DESIGN NAME OR END ITEM NAME

SE_DEVL_COST NUM 9,2
COST OF SUPPORT EQUIPMENT DEVELOPMENT
UNIT OF MEASURE - $1000

SENSTVY_CD CHAR 1
SENSITIVITY CODE INDICATES: NONE, LRU COST, SRU COST, LRU MTBF, OR A

HI_SENSTVY NUM 2,1
UPPER RANGE OF SENSITIVITY RATIO

LO_SENSTVY NUM 2,1
LOWER RANGE OF SENSITIVITY RATIO

SENSTVY_TYPE NUM 1
"0" INDICATES TO COMPUTE SENSITIVITY SOLUTION FOR THE EXTREMES
OF THE INDICATED RANGE. "1" INDICATES COMPLETE SENSITIVITY.

RVSN_ID CHAR 20
REVISION IDENTIFIER

WT_RATIO_CONUS NUM 7,3
RATIO OF PACKAGED ITEM WEIGHT TO ITEM WEIGHT FOR CONUS SHIPMENT

WT_RATIO_OS NUM 7,3
RATIO OF PACKAGED ITEM WEIGHT TO ITEM WEIGHT FOR OS SHIPMENT

TECH_DATA_COST NUM 6,2
COST RATE PER PAGE OF TECHNICAL REPAIR DATA
UNIT OF MEASURE - $/PAGE

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