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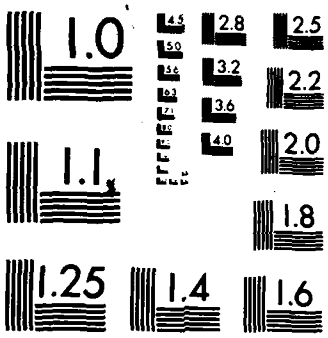

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CAD/CAM TECHNOLOGY WORKING GROUP REPORT

(IDA/OSD R&M STUDY)

Jack D. Osborn
Structural Dynamics Research Corp.
Working Group Chairman

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August 1983

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

This document records the activities and presents the findings of the CAD/CAM Technology Working Group, part of the IDA/OSD Reliability and Maintainability Study conducted during the period from July 1982 through August 1983.

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CAD/CAM TECHNOLOGY WORKING GROUP REPORT

(IDA/OSD R&M STUDY)

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Working Group Chairman

August 1983

INSTITUTE FOR DEFENSE ANALYSES
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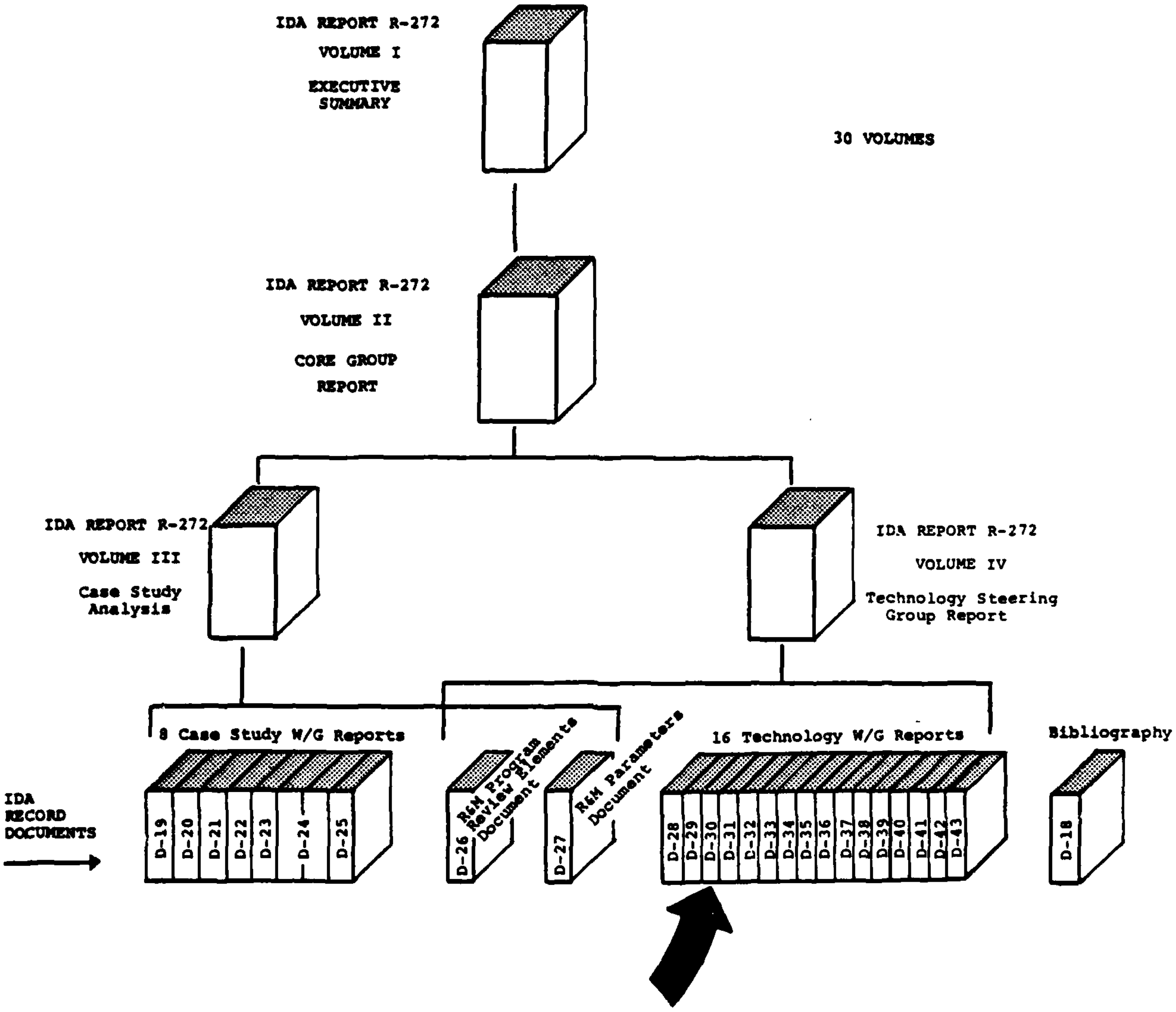
RELIABILITY AND MAINTAINABILITY STUDY

— REPORT STRUCTURE —



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PREFACE

As a result of the 1981 Defense Science Board Summer Study on Operational Readiness, Task Order T-2-126 was generated to look at potential steps toward improving the Material Readiness Posture of DoD (Short Title: R&M Study). This task order was structured to address the improvement of R&M and readiness through innovative program structuring and applications of new and advancing technology. Volume I summarizes the total study activity. Volume II integrates analysis relative to Volume III, program structuring aspects, and Volume IV, new and advancing technology aspects.

The objective of this study as defined by the task order is:

> "Identify and provide support for high payoff actions which the DoD can take to improve the military system design, development and support process so as to provide quantum improvement in R&M and readiness through innovative uses of advancing technology and program structure."

The scope of this study as defined by the task order is:

> To (1) identify high-payoff areas where the DoD could improve current system design, development program structure and system support policies, with the objective of enhancing peacetime availability of major weapons systems and the potential to make a rapid transition to high wartime activity rates, to sustain such rates and to do so with the most economical use of scarce resources possible, (2) assess the impact of advancing technology on the recommended approaches and guidelines, and (3) evaluate the potential and recommend strategies that might result in quantum increases in R&M or readiness through innovative uses of advancing technology.

The approach taken for the study was focused on producing meaningful implementable recommendations substantiated by quantitative data with implementation plans and vehicles to be provided where practical. To accomplish this, emphasis was placed upon the elucidation and integration of the expert knowledge and experience of engineers, developers, managers, testers and users involved with the complete acquisition cycle of weapons systems programs as well as upon supporting analysis. A search was conducted through major industrial companies, a director was selected and the following general plan was adopted.

General Study Plan

Vol. III • Select, analyze and review existing successful program

Vol. IV • Analyze and review related new and advanced technology

Vol. II (• Analyze and integrate review results
(• Develop, coordinate and refine new concepts

Vol. I • Present new concepts to DoD with implementation plan and recommendations for application.

The approach to implementing the plan was based on an executive council core group for organization, analysis, integration and continuity; making extensive use of working groups, heavy military and industry involvement and participation, and coordination and refinement through joint industry/service analysis and review. Overall study organization is shown in Fig. P-1.

The basic technology study approach was to build a foundation for analysis and to analyze areas of technology to surface: technology available today which might be applied more broadly; technology which requires demonstration to finalize and reduce risk; and technology which requires action today to provide reliable and maintainable systems in the future. Program structuring implications were also considered. Tools used to accomplish

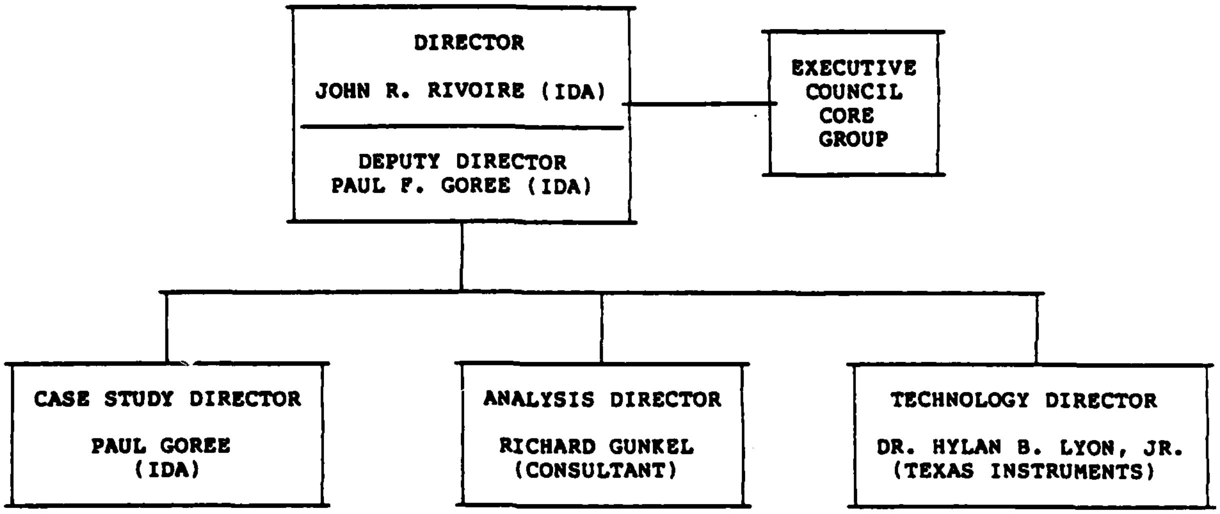

FIGURE P-1. Study Organization

this were existing documents, reports and study efforts such as the Militarily Critical Technologies List. To accomplish the technology studies, sixteen working groups were formed and the organization shown in Fig. P-2 was established.

This document records the activities and findings of the Technology Working Group for the specific technology as indicated in Fig. P-2. The views expressed within this document are those of the working group only. Publication of this document does not indicate endorsement by IDA, its staff, or its sponsoring agencies.

Without the detailed efforts, energies, patience and candidness of those intimately involved in the technologies studied, this technology study effort would not have been possible within the time and resources available.

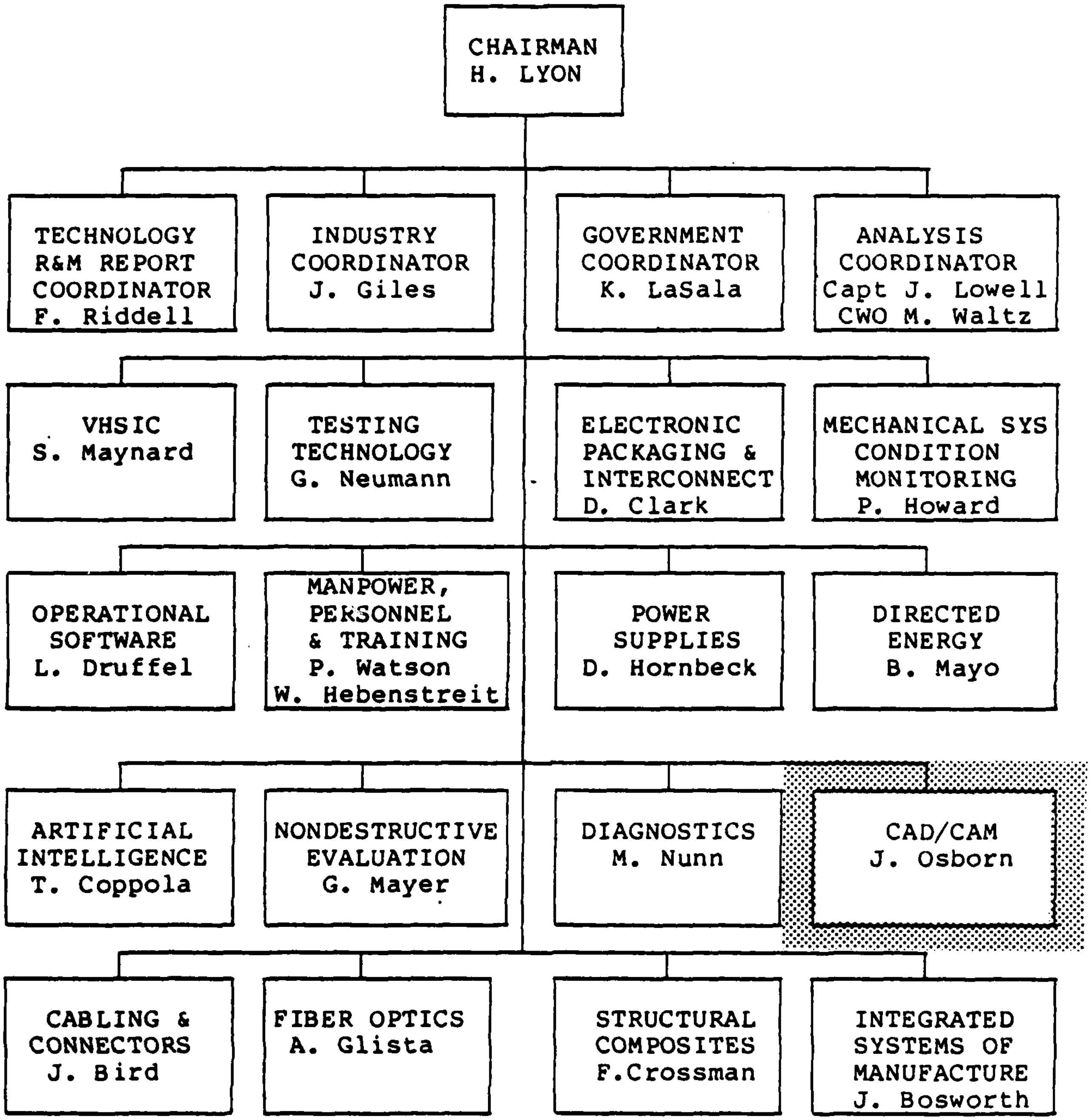

FIGURE P-2. Technology Study Organization

OSD/IDA R & M STUDY

CAD/CAM TECHNOLOGY WORKING GROUP

REPORT

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APRIL, 1983

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Jack Osborn

Chairman, CAD/CAM Technology Working Group

DURING THE COURSE OF THE OSD/IDA R & M STUDY THE INTEREST WITHIN THE SERVICES RESULTED IN THE INITIATION OF A TRI-SERVICE CAD R & M PROGRAM, DESCRIBED IN APPENDIX A.

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D. Example of Computer-Aided Technologies in Use

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- SDRC Newsletters and Case History Briefs

OSD/IDA R & M STUDY

CAD/CAM TECHNOLOGY WORKING GROUP

EXECUTIVE SUMMARY AND RECOMMENDATIONS

STATEMENT OF WORK

GOAL: To identify the means by which computer-aided technologies can lead to quantum improvements in R & M

SCOPE:
1. Articulate a model of the process of taking a weapons system from concept to product using computer-aided technologies
2. Identify critical information flows
3. Define the engineering process that takes advantage of these technologies

ISSUES:
1. Using CAD/CAM to wire in the implementation of R & M
2. Identifying the unnecessary loops in the process
3. Establishing the concept of significant reduction in manufacturing time
4. Information Flows

This Report

Two major issues concerning Computer-Aided Technologies are developed in this report.

- Effective Application of Existing Computer-Aided Technologies
- Communications among sub-sets of Computer-Aided Technologies

The effective application development includes all items from Work Statement Scope, and items 1, 2, and 4 from the Work Statement Issues.

Communications development includes Item 2 from the Work Statement Scope, and items 2, 3, and 4 from the Work Statement Issues.

In this report CAD/CAM is considered in its very broadest definition from early design concept, to selection of a "best" concept, to detail engineering, to drafting, to production engineering, to manufacturing, to product. It is intended to cover the broad spectrum of Computer-Aided Technologies of which CAE (Computer-Aided Engineering), CAD (Computer-Aided Drafting or Design). CAM (Computer-Aided Manufacturing), NC-CNC-DNC (Numerical Control), and CIM (Computer Integrated Manufacturing) are examples of sub-sets.

Improvements in the application of existing technology or in communications between sub-sets of these Computer-Aided Technologies will have a major impact not only on improved reliability or designed in maintainability, but on our National productivity.

Effective Application of Existing Computer-Aided Technologies

The Problem: Excellent Computer-Aided Technology exists. More is developing. Yet, these technologies are often mis-applied, applied too late in the design cycle, or are simply under-utilized.

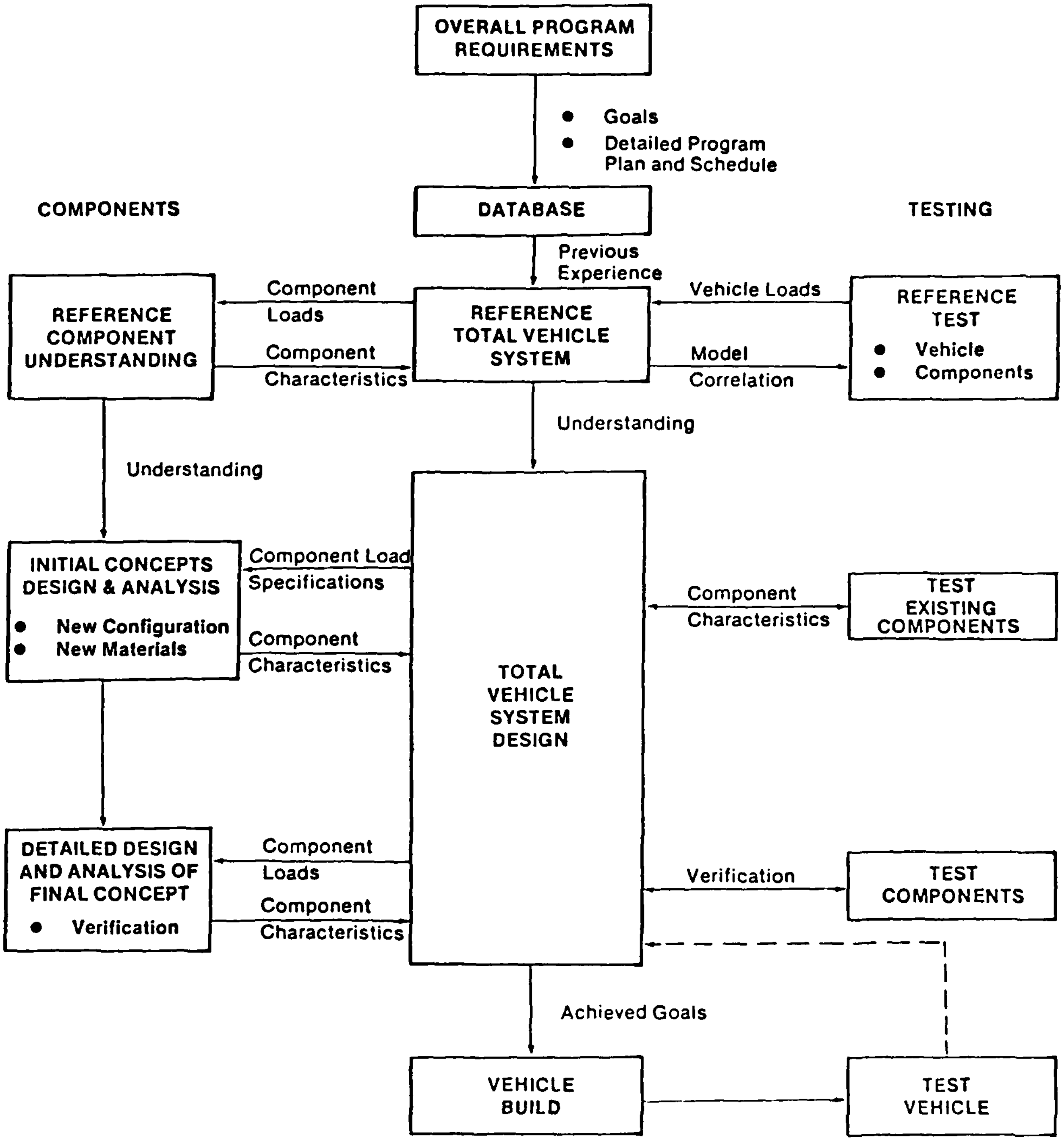
Summary: The report articulates a model of the process of taking a weapons system from concept to product using Computer-Aided Technologies. The model is in the form of a proposal for the development of an hypothetical amphibious tracked attack vehicle, the (ATAV).

The model is focused in the Computer-Aided Engineering (CAE) process. It is an important part of getting a weapons system from concept to product in a mechanical engineering process as illustrated. There are good examples of this same process in the real world illustrating savings in time and dollars, but more importantly arriving at better designs because many concepts could quickly be evaluated before the design became "locked in." Had an electronic chip design been used as an example, the Computer-Aided Design (CAD) sub-set of Computer-Aided technologies would have been focused upon. (During this study a highly effective chip design system was observed at the Naval Avionics Facility, Indianapolis, resident on a CAD/VAX Environment.)

Other sub-sets such as CAM or NC could also provide striking examples of savings in time and dollars. The linking of these sub-sets then becomes a multiplier of the effectiveness of Computer-Aided Technologies. The problems of achieving these links are covered under Communications.

An Illustration:

This illustration of the CAE process stresses the use of a System Model, early relative evaluation of various concepts using simple or coarse analytical models, and the selection of a "best" concept before proceeding with design. When applied this process provides the highest probability that the design effort will be spent on the



Overall Approach to Vehicle Design

most correct design concept so that effort is not spent developing poor concept. Tooling or other investment do not become locked into bad concepts that are later very difficult to change. In most cases, late changes result in cost overruns and patched up products. As this process relates to R & M, the early evaluation of many concepts derives a best concept. Careful thought to R & M when deriving this "best concept" assures the highest probability for reliability and "designed in" maintainability. The process also permits later evaluation of test data with an understanding of what should be happening in the system. This permits corrections evaluated on design assumption modifications. Testing no longer indicates a simmple pass/fail. The best fix for the behavior demonstrated by the test can be developed using the system model.

An examination of some of the savings inherent in Computer-Aided Technologies is illustrated here. The first table is from the CAD/CAM Sub Committee report to MTAG-82, headed by Fred Michel, Director of Manufacturing Technology, US Army DARCOM.

MTAG-82

CAD/CAM SUBCOMMITTE

CAD/CAM IS PRODUCTIVITY

- Product Design Engineers 5 to 1
- Process Engineers 6 to 1
- Tool Design Engineers 4 to 1
- Facilities Engineers 7 to 1
- Industrial Engineers 2 to 1
- Quality Engineers 3 to 1
- N/C Design Centers Productivity 30% to 40%
- N/C Programmers 80%
- Skill trades 30%
- Business 4 to 1
- Reduced Lost Time for Direct Labor
- Automated Inspection
- Equipment Utilization 10% to 20%
- Work in Process Reduction 25%
- Manufacturing Cycle Time Reduction 75%

SOURCE: Various

These results can be multiplied by adding in CAE. It is estimated that an added 27% in time alone, can be achieved by using CAE with CAD. Perhaps, the best comment on what Computer-Aided Technologies can do when they are applied came from the Vice President and General Manager of a major supplier of road building equipment. Commenting on the use of CAE, he stated that "Not only did we save $500,000 and 6 months of time, but without this technology we couldn't have done our redesign this way at all." The company had looked at a combination of five different configurations for the suspension of a new road scraper. The vice president noted that it would have taken twice the time and more than twice the money to evaluate only one concept using traditional methods. The real payoff was the discovery of a better concept before detail design began. Without the use of CAE's early relative concept evaluation; the company would have spent their year working on the wrong concept.

Recommendations:

- Promote the use of Computer-Aided Technologies. Computer-Aided Engineering with early relative evaluation of many concepts is demonstrated in the model in the report. This early relative evaluation improves the probability that all of the functions that follow will be applied to the "best concept" available among the alternatives. It speeds the entire process by:
    - Starting the engineering process with relative selection of a "best concept."
    - Builds in reliability by using a systems model to evaluate the effect of components as they are added.

- Permits the logical thinking through asembly so that maintenance is enhanced.
- Provides understanding of the final product, by comparison of test data to the systems model. This permits fast, accurate analysis and correction of problems that may appear after manufacture.

Each Computer-Aided Technology sub-set has its own "rewards" for proper use. Companies demonstrating the use of these technologies should be rewarded for their ability to shorten the weapons development cycle.

- Use the advantages that exist now in each sub-set of the technology such as CAE, CAD, CAM, NC, CNC, DNC, Robotics, Parts Systems, and so on to maximize productivity, minimize rework in manufacturing, and to assure the highest probability that the product produced will be reliable and can be maintained.

Communications Among Sub-Sets of Computer-Aided Technologies

The problem: Each sub-set of Computer-Aided Technologies has been developed to optimize the task of that sub-set, for example Computer-Aided Drafting. It has logically been developed to accomplish the task and to pay for itself out of economic paybacks generated by savings within. The sub-set CAD (the drafting function), is an excellent example of marked gains in time, effectiveness, and lower cost by the optimization of one sub-system.

The problem is that these sub-sets do not effectively communicate with each other or, in most cases do not communicate critical information flows at all. The same data is recreated in many of the sub-sets, mostly by manual transfer of critical information. Re-entry of data costs time and money.

Summary: There are many efforts by bright, dedicated people addressing the data communications and interfacing problems. These include.

- IGES - Initial Graphics Exchange Specification supported by the National Bureau of Standards
- ANSI - American National Standards Institute
- IPAD - Integrated Program for Aerospace Design supported by NASA
- I-CAM - Integrated Computer-Aided Manufacturing supported by the Air Force
- CAM-I Computer-Aided Manufacturing International supported by the Industrial Community
- Standard Communications Protocols (i.e. ETHERNET, DECNET, SNA, etc.
- Standard Graphics Specification (i.e. Sigraph, ANSI, GKS, etc.)

The successful implementation of one of these efforts or others like them, is inadequate to solve the problem. The implementation and coordination of all of them is necessary to relieve our current situation and define the direction for further investigation. Because the task is so large, it is important that we provide the funds to accelerate current efforts and develop interfaces and integration capabilities. If this is accomplished the payoff's will far exceed that which is now planned.

Recommendations:

- Fund a demonstration system by designing an integrated system, developing and installing it at a major defense contractors shown schematic in Figure 1.
- Fund NASA to accelerate the IPAD project and move the Data Base system being developed to several other computers.
- Fund the National Bureau of Standards to provide working funds to the IGES working groups, in order to accelerate the format specifications of CAD data and develop modules which make the data compatible with data base management systems.
- Fund the Air Force to accelerate the I-CAM programs for manufacturing and provide compatibility with the base management systems.
- Fund CAM-I to complete the specifications for transferring data and interfacing with a geometric modeling module.
- Fund the development of a generic geometry manipulation module starting with CAM-I's interface specifications and Boeing's geometry specifications.

- Fund the development of a generic user interface and 3D graphics display module.
- Provide matching funds to the CAD software and hardware manufacturers to implement the data transfer formats which are specified.
- Fund the computer manufacture to provide compatibility among the several communications protocols which are being developed.
- Provide matching funds to defense contracting to accelerate the implementation of a data base system in their product development cycle and use of the other modules which are being developed.

Recommendations Summarized in Terms of Technology Issues

TECHNOLOGY INSERTION

Currently, there is an extensive base of CAD/CAM technologies. However, these technologies are often improperly applied, applied too late in the design process or are simply not used enough. The effectiveness of these technologies has been shown in major commerical applications and, to a lesser extent, in some military developments. Although there is a general awareness of the potential offered by CAD/CAM, the hinderances to its wide use center around the understanding of the many benefits that it can provide in specific developments and a full comprehension of the magnitude of the return on what is perceived by management to be a substantial investment. Therefore, the primary issues that confront the use of present CAD/CAM technology are: (1) the need to develop a CAD/CAM awareness campaign; (2) the need to establish incentives that make it economically advantageous (in the short term) for industries to employ CAD/CAM.

TECHNOLOGY MATURATION

There are now several programs underway for the maturation of computer-aided design and manufacturing (CAD/CAM) technology. Consequently, the primary issue for rapid CAD/CAM maturity is one of accelerating these programs in order to conduct critical capability demonstrations. Programs that should be accelerated and/or expanded are: the NSAA IPAD project; the NBS IGES working groups; the Air Force I-CAM project, development of generic geometry manipulation modules starting with CAM-I interface specifications and geometry specifications. Projects that develop compatibility among the several communication protocols and the development of contractor data base systems should be strongly encouraged to control the data flow between different distributed data bases. These efforts should be accompanied by the establishment of an integrated CAD/CAM system at major defense contractors to serve as a demonstration of CAD/CAM capability.

TECHNOLOGY CREATION

The primary technology creation issues for CAD/CAM technology are the development of:

- A generic three-dimensional geometry model or "engine".
- A generic user interface module.
- Systems to control the flow of data between distributed data bases of various CAD/CAM subsets.
- Modules to provide manufacturing constraints and related data in real-time during the engineering design process which would povide a feedback loop to design from manufacturing.

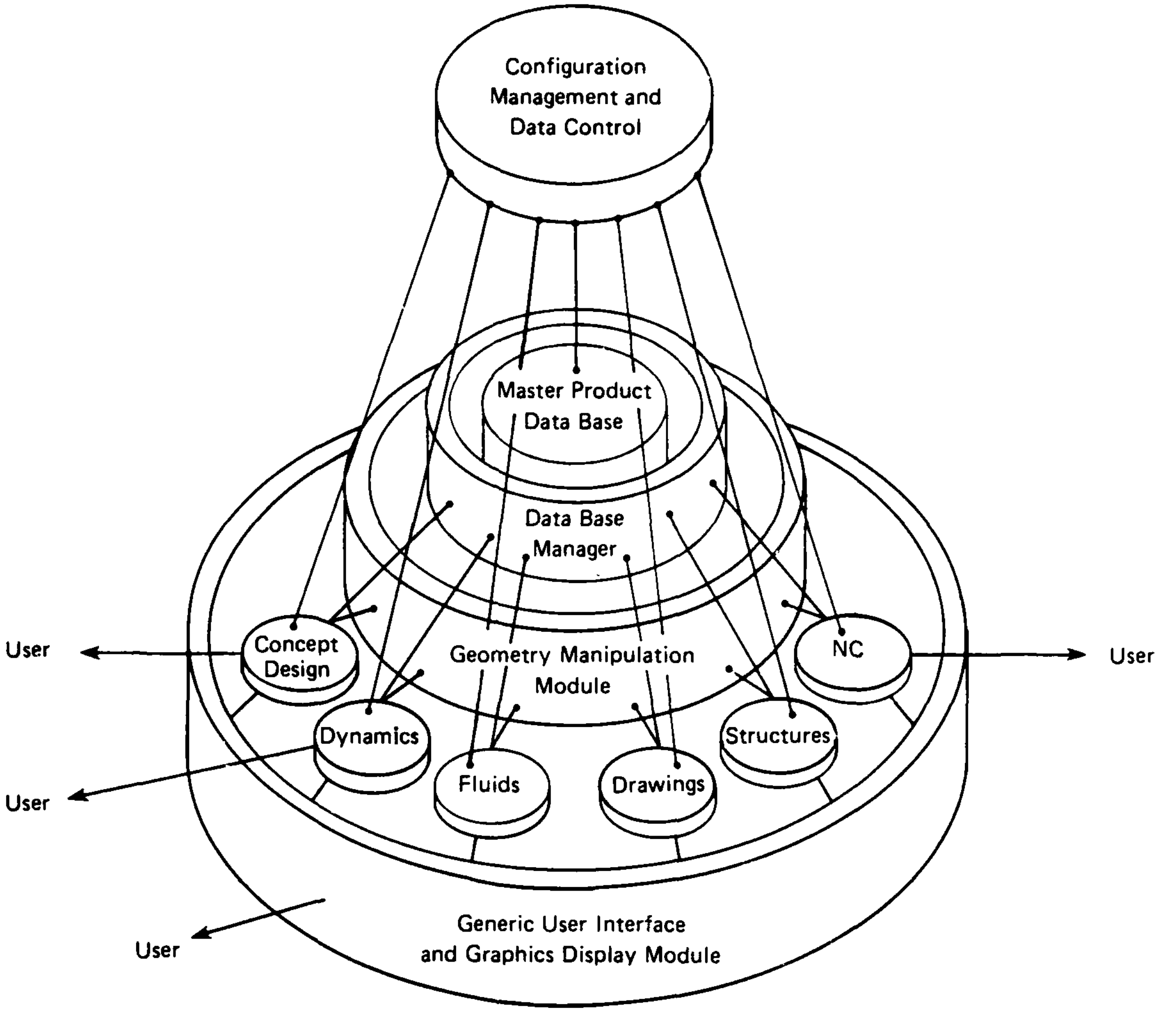


Figure 1
Integrated CAE/CAD/CAM/CIM System

OSD/IDA R & M STUDY

CAD/CAM TECHNOLOGY WORKING GROUP

REPORT

April, 1983

INTRODUCTION

The purpose of this report is to articulate a model of the process of taking a weapons system from concept to product using computer-aided technologies. Since CAD/CAM technologies have been available for a number of years the logical question is "Why haven't greater benefits in R & M been achieved using CAD/CAM?" This report will provide some insight to this question by examination of the engineering process that takes advantage of CAD/CAM technologies, and the examination of critical information flows in this process. Both the process and information flows will be described in the model (Part II). Part III will focus on Communications of information flows.

In the context of this report CAD/CAM is considered in its broadest definition. In its earlier years, CAD was, and still sometimes is, defined as Computer-Aided Drafting. It was considered to be an automation of the drafting process. As such it did and still does provide quantum advances in productivity by cutting the time required to produce drawings significantly.

CAD, in this paper, includes Computer-Aided Drafting and it includes Computer-Aided-Engineering. CAE is defined[1] as a set of engineering applications based on four interrelated computer technologies:

1. Computer data bases and communications
2. Computer graphics and geometric modeling
3. Computer simulations and analyses
4. Data acquisition and control

Each of these four areas of computer applications provides tools for modeling product performance. CAE modeling tools have their highest leverage and the highest ultimate pay backs when applied early in design.

---

[1] Marks, Peter, Managing Computer-Aided Engineering Technology, AMA Management Briefing, 1983, American Management Associations, New York. Page 8.

CAM refers to Computer-Aided Manufacturing. This is in the form of numerical control programming, parts coding, or other machine instruction tied into a data base created by a CAD system, or in some cases geometric data directly from a CAE model.

Computer-Integrated Manufacturing, CIM, is being used by various writers to describe an integrated system or CAE, CAD, CAM, Robotics, and data bases to describe factory automation or "Factories of the Future."

One set of tools that describes these Computer-Aided Technologies is the GE Engineering System used in mechanical engineering to speed the product development process.

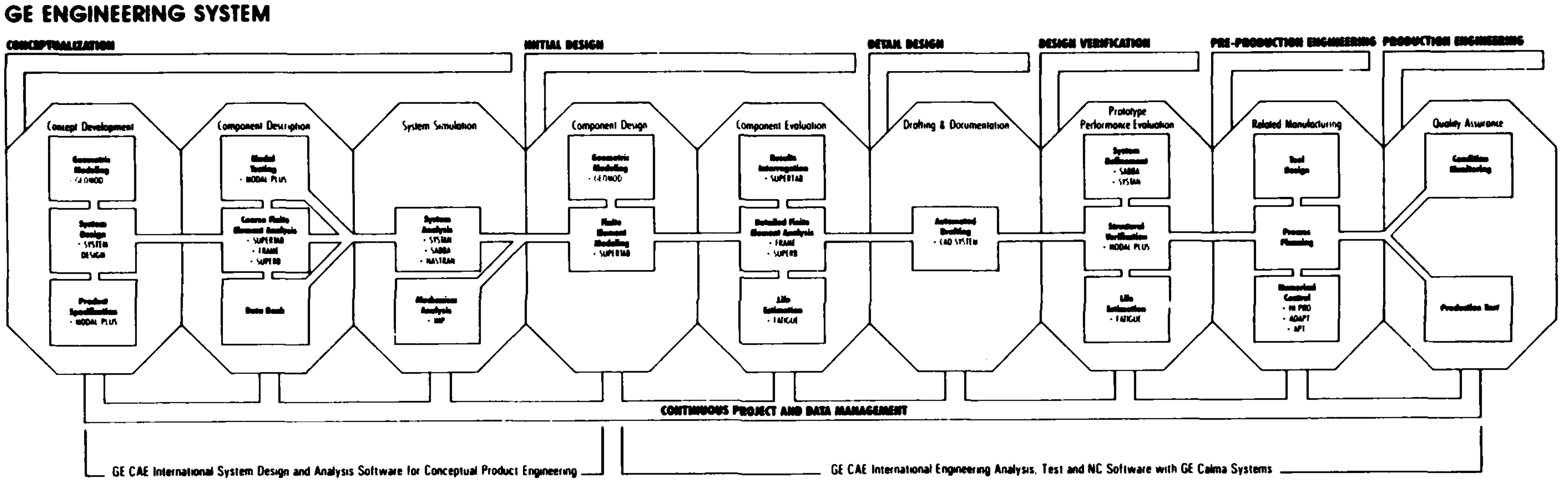
GE ENGINEERING SYSTEM
CONCEPTUALIZATION
INITIAL DESIGN
DETAIL DESIGN
DESIGN VERIFICATION
PRE-PRODUCTION ENGINEERING
PRODUCTION ENGINEERING
Concept Development
Geometric Modeling
· GEOMOD
System Design
· SYSTEM DESIGN
Product Specification
· MODAL PLUS
Component Description
Modal Testing
· MODAL PLUS
Coarse Finite Element Analysis
· SUPERTAB
· FRAME
· SUPERB
Data Bank
System Simulation
System Analysis
· SYSTAN
· SABBA
· NASTRAN
Mechanism Analysis
· IMP
Component Design
Geometric Modeling
· GEOMOD
Finite Element Modeling
· SUPERTAB
Component Evaluation
Results Interrogation
· SUPERTAB
Detailed Finite Element Analysis
· FRAME
· SUPERB
Life Estimation
· FATIGUE
Drafting & Documentation
Automated Drafting
· CAD SYSTEM
Prototype Performance Evaluation
System Refinement
· SABBA
· SYSTAN
Structural Verification
· MODAL PLUS
Life Estimation
· FATIGUE
Related Manufacturing
Tool Design
Process Planning
Numerical Control
· NC PRO
· ADAPT
· APT
Quality Assurance
Condition Monitoring
Production Test
CONTINUOUS PROJECT AND DATA MANAGEMENT
GE CAE International System Design and Analysis Software for Conceptual Product Engineering
GE CAE International Engineering Analysis, Test and NC Software with GE Calma Systems

FIGURE 1

This describes the parts of a CAE-CAD-CAM-CIM System in terms of tools. Let us now look at these tools as they could be applied to the development of a new amphibious tracked armored vehicle, or hypothetical ATAV.

THIS MODEL OF THE DEVELOPMENT OF THE ATAV IS BASED ON COMPUTER-AIDED ENGINEERING (CAE) AND ITS BENEFITS. EACH SUB-SET OF COMPUTER-AIDED-TECHNOLOGIES SUCH AS CAD, NC, ROBOTICS, PARTS SYSTEMS, ETC., HAS IT OWN EFFICIENCIES NOW EXISTING THAT SHOULD BE FULLY EXPLOITED TO IMPROVE PRODUCTIVITY.

The message this part of the study is trying to convey, is to USE WHAT EXISTS, or the INSERTION of existing technology.

NOTE:

The reader may substitute other CAE tools as appropriate in this model, for example where NASTRAN is used, ANSYS might be substituted. The author has used programs with which he is most familiar. See Appendix E, CAE Computer-Aided Engineering, 1982 SYSTEMS & Software Annual for a representation of other available programs.

PROGRAM MODEL FOR COMPUTER-AIDED ENGINEERING TECHNOLOGY TRANSFER AND APPLICATION TO AN HYPOTHETICAL WEAPONS SYSTEM THE AMPHIBIOUS TRACKED ARMORED VEHICLE (ATAV)

Prepared

for

OSD/IDA R & M STUDY
CAD/CAM TECHNOLOGY WORKING GROUP

Submitted

by

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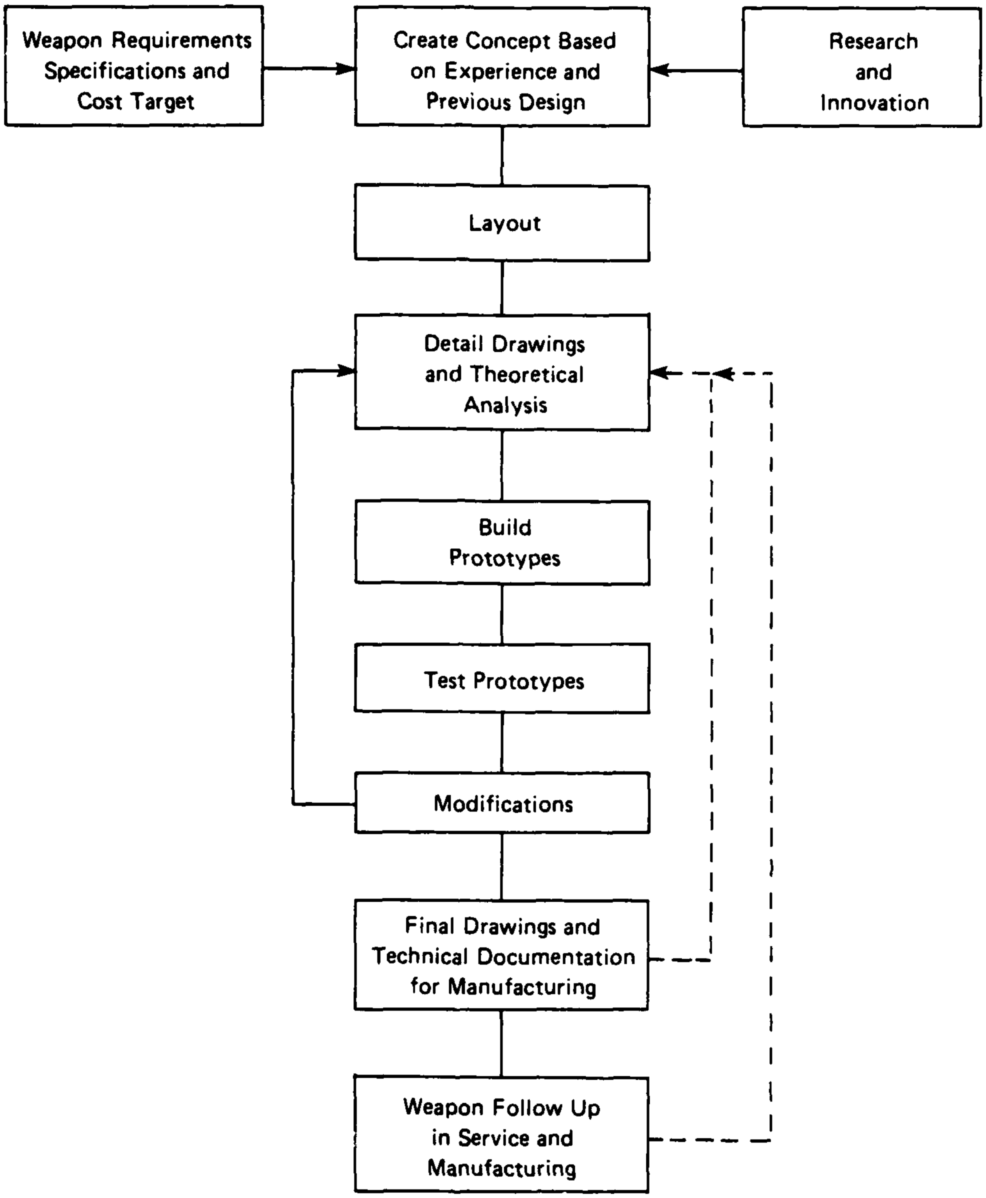


Figure 1
Typical Weapon Design Process in Mechanical Engineering

1. Model Introduction and Objectives

The traditional process for the development of a weapons system like the ATAV is shown in Figure 1.

This simplified flow chart shows the development process that traditionally starts with a concept based on prior experience, more likely with a former amphibious vehicle that will be "modernized" or "upgraded" to the new weapon. The result of this process is a set of drawings and technical documentation which is passed "over the wall" to manufacturing. Manufacturing is then expected to manufacture a low cost, quality product. Frederick J. Michel, Director, Manufacturing Technology, US Army Development and Readiness Command, in his CAD/CAM Subcommitte Report for MTAG-82 stated this problem very well, "And with the event of CAD and CAM this problem has not gone away... with the computerization of the engineering and design activities and the introduction of CNC, DNC, FMS, *simulation and other techniques* on the factory floor, we have not changed our approach. We continue to think of engineering and the factory as two separate entities, two separate two separate worlds."

For our hypothetical case, ABC Ordnance Corporation has embarked on a plan to improve productivity. We will examine this increased productivity by increasing automation of the engineering process. ABC Ordnance Corporation has already taken a typical first step in this process, the acquisition of a Computer-Aided Design (CAD) System. The next logical step is to provide the analysis, design, and test engineers with automatic access to the geometric data residing on the CAD system. Finally, an integrated set of analysis, design, and test software tools and compatible computer hardware should be incorporated to complete the total Computer-Aided Engineering (CAE) system. This process must be tailored to meet the specific needs of ABC Ordnance Corporation. It should have the capability of sending geometric data to manufacturing.

SDRC proposes to assist ABC in meeting this important objective. We are confident that together we can put ABC on the forefront of CAE technology. The accompanying increase in productivity will help ABC remain a major force in the military tracked vehicle market.

ABC Corporation is about to begin a sixteen-month effort to design a new amphibious tracked armored vehicle, the ATAV. Features of this new vehicle include:

- 20-man capacity plus 3- man crew
- low mass for air transport and buoyancy
- low cost
- C-141 airlift capacity
- mobility over 9-foot wide trench, 3-foot high wall
- rear door loading
- high speed over land and water

Since this is a competitive design phase, it is important that ABC develop a vehicle that meets or exceeds government specifications with the lowest possible mass and cost and the least development risk. Since prototype hardware will not be tested during this phase, it is important that ABC analytically demonstrate the specific performance capability of the new design.

Design concerns to be addressed in the ATAV conceptual design include:

- Packaging
    - maximum space utilization
    - minimum external size
    - crew capacity
    - gun clearance
    - mass properties

- Buoyancy
- Ballistics/survivability
- Visibility
- Mission variants (packaging and performance)
- Mobility (water and land)
- Ride
- Vibration
- Acoustics
- Gun stability
- Strength
- Fatigue
- Reliability
- Maintainability
- Manufacturing - tolerance
- Maximum Mission Effectiveness
- Minimum Cost
    - Rollaway
    - Life Cycle

By using the ATAV as a "pilot project" for transferring CAE technology into the ABC Ordnance Corporation, the opportunity exists to simultaneously optimize the vehicle design for high performance and low cost.

As shown in Figure 1, the envisioned CAE technology transfer program spans a time frame at least through the end of 1983 and possibly well into 1984. The timing depends upon ABC plans for computer hardware and software acquisition, training, staffing, etc. This obviously will entail a substantial commitment of funds. One of the most important tasks to be accomplished this year is to develop a CAE implementation plan. This joint effort between ABC and SDRC will result in a comprehensive plan including costs, schedules, and estimated incremental payback (ROI).

To facilitate technology transfer, a team approach is envisioned in which ABC and SDRC engineers will work together on all aspects of the project. Some tasks will involve predominantly ABC and others

OVERALL CAE IMPLEMENTATION SCHEDULE

1982 1983 1984

PHASE I

CAE EVALUATION PLANNING AND APPLICATION TO ATAV

DETAIL SCHEDULE AND COST

PHASE II

CAE IMPLEMENTATION

- TOOLS
- PROCESS
- APPLICATION

PHASE III

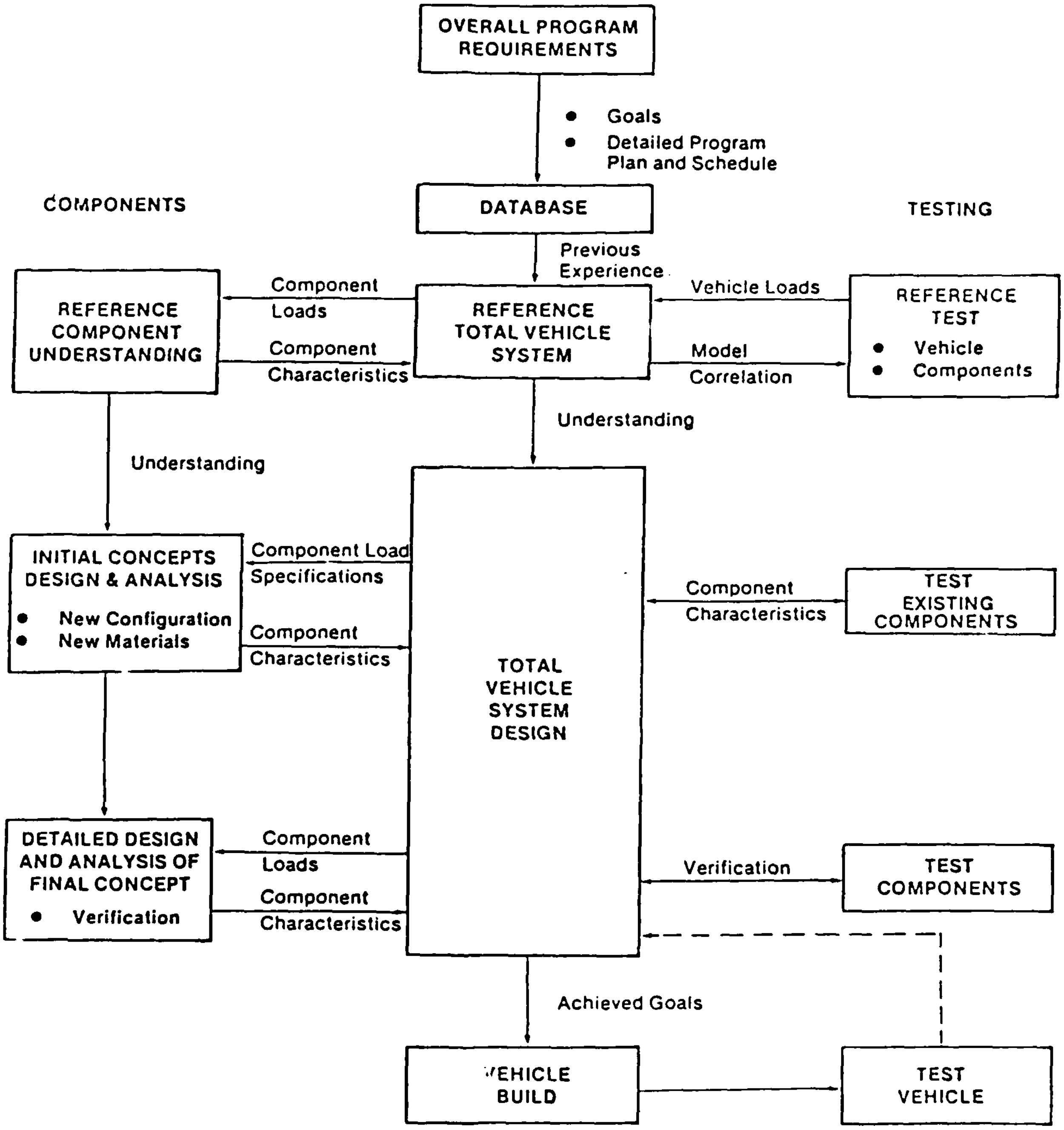
- CONTINUED APPLICATION
- ADVANCED DEVELOPMENT

predominantly SDRC, but all will be coordinated by the ABC and program managers to achieve program objectives. The proposed program consists of:

- CAE process
- CAE tools
- CAE application

These are discussed in detail in Section 3.

Cost and schedule information in this proposal covers tasks to be accomplished in 1982. Some tasks will continue into 1983, and several will not start until next year. Obviously, all of this is subject to ABC approval. We have attempted to prioritize tasks to keep the overall program within scope. We are anticipating changes as we begin to interact with ABC and tasks become more clearly defined. For this reason, we have quoted costs on a time-and-materials, not-to-exceed.



Overall Approach to Vehicle Design

2. CAE Approach

The CAE process as applied to vehicle design is shown in Figure 2. The process begins by defining in detail the vehicle design goals and constraints from government specifications and system mission analysis. A thorough review of previous similar ABC vehicle design, test, and analysis experience is carried out to document an initial design data base. Reference testing and analysis are carried out as needed to supplement existing ABC data and to further understand the prior vehicle's behavior. The objective is to begin the new design from a position of knowledge. The reference vehicle review can be carried out as three tasks.

(1) testing to more accurately define loads and to correlate analytical models,

(2) total reference vehicle system models to understand the fundamental causes for the performance of the existing vehicle, such as ride, and

(3) individual component analysis to determine and understand existing components' behavior such as torsion bar or track bushing life.

Without this important reference knowledge to guide the new design, much more time and costly iterations are required in the new design tasks or a less than optimal vehicle results. Understanding is the result of the reference review.

The CAE new vehicle design activity centers around a series of total vehicle system models. These start with simplified or coarse design concept vehicle simulations that allow investigation and ranking of new

new overall vehicle configurations. In conjunction with this, new component designs are developed with timely analytical support leading the designer. The total vehicle simulations define component loads and specifications while the component design and analysis work updates the total vehicle simulations with actual component characteristics. The exchange of timely information between the component designers and the total system designer is a critical aspect of this program. It is important in this early stage of the design process that all analysis work be done as simply and quickly as possible. This is necessary so that the analysis work can lead the design, rather than simply validate the finished design when little time is left. New components that may already exist may be tested at this time to obtain their properties to refine the system models.

For the ATAV, this initial concept design phase ends nine months after the start of the program.

The design geometry, total vehicle simulations, and component models become more detailed as the final design becomes better defined. Detail models of critical areas previously identified such as joints, corners, fasteners, etc., are developed to guide the design of these areas.

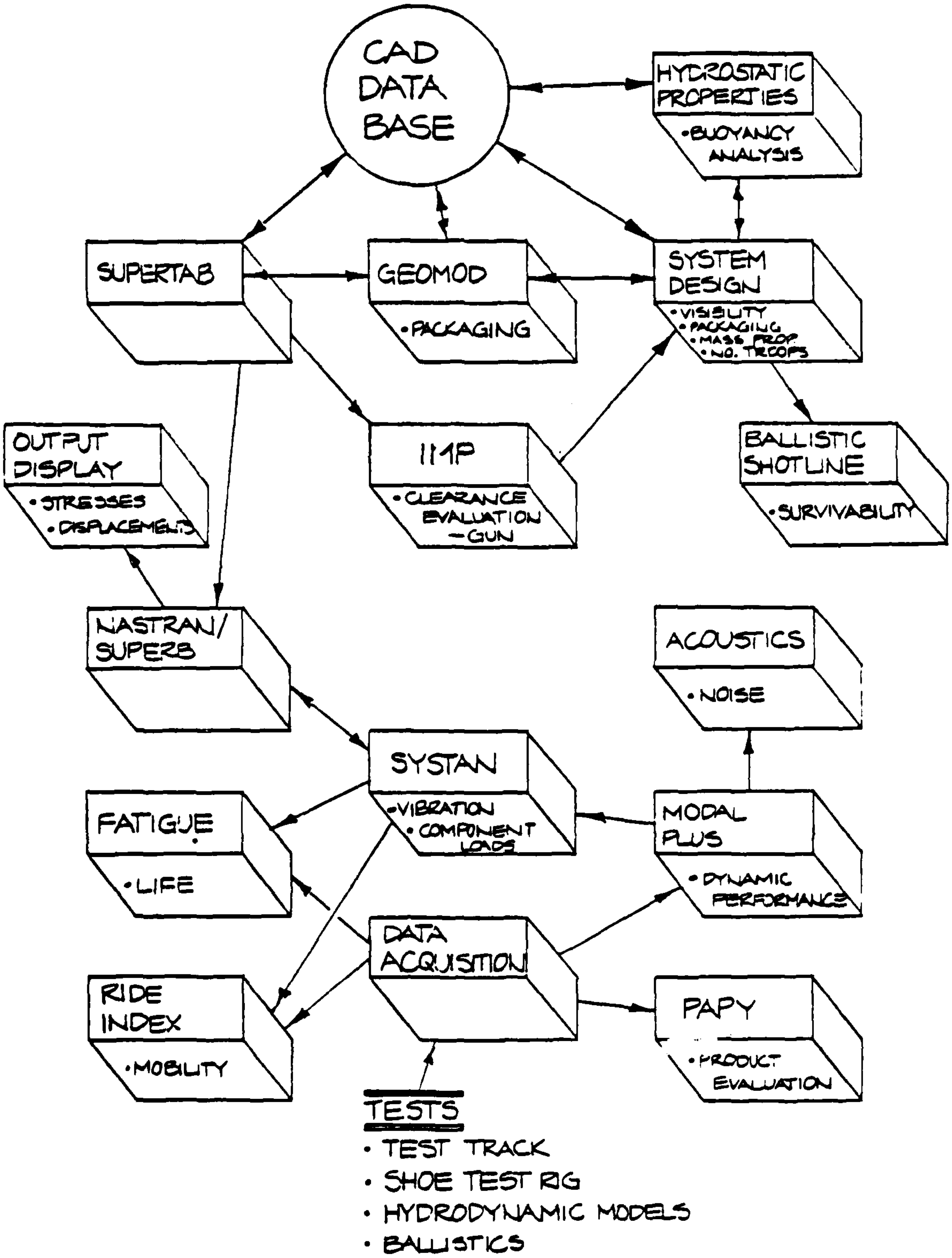
The detail design phase is completed approximately sixteen months after the start of the program. As prototype components become available, they are bench-tested to quickly validate their performance.

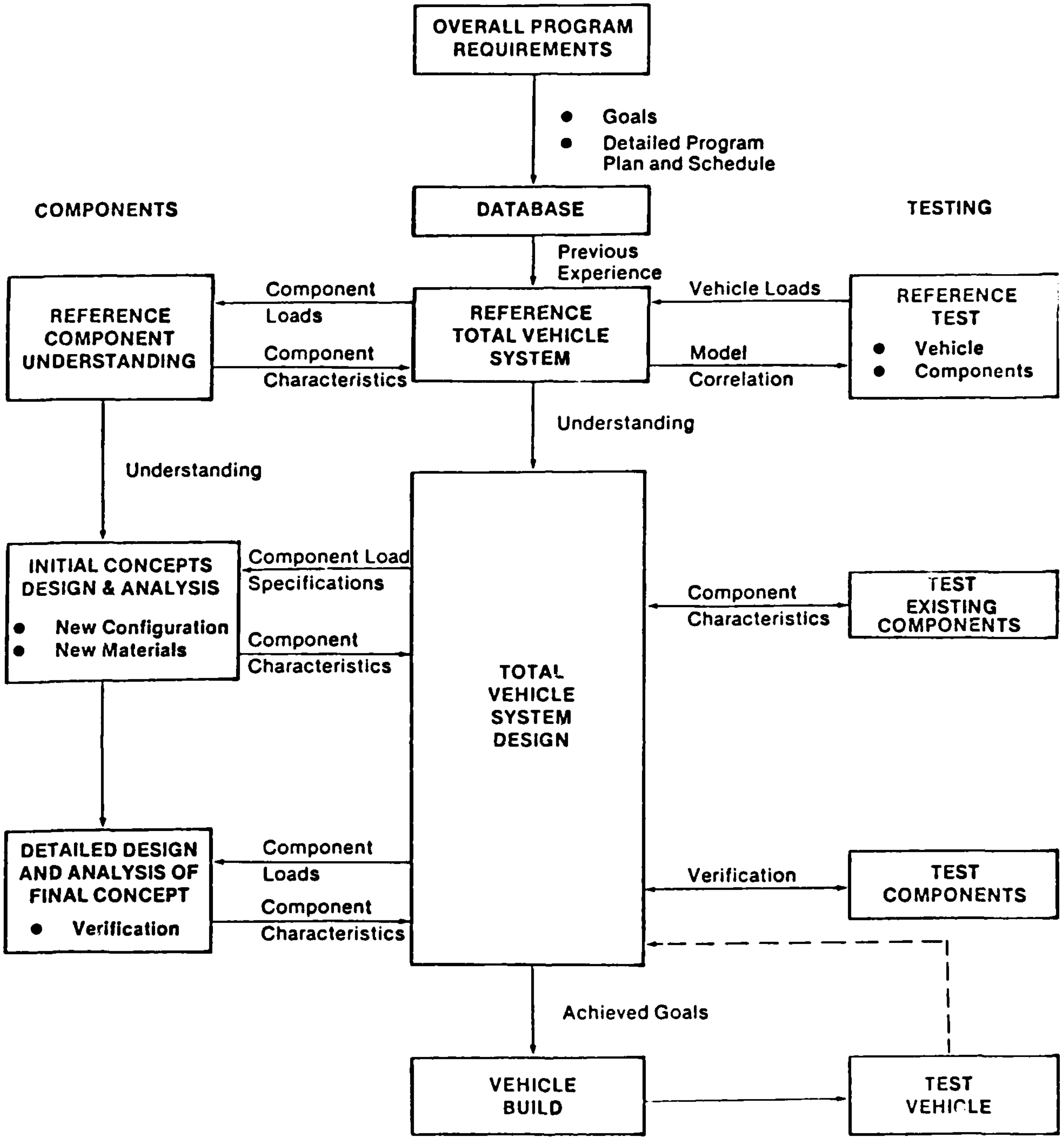
A prototype vehicle test is carried out when the initial prototype vehicle is built. The objective is to quickly verify vehicle and component performance. If any problems are discovered, the previously developed simulations are used to quickly investigate design modifications.

Documentation of all program results is stored in the "corporate" data base.

Let us now look at each of the tasks in the CAE process as they are applied in a project.

CAE TOOLS


CAD DATA BASE
HYDROSTATIC PROPERTIES
•BUOYANCY ANALYSIS
SUPERTAB
GEOMOD
•PACKAGING
SYSTEM DESIGN
•VISIBILITY
•PACKAGING
•MASS PROP.
•NO. TROOPS
OUTPUT DISPLAY
•STRESSES
•DISPLACEMENTS
IMP
•CLEARANCE EVALUATION —GUN
BALLISTIC SHOTLINE
•SURVIVABILITY
NASTRAN/ SUPERB
ACOUSTICS
•NOISE
SYSTAN
•VIBRATION
•COMPONENT LOADS
FATIGUE
•LIFE
MODAL PLUS
•DYNAMIC PERFORMANCE
DATA ACQUISITION
RIDE INDEX
•MOBILITY
PAPY
•PRODUCT EVALUATION
TESTS
• TEST TRACK
• SHOE TEST RIG
• HYDRODYNAMIC MODELS
• BALLISTICS



Overall Approach to Vehicle Design

PHASE I: PROJECT INITIATION

Task 1: Program Requirements

The objective of this task is to accurately define and set the vehicle specifications, goals, and constraints. This will be accomplished through the government specifiations and a study of the vehicle's mission analysis. Specific areas to be defined include:

- Design Criteria
  - speeds
  - range
  - capabilities
- Duty/Cycle/Environment
- Features
- Commercial Components
- Noise
- Ride
- Outside Dimensions
- Mass
- Cost
- Manufacturing Facilities

This task will result in a detailed engineering description of the new vehicles and hence guide the design effort. These overall specifications must remain fixed throughout the development program - since the CAE process will fully optimize the design, relatively small changes can drastically affect it and cause previous work to be discarded.

At this time, detailed planning and scheduling of the project team's tasks should be completed. This includes manpower and facilities planning as well as program organization and timetable scheduling. Specific action plans for each design team individual will be defined.

Task 2: Data Base Review

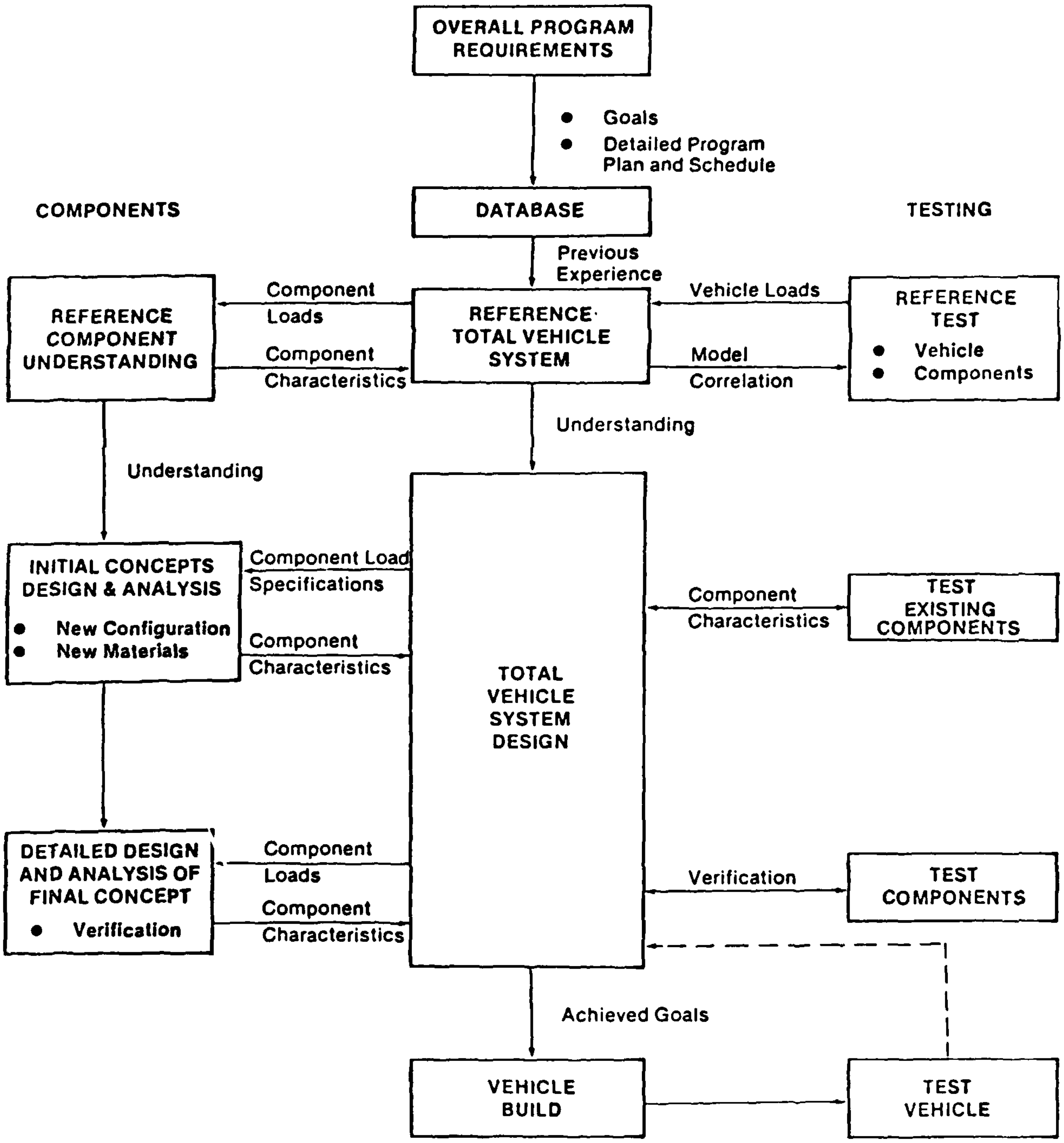
The objective of this task is to review and organize previous vehicle design, test and analysis experience as a starting point for the new design. Implied in this effort is the selection of an existing reference or vehicle similar to the ATAV such as the M-113 vehicle or the ALVIS AVP.

Previous data base information could include:

- Vehicle/Component Loads Set
- Duty Cycle
- Previous Test and Analysis Data for All the Design Concerns
- Reference Performance Levels that are to be Achieved or Bettered - for Example, Ride and Noise
- Previous Field Problems
- Cost/Mass Breakdown of the Reference Vehicle

The purpose of this review is to understand the fundamental behavior of the reference vehicle (with known field performance). This will help to direct the new design effort most efficiently. For example, it is important to know why the existing vehicle has good or poor ride quality, what causes its noise level, or why critical components fail before the new design starts.

Plans should be made to obtain any important missing information from either testing or analysis of the reference vehicle as described in the next section.



Overall Approach to Vehicle Design

PHASE II: REFERENCE VEHICLE REVIEW

The objective of the reference vehicle review is to obtain any important missing information about the reference vehicle. This activity can include:

- Reference Testing
- Reference Total Vehicle Simulations
- Reference Component Analysis

Task 1: Reference Tests

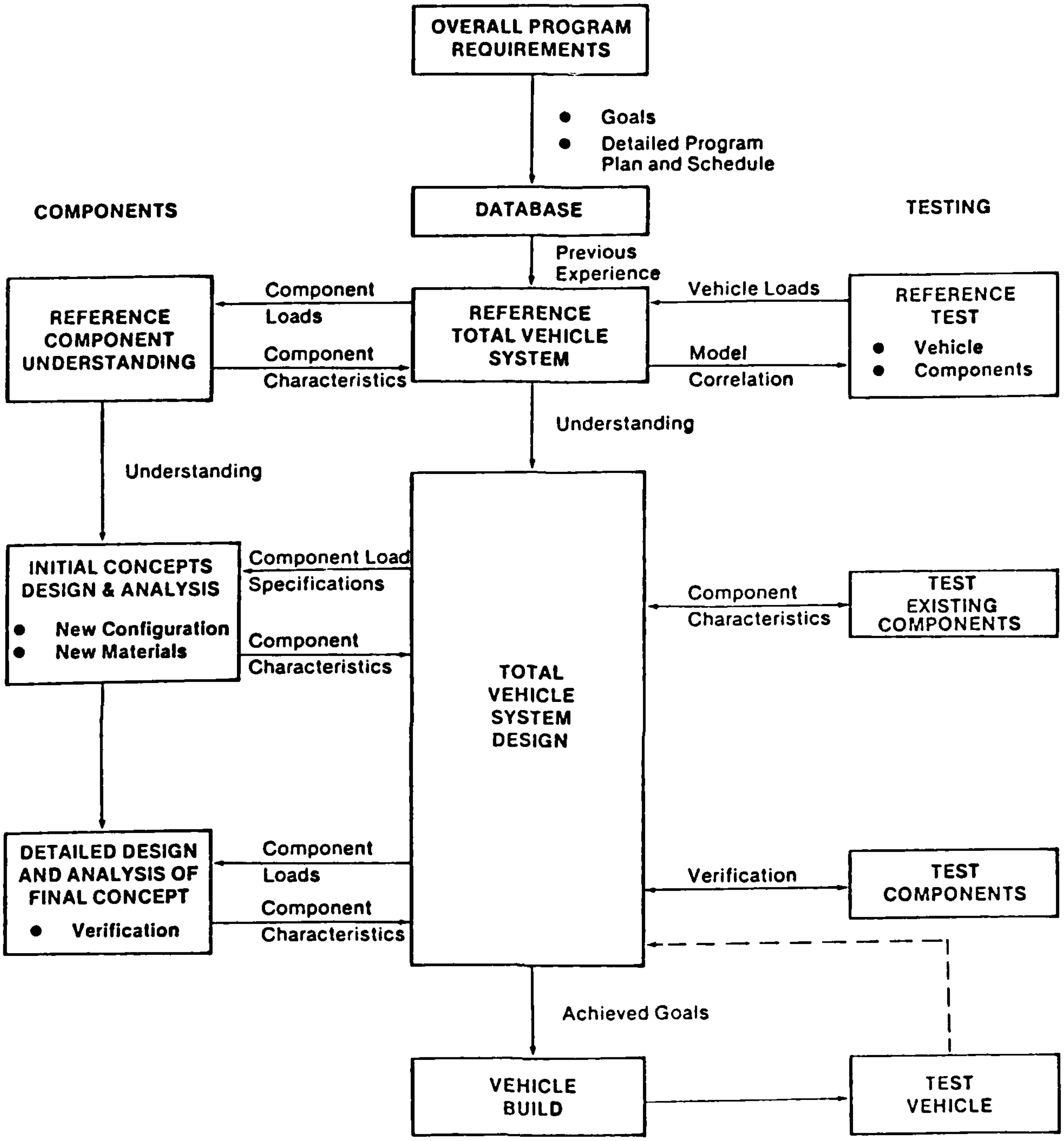
The reference vehicle testing may involve a series of tests to be performed on the reference vehicle. These tests either measure important parameters directly (such as loads) or measure characteristics (such as stress) to correlate and support reference analytical model development. As in all phases of this program, a close interaction between the testing and analytical work is important. This is achieved through the program manager.

Potential testing activities include:

- Operating Loads Test - The objective is to accurately define a vehicle duty cycle and vehicle load set that can be applied to analytical models. Both shock absorber, spring, bump stops would be instrumented at several wheels. In addition, accelerometers would measure overall vehicle motions. Data would be processed in histogram form to conveniently document the duty cycle.
- Structural Behavior - The objective of this test is to measure strains and deflections in critical components at selected areas (such as the frame joints or corners). These measurements would be obtained during a series of prescribed duty cycles

and staged events. This information would then be used to correlate an analytical model to the test data to ensure that an accurate simulation is obtained.

- Ride/Vehicle Dynamics Test - The objective of this test is to measure the actual ride of the reference vehicle over a known terrain. These ride levels are again compared to an analytical simulation to ensure that an accurate simulation is obtained. The reference vehicle ride levels become the design goals that the new vehicle must achieve. Acceleration at several locations would be measured and input to SDRC's RIDEINDEX program to predict watts absorbed and hours to decreased proficiency. Vehicle dynamic structural characteristics such as resonant frequencies and deflection mode shapes would also be measured at this time.
- Operator and Passby Noise Tests - The objectives of these tests are to determine the reference vehicle noise level for comparison to the new vehicle and to determine noise sources and noise paths. This information will guide the new vehicle design with respect to reducing noise levels.



Overall Approach to Vehicle Design

Task 2: Reference Total Vehicle Simulations

The purpose of developing and correlating reference vehicle simulations is threefold:

- to develop confidence in analytically predicting vehicle behavior since no hardware will be produced in the first sixteen months' effort.
- to understand fully the behavior of the reference vehicle so as to guide the new design effort.
- to serve as a baseline to evaluate the new vehicle's performance

A series of vehicle simulations may be developed to include:

- Loads Model - From the overall vehicle load set of, say, 5 G bump, 9 G pothole, etc., a loads model is developed to predict component loads. These loads are then used to design and analyze components.
- Ride/Vehicle/Dynamics - A simplified vehicle structure/suspension model is developed. Modes and vehicle ride are correlated to the test-measured data.
- Buoyancy Model - The vehicle buoyancy model is developed and compared to actual buoyancy measurements.
- Other Total Vehicle Simulations

In many cases, the new vehicle simulations will be simply modifications of these references vehicle simulations.

Task 3: Reference Component Understanding

The objective of this activity is to understand critical component behavior under the various component load cases generated from the previous system models. Finite element models of the critical components are developed, and their stiffness and stress distributions are determined. Carefully studying these component analyses in terms of load flow with the component, type of stresses, etc., provides an understanding of why the component is good or bad. This insight is then used in the subsequent task of new component design to guide the new design effort.

Computed component characteristics, such as hull stiffness and mass distributions, are used to improve the total vehicle simulations previously described.

Task 4: New Vehicle Design

The objective of this task is to design the new vehicle with appropriate analysis and test support. The vehicle design phase is separated into a concept design phase and a detailed design phase as in the ABC program plan. Each phase is comprised of several interactive tasks--hence the need for effective program management. In addition, all of the vehicle performance factors (often conflicting) must be addresssed as the vehicle is designed.

The concept design phase begins with generating overall total vehicle and specific component concepts. These conceptual ideas are supported and evaluated with appropriate analytical tools. It is necessary to iterate between the total system and components until an acceptable initial design is achieved. The rapid interaction and communication of information between the component design team (design, analysis, and test engineers) and the total vehicle designers in this early phase is critical to the overall success of the vehicle design. The right decisions have to be made at this time so that the "best vehicle" concept and component concept designs are selected for subsequent optimization. To make these design decisions, analytical support information and guidance must be available quickly. Test support for new existing off-the-shelf components that may be used in the new design is also provided at this time.

The detail design phase then proceeds after concept finalization. Both the design and analytical support work become more detailed to answer specific design questions. Design iterations continue until program performance goals are achieved.

Total Vehicle System Design

The objective of this task is to design the overall vehicle configuration and to optimize the vehicle performance concerns. Based on experience and the previous reference review, new vehicle concepts are developed in brainstorming sessions with ABC and SDRC personnel. The GEOMOD, SYSTEM DESIGN, and CAD graphics tools are used to visualize and explore system packaging optimization.

Various total vehicle system models are then developed (or previous reference models are modified) to evaluate the initial vehicle concept design configurations. These simple system models will help the design team:

- Compare to reference vehicle performance
- Give relative evaluation of changes in configuration

- Give relative evaluation of changes in configuration
- Relate vehicle performance to various component characteristics
(parametric studies)
- Define component specifications and loads
- Assist in selecting the best configuration

A series of total vehicle system models will be developed to address each of the vehicle performance concerns. These include:

Performance

- Mission Effectiveness
- Packaging
- Mass
- Cost
- Buoyancy
- Ballistics/survivability
- Mobility
- Visibility
- Ride
- Vibration
- Acoustics
- Gun stability
- Heat balance
- Strength
- Fatigue
- Wear/life
- Reliability
- Maintainability
- Manufacturability

CAE Tools

- CAD/CAM
- GEOMOD
- SYSTEM DESIGN
- IMP
- HYDROSTATICS
- BALLISTICS
- SUPERTAB
- SUPERB/NASTRAN
- OUTPUT DISPLAY
- FATIGUE
- SYSTAN
- RIDE INDEX
- MODAL-PLUS
- ACOUSTICS
- PAPY
- CAM

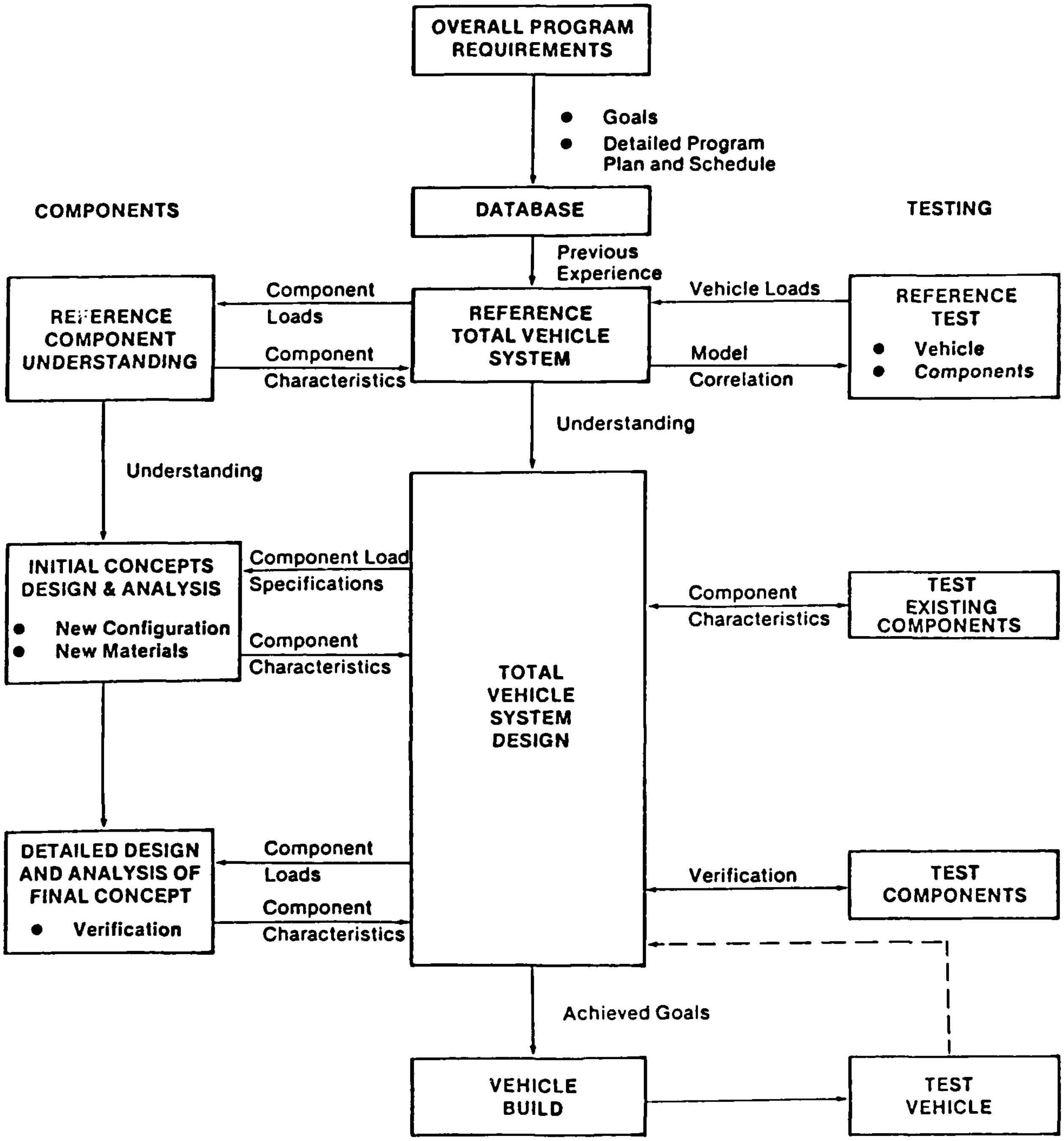
It is likely that these various system or total vehicle performance factors will lead to conflicting objectives and requirements for the component designer. These total vehicle simulations define component loads and specifications to the component designer in an interactive manner. That is, as the component is designed and its actual characteristics are more clearly determined, the system models are updated and new overall vehicle responses predicted and compared to the goal values. Hence, as design proceeds, a series of loops is created between the total vehicle and the component designs. It is important that these total vehicle and component models are initially simple so that they can be exercised quickly by the design team to answer "what if" design questions. They lose much of their impact if they track behind the design, and design direction is then lost.

As the concept design is finalized and detail design continues towards the final prototype design, these system models become more detailed and predict more accurately the total behavior. They answer increasingly more complex design questions on a firmer design. That is, they are used to fully optimize the selected design for all the performance factors.

New Component Design

The objective of this task is to define and develop efficient structural component concepts and designs. Based on experience and the reference component evaluation, new component design concepts are generated with new structural configurations or alternative materials by the various component design teams.

Starting from the total vehicle simulations, a component load set is defined as well as potential packaging space allocated within the vehicle. A simplified yet accurate geometric model is developed to define the packaging constraints from the overall package layout. The component design teams develops various component concepts in rough geometric form supported by simple analytical tools. The best concept is selected considering performance as well as cost and ease of manufacturing.



Overall Approach to Vehicle Design

As in the use of total vehicle models, the component analysis is only useful it it is fast enough to "lead" the design and guide the designer rather than following the design and simply verifying that it is acceptable or unacceptable.

The underlying principle here is to use the analytical tools to quickly predict the performance of several potential design concepts. The intent is to obtain an understanding of the fundamental structural characteristics which lead to improvement and eventual selection of the overall best component design. Too often, analytical tools are used only to confirm or reject the thickness of a part that is completely designed and no time remains for the analytical work to impact the component design questions. These may be broken into local models of critical areas previously defined by the coarse concept evaluations. By applying standard weld concentration factors to the nominal near welds as well as by knowing the component duty cycle, fatigue life for components can be estimated.

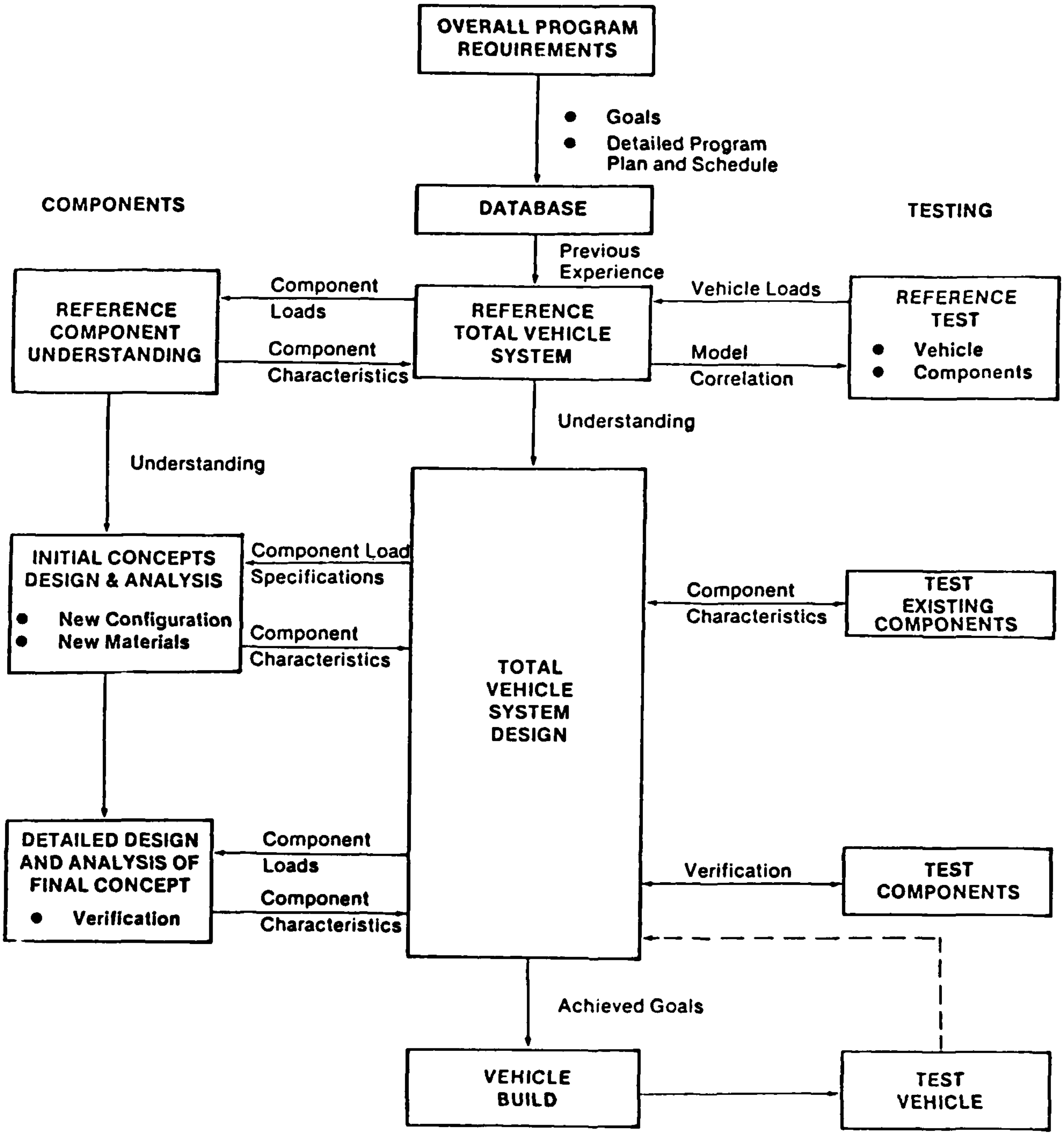
Component characteristics, such as stiffness, and mass distributions that are determined in this phase are then fed back to the total system models to improve their accuracy for predicting total vehicle performance. Again, this is an iterative and interactive process with continuous communication between all team members. Final component layout drawings are produced on the CAD system. Manufacturing software is utilized to generate N.C. tapes as appropriate to build a prototype.

New Component Testing

The objective of this activity is to support the new vehicle development through testing of off-the-shelf components or to test new design concepts in either a cobbled prototype or new component testing activity.

New off-the-shelf or commercially available items may include shocks, powertrain components, weapons systems, etc. The intent is to determine their characteristics for use in the previously discussed system models. An example could be the noise and vibration characteristics from a new proposed transmission or engine. Their particular excitation would be used as input to appropriate vehicle simulations to determine compatibility with the total vehicle.

Testing of any fabricated prototype ABC components should also be carried out as these parts become available. Their stiffness and stress levels should be measured under the system-determined load cases and boundary conditions discussed earlier. These results should be compared to predicted component stiffness and stress values. If overstressed areas are found, the component models should be refined to duplicate the failures, and design modifications should be generated until an acceptable performance is obtained.



Overall Approach to Vehicle Design

Task 5: Prototype Build and Test

Final prototype testing pinpoints any critical areas that the analytical approach may have missed. For example, if a stress problem is discovered because a component model was too coarse or weld concentration factor too low, the component or system model can quickly be modified to correlate to the test data and design modifications can be implemented until an acceptable design is achieved. Hence, previous analytical models significantly speed up the hardware development phase by helping to identify successful fixes to test identified problems.

The prototype tests also correlate all of the previous analytical work that will become the data base for the next generation vehicle. Hence, the reference review phase will have already been carried out for the next generation vehicle.

The prototype testing would be comprised of two phases: First, short duration, extensive tests aimed at documenting ride, noise, dynamics, structural behavior, and fatigue life estimates would be conducted. These attended tests would involve recording data for certain staged events and duty cycles. This would provide information to confirm the analytical models used in the design phases and to identify possible problem areas. These tests would have many tasks in common with those described for the Reference Vehicle Tests. Second, longer duration, unattended tests would be conducted aimed at documenting duty cycles and strain levels. This strain information would be collected using small microprocessor data storage units that can be left on the vehicle for longer periods of time. The resulting data, which is in histogram form, would be suitable for duty cycle confirmation and fatigue life estimates.

Task 6: Documentation

The objective of this task is to completely document the project results. If this is done properly, this project will serve as the reference vehicle for the next generation vehicle. Hence, no reference vehicle work would be required in the next vehicle design program.

Documentation should be in detailed report form as well as in a computerized relational data base. SDRC supports the REGIS data base program developed by General Motors Corporation.

The data base documentation should be an ongoing process during the entire program as results of various tasks will be required during the project execution.

PHASE III: CAE TOOLS

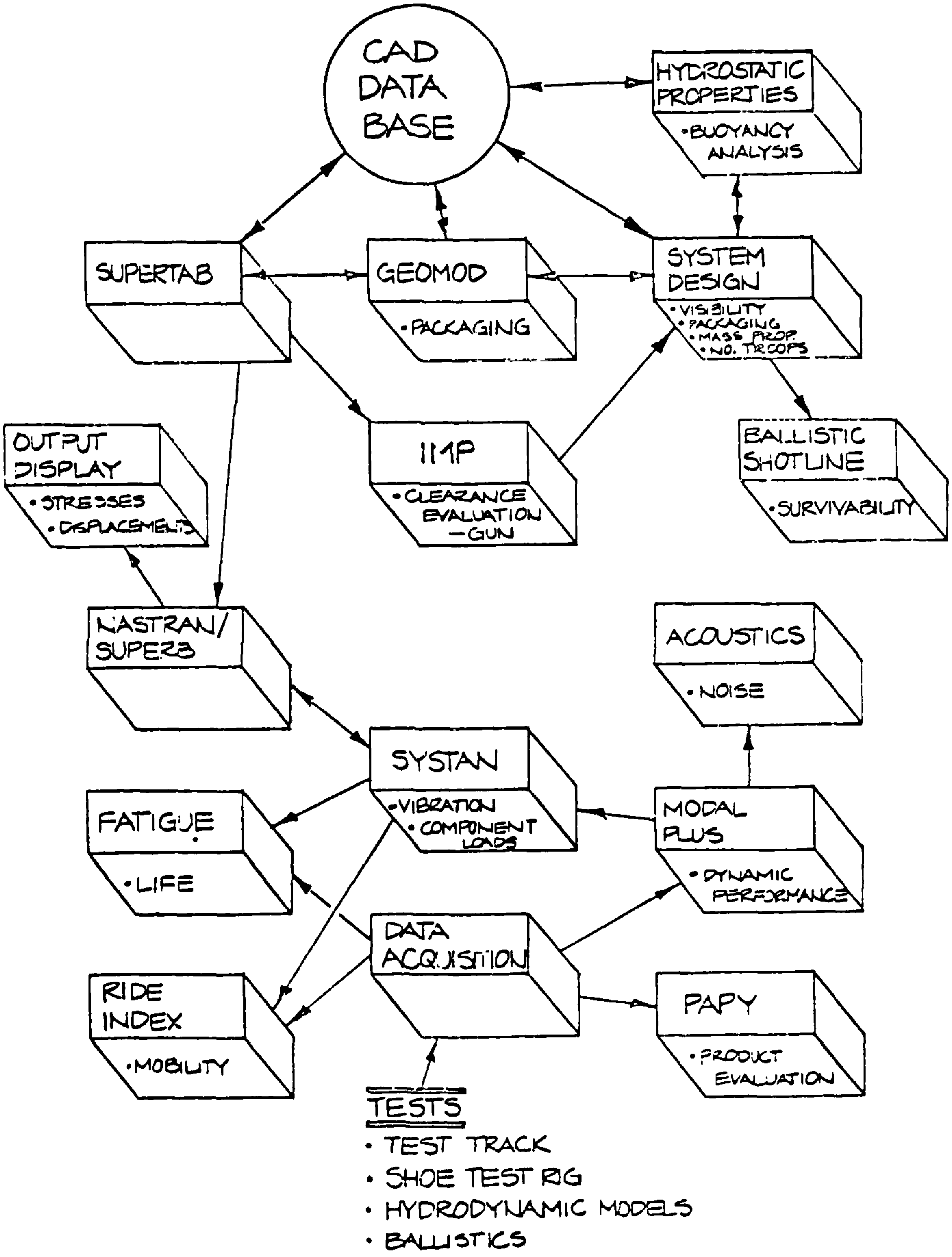
The total set of design tools required to fully automate the design of new high performance vehicles is shown schematically in Figure 3. This proposal is concerned only with CAE and its interfaces with the CAD geometry data base in place at ABC.

Major elements of the CAE software system envisioned for ABC tracked military vehicle design are shown in Figure 4. These CAE tools are either geometry-, testing-, or analysis-related tools for the design engineer. The diagram illustrates which tools are linked together or feed each other. Some of these interface links will have to be developed. The design concerns addressed by the various tools are shown under each tool.

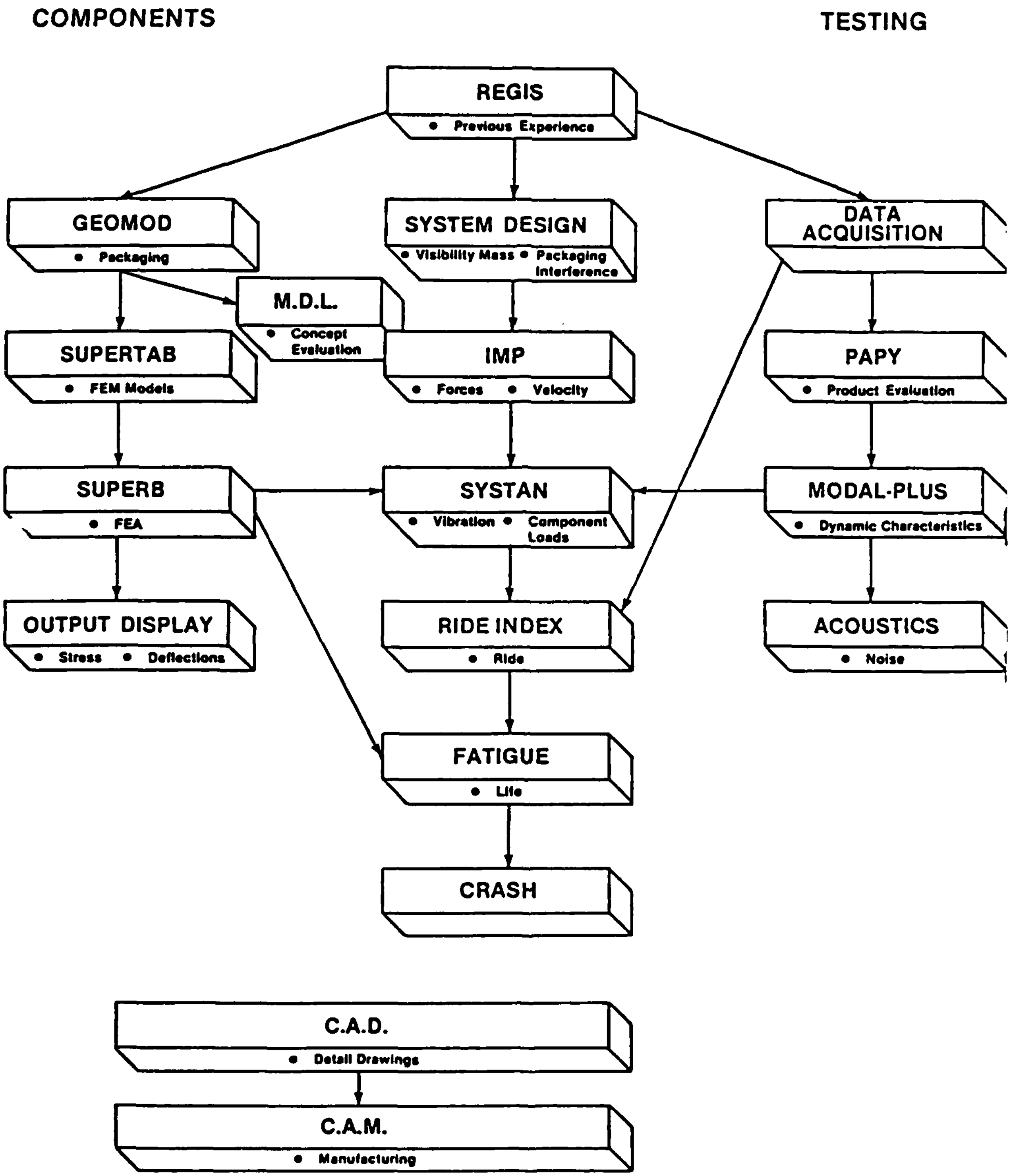
Starting from the CAD geometry data base, the GEOMOD solid modeling program can create component geometric models and perform packaging studies such as interference checks. These components can then be assembled in SYSTEM DESIGN to study visibility, vehicle packaging, vehicle mass, center of gravity, cargo capacity, etc. In conjunction with the IMP mechanism program, dynamic interferences can be investigated such as during full range gun excursions. The Hydrostatic Properties program also interfaces with the vehicle geometry to predict the buoyance properties of the vehicle. The results of the Ballistics program can also interface with the vehicle geometry to predict the crew survivability for a variety of hits.

The SUPERTAB program interfaces to the geometry data base and is used to develop the finite element models of components. These models are then run on the SUPERB or NASTRAN program with output sent to the OUTPUT DISPLAY program to make it easier to visualize results and predict component stresses and deflections. The various component properties are input to SYSTAN

CAE TOOLS


CAD DATA BASE
HYDROSTATIC PROPERTIES
•BUOYANCY ANALYSIS
SUPERTAB
GEOMOD
•PACKAGING
SYSTEM DESIGN
•VISIBILITY
•PACKAGING
•MASS PROP.
•NO. TROOPS
OUTPUT DISPLAY
•STRESSES
•DISPLACEMENTS
IMP
•CLEARANCE EVALUATION —GUN
BALLISTIC SHOTLINE
•SURVIVABILITY
NASTRAN/ SUPERB
ACOUSTICS
•NOISE
SYSTAN
•VIBRATION
•COMPONENT LOADS
FATIGUE
•LIFE
MODAL PLUS
•DYNAMIC PERFORMANCE
DATA ACQUISITION
RIDE INDEX
•MOBILITY
PAPY
•PRODUCT EVALUATION
TESTS
• TEST TRACK
• SHOE TEST RIG
• HYDRODYNAMIC MODELS
• BALLISTICS

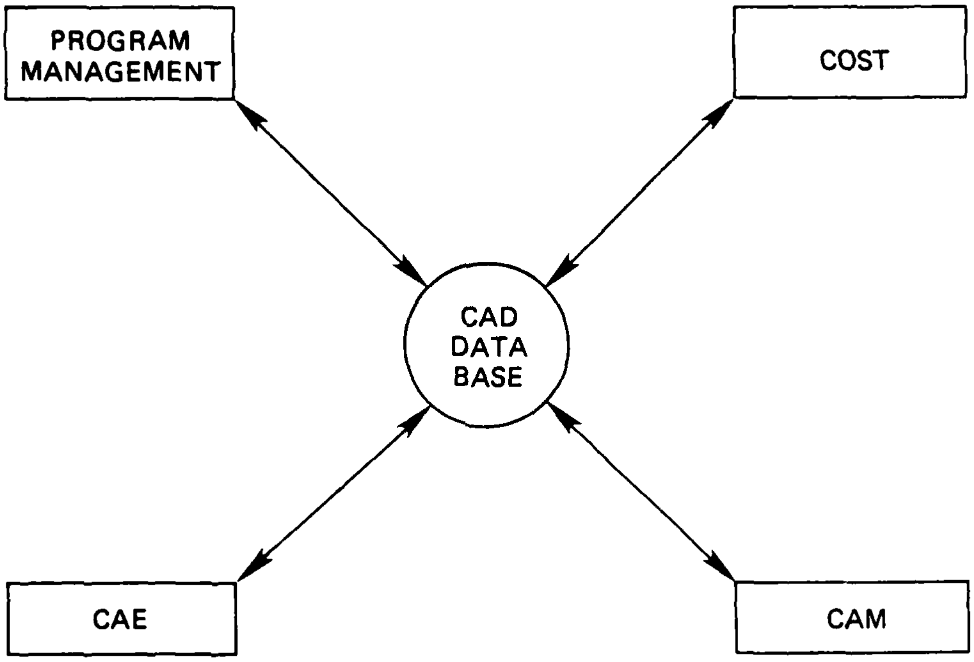
C.A.E. Tools


COMPONENTS
TESTING
REGIS
• Previous Experience
GEOMOD
• Packaging
SYSTEM DESIGN
• Visibility Mass • Packaging Interference
DATA ACQUISITION
M.D.L.
• Concept Evaluation
SUPERTAB
• FEM Models
IMP
• Forces • Velocity
PAPY
• Product Evaluation
SUPERB
• FEA
SYSTAN
• Vibration • Component Loads
MODAL-PLUS
• Dynamic Characteristics
OUTPUT DISPLAY
• Stress • Deflections
RIDE INDEX
• Ride
ACOUSTICS
• Noise
FATIGUE
• Life
CRASH
C.A.D.
• Detail Drawings
C.A.M.
• Manufacturing

to develop overall vehicle system models for studying vehicle vibration, component loads, and vehicle dynamic response. Total vehicle properties are then input to the RIDEINDEX program to predict hours to decrease proficiency or watts absorbed by the crew for various types of terrain. The SYSTAN and SUPERB program results are input to the FATIGUE program to estimate individual component fatigue life.

Test data from actual vehicles such as strain or acceleration measurements is input to the DATA ACQUISITION program. This information can be manipulated in the PAPY program to evaluate more easily a product or to the FATIGUE program to estimate life. The MODAL-PLUS program is used to determine a product's dynamic performance such as frequency response and deflection mode shapes. Specialized ACOUSTICS software exists and for determining cavity resonances, identification of noise sources, and sound pressure levels from vibrating surfaces. Finally, the MODAL-PLUS program can be used to determine component properties experimentally for inclusion in the SYSTAN system simulation programs.

DATA BASE



CAE Design Tools

PHASE IV: CAE APPLICATION

Now that the specific tasks of the CAE process have been described, let us look at the application of computer-aided technologies to some specific items as shown in Table 1.

Table 1. Computer-Aided Engineering Discussion List

ATTACHMENT III (RFQ)

1. Computer Interface
2. Autoloader, Gun Stability and Accuracy with Modal Analysis
3. Buoyancy
4. Acoustics
5. Vibrations/Fatigue-Structure
6. Structure-Test-Feedback Design Technique
7. Fatigue Life Benefit of Case Hardening Torsion Bar Applications
8. Tolerance Analysis
9. Clearance Evaluations
10. Torsion Bar Cumulative Damage Analysis
11. Elastomer Fatigue Analysis
12. Weight and Mass Properties
13. Ballistics-Shotline Programs
14. Transmission Torsional Vibration Analysis
15. Power Train Programs
16. Hull/Structural Analysis
17. Composite Structure

4.1: Structural Analysis

Objective:

Develop a structural dynamics computer program which will allow vehicle configuration data to be extracted from ABC's/CAD System and analyze the stress and deflections throughout a tracked vehicle unitized hull for a variety of input dynamic load conditions.

Approach:

4.1.1: With the aid of ABC personnel compile a catalog of existing ABC hardware and software.

4.1.2: From 1.1 above and a subset of programs shown in Figure 5 attached, draw a CAE plan for ABC for both near-term and long-term goals. This includes:

a. Checking out the characteristics and applicability of ABC's CAD System and IGES File for this program.

b. Evaluating the CAD System for this program and making a written report to ABC on its applicability, program adaptability, and problems.

c. Checking out ABC's operation system for this IBM computer facility, and evaluating needs for development of this program.

d. Recommending program equipment and procedural changes for ABC's current facilities which would further the application of the above computer program.

4.1.3: Provide the programs recommended in 4.1.2 above with complete user documentation. Also assist in making the programs operational on existing and new hardware at ABC.

4.1.4: Using hull structural analysis as an example and using ABC personnel, demonstrate the capability of the above program package and documentation on ABC equipment.

4.1.5: Provide the following communications:

a. A progress meeting to be held weekly between ABC and SDRC alternately at each company's facility.

b. A monthly letter-type progress report to be submitted to ABC by the tenth of each month.

c. A final report, program package, and documentation to be delivered to ABC at program completion.

d. An interface and contact relationship with ABC personnel such that ABC is fully aware of the program development work and is able to use, update, and maintain the program after completion.

4.2: Buoyance Analysis

Objective:

Develop a buoyance floating vehicle attitude computer program which will allow vehicle configuration data to be extracted from ABC's CAD System. And, in conjunction with the ABC current Hydrostatic Properties Program and independently supplied weight and center of gravity data, determine the buoyancy, reserve buoyancy, hull waterlines, and vehicle righting moments for any pitch and/or roll displacement.

Approach:

4.2.1: Learn from ABC personnel the current capabilities of the ABC buoyancy program. Investigate the potential for buoyancy calculations including pitch and roll. Investigate programs available for Naval architects.

4.2.2: Develop a specification for the optimum capability and cost program to meet the following constraints. The program should also be flexible enough to allow vehicle configuration data to be input or changed manually. The program should be able to automatically interface with ABC's CAD System and easily accommodate revisions to that system. The overall program should use or adapt ABC Hydrostatic Properties Computer Program and be able to accommodate future changes which might be expected to develop for these programs.

This includes:

a. Check out the characteristics applicability of ABC's CAD System and IGES file for this program.

b. Evaluate the CAD System for this program and make a written report to ABC on its applicability, program adaptability, and problems.

c. Check out ABC's Operating System for its IBM computer facility, and evaluate needs for development of this program.

d. Recommend program, equipment, and procedural changes for ABC's current facilities which would further the application of the above computer program.

4.2.3: Make necessary changes to software including the addition of programs shown in Figure 5 and make the new program operational on the ABC equipment.

4.2.4: Use ABC personnel to demonstrate the capability of the above program package and documentation on ABC equipment; use ATAV vehicle design for this purpose.

4.2.5: Provide the following communications:

a. A progress meeting between ABC and SDRC alternately at each company's facility.

b. A monthly letter-type progress report to be submitted to ABC by the tenth of each month.

c. A final report, program package, and documentation to be delivered to ABC at program completion.

d. As interface and contact relationship with ABC personnel such that ABC is fully aware of the program development work and is able to use, update, and maintain the program after completion.

4.3: Autoloader, Gun Stability and Accuracy with Model Analysis

Objective:

To develop an analysis procedure utilizing a computer model for identifying vehicle mode shapes and frequencies to be used for the design and analysis of armament mountings.

Approach:

4.3.1: With the aid of ABC engineers identify the dynamic problems associated with the integration of the armament assemblies with the vehicle.

4.3.2: Develop an analysis plan utilizing the computer programs recommended in Figure 5 for Task 3.1 and SYSTAN. Define the input data and sources (test, data library, design drawings) and typical operating constraints. Define data and format required by armaments engineer.

4.3.3: Implement plan and check out by application to the ATAV armament using ABC engineers.

4.3.4: Document, report, and set up permanent ABC/SDRC interface for hot-line assistance.

4.4: Vibrations/Fatigue - Structure

Objective:

To develop an analysis procedure utilizing a computer model to analyze the vibration response in a system over the operating life of the system and feed data into a computer program which will provide a statistical evaluation of the reliability of the system from a fatigue standpoint.

Approach:

4.4.1: With the assistance of ABC engineers identify all vibration-and fatigue-inducing environments during the service life of a vehicle. Identify all fatigue-sensitive areas of the structure.

4.4.2: Develop an analysis plan including the SDRC programs SYSTAN and FATIGUE and include the possibility of input data from tests and MODAL-PLUS.

4.4.3: Acquire or develop from test data, fatigue life curves for materials in fatigue-sensitive areas of the structure.

4.4.4: Install and make the computer programs operational on ABC equipment.

4.4.5: Demonstrate the applicability of the procedure by analysis of the fatigue life of some of the most sensitive components of the ATAV vehicle.

4.4.6: Document, report, and make recommendations for future development of the procedure. Set up a "hot-line" interface between ABC and SDRC for use of this procedure.

4.5: Fatigue Life Benefit of Case-Hardening Torsion Bar Applications and Torsion Bar Cumulative Damage Analysis

Objective:

To reduce the cost of torsion bars by more accurately defining torsion bar loads and more accurately calculating torsion stresses and fatigue life. More accurate calculations may lead to use of less expensive material.

Approach:

4.5.1: List potential problems, design constraints, experience with alternative designs, loads, and test data

4.5.2: Prepare an analysis procedure plan including software to be used, complexity of structural models, sources of data, program output data and formats, failure criteria, failure data to be used.

4.5.3: Implement plan on ABC equipment. Demonstrate accuracy of procedure by application to an existing torsion bar system from which test data has been taken. Demonstrate utility by limited preliminary parametric studies to identify useful redesign trends.

4.5.4: Document, report, and set up ABC/SDRC hot line for future procedure troubleshooting.

4.6: Elastomer Fatigue Analysis

Objective:

To develop structural analysis procedures for elastomeric components used in ABC vehicles and specifically to develop critical with which to select the most promising track-bushing designs for life cycle tests. The first application goal is to increase the mean bushing life from 5,000 to 8,000 miles.

Approach:

4.6.1: Draw up an analysis plan which includes:

- a. A review of the bushing functions
- b. Loads on bushing
- c. Materials available and methods of obtaining structural properties including relaxation modulus, $E(t,T,\varepsilon)$, dynamic modulus, cyclic failure properties (compression and shear) and others.
- d. Analysis procedure, including computer codes to be used.
- e. Criteria to be reviewed as candidates for predicting failure--for example, deviatoric strain energy, total strain energy, etc.
- f. Redesign possibilities.

4.6.2: Put selected computer codes on ABC equipment and make them operational.

4.6.3: Collect necessary material properties data either by testing at ABC, by subcontract to testing labs, or from library sources.

4.6.4: Exercise analysis for current existing design including stress/strain calculations for pre-load (bushing to track shoe assembly) and operating loads. Attempt to obtain correlation with real service life data. Attempt to explain inverse correlation of the predicted life for some proposed designs with service life tests. Hence, determine applicability of procedure.

4.6.5: Document, report, and make recommendations for further development of the procedure. Set up a hot line interface between ABC and SDRC for this analysis procedure.

4.7: Miscellaneous Items Tasks 4, 6, 8, 9, 12, 13, 14, 15, and 17. Table 1

Objectives:

To develop CAE procedures, select available software, and specify, where necessary, software modifications to improve and accelerate structural design and analysis of the referenced components and environments. Make these procedures operational on ABC equipment.

Approach:

4.7.1: For each of the tasks SDRC engineers will spend a day with the cognizant ABC engineers to identify the principal problems associated with each subject and the state-of-the-art for design and analysis for each subject at ABC.

4.7.2: For each of the tasks SDRC will briefly review its applicable SDRC tools and experience.

4.7.3: Write a letter report to ABC recommending steps to be taken to improve design and analysis procedures, including acquisition of software and test equipment and procedures. Cost, schedule, and level of ABC participation required for each task will be included.

Conclusion to Part II

The process outlined in the hypothetical ATAV development program has been used successfully in many products. The flowchart Overall Approach to Vehicle Design has the same basic form used for automobiles, engines, turbine wheels, gun breeches, mobile lighting systems, locomotives and so on. There are products where there is no prototype such as the huge draglines used for strip mining. Each of those machines is actually assembled on site over a one to two year period. Here the system model is used to gain confidence that the product, when assembled, will perform. There are many similar products, for example a ship, where there is no prototype. The point made here is that the generalized model has been modified as appropriate to address the characteristics and development process of the particular product.

There are many good examples of the use of CAE process. Some of the programs include:

Shipbuilding

- Finite Element Analysis Evaluation of an LNG Tanker Insulation Structure
- Design Audit and Subsequent Modification of a Submarine Main Propulsion Gear Set
- U.S. Navy Noise Reduction Programs to Minimize Vibration and Associated Noise Transmission of Equipment Platforms
- Surface Ship Gear Train Analysis
- On Board Turbine Mounting System Testing Program
- Tugboat Driveline Damping to Remove Excessive Vibration
- Tank Slosh

Military Vehicles

- Hull, Turret Support and Track Design of an Amphibious Landing Craft
- M-1 Track Pad Evaluation
- Redesign of a Mobile Crane for Nuclear Weapons Recovery
- Hydrapneumatic Suspension for an Armored personnel carrier

Automotive

FRAME, SUSPENSION & TIRES

- Low Mass Trailing Arm Rear Axle Design
- Dynamic Spindle Tests
- Cab Mount Design
- Frame Joint Flexibility Studies
- Low Mass Stamped Spindle Designs
- Suspension Arm Designs
- Rear Suspension Transmissibility Improvements
- Engine Mount Test
- Low Mass Control Arm Designs
- Tire Uniformity Test Development
- Energy-Absorbing Bumper Designs
- Low Mass Wheel Designs
- Low Mass Knuckle Designs
- Disc Brake Caliper Designs
- Tire Vehicle Interaction Design Studies
- Durable MacPherson Strut Design
- Low Mass Crash Designs
- Axle Noise Reduction

BODY

- Durable Unibody/Joint Designs
- Low Mass DECKLID Design
- Floor Pan Boom Noise Reduction
- Low Mass Tailgate Design
- Body-In-White Modal Analysis
- Low Mass Door Design
- Plastic Truck Cab Design
- Low Mass Door Intrusion Beam Design
- Body Suspension Ride Optimization
- Windshield Wiper Noise Reduction
- Low Mass Seat Design
- Structure Acoustic Boom Noise Reduction
- Low Mass Fuel Tank Design
- Deck and Steering Column Vibration Reduction

Engine/Powertrain

- Connecting Rod Bolting Improvement
- Low Mass Piston Design
- Block Noise Reduction
- Piston Connecting Rod Interaction Design Studies
- Crankshaft Flywheel Interaction Design Studies
- Transmission Noise Reduction
- Cylinder Head Durability Designs
- Valve Cover Isolation Designs
- Torque Converter Vibration Reduction
- Radiator Designs
- Automatic Transmission Vibration Reduction
- Exhaust Manifold Design
- Low Mass Differential Torque Tube Designs
- Sheet Metal Oil Pan Noise Reduction
- Muffler Shell Noise Control
- Rotary Engine Durability Design
- Drivetrain Modal Anaysis
- Low Mass Carrier and Differential Cross Brace Designs
- Transmission Gear Noise Reduction
- Clutch Plate Vibration Reduction
- Clutch Spring Damper Assembly Analysis
- Plastic Fan Blade Design
- Drivetrain Clutch Effect on Ride
- Low Mass Transmission Extension Design
- Distributor Noise Reduction
- Exhaust Pipe Noise Reduction

Aerospace

- Airframe Design and Analysis

Space Shuttle Launch

- Space Shuttle Solid Rocket Motor Vibration
- Booster Separation Motor Cover Life
- Pogo Studies: Main Propulsion Test Article
- SSME Turbopump Vibration
- Main Oxidizer Valve Failure
- Orbiter Panel Life Studies
- Designing Robots for Space Applications
- Modal Testing to Confirm Calculated Tile/Structure Response
- Space Shuttle Crew Seat

Satellite Systems

- Pre-Qualification Troubleshooting of the Marecs Satellite
- Modal Survey of Meterological Satellite

Transporter Design

- Mobile Command Control Communication System

NASTRAN Model Refinement Using Modal Test Data

Interior Noise Reduction of Aircraft

- Aircraft Fuselage Noise Transmission Studies
- Acoustic Structure Interaction Analysis

Modal Test on an Airplane Flight Simulator Visual Display System Support Structure

Impeller Design Stress Analysis

Design of a Mixer Nozzle

Computational Fluid Mechanics

These are all actual projects which used Computer-Aided Engineering technologies. Some of the companies involved were:

- A. M. General
- ARCO Metals
- Bombardier
- Borg-Warner
- British Rail
- Cadillac Gage
- Caterpillar Tractor Co.
- Cincinnati Gear
- Cooper Energy Services
- Cummins Engine Company
- Dana Corporation
- Delaval
- Eaton Corporation
- Emerson
- Euclid
- Fiat - IVECO
- FMC
- Ford Motor Company
- Freightliner
- Fruehauf
- General Electric Company
- General Motors Corporation
- International Harvester
- J. I. Case
- John Deere
- Kenworth
- Layland Vehicles
- Martin Marietta
- McDonnell - Douglas
- NASA
- Outboard Marine
- Peterbuilt
- Perkins Elmer
- Simmonds Precision
- Terex
- Toyo Kogyo Company
- Volkswagon
- Wabco
- Wayne Bus
- White/Volvo
- U. S. Army
- U. S. Navy
- U. S. Air Force
- Zollner

From the above lists of programs and companies, one can see that existing tools are being applied, yet not widely enough. The widespread application of all sub-sets of Computer-Aided technologies should be encouraged.

TECHNOLOGY INSERTION

ALTHOUGH THE MODEL OF THE DEVELOPMENT OF THE ATAV FOCUSED ON COMPUTER-AIDED-ENGINEERING (CAE) AND ITS BENEFITS THE MESSAGE IS TO USE EACH SUB-SET OF COMPUTER-AIDED-TECHNOLOGIES SUCH AS CAD, NC, ROBOTICS, PARTS SYSTEMS, ETC. EACH HAS ITS OWN EFFICIENCIES NOW EXISTING THAT SHOULD BE FULLY EXPLOITED TO IMPROVE PRODUCTIVITY.

The second major issue developed in the next section is that when communications between sub-sets are resolved, Computer-Aided Technologies as a whole will provide benefits greater than the sum of their parts.

III. COMMUNICATIONS (OR INFORMATION FLOW BETWEEN MAJOR SUB-SYSTEMS OF COMPUTER-AIDED TECHNOLOGIES)

The Barriers for Information Flow ("Walls")

In his CAD/CAM Subcommitte report to MTAG '82, Frederick Michael, Director, Manufacturing Technology, U.S. Army DARCOM, had an example of the state of CAD/CAM. He diagramed the "wall" between engineering and manufacturing referring to the traditional problem of a product being engineered, drawings made and passed to manufacturing who then "re-engineer" it so that it can be manufactured. This diagram then shows CAD and CAM separated by that same wall and suggests that CAD/CAM be written CADCAM as the systems should be together.

That traditional wall may still exist because of the older problems of poor or non-existent communication between engineering and manufacturing but there is an entire new problem that inhibits bringing the wall down today. That problem is the difficulty of the various sub-systems of computer-aided technologies to "talk" to each other and move the critical engineering information and other data between computer-aided technology sub-systems. The "wall" is no longer "just" between CAD and CAM but between CAD, CAM, CAE, DNC, CNC, Robotics, Specialized Routines, Bill of Materials, Lofting, Analysis, Layout, etc.

The reason is simple to state: Each of these sub-systems was independently developed for the greatest ease and convenience of its own set of users, many without regard to that sub-system potential for interaction with other systems. Each sub-system was developed to optimize its own task. Now it has become apparent to most that an integrated system will yield much higher productivity than the simple sum of the efficiencies of the sub-systems.

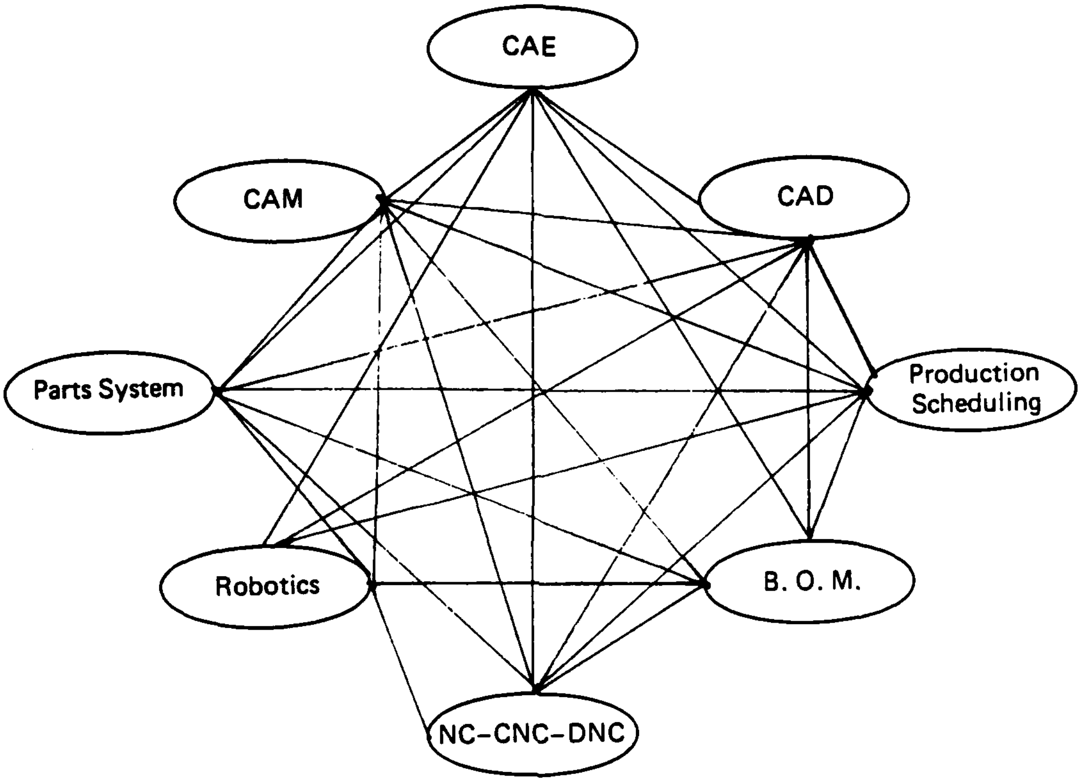
Achieving Significant Reduction in Manufacturing Line

Brief mention has been given in the ATAV example of reductions in manufacturing time by designing in reliability/maintainability. Implicit here also is the idea that manufacturing constraints are considered in the engineering phase. But a major time savings is the elimination in each of the sub-sets of Computer-Aided Technologies of re-creating the same data, such as geometry, in each sub-set. That is why it is very important to break down the "walls" to information flow. The work in an earlier sub-set can then be leveraged by a later one in the process. There is also the advantage gained by communication,of the elimination of re-work, by precluding errors made in the repeated re-entry of data.

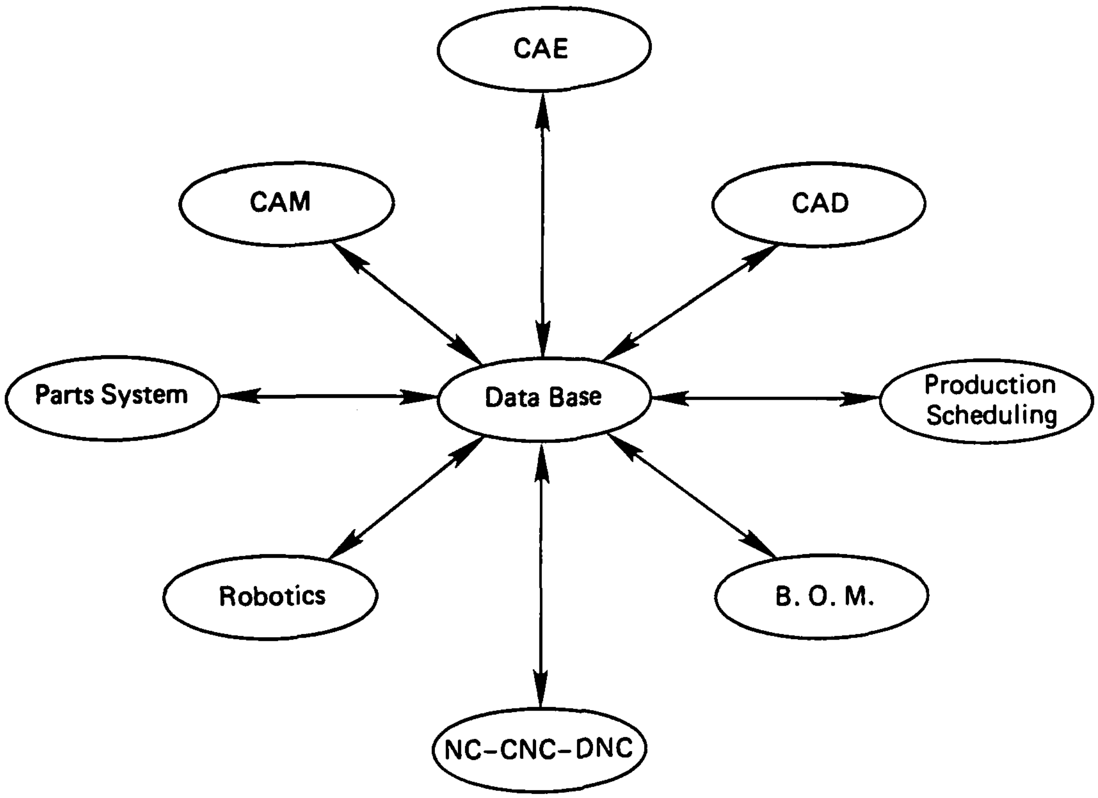
Getting the Computer-Aided Sub-Systems to Talk

There are many fine efforts and a wealth of good minds taking a number of different approaches to the enhancement or establishment of communications between computer-aided technology sub-sets. Some of these will be mentioned shortly.

First, a comment is in order regarding the tremendous investment made by thousands of companies in industry and efforts within DOD itself. Each system, many proprietary and very marketable, has been developed with major investments in dollars and manpower. There is quite logically a *strong* resistance to giving up these hard-won achievements. *Integration scenarios must keep this past investment in mind if they are to achieve the end result, communication.* If past investment is ignored efforts at integration will be rejected and fail. Having set the protection of investment issue squarely before us, let us look at a typical way industries or government first try to achieve integration. It is usually by trying to get each of the sub-systems to talk to and from each other to pass critical information flows. The result might look like this.



The confusion is obvious. There are too many communication paths developed much too quickly. A good systems person will tell you very quickly the solution is to go through a data base. The problem then simplifies like this.



Okay, it's obvious that a single communication path into and out of a data base storing relevant data or information will simplify the flow. Why is there still a problem? Is it because one sub-system speaks "French", another "German" and still another "English"? Initially, but only partially. If all programs were written today in the same code, say, FORTRAN, communications might be a step or even several steps closer, but the information transfer would still not exist.

Complex Problem

The answer to information transfer is complicated because each sub-system is optimized toward a goal of making its own task highly efficient. This is proper because the payback for its individual efficiency pays for (funds) the development effort to get the system in place. But, as the hardware developed specific to the task, so the software developed to drive those machines (computer) to its own purpose. We are then faced with subsystems using not only different languages, but also different computers, formats (8, 16, 32 bytes words), protocols, geometric descriptions, etc.

O'hers are also making huge investments to optimize their own views of this world. And from this a point emerges:

- The appropriate framework for each companies computer-aided technology world is not identical.
    - The functions are similar, but not the same
    - The composition of a specific sub-group such as analysis, is similar, but application dependent
    - Each companies facilities for manufacturing and its equipment are different
    - The end products are different

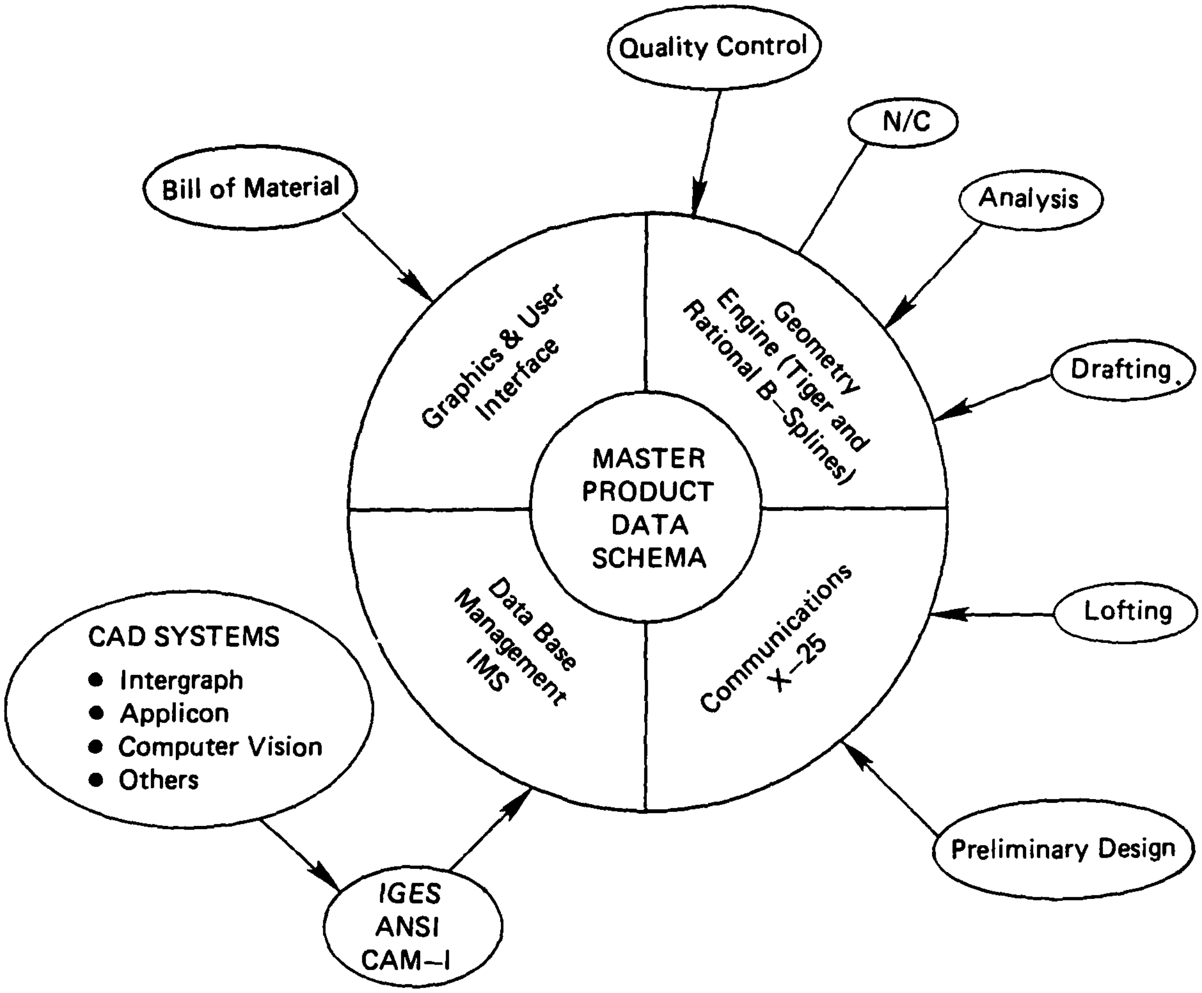
This leads us directly to the current ongoing work to give common links to very complex, different computer-aided technology worlds.

Current Efforts

There are many groups of hard-working, smart people engaged in various ways to project common linkages to breakdown the barriers to communication of information. Here is a sample of some major efforts.

- The IGES Committee

  The efforts of this committee to set for standards for the communication of geometry through files is well-known.
- ANSI Standard Y 14.26M. This effort is to standardize a file input/output. It includes prior ANSI work and IGES II (IGES plus Rational B-splines and Finite Element)
- The NASA IPAD project. This effort is to define a standard economical data base structure for common input/output to the data base. Currently it exists only on CDC.



Approximation of Boeing's Ideas
for a Communications System

- The Air Force I-CAM Programs. These programs IISS, IDSS, IIMS, and so on, include a general User Interface Management System (UIMS). This system is being developed for multiple terminal capabilities and for multiple CPU capabilities. It is a data base manager for engineering requirements.
- The CAM-I effort to define a boundary file specification for non-ambiguous consistent objects relating surfaces and curves. This again is a file communication effort for community solids data.
- DMCS (Data Management and Control System). This effort by industry (GE and SDRC) is to write a global "traffic cop" system to find, authorize release of, release, and re-enter data. It is the electronic equivalent to the old document control system and people. The system overlays the data base, understanding
  - Organization (who authorizes, sees, changes, or replaces data)
  - Project (What groups are authorized, need what data)
  - Product (Identifies parts or sub-systems related to a product. Examples a valve part or an engine requirement for manifolds, cleaners, etc.)
- The Boeing System described above
- Various "Language" developments, such as ADA.

There are other fine efforts ongoing all trying to solve the information flow problem.

The successful implementation of one of these efforts or others like them is adequate to solve the problem. The implementation and coordination of all of them is necessary to relieve our current situation and define the direction for further investigation. Because the task is so large, it is important that we provide the funds to accelerate current efforts and develop interfaces and integration capabilities. If this is accomplished the payoff's will far exceed that which is now planned.

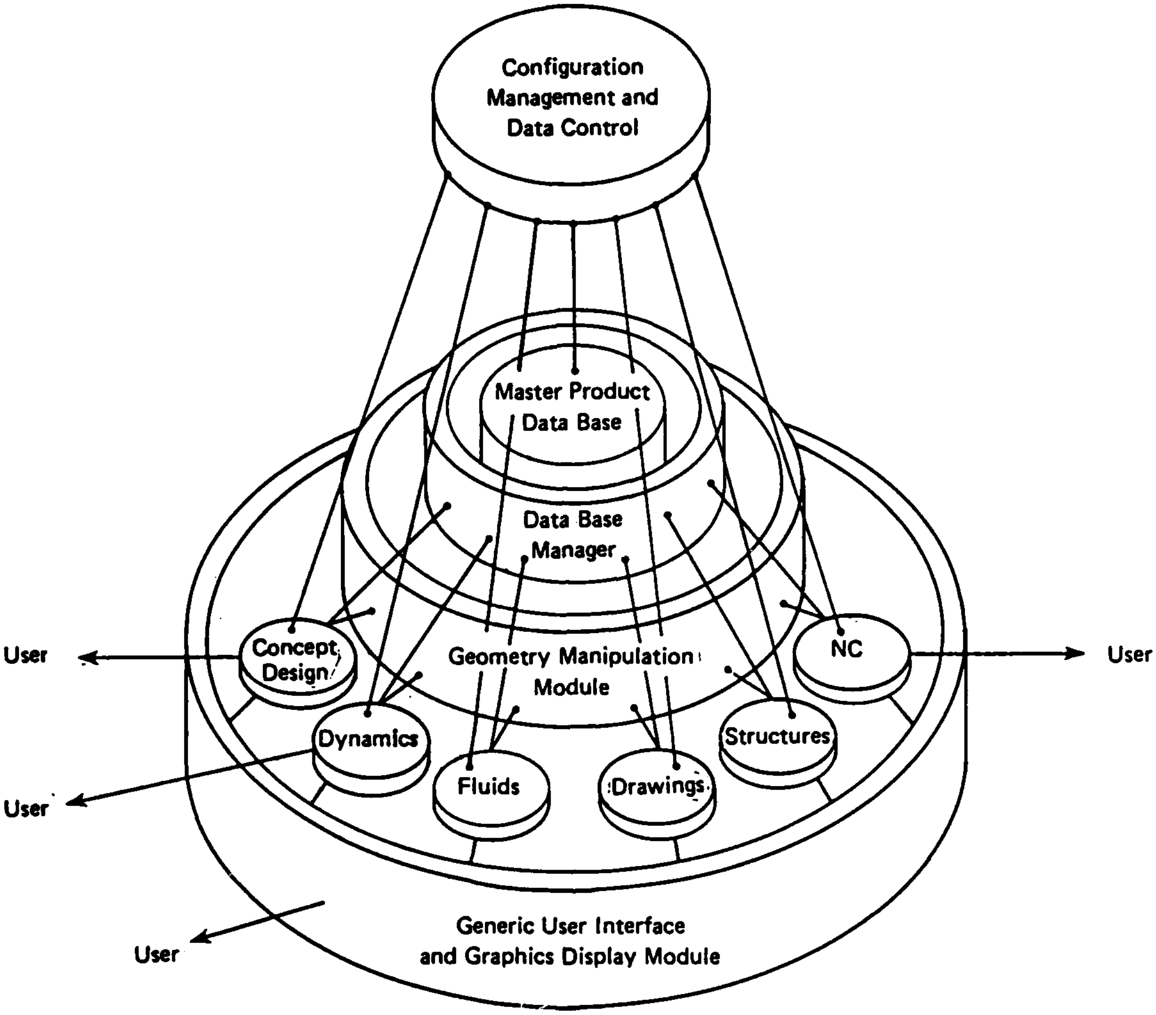


Figure 1
Integrated CAE/CAD/CAM/CIM System

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APPENDIX A

Potential Computer-Aided Design Reliability and Maintainability Demonstration Initiated by the Services During the Course of the Study

Computer-Aided Design Reliability and Maintability Demonstrations

Problem Statement

The opportunity exists today to significantly and dramatically improve the capability to design for supportability. This opportunity exists now because of the "explosive" emergence of CAD as the daily working procedure within the American defense industry. One of the major reasons for this rapid growth is that CAD greatly reduces the time and engineering man-hours required to produce a new design, (Improvements of 4:1 are often reported)

The defense industry is a world leader in the area of computer aided design. However the use of CAD to address R & MIS still in its infancy. While there are isolated activities which are adapting R & M techniques to run off of CAD data bases, they are primarily IR & D programs and not part of the engineering mainstream. As a result few R & M techniques are readily accessible in CAD. In addition, some interfaces among engineering disciplines (design, R & M, field engineering etc.) have not been developed to effectively use CAD/CAM.

Technical Solution

Because of the large benefits which will accrue to DOD as a result of the widespread use of CAD/CAM to address R & M considerations. It is important that DOD work with industry to provide direction and support for this area. In achieving this objective DOD should take a three -pronged approach of technology creation, technology maturation, and technology demonstration.

TECHNOLOGY CREATION. DOD and Industry should work together to develop a comprehensive set of standard software modules which incorporate the best R & M techniques available for use in computer-aided-design. These modules should be developed so that each can stand alone and be incorporated into an existing CAD system by itself if needed or used as part of the larger R & M CAD package. This R & M analysis package should be made available across the industry. This will provide a Government/Industry standard which will insure a high level of R & M which will be regularly achieved.

DOD should also continue its support of efforts to develop the interfaces among the various CAD systems and the different analysis disciplines. This includes the Initial Graphics Exchange Specification (IGES) work of the National Bureau of Standards and of the Air Force Wright Aeronautical Laboratory's Integrated Design Support System.

TECHNOLOGY MATURATION. If DOD and industry attempted to develop all new R & M modules the cost would be probibitive. However, a number of analysis modules exist which may be adapted to run in a interactive mode in the CAD environment. These include, for example, software programs to do testability, optimal level of repair, accessability or equipments, and MTBF estimations. The best in each area should be identified and modified for use in CAD. By modifying proven software in large amounts, time, cost and risk will be avoided. Nevertheless, in those R & M areas where no modules exist, DOD may need to fund some development work. As these R & M modules are modified or developed they should be made available for use across the industry.

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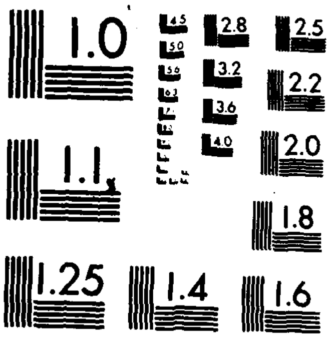

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TECHNOLOGY DEMONSTRATION. DOD should fund two types of demonstrations. The first set of demonstrations will demonstrate the usefulness of automating the R & M analysis into CAD for use on major weapon systems. These demonstrations should have the following characteristics:

1. High visibility weapon system program
2. Currently in design
3. High potential payoff
4. Inexpensive
5. Short duration (quick output)
6. Wide application of the technology demonstrated

These demonstrations will give a good indication of the actual improvements that may be expected from the widespread use of CAD in R & M. Each of the Services have identified a number of candidate short-term demonstration projects. These projects are attached.

The second set of demonstrations will provide evidence of the usefulness of new R & M modules are developed. This should be done as part of the technology creation efforts.

Benefits

There wil be numerous benefits f orn a concentrated effort to bring R & M analysis into CAD. They include: the demonstrated improvements in R & M on selected systems; reduced engineering man-hours to achieve R & M goals; the ability to analyze many more alternative configurations within a given time period; automation of the routine R & M analysis tasks; faster program turnaround time; the development of a single design database which will provide traceability from R & M characteristics back to the design decisions which produced them (R & M configuration management).

While these benefits will likely pay for the entire program in and of themselves, the most important benefits will occur when R & M is fully entrenched in the CAD process. Once the power to improve R & M is fully demonstrated and documented, other programs, and industry, itself would go on to expand the use the CAD to improve R & M in manyother areas. The end result would be weapons with truly outstanding R & M characteristics.

Costs

A number of excellent short term demonstrations could be done for approximately 5-10 million dollars. They could be accomplished from 1-2 years following contract award. The maturation projects which would take existing R & M analysis software and adapt it for use in CAD would take 3-5 years and cost 20-30 million dollars. The creation projects will develop the sstem architecture, specify the necessary interfaces among engineering disciplines and will develop the required software modules to fill any holes in our R & M analysis package. The creation projects will take 3-5 years and cost 30-60 million dollars.

Implementation

As a result of the OSD-IDA R & M activity the three Services have initiated a Tri-service CAD R & M program. They have identified a number of candidate projects suitable for short term CAD R & M demonstrations. Recognizing the critical importance of Industry participation to the success of this effort, a Industry/Government advisory panel is being set up. (The National Security Industrial Assocation has agreed to help in identifying appropriate members).

Contact

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Autovon 785-3871

DEPARTMENT OF THE ARMY
HEADQUARTERS US ARMY MATERIEL DEVELOPMENT AND READINESS COMMAND
5001 EISENHOWER AVENUE. ALEXANDRIA. VA. 22333

DRCQA-E 21 July 1983

SUBJECT: Candidate Demonstration Projects on CAD/CAM for the OSD R&M Study

Commander
Air Force Systems Command
Air Force Human Resources Laboratory/Mr. A. Herner
Wright-Patterson Air Force Base, OH 45433

1. Enclosed are the following candidate demonstration projects:

TECHNOLOGY CREATION

- CAD Reliability Module ($15,000,000 to demonstrate; $200,000,000 to fully implement)

TECHNOLOGY MATURATION

- CAD/CAM for Polymer Composite Reliability ($1,000,000)
- CAD/CAM to Enhance VHSIC Reliability by Scanning Photoacoustic Microscopy ($750,000)
- CAM Weld Quality Monitor and Control System ($550,000)

TECHNOLOGY INSERTION

- Microcomputer Reliability and Statistics Package ($100,000)
- Quality Measurement Plan ($93,000)
- Computer-Aided Stress Analysis for Engineering Changes in Kinetic Energy Tank Ammunition ($85,000)

2. Please refer any questions to Mr. Harry L. Light, DRCQA-EQ, AV 284-8916.

FOR THE COMMANDER:

Arthur H Nordstrom

1 Encl
as

ARTHUR H. NORDSTROM, JR.
Chief, Engineering Division
Product Assurance and Test Directorate

1. PROJECT TITLE: CAD Reliability Module

2. PROJECT DESCRIPTION:

It is proposed to develop and implement a computer aided design (CAD) system that will provide a global scenario to assure the consideration of reliability as an on-going process in the design phase. The system will enable the design engineer to utilize a menu driven, computer based, reliability centered design program that will allow entry at the part, assembly or end item level. The system will take the designer progressively through the program prompting him to enter manufacturing, use, operating conditions and various other parameters during the process. Once the design is completed the module will be capable of simulating certain operational tests; predicting occurence and cause of failure. The CAD system will be developed to use standard language and Initial Graphics Exchange Specification (IGES).

3. PROJECT PHASES:

Phase I, Project Definition: Identify those elements that influence reliability. Cost - $5 million.

Phase II, Define details for shell structure developed in Phase I. Develop system that can be broken down into building blocks. Develop building blocks. Develop simulation capability - Cost $10 million.

Phase III, Implement the system at DARCOM design locations and selected Army contractors as an on-line, interactive system - Cost $200 million.

CAD/CAM for Polymer Composite Reliability

CAD/CAM models have recently been developed (D. H. Kaelble, Rockwell Science Center) under Army Research Office sponsorship which address the reliability of polymer composites in response to service use temperatures, conditions of stress and strain, and effects of time and environmental exposure upon composite stiffness, strength and fracture toughness. These predictive CAD/CAM models for polymer composites correlate structural performance, reliability and durability with three generic classes and sizes of internal defects, (see Table below) which are based on the chemistry of raw starting materials, defects introduced during manufacture of composite structures, and the interaction of these two classes of intrinsic defects with environmental and mechanical stresses to produce a third class of defects of macroscopic dimension (interconnected microcracks and macroscopic crack growth).

GENERIC TYPES OF DEFECTS AFFECTING POLYMER COMPOSITE RELIABILITY

Defect	Dimension	Properties Affected
1) Chemical structure (atomic, molecular)	1-100A	Critical design properties - glass transition Tg, moisture absorption, dimensional changes
2) Manufacturing-induced (inclusions, voids, debonds)	>10μM	Strength, creep, interfacial properties
3) Latent defects arising during service (origin from defect types 1 and 2)	macroscopic	Fatigue, fracture toughness, dynamic properties

The recognition of intrinsic structural defects, the effects of subjecting them to service life conditions, and their contributions to polymer composite reliability represents an important extension in the analytical modelling and reliability for structural polymers, adhesively bonded metals and high strength fiber reinforced composites, and should provide strong criteria for chemical and manufacturing optimization of polymer composite reliability.

The proposed program is to further develop these initial CAD/CAM models for polymer composite reliability by an interactive experimental and advanced modelling effort aimed at verifying the model and markedly improving the reliability and maintainability of polymer composites for military applications.

Proposed Level of Effort	$250 K / year for 4 years
Total	$500 K
	$1000 K

CAD/CAM to Enhance VHSIC Reliability by Scanning Photoacoustic Microscopy

Scanning photoacoustic microscopy (SPAM) is a new nondestructive evaluation technique developed by Wayne State University under Army Research Office sponsorship which is proving more useful than x-rays, dyes, and ultrasound in finding surface and near-surface microscopic flaws in metals, ceramics, and other solid materials. It is based on utilizing a pulsed light source (laser, electron beam, or other) to generate thermal waves that probe the surface and near-surface regions, are interrupted by flaws which cause reflections to the surface where an acoustic signal is detected and analyzed by computer which generates a visual image of the defect. Laser light source studies have demonstrated resolutions of flaws in ceramics and integrated circuits of the order of 6 μM; latest developments indicate that an electron beam light source can be utilized to reduce the beam spot size in order to resolve submicron-size flaws. Thus, submicron dimension devices, their interconnects and metallized layers may be inspected during manufacture or in service to improve the reliability of new VHSIC concepts.

The proposed effort is to develop CAD/CAM models for automated inspection of VHSIC circuits utilizing scanning photoacoustic microscopy to resolve performance limiting defects down to the submicron scale.

Proposed Level of Effort	$250 K / year for 3 years
Total	$750 K

1. PROJECT TITLE: CAM Weld Quality Monitor and Control System

2. COST: FY84 285K, FY85 265K

During the welding process, changes in parameters, consumables, and the weld arc atmosphere can occur without the operator's knowledge. These changes may result in thermal damage to the base materials and defects (e.g., hydrogen induced cracking, porosity, embrittlement, lack of fusion and penetration) which seriously reduce the strength and service life of the welded joint. The cost of locating and repairing these defects constitutes a significant portion (25 to 40 percent) of the total weld fabrication cost. Prior attempts have been made to develop techniques to quantitatively measure welding comditions. These methods, however, often require direct sensor to workpiece contact and are not considered suitable for production environments because of sensor temperature limitations, joint geometry limitations, and time lags which reduce the validity of the information obtained. What is needed is an automated non-contact weld quality monitor system capable of the adaptive or in-process control of welding conditions in real time.

The technology gained from this project is applicable to any automated welding, cladding, surface alloying and high energy beam heat treating application specific to the manufacture of DoD materiel. Examples would include: 1) joining high hardenability armor plate which is inherently susceptible to hydrogen induced cracking, 2) joining reactive metals such as titanium which are susceptible to embrittlement by interstitial contaminants, 3) laser heat treating gears and bearing surfaces, and 4) dissimilar metal joining and cladding operations such as the bonding of copper rotating bands to artillery munitions.

Implementation of the WQM in the computer-aided manufacture of DoD materiel will result in improved weldment quality and productivity through greatly reduced or eliminated inspection and repair costs, reduced personnel factors, improved cycle times and more efficient utilization of equipment. The savings to investment ratio for a single rotating bend application is expected to exceed 8.3.

POINTS OF CONTACT: AMMRC, William S. Ricci, (617) 923-5234, CERL, Frank Kearney, (217) 352-6511.

MICRO-COMPUTER RELIABILITY AND STATISTICS PACKAGE

The use of localized small scale main frame computers (i.e., mini-computers and micro-computers) is becoming more and more common place as emphasis is placed on workplace automation and local analysis and control functions. These computers are characterized by flexible programming capabilities, color graphics, and versatile hardcopy utilities. They are ideally suited for the implementation of compuer-aided design and manufacturing.

While extensive software exists for such functions as word processing and financial analysis, no acceptable package exists for reliability and statistically oriented functions. This effort proposes to develop a standardized software package to utilize the full capabilities of micro-computers for reliability analysis. Included would be routines for graphical data analysis, design and analysis of experiments, RAM (reliability/availability/maintainability) calculations, and the associated statistical and graphics subroutines. These programs would all be written in ANSI BASIC.

The result of this effort will be the above mentioned software package and appropriate documentation.

This project will be fully effected through a 1 man year effort ($100K)

EDWARD LONIEWSKI
x3008

QMP (QUALITY MEASUREMENT PLAN)

QMP is a new method of reporting and analyzing quality assurance audit results for Bell System management. The analysis features an empirical Bayesian development whereby past performance provides the backdrop for our current quality estimates. The modern control chart reporting format features Box-Whisker plots that depict percentiles of the estimated current quality. The location summary format presents the current qualities across many products and as such evaluates the performance of an entire manufacturing facility. This capability for a timely response to quality deterioration within a facility would substantially reduce fielded defective materiel.

Our proposed REL/CAD/CAM effort is to:

1. Develop a predictive capability for the QMP/QEP* model to armament systems, based on the Kalman Filter approach and evaluate the proposed QMP/ASP** alternative to MIL-STD-105D.
2. Perform a case study on one of our major suppliers.

The results of this effort will be:

1. A technical report summarizing the methodological research performed.
2. Preliminary development of computer software to support implementation of QMP techniques.

Required funding for FY84 -$93K including 1 man year of effort, including travel. The development of a complete software package will require the continuation of the project thru FY85 with additional funding.

*Quality Measurement Plan/Quality Evaluation Plan

**Quality Measurement Plan/Acceptance Sampling Procedure

12 Jul 83
J. Damen

Computer Aided Stress Analysis for Engineering Changes in Kinetic Energy Tank Ammunition

A state of the art approach with industry available CAD/CAM software is the only comprehensive vehicle for determining the stresses at gun launch of kinetic energy rounds with core-buttress thread type geometry. Current effort approaches the problem in a piecewise and incomplete manner, to the neglect of considering the complexity on non-ideal mating surfaces of the buttress threads. Actual production with tolerances, and possible proposed engineering changes depart from ideal tractable geometry, and the effect on round integrity is partially left to an engineering estimate. It is proposed to do the M833 kinetic energy round properly to determine launch stresses with CAD/~~CAM~~ software and do this for rapid engineering answers. From experience it is expected that an excess of 10,000 finite elements is needed to establish geometry, with element type chosen judiciously by consultants. Several similar geometries will consider realistic variations in manufacturing, along with some judicious actual design changes to see the trend of the stresses. Estimate for the M833 is $85,000. A tape is generated with the geometries for later CAD/CAM consideration. Purpose is to generate greater reliability in stress patterns calculated. This stress eventually becomes basic input to fracture mechanics and crack size determination.

COMPUTERIZED SYSTEMS ANALYSIS TECHNIQUES FOR APPLICATION TO PROVE-OUT OF PBM FACILITIES

During the last five years there has been significant progress in development of procedures for conducting the systems analysis of production facilities. The objective of these analyses is to measure the production capability of the facilities based on equipment level RAM and production data gathered during the formal facility prove-out phase. Mathematical models, statistical techniques and computer programs have been developed to size and predict performance of production lines, to plan demonstration tests, and to analyze the demonstration test data.

The purpose of this project will be the refinement and interfacing of the existing methodology into a single integrated prove-out system analysis package. This will require modification of the existing software and the preparation of interactive executive software. In addition, a handbook/user's manual will be prepared for the overall automated procedure. Implementation of the results of this project will enable consistent, accurate and timely conduct of the systems analyses needed to measure production capabilities of facilities required for mobilization.

This effort will require one-man year of effort and travel at $95K.

The results of the project will be a complete system analysis software package including a handbook/user manual

JOHN MARDO
x3008

AREA: COMPUTER AIDED TECHNIQUES FOR CONSOLIDATING AND TAILORING LIFE CYCLE SUPPORT ELEMENTS

CONTRACTOR: NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA
NAVAL SEA SYSTEMS COMMAND, PMS 406

PROGRAM: GENERIC COMPUTER AIDED LIFE CYCLE SUPPORT SYSTEM

R&M TO BE DEMONSTRATED: COMPUTER AIDED TAILORING OF KEY LIFE SUPPORT ELEMENTS IN THE ADVANCED LIGHTWEIGHT TORPEDO

COST: $.75M

SCHEDULE: 12 MONTHS

IMPLEMENT COMPUTER AIDED LIFE CYCLE SUPPORT WITHIN THE ADVANCED LIGHTWEIGHT TORPEDO PROGRAM

PROBLEM STATEMENT: No single system currently exists which will allow the integrated analyses of all elements which impact on system operational suitability as defined in Department of Defense (DOD) Directive 5000.1. DOD contractors and government agencies have specialized software which allow separate analyses of certain unique elements, such as configuration management and provisioning, of operational suitability. Many times this software has been tailored to meet system-specific requirements and thus cannot be employed across a full range of systems types. Because of the interrelationships among the elements of operational suitability, there is significant redundancy and waste in conducting separate analyses. Further, the answers lack consistency because these fragmented analyses too often employ different input data. The end result is a distorted picture of the service's capability to support the emerging system. State-of-the-art software, hardware and analytical techniques will support the development of an Integrated Operational Suitability System (IOSS). The payoff is significant. Benefits, such as reductions in life cycle cost, improved system availabilities and decreased acquisition costs are all possible.

PROPOSED SOLUTION: It is proposed that the IOSS be developed in phases and by employing a current acquisition, the Advanced Lightweight Torpedo (ALWT) as both a testbed and model. The Trident Integrated Data System (TIDS) is proposed as the IOSS core. TIDS, as it currently exists, is adaptable to any product manufactured by a typical DOD contractor utilizing MILSPEC fabrication procedures and test documentation. Further, the system has a wide range of capabilities. For example, TIDS provides for the timely and systematic acquisition of data relative to performance and test, manufacturing and quality, problems and failures and equipment location and status. Thus, TIDS can be utilized in configuration management, performance evaluation, resource mangement, failure reporting, test equipment support and software engineering, etc.

Phase I: Phase I will consist of enhancing the basic TIDS with selected new capabilities and testing the prototype IOSS on the ALWT acquisition. Phase I will begin by employing the ALWT acquisition as a model to determine what data requirements are necessary to define selected elements of operational suitability. The elements selected will be those contained in the NUSC Integrated Logistics Support Analysis (NILSA) program and the Timely Spares Provisioning (TSP) program. As both of these programs are of imminent application to the ALWT acquisition, IOSS development will immediately benefit from real world experience. TIDS capabilities will be compared to NILSA and TSP capabilities. Deficiences in TIDS will be documented and functional specifications for software to correct the deficiencies developed. Based on these functional specifications, TIDS will be up graded to form the prototype IOSS. The prototype IOSS, made up of TIDS, NILSA and TSP integrated into a single system, will then be tested on the ALWT acquisition. The test results will be evaluated and any refinements necessary identified and made the prototype IOSS.

Phase II: At a significantly reduced cost, due to the core system being integrated and generic, Phase II will consist of expansion of the prototype IOSS capabilities. A more accurate definition of Phase II will be made at the completion of Phase I. In general, the following [illegible] would seem appropriate;

Establish IOSS at NOSC in support of ALWT as NOSC standard system.

Proivde final implementation, application and operational documents.

Provide tailoring procedures for other programs and systems.

Incorporate such features and elements as may be considered appropriate based on operational exerpience gained in Phase I to broaden utilization of IOSS within the Department of the Navy.

TIME TABLE: The following time table is considered realistic.

Operational System On-line (not to exceed)

NILSA for Navy and ALWT Prime contractor	2 Months
TIDS for Navy and ALWT Prime contractor (Including initial IOSS modifications)	4 Months
TSP	TBD
TOTAL TIME for PHASE I	12 Months

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INDUSTRY DEMONSTRATIONS OF RELIABILITY AND MAINTAINABILITY IN COMPUTER AIDED DESIGN

Problem Statement

Reliability, maintainability and logistics (RM&L) are significant factors in the combat support of Department of Defense (DOD) weapon systems. Because of these factors, the defense industry designs new weapons and equipments in accordance with the appropriate military standards, specifications, etc. Most often, the function of ensuring that RM&L standards are being met is placed in the hands of technical personnel outside the mainstream of the engineering design process. In this environment, with respect to supportability, the engineering process becomes iterative. A specific design is produced by the design engineer, reviewed by the maintenance engineer, and then redesigned by the design engineer. This is a costly process for the company, and often results in systems which are difficult to maintain.

The opportunity exists today to significantly, and dramatically, improve the capability to design for supportability. This opportunity exists now because of the convergence of three historical trends. The first trend is the steadily increasing demand of the Department of Defense to improve the reliability, maintainability of systems while reducing manpower and costs. The Carlucci Initiatives and the Department of Defense Directive 5000.39 are recent examples of this growing interest.

The second trend is the accumulating evidence which indicates that Reliability maintainability and logistics support characteristics can be designed into a system beginning with early conceptual studies. This research indicates, also, that one of the best ways to improve design for support is to put the reliability maintainability and logistics data and factors directly into the daily working procedures used by the design engineering personnel.

The third trend is the "explosive" emergence of computer aided design (CAD) as the daily working procedure within American industry for design of products. One of the main reasons for this rapid growth is that CAD greatly reduces the time and engineering labor hours required to produce a new design. The opportunity exists to link these three trends and to develop the technical capability to put R&M factors and data directly into the CAD process being used by the defense industry. This technical capability does not exist today except in limited scope in isolated cases. The current status of design for support is primarily that of analyses being done "off-line" from the main performance engineering design activities, and often being performed "after the fact" with regard to major design decisions. The development of the technical capability to put R&M factors directly into the main CAD process can change this picture. Design for supportability can become an "on-line," "during the fact" design activity.

As stated previously, many DOD contractors have major CAD facilities. They use these facilities to rapidly create engineering drawings and to do many performance related analyses. While there exist a number of isolated activities (chiefly IR&D) looking at R&M in CAD, it is not yet widespread across industry. This is due to three reasons.

1. Doing R&M in CAD is a relatively new activitiy for most firms.
2. There are few R&M analysis techniques which are readily accessible in CAD.
3. Some interfaces between engineering disciplines (Design, R&M, Field engineering) have not yet been developed so as to effectively use CAD/CAM.

Technical Solution

In order to overcome these problems DOD should push to accomplish the following:

1. Demonstrate the feasibility and usefulness of putting R&M into CAD (short term).
2. Develop a comprehensive set of R&M analysis packages for use in CAD (long term).
3. Support the development of automated interfaces among all engineering disciplines (long term).

In the near term the most important thing DOD can do to foster widespread use of CAD to address R&M considerations is to find a series of CAD demonstrations. Each of these demonstrations should have the following characteristics:

1. High visibility hardware program.
2. Currently in design.
3. High potential payoff.
4. Inexpensive.
5. Short duration (quick output).
6. Wide application of technology demonstrated.

The Air Force Human Resources Laboratory has conducted an industry survey to identify candidate programs which would meet the above criteria. While the survey was by no means exhaustive, it did provide several excellent examples of what can be done in this area.

A number of major aerospace firms were contacted and nine potential demonstrations identified. Each of these programs were $2 million or less and ran from 1-2 years in length. They fell evenly into four categories: 1) Testability, 2) 3D analysis of structure, 3) Thermal stress, and 4) Avionics reliability Logistic Support Analysis Methods. These nine examples are described in the attacment to this report. We recommend that one or more demonstrations from ach category be performed.

If parallel with the demonstrations but with a longer time horizon (4-5 years) DOD should begin to identify what R&M analysis packages need to be adapted/developed for use in CAD. The goal should be to adapt the most successful techniques across industry.

Lastly, DOD should, as a long term goal, work to make sure that the various CAD/CAM systems all talk to one another. This can be best done by providing funding and direction to develop standard interfaces among the various systems.

Benefits

The benefits of a series of demonstrations will be several:

1. It will reduce R&M engineering manhours on the selected systems by as much as 50%.

2. It will improve mission reliability of selected systems by as much as 10%. However, while these benefits would likely pay for the entire program in and of themselves, the most important benefits will occur when R&M is fully enteractual in the CAD process. Once the power of CAD to improve R&M is clearly demonstrated, other programs and industry itself would go on to expand the use of CAD to improve R&M in many other areas. The end result would be weapons with truly outstanding R&M characteristics.

Costs

A number of excellent demonstrations could be done for approximately 5-8 million dollars. They could all be accomplished from 1-2 years following contract award.

Implementation:

It is recommended that the Air Force Human Resources Laboratory be tasked with conducting these demonstrations and with spear heading the R&M analysis in CAD standardization effort. They have done much work to inject R&M factor into CAD and have currently planned a Research and Development program similar to the one outlined here. It is suggested that a number of competitive awards be made to do the demonstrations so that the best industry inputs can be assured. Finally it is recommended that normal Air Force mechanisms be used to fund and manage the demonstrations. With regard to the development of interfaces among different CAD systems, it is recommended that AFWAL's Integrated Design Support System be also funded.

EXAMPLE PROJECTS

AREAS:
Testability
3-D Analysis of Structure
Thermal Stress Analysis
Logistics Support Analysis Methods

AREA: Testability
CONTRACTOR: Honeywell
PROGRAM: VHSIC
R&M TO BE DEMONSTRATED: Design For Testability
COST: $1M
SCHEDULE: 16 Months

VHSIC DESIGN AUTOMATION FOR FIELD MAINTAINABILITY AND RELIABILITY

I. INTRODUCTION

Improving reliability and maintainability of tactical Air Force avionics systems is becoming more important. Integration and application of VHSIC technology to Avionics systems and subsystems requires parallel development of new approaches to logistic support to ensure that future field maintenance needs are well planned and in place when needed. The goal is high availability of the weapon system in order to maximize force readiness.

As an Air Force VHSIC contractor, Honeywell is keenly aware of both the challenges and payoffs VHSIC will bring to the field maintainability and reliability areas. Honeywell is demonstrating its VHSIC technology with a chip not intended for automatic targeting from (EO) sensors. This Electro-Optical Signal Processor Brassboard (EOSP), will be demonstrated in December 1984. Honeywell has a comprehensive approach to chip level production and on-line fault isolation, and self-healing capabilities built into the Honeywell chips can be used to increase the system-level MTBF by as much as 300 percent.

The impact of these VHSIC capabilities on field maintenance and system reliability concepts needs to be addressed in a comprehensive program. The proposed program has two thrusts:

1. A critical technology demonstration which extends the chip-level testability and fault tolerance features and the associated Design Automation (DA) tools in the Honeywell brassboard to simplify system-level field maintainability and reliability functions. The demonstration can take place at the conclusion of the VHSIC program in December 1984.

2. A study of the critical logistics functions (including testability, reliability, maintainability, documentation, and human resources) to develop a methodology for the optimal allocation of these resources to maximize overall system-level field maintenance effectiveness. This methodology will serve as a baseline for specifying a new set of design automation tools for maintainability and reliability engineering (M&RE).

We believe that the two-fold approach of demonstrating the critical VHSIC design automation technology to validate the field maintenance methodology will result in the highest payoff program. This program will serve to bring M&RE into the mainstream of VHSIC by bringing the considerable resources of VHSIC to bear on field maintenance, which is one of the strongest life-cycle cost drivers in avionics today.

(Insert Figure 1).

II. VHSIC DA TOOLS FOR TESTABILITY AND FAULT-TOLERANCE

As part of Honeywell's current VHSIC Phase I contract with AFWAL, we are developing a VHSIC chip set and brassboard demonstrator for electro-optic signal processing (EOSP). Our chip set, comprised of three types, involves complexities in excess of 15,000 gates. Each chip type incorporates a section of logic which is dedicated to self-test and external testability, as well as special-purpose interconnection paths to provide a level of fault-tolerance for single chip failures. The core of our self-test and external test approach involves the concept of serial shift paths. In this approach, all blocks of combinational, asynchronous logic are provided with serial/parallel registers at the inputs and outputs. All of these registers are then serially connected into test loops, and all loops are then multiplexed into a single self-test interface logic block. In this way, we provide for thorough testabilitiy of the internal logic in each of our VHSIC chip types. This method allows for fault detection and isolation directly to the chip level by either the on-chip test analyzer, or by an external test system.

This approach does not address are the issues of input/output and functional testing at the pin level. Nor does it allow for board level and subsystem-level fault notification during self-test due to the lack of an executive controller in our current brassboard. Demonstrating these hardware and software enhancements to our existing brassboard design and its associated test/development hardware/software form the basis for our proposed demonstration.

Design-For-Test Demonstration

To demonstrate our design-for-test methodology, we propose to augment our existing EOSP brassboard subsystem with additional hardware for circuit card fault detection/isolation/notification, and additional serial shift paths for test at the subsystem/sensor I/Q level. These hardware enhancements will be supported by additional microcode and FORTRAN code in our development system to effectively demonstrate:

- self-test performance.
- card and chip level fault detection, isolation, notification, and simulation.
- subsystem testability.
- analytical measurement/tradeoff of test performance versus test resource allocation (i.e., microcode memory and execution speed).

Benefits Derived From the Demonstration

Honeywell's design-for-test methodology allows the system designer to create a hierarchical test environment both within a processor subsystems and external to it. This hierarchy can extend to the system-level in aircraft such as the F-16 (or swept wing).

We propose to use the information gained from our demonstration of design-for-test in combination with Air Force systems which use VHSIC technology. A likely candidate for this model would be the VHSIC implementation of the Imaging Sensor Autoprocessor (VISA) subsystem currently under simulation and development by Honeywell. The VISA processor is suitable for integration with high performance aircraft like the F-16, and will rely heavily on VHSIC technology. The development of an analytical test model for this system would allow optimal design of the

IV STATEMENT OF WORK

Task 1 - Study of the Impact of VHSIC on M&RE

A systematic study which relates the built-in testability and fault tolerance at the VHSIC chip level with maintenance and reliabiity concepts in tri-service systems and other logistics elements (including CAE for documentation and human resources). This task will identify the critical technology demonstration needs to validate the overall VHSIC maintainability and reliability methodology to be developed in the next task.

Task 2 - Methodology for VHSIC Resource Allocation for Field Maintenance

A comprehensive strategy will be developed to model the cost/benefit of each of the VHSIC resources (testability, fault tolerance, computational power) to define a logistic support analysis methodology to allocate these resource for the optimum configuration of the field maintenance concepts. This methodology will be validated by applying it to selected tri-service systems which are candidates for the Honeywell VHSIC chips.

Task 3 - Critical Technology Demonstration

This task extends the Honeywell ROSP Brassboard test software and hardware and the system-level test DA software to tie chip-level testability and fault tolerance features into LRU, subsystem and system-level field maintenance concepts. The results will be a demonstration of the simplification of field maintenance steps and automatic test equipment by demonstrating system-level self-test and fault isolation.

Task 4 - Specify DA Tools for VHSIC M&RE

The validated methodology of Tasks 2 and 3 will form the basis for requirements specification of design automation tools which will be needed to implement the methodology for VHSIC design for M&RE. The DA tools may include expert (knowledge-based) systems which cast the design methodology into production roles.

V. SCHEDULE AND COST ESTIMATES

The schedule of the 16 month program is shown in Figure 3. It culminates in a critical technology demonstration at the end of 1984 (coincident with the VHSIC brassboard demonstration). (Insert Figure 3).

Table 1 gives a breakdown of the man hour estimates for the four major tasks proposed. The precise effort required will depend on the specific scope of the critical technology demonstration. For budgetary purposes, a rough order of magnitude estimate of this scope is $1M. (Insert Table 1).

AREA: Testability
CONTRACTOR: General Dynamics/Fort Worth
PROGRAM: F-16 Stores Management System
R&M TO BE DEMONSTRATED: Diagnostic Design
COST: $2M
SCHEDULE: 24 Months

PROPOSED PROJECT FOR INCORPORATING RELIABILITY, MAINTAINABILITY, AND SUPPORTABILITY (RM&S) FACTORS INTO COMPUTER AIDED DESIGN (CAD)

Objective: Redesign of the F-16 Stores Management System (SMS) Remote Interface Unit (RIU) Utilizing CAD with Automated Testability Analysis

- Some of the major technical and support problems we are trying to resolve are as follows:

  1. CAD equipment will allow the hardware/software designer to vastly improve the speed and accuracy of his design. If RM&S features and requirements are not convenient for the designer, they will probably not get designed-in during initial design.

  2. If the design engineer requires RM&S inputs such as design trade offs during initial design formulation, manual inputs will slow the process and could negate some of the gains made by design automation.

  3. There is a need to accomplish real-time testability analysis so that the test engineer and the avionics equipment engineer communicate early during the design phase rather than as an after-thought several years later during ATE interface design.

  4. There is a need for an interactive diagnostics system such as LASAR which will provide real-time testability analysis rather than as an after-thought several months after design is complete.

  5. Increased system complexity and interface between other systems tend to complicate design and decrease design visibility. Design automation is required to provide systems which are supportable (i.e., tech data, training, SE, etc.) when the hardware reaches the field.

- Some of the benefits of providing RM&S design features in CAD equipment are as follows:

  1. RM&S requirements, lessons learned and system diagnostics can be greatly enhanced during initial design.

  2. Hardware and software design and development, and their required tech data and support equipment, for a simple avionics systems are multi-million dollar projects. ITAs for complex module boards can be as high as $1M. Appreciable savings in design phase due to decreased designer and test technician workload plus decreased delays and increased testability accuracy can be a large cost avoidance and development program enhancement.

3. Real-time testability analysis such as an online LASAR capability will tend to improve testability and increase interaction between the avionics design engineer, the system test engineer, the support requirements engineer and the support equipment design engineer. Considerable engineering manhour saving and increased accuracy can be realized by designing from a common, automated, interactive data base.

4. Increased design accuracy and providing RM&S features in initial design tends to minimize costly design changes in the field as well as improve the support posture of the system in the field.

5. Real-time testability analysis should decrease development time of support systems and should minimize the possibility of unsupportable systems in the field due to lack of training and SE.

O R & D Tasks

One of the major tasks in this project is to develop the hardware/software interfaces (design data base) between the CAD equipment and the testability analysis such as the LASAR. GD/FW has extensive background and experience in utilization of LASAR testability models. GD/FW depot test design engineers are constantly striving to shorten analysis time and improve LASAR usefulness. GD/FW has negotiated with Ogden depot to acquire a LASAR 6 system which will be hosted on a VAX system. This LASAR system is the Air Force's newest equipment and appears to have the capability to readily adapt to a CAD environment. It is anticipated that these equipments will be available by the time we are ready to design the interface. (Insert Figures 1 & 2).

RM&S - CAD Concept

The goal of the RM&S - CAD Concept is to integrate the avionics hardware, test equipment and RM&S design efforts using a CAD work station, large scale computer hardware/software network system. The network system is comprised of three types of computer-aided design engineering work stations that communicate with a common design database. The database itself will reside in a large scale computer system to which a CAD work station can become a "smart" terminal for purposes of reading and/or updating in a timesharing environment. While in the "smart" terminal posture, the CAD work station will have the capability to use the software which resides in the large scale computer system or it can operate in a stand-alone posture using its own software. The LASAR testability computer model is a complex computer program that will reside in the large scale computer system but will have an interactive interface wth the test equipment CAD work station. This interface will allow the test equipment design engineer to initiate and control execution of the program as his tasks dictate.

The avionics and test equipment CAD work stations will contain the necessary software to allow the designer to produce hardware designs while the system is in the stand-alone posture. These stations will contain some testability software. RM&S analysis software will be used by these CAD work stations to aid the engineer in making the avionics and test equipment design. Periodically during the design process the avionics hardware design engineer will release a preliminary design to the design database. This design can then become available (1) to the RM&S engineer for more rigorous RM&S analysis, (2) to the test engineer for rigorous testability analysis using LSAR, and (3) for use in test equipment design. Change suggestions as a result of RM&S analysis and testability analysis will be fed back to the designer via the design database. The RM&S CAD work station will also be used to maintain (update) the RM&S factors contained in the design database.

The following are major milestones for concept implementation:

Design and development of the RM&S - CAD work station analysis system (several electronic hardware CAD work station analysis systems are available commercially).

Design and development of design database.

Design and development of the interface (1) to transform the design data contained in the design database into the form required for input into the LASAR testability computer model and (2) to transform the LASAR testability analysis results into the form that can be placed into the design database.

AREA: 3-D Analysis of Structure
CONTRACTOR: General Dynamics/Convair
PROGRAM: Cruise Missile Avionics
R&M TO BE DEMONSTRATED: Inspection Criteria
COST: $1.5M
SCHEDULE: 18 Months

DAMAGE TOLERANCE ACCEPTANCE/REJECTION CRITERIA ANALYSIS

PROBLEM:

Performance of damage tolerance analysis for development of inspection/rejection criteria of missiles is costly and cumbersome. However, failure to determine adequate criteria for acceptance or rejection of encanistered or encapsulated missile assemblies with evidence of external damage (scratches, dents) could result in costly return transportation, checkout and pipeline replacement of serviceable missiles in storage and launch platform upload of failed missiles or in proliferation of checkout equipment to operational sites to verify serviceability upon receipt. This is particularly true of the ever increasing "Wooden Round" support concepts for advanced systems. Automation of finite area analysis techniques used to determine transfer of forces to missile avionic equipment and predict visible external damage resulting from these forces would result in significant manhour savings. The risk of acceptance of damaged missiles or rejection of serviceable vehicles would be greatly reduced.

TECHNICAL SOLUTION:

CAD technology can be ued to develop a model to subject the vehicle under an analysis to forces at any angle to the vehicle/canister surfaces with a range of magnitude to simluate impacts that might actually be applied during handling transportation and loading operations. Modeling the transfer of these forces to avionics installations and modeling the resultant surface deflections would provide correlation between visible surface damage and vehicle serviceability. Parametric inspection/rejection criteria can then be provided to the technician in the field.

R&D REQUIREMENTS:

Model development will require identification of data elements to be input from the CAD engineering data base and interface with algorithms for transfer of impact forces through the vehicle. This includes characteristics and dimensions of material, mounting characteristics and shock limits and sensitivities for installed avionics. Validation of the model would be performed through comparison of model predictions with results from instrumented test specimens in the laboratory.

TECHNOLOGY DEMONSTRATION:

The model would be demonstrated on the CAD terminals. Videotapes of CAD CRT presentations would be prepared in conjunction with videotaping of actual hardware undergoing testing in the lab to validate results of the model.

CANDIDATE HARDWARE:

Candidate hardware for performance of the analysis and demonstration of the technology will be cruise missile canister, airframe assemblies and avionic equipment.

BENEFITS:

Development of a damage assessment model will significantly reduce engineering manhours and increase the accuracy of damage tolerance analysis. Risk of rejection of serviceable missiles would be reduced. This would result in savings of at least 50% of engineering manhours after model development, a 10% reduction in missile pipeline costs and an improvement in system availability.

COST AND SCHEDULE:

This study is estimated at $1 to 1.5 million over 12 to 18 month period. Cost and schedule within these ranges will be impacted by the availability of production type avionics equipment for model validation.

AREA: 3-D Analysis of Structure
CONTRACTOR: Westinghouse
PROGRAM: B-1 Radar
R&M TO BE DEMONSTRATED: Line Replaceable Unit Design
COST: $1.5M
SCHEDULE: 15 Months

AVIONICS CAD/CAM DEMONSTRATION

PROBLEM STATEMENT

Our future weapon systems will be designed, developed and supported by CAD/CAM systems. Today CAD/CAM systems are coming on-line and being used as efficient aids in the design process but they are not yet fully developed and much has to be accomplished to show their practical use at the avionics system level. Specifically, the engineering data and the three-dimensional information resident in these systems provides an opportunity to do early trade-off analysis and support system design in a more efficient manner. Although prime contractors have taken early initiatives in using CAD/CAM, the full benefits of these systems in development and suppport of avionics equipments has yet to be demonstrated.

Fielded weapon systems have shown their dependancy on the proper operation and efficient repair and maintenance of avionics LRUs. To provide the support needed to keep system readiness at higher levels, CAD/CAM technology applied to avionics systems needs to be made an integral part of fielded weapon systems design. A major step to accomplish this would be a demonstration that shows improved design and support system analysis and the creation of electronic user oriented data that can be accessed from remote field locations in support of avionics systems.

TECHNICAL SOLUTION

CAD/CAM technology has the capabilities to allow designers, support personnel, and users direct access to an engineering data base. It can provide improvements in performing major depot functions, refurbishment, remanufacturing, and in carrying out major modifications efforts. Its capabilty needs to be explored by a fully integrated demonstration to show the improvements that can evolve from the development of technical and support information and the end support products which can be electronically delivered and accessed directly by the Air Force and prime contractors is recommended.

This demonstration of CAD/CAM technology should be applied to an avionics system which is part of an emerging weapon system. The program to be used as demonstration project will be selected in conjunction with the Air Force and detailed tasks selected to complement ongoing prime system program activities. This visible application would advance the current state of CAD/CAM system development and serve as a pilot project for future systems. It will show readiness considerations that can be accomplished early in the design process as a result of CAD/CAM technology and the use of this technology by both designers and support personnel.

A specific LRU from a radar system will be selected as a demonstration test bed and CAD/CAM technology applied throughout the design and support system development for his equipment. This demonstration will show a complete picture of how CAD/CAM technology can be used. It will identify the changes (new equipments, procedures, data requirements, etc.,) that must take place as a shift is made by suppliers and the Air Force to rely on electronic data forms. No new R&D will be needed to conduct this demonstration. The need is for procedural development to fully use the existing capabilities of CAD/CAM systems by designers and support personnel.

CAD/CAM systems have many capabilities that have not been fully explored. To date they are very often used as efficient design aids to solve immediate problems. For example, the generation of two-dimensional drawings is a common application because it increases the efficiency in performing required tasks and the delivery of required information. It does not push the system to fully use its inherent qualities. The recommended demonstration will start with design data which can be used in various trade-off analysis and will contain a three-dimensional data base that can be used directly by support designers to generate repair and maintenance information and explore assembly/disassembly processes. This demonstration will show some changes in the established philosophy for designing, creating drawings, and exploring support system trade-offs. It will provide an efficient means for generating user information directly from the engineering data bases earlier in the design process than it is currently done today.

As a valuable by-product the suggested demonstration will establish a direct link of an end user to a current complete data base that can be used to keep equipment working. It will follow an integrated readiness center philosophy that gives the user a closer tie to support information and provides current configuration status for the equipment. This user link to source data will show how future systems can be supported.

DEMONSTRATION TECHNIQUE

The demonstration will be configured to use CAD/CAM completely for the engineering design and suppport design of a single Line Replacement Unit (LRU). Both designers and logistics support personnel will access the design data base and use it to design the equipment and to conduct support trade-offs. The design data base will be used to create the end item documentation products. Final documentation such as an illustrated parts breakdown, and maintenance and repair information will be created from the CAD/CAM system data and formatted for delivery to other electronic data systems. It will have the capability of being rapidly updated to reflect system changes. This will include the creation and use of three-dimensional drawings which will describe the LRU. The three-dimensional views of the LRU configuration will be used to review the assembly/disassembly tradeoffs that are necessary in conducting a maintenance analysis. All paper delivery requirements will be fulfilled by the electronically formatted CAD/CAM outputs. Part of this demonstration will show how reliability and maintainability design considerations can be included in CAD/CAM systems and used during the system development. Specifically, the data base will contain reliability data that can be accessed by reliability personnel to perform analysis.

The major task areas involved in developing and carrying out the demonstration are:

1. <u>LRU Selection</u> - Select and coordinate the equipment which shall be used as a test bed. This will involve establishing a complimentary posture for the demonstration that will enhance the development of the related hardware and will not compromise established program delivery requirements.

2. Data Base Creation - Create a complete engineering data base that can be accessed by design and support personnel. This will include three-dimensional information needed to create technical illustrations, reliability data, and maintenance/repair information.

3. Drawing Development - Develop all drawings on the CAD/CAM system using a logical assembly order for the creation of all drawings.

4. Reliability Analysis - From a CAD, or an associated terminal, conduct a reliability analysis using information available from the CAD/CAM data base.

5. Maintainability Analysis - Conduct a review of the maintainability considerations using the CAD/CAM system. This review will ensure access to parts for maintenance and the ability to assemble and disassemble for repair purposes.

6. Support Design - Show the early access of design information by support personnel who need to generate user oriented repair and maintenance information. Use the CAD/CAM system to establish a closer tie of support personnel to the detailed design information.

7. User Product Delivery - Develop a final electronic data delivery format for the CAD/CAM generated information which can be accessed by field users. This will include a demonstration of a fault insertion and repair using the CAD/CAM information.

8. Documentation - The several demonstration areas will be documented and a lessons learned file established to guide the expanded use of CAD/CAM in design and support of avionics equipments.

BENEFITS

Some of the benefits that will result from this demonstration are:

1. It will provide positive evidence of an application of CAD/CAM technology at the avionics LRU level showing how design, development, and support considerations can be integrated by this technology. It will demonstrate how reliability and maintainability information can be made part of a CAD/CAM data base and used in the development of avionics equipment. In addition, it will show an efficient way to integrate support considerations early in the design process. It will demonstrate the efficiencies that can be realized by having many functional groups of the equipment development team rapidly access a common data base.

2. It will provide a pilot definition of the way avionics LRUs will be designed and documented in future systems. This will include a definition of procedural changes (i.e., creating a drawing in an assembly sequence) and the functional interfaces (engineering, reliability, maintainability, technical support, etc.). It will show the costs, time and personnel savings that can be achieved.

3. It will provide a first "lesson learned" experience with CAD/CAM applications designed to provide user oriented information directly from suppliers' files. This provides potential for improved readiness by having current and direct access to configurations, repair and maintenance information.

4. It will demonstrate a form of data delivery that can significantly reduce the paper trail that follows systems to the field.

5. It will establish an improved way for the Air Force to communicate with their suppliers and for their suppliers to assist in support of fielded equipments.

BUDGET PLANNING COSTS AND SCHEDULES

For planning purposes, it is estimated that the suggested demonstration could be conducted for $1.5M. It would cover a time period of approximately 15 months.

AREA: Thermal Stress Analysis
CONTRACTOR: Boeing
PROGRAM: Improved Minuteman Physical Security System
R&M TO BE DEMONSTRATED: Thermal Stress Analysis
COST: $1.3M
SCHEDULE: 14 Months

THERMAL MANAGEMENT AND RELIABILITY (TM&R) ANALYSIS DEMONSTRATION PROGRAM

1.0 Statement of the Problem

Conventional PCB packaging design procedure is concerned primarily with the routing of the signals. Component placement is selected to minimize the difficulty of routing the signals. As an example, the consequence of this design procedure will place the component with the most pins (and thus signals) in the territory near the center of the board. If the board is of the edge-cooled variety, this results in the component being placed near the hottest spot on the board. As a result of the sensitivity of component reliability to component termperature, the component would have a failure rate greater than it would have had at a location nearer to the heat sink (board edge). These facts are known and an experienced designer will select a part placement to attempt to minimize the failure rates. However, it is difficult to account for effects of the different power dissipations and temperature dependent reliability function; of the many types of components used on a board.

The problem lies with providing the designer with an analysis tool which will facilitate analysis of thermal considerations so that their impact on the design can be taken into account during the design phase of an electronics design program. Existing computer-aided design tools can be used to develop the necessary analysis data, but these are usually not integrated and the necessary iterations are complex and time consuming. As a result, it is impractical to synchronize these analyses with the typical hardware design schedules. This makes it difficult to incorporate the thermal design considerations into the design before other CAD tools are used for the detailed layout of the design.

This proposal addresses a way to speed up and integrate the thermal design analyses. This will enable timely inclusion of their performance in the sequence of electronic computer aided design steps and the impact of their results in the design cycle. This will produce more reliable and less expensive electronics packaging designs.

2.0 Technical Solution

Boeing proposes to use the Integrated Thermal Avionics Design (ITAD) System to demonstrate gains which can be realized with modern CAD tools. ITAD was developed by Boeing under contract to AFFDL. ITAD is an extremely flexible system which can be used by the electronic packaging engineer to determine the optimum (minimum failure rate) PCB packaging design for a known thermal environment.

ITAD is comprised of the core software and an extensive group of analysis programs. The executive segment of the core software is used to implement "user friendliness" via menus. It provides for a number of predefined design procedures. A design procedure is the specification of a number of analysis programs and their order of execution. The executive leads the user through his selected scenario step by step. At the start of each step the executive calls the Input Processor. The Input Processor serves as a "user friendly" interface between the user, the data base, and the particular analysis program for the current scenario step. It leads the user through a review of the data elements resident in the data base which will be required for input to the analysis. When the designer is satisfied with the data values the Input Processor extracts them from the data base and formats the input file for the analysis program.

The executive then launches the analysis program for execution and calls the Output Processor when the analysis program output file is available. The Output Processor searches the output file for data elements which will be required for subsequent analysis steps and updates the data base with new values. The executive then proceeds to the next scenario step where the cycle through the core software is repeated. Upon completion of the scenario, the design "solution" is contained in the data base. All of the output files are also available as a user option. The Data Base Management System (DBMS) is another core software utility. It has a query language which may be used to directly examine the content of the data base.

The following analysis programs are currently integrated into ITAD:

A) LRU/PCB Thermal Analysis (SINDA)
B) Thermal design optimization (OPTEMP)
C) Part placement routability (DAP)
D) MIL HDBK 217 reliability analysis (ORACLE)
E) Thermal Conductance Evaluation (QMHO)
F) Preliminary ECS design (AIRSCOPE)
G) High Power System design (CAPSD)
H) Life Cycle Cost (LCC/PRICE)
I) Flight Penalty (FPEN)

A brief description of each program follows:

- PCB and LRU Thermal Analyses are two separate thermal models which use the SINDA general purpose analysis program. The two models handle the PCB and LRU design parameters as variables and thus are applicable to a wide range of PCB's and LRU's.

- Electronic component reliability analysis is handled by ORACLE, the computerized version of MIL-HDBK-217D.

- OPTEMP II is optimization analysis code written specifically for ITAD. Its five functions are: to select the optimum order of electronic components in a linear thermal environment; to select the optimum order of serial PCB's relative to a coolant; to select the optimum allocation of coolant to parallel branched LRU's; and to select the optimum serial combination of parallel branched LRU's relative to the coolant.

- Routability assessment for a specific PCB part placement is handled by the DAP program.

- Life Cycle Cost analysis is handled by the LCC program which is based on the LSC model in conjunction with a downtime cost model and user supplied acquisition cost.

  For airborne systems, an analysis (FPEN) is incorporated for evaluating the increase in aircraft fuel cost.

* QMHO is an interactive utility useful for evaluating heat transfer coefficients and thermal conductances.

AIRSCOPE is an aircraft environmental control system preliminary design analysis.

HPSPD is an airborne high power system preliminary design analysis.

The items above marked with an asterisk (*) will be useful for this proposed demonstration.

It is anticipated that the following scenario will demonstate the gains in reliability achievable with ITAD:

- Establish Equipment Environment.
- Conduct LRU Internal Thermal Analysis.
- Conduct PCB thermal Analysis for existing design.
- Conduct Reliability evaluation for existing design to establish baseline values and to validate analysis procedure.
- Select trade strategy with most potential.

Those supported by existing ITAD are:

1. Reposition parts on each PCB to achieve minimum failure rate based on thermal considerations
2. Upgrade quality of parts used
3. Select thermally optimum coolant distribution network
4. Combinations of 1, 2, & 3

- Conduct trade to determine potential gain in reliability.

An additional result of this scenario is a temperature survey of all the components on each PCB. Thus any problem components will easily be identified. Any special purpose heat sinking required for these problem components may be incorporated into the design and an additional cycle through the analysis programs will readily identify new component temperatures and reliabilities.

A fundamental design requirement of ITAD was that additional analysis programs could be readily integrated into ITAD for use in a scenario. This design requirement is satisfied, thus, if additional analysis programs are available and appropriate for the selected trade, they could be integreated to take advantage of the features of ITAD.

ITAD was implemented initially for airborne avionics where individual PCB's seldom exceed a size of 6 X 9 inches. No modifications to ITAD software are expected for use of ITAD in PCB's of this size or smaller. However, as the IMPSS is partitioned, larger PCB's may be encountered. We may then have to modify some parameters in ITAD software. These modifications are considered minor.

ITAD has an extensive electronic components library in the data base. It is anticipated that the library will suffice for a high percentage of PCB's. As new components enter the marketplace and are used on new IMPSS designs the library will have to be updated.

The data base requires definition of a data model to contain all of the data required in ITAD. Currently only aircraft weapon systems are supported with a data model.

3.0 Demonstration

The following paragraphs briefly describe the planned TM&R Analysis Demonstration program.

3.1 CAD Techniques to be Demonstrated

Using ITAD, Boeing will analyze the developing designs for the electronics of the IMPSS. The analysis will be phased with the project to allow time for recommendations to be implemented on a timely basis. The steps to be followed in the demonstration consist of establishing the thermal environemnt followed by an internal thermal analysis on the existing design. This then leads to a reliability evaluation of the existing design, as a baseline.

The CAD techniques supported by ITAD will then be applied in a trade study which allows repositioning of parts on boards, upgrading parts quality, and adjusting the coolant distribution network as necessary to optimize the reliability. The optimization goal will be to minimize life-cycle costs for the system.

Using the baseline data established on the initial designs and the potential improvements established by the application of the advanced CAD techniques collectively applied using ITAD, the demonstration will verify that the application of these techniques can significantly reduce electronic system life cycle costs thru increased reliability. The demonstration will show that this can be done in a timely manner consistent with actual schedules of a real hardware development program.

3.2 Candidate Program

The Boeing Company has selected the Improved Minuteman Physical Security System (IMPSS) as its candidate program. The work package is a replacement for the existing physical security system for Wings I and VI. The new system is a monostatic radar using advanced microprocessor techniques. Doppler filtering and processing is used to achieve high probability of detection of intruders along with low nuisance alarm rate. The contracting agency is OO-ALC. The contract number is F42600-83-D-0123. The PCO is Annbel L. Byrd [(801)-777-4891]. The program is underway and authorization has been approved through qualification testing. PDR is scheduled for October 1983 and CDR is scheduled for May 1984.

3.3 Computer-Aided Design Equipment

ITAD uses a local minicomputer and color display system as the user interface to VAX and CYBER computers. The larger computers host most of the ITAD software, the data bases, and the analysis programs used by ITAD. To minimize rehosting problems for the demonstration we propose to purchase a duplicate of the existing ITAD terminal system, and use the existing software. Existing VAX and CYBER computers will be used for the main frame units.

The ITAD terminal system consists of a DEC PDP 11/23 minicomputer with two 10MB hard disk drives. It is interfaced to a Genisco color display system capable of displaying 256 colors from a menu of 16 million colors. Black and white hard copy is obtained from a Tektronix video hard copy unit, or a letter quality printer. Color hard copy is obtained from a 8-color pen plotter or a Matrix color camera. The latter provides 8 X 10 Polaroid copies (example attached) or 35mm slides. Communications to the main frame computers are via a 1200 baud modem and a commmercial telephone line. The local terminal system also supports ITAD documentation preparation and maintenance with a word processor, accessed from local wired terminals.

The ITAD minicomputer and color display system was selected from mature hardware systems in 1980. Subsequently, more capable equipment has appeared on the market. Our present intent is to duplicate the existing ITAD hardware for this demonstration. This will assure compatibility with existing ITAD terminal software. However, an early task will be to review more recent computer/display systems for compatibility with ITAD terminal software, and the ITAD system. This could result in selecting hardware which is functionally equivalent, but not identical with that described above. Such new hardware, if selected, could be expected to provide faster user response, capabilities for expanded local functions, higher reliability, and lower cost. Some R&D would probably be required to rehost the existing terminal software.

4.0 Benefits

It is estimated that the failure rates of PCB's in airborne avionic systems can be improved by 25% by employing the design principles implemented in ITAD. The gain in reliability results from placement of the individual components in the actual thermal environment cognizant of the sensitivity of component reliability to its temperature.

As a result of the elevated temperature of the thermal environment experienced by most airborne avionic equipment, the gains in reliability are expected to be greater than those anticipated where the same design principles are applied to ground based equipment. Thus the gain in reliability of the IMPSS with the use of ITAD can not be expected to exceed 25% over conventional design procedures.

5.0 Estimated Cost

Boeing believes that a detailed statement-of-work can be developed to accomplish the TM&R Analysis Demonstration program for a budgetary estimate of $1.3M. This program assumes no GFE except the ITAD software which Boeing has in hand. We have assumed permission to use this software will be granted by the ITAD program manager, Dr. George Kurlyowich of AFFDL. As part of the TM&R Analysis Demonstration program, Boeing intends to purchase a duplicate set of ITAD terminal equipment (color display, terminal computer, plotter, and color camera), or its functional equivalent, and use its own CDC Cyber and DEC VAX computing resources. The ITAD terminal equipment will be owned by the government and delivered at the completion of the TM&R Analysis program. Boeing has proposed this approach of duplicating the ITAD terminal equipment because Dr. Kurlyowich has indicated that there would be a conflict in the planned use of the ITAD contract.

6.0 Schedule

Figure 6.1 shows a 14 month schedule for the TM&R Analysis Demonstration Program. The schedule starts in mid-July 1983. It is important that the program start close to this date in order to have an influence on the IMPSS program. The tasks shown in Figure 6.1 allow some flexibility in definition and can be negotiated in the Statement-of-Work. (Insert Figure 6.1).

AREA: Thermal Stress Analysis
CONTRACTOR: General Dynamics/Convair
PROGRAM: Cruise Missile Avionics
R&M TO BE DEMONSTRATED: Avionics Component Reliability
COST: $1M
SCHEDULE: 12 Months

THERMAL INDUCED RELIABILITY DEGRADATION ANALYSIS

PROBLEM:

Increasing sophistication and complexity of aircraft/missile system avionics combined with requirements to reduce vehicle cross sections and observability, have resulted in high density packaging of avionic equipment. The potential for thermal build-up in avionics equipment areas is compounded by the requirement to minimize surface interruptions such as cooling vents in order to achieve low signature requirements for vehicle survivability. As ambient temperatures approach 100°C, further increases dramatically increase failure rates at the printed circuit level of assembly. The build-up of ambient temperatures throughout a mission may vary with equipment operating cycles and transfer of heat from the vehicle skin. Thus, analysis of the thermal characteristics of aerospace avionics system and resultant degradation of component/system reliability is a complex process, requiring many engineering manhours. Dimensional and volumetric data must be transferred from engineering drawings to input existing models.

TECHNICAL SOLUTION:

Special and dimensional data required for analysis of thermal propagation is resident within the CAD data base. This includes data on individual modules as well as their relationship to each other when installed in the vehicle. Studies on performance of thermal propogation of thermal propogation analysis using CAD have been conducted at the Flight Dynamics Laboratory at Wright-Patterson Air Force Base. Marriage of this analysis technique with CAD automation of reliability prediction techniques would provide a model for analysis of avionics reliability degradation for various mission profiles and environmental conditions.

R&D REQUIREMENTS:

Using the Flight Dynamics Laboratory CAD thermal analysis as a baseline, R&D required to develop this model would primarily consist of CAD automation of reliability prediction models. This automation would require update of environmental K-factors as the thermal propagation model indicated changes in operating temperature for each printed circuit assembly under analysis. Interface the model with CAD color graphics terminals would also be developed, enabling display of reliability degradation through color changes of the displayed modules.

TECHNOLOGY DEMONSTRATION:

Demonstration of the thermal degradation model would include a three dimensional color presentation of a cruise missile avionics area and running of the model to simulate multiple mission profiles and two or more design changes to change the thermal characteristics of the avionics suite. Graphic plots of temperature and failure rate of individual printed circuit cards would also be produced.

CANDIDATE HARDWARE:

Candidate hardware for performance of the analysis and demonstration of the technology will be cruise missile avionic equipment.

BENEFITS:

Development of the automated reliability degradation model would result in significant reduction of engineering manhours. This analysis is an iterative process, therefore, the capability of moving assemblies within the CAD data base without having to re-input dimensional data would facilitate rapid assessment of changes to correct thermal problems. Reliability of avionics installation could be optimized through successive iterations of the model, increasing overall mission reliability of the system. Cost and reliability improvements would approximate a 50% savings on engineering manhours and a 10% improvement on mission reliability.

COST AND SCHEDULE:

This study is estimated to require $750K to $1M over a 12 month period. Cost will be impacted by the degree of transferability of the Flight Dynamics Laboratory thermal model to computervision requirements.

AREA: Thermal Stress Analysis
CONTRACTOR: Sperry
PROGRAM: Advanced Tactical Radar
R&M TO BE DEMONSTRATED: Thermal & Mechanical Stress Analysis
COST: $.5M
SCHEDULE: 12 Months

RELIABILITY AND MAINTAINABILITY IMPROVEMENT STUDIES

Procedure: A turnkey CAD system and an associated main computer will be used to generate and analyze a project descriptive data base. Using the descriptive base generated on the CAD system, an analysis of failure modes and stress levels (mechanical and thermal) will be made on the main computer. The results of those analyses will be visualized on the CAD system. Accessibility studies will be performed on the CAD system using its 3-D view manipulation and parts 'explosion' capabilities. The initial system physical design will be entered onto the CAD system. Modeling sequences representative of the mechanical and thermal stress/failure levels of the initial design, and of access/maintainability problems will be developed to allow visualization of these areas. These sequences will be archived on magnetic tape, and a design improvement cycle started. The time and work level required to get to significant improvement stages will be recorded, together with the resulting model demonstration sequence. When the final design is reached, (with its associated model sequences) the flow of the development, and the resulting improvements will be demonstrated by displaying the sequential model displays in a semi-animated mode.

Equipment: The proposed effort would use a Computer Vision CADS 4 system as the turnkey CAD system. It has its own computer (a 'OCP200'), two color (high resolution) work stations and two monochrone work stations, it has a 300 mbyte disk system for active data bases, a magnetic tape servo, and access to a large Versetec plotter. The associated computer will be either the 'in-house' U1100/80 main computer, as a D3C VAX system (probably both will be used in different phases of the analysis).

Software: The CADS 4 system provides the basic software needed to generate the 3-D project deck base, to interface with the analysis programs, and to generate the required 'model sequences'. Using off-line processing it can display solid modeling image sequences to show fit interference, and accessibility procedures.

The 01100/80 system currently hosts the MASTRAN mechanical and thermal analysis program.

Other programs, as needed, will be obtained/generated, most probably on the D3C VAX system.

AREA: Logistics Support Analysis Methods
CONTRACTOR: McDonnell Douglas
PROGRAM: C-17
R&M TO BE DEMONSTRATED: R&M Data Base System
COST: $2M
SCHEDULE: 12 Months

OPPORTUNITIES FOR DEMONSTRATING RELIABILITY AND MAINTAINABILITY ENHANCEMENT THROUGH COMPUTER AIDED TECHNOLOGY - C-17 AIRLIFT SYSTEM

Introduction

A major element of the initial modestly paced development effort on the C-17 system has been to put in place the Reliability and Maintainability (R&M) technology that will concentrate the design effort effectively in this area. This has presented a significant challenge, which has been addressed through a broad approach, applying both traditional and new techniques. The material which follows addresses primarily the new techniques which rely heavily on computer aids.

The thrust of the effort shows clear promise and will lead to opportunities for demonstration in the very near future. Some elements, however, are aimed farther down the road and are more conceptual at this time. Acceleration of these elements would be required to achieve an early demonstration of their effectiveness.

The Problem to be Solved

Operating and support costs represent a major portion of the cost of weapon systems. Also, a system is only as effective as its reliability and availability will allow. The reliability, maintainability, and availability of a given system is basically establised in its design and development cycle. Once it has reached production little can be effectively done to substantially improve reliability and maintainability beyond the normal maturation process, without large cost impact. Therfore, R&M enhancement must occur early in the system development effort, for maximum impact.

Challenging top-level R&M specifications have been written for the C-17. However, the mechanisms that will assure their achievement did not initially exist. Logistic Support Analysis (LSA) programs were in a very conceptual stage and even at that stage did not appear to address the specific needs of the early system design and development phase. At the same time they were so broad in context that their usefulness did not appear timely to the impact we sought. Traditional functional approaches to R&M management were fragmented into several organizations, each with its own techniques and largely independent historical databases and models. Extensive manual data handling further reduced the effectiveness of these approaches.

As more and more of the design effort enters the "computer-aided" environment, R&M efforts are logically moving toward the same environment. The problem here is how to best take advantage of the opportunities this movement presents.

Technical Solution

In addition to affirming effective traditional techniques, a major effort is under way on the C-17 program to significantly enhance R&M efforts through new techniques. These fall into three categories:

- O Development of a common R&M database with computer aids for estimating, allocating, and managing R&M impact.
- O Conceptual development through experimentation with the man/tool/machine interface in the Computer-Aided-Design (CAD) environment.
- O Concern for the "human reliability" aspect of what is mostly represented as a "machine reliability" issue.

We have concentrated most heavily on the first of these categories, the development of a common R&M database. These efforts are bearing fruits and will support a demonstration as we move further into the design phase. Additional development is needed, but it will occur as an essential ingredient of the C-17 program effort.

The R&M database system is viewed as a companion to an LSA program. It is broader in the reliability and mission modeling areas and narrower in the overall logistic support area. It is focused on impacting the system in its design and development phase. Its major elements include the following:

- O An accurate, centralized, hierarchical description of the aircraft systems and subsystems to at least the LRU level. Built-In-Test (BIT) features are integral to this description. (This aspect is proving to have value beyond its R&M application.)
- O An accurate, centralized description and model of the system operational missions and mission requirements.
- O Logical correlation to existing historical databases and supplier information files for extracting source and comparative data.
- O Computer aids to assist the R&M engineer in the development of component R&M estimates, including cross-checks for consistency and commonality where it must exist.
- O Interfaces with the analytical programs which integrate the pieces into the whole for top level visibility. The focus is primarily on the Reliability, Maintainability and Availability objectives in their own right (Mission Completion Success Probability, MMH/FH, Full Mission Capable Rate, etc.). However, life-cycle-cost (LCC) links are being developed.
- O An effective management process using allocations, reserves, and comprehensive reporting; combining top level visibility with bottom level knowledge.

Efforts in the second category, developing a computer-based representation of the man/tool/machine interface, are still conceptual. With more and more of the initial system definition occurring in a three-dimensional computer environment, the ultimate development of the man/tool interface or counterpart is inevitable. The visual benefits provided by computer graphics carry an obvious promise of early visibility into the spatial aspects of maintainability. A significant amount of additional development is necessary to reach a meaningful demonstration of this technology. However, the effort could be concentrated on a relatively small portion of the entire system to reach a demonstration capability in a relatively short time. Placing the man and tool representations in the computer will be relatively easy, and in fact exist in part. The greatest challenge may be in training people to use the system and controlling the cost.

The last category mentioned above, the concern for "human reliability", is yet to be given concrete direction. Any near-term demonstration of new R&M technologies could only touch on this aspect. However, we will continue to address the issue and would incorporate in any demonstration whatever has been developed at the time.

Demonstration Possibilities

The identification of the problem and its technical solution has been given much attention. However, a specific demonstration of the solution, other than through its direct impact on the C-17 design and its R&M performance, has not been planned. Therefore, the thoughts that follow represent initial reactions to the possibility of such a demonstration. A significant portion of the funding for such an effort would be devoted to carefully detailing the demonstration to achieve as much visibility as possible.

Ideally, a phased demonstration would be most effective, covering progressive steps in the development through preliminary design, final design, and ultimately flight and operational testing. Specific near-term demonstration opportunities on the C-17 system will depend on the rate at which the program proceeds. A likely approach would be to concentrate on the detail design features of a portion of the system while covering the broad impact of the new R&M technologies on the whole system at the preliminary design level. A follow-up effort or efforts could demonstrate longer-term impact.

The demonstration would consist of a complete written documentation of the process and its measured and subjective impact. An onsite demonstration of the process in action would be offered. Offsite active demonstrations would be more difficult, but could be developed.

The demonstration would cover the overall approach to improving R&M, but focus on the new techniques involved, which have been discussed in the "Technical Solution" section above. The demonstration would concentrate on the effectiveness of these techniques in focusing design efforts on R&M improvement and adequacy. It will be important to show personal designer reaction to the process, as well as specific measured numerical impact.

Benefits

While significant individual engineering labor savings will materialize from these new techniques, we believe the greater concentration on R&M improvement will largely offset these front-end savings. The primary benefit will accrue to the end product, resulting in a significantly more reliable, maintainable and available system. Attendant operating and support cost reductions will be substantial.

The intent is to assure the attainment of R&M objectives that have been established for the C-17. These represent on the order of 40 percent improvement over the best of the existing airlift aircraft. This is in spite of greater mission capability and more demanding operational mission requirements, including operations into small austere airfields with little or no support facilities and a high frequency of operation in the demanding roles of airdrop, low altitude cruise, and close formation flying. This represents the best indication of the magnitude of benefit the new techniques will provide.

Cost and Schedule

Cost and schedule are closely related. Also, there is a good deal of flexibility in both, depending on the specific demonstration to be undertaken. We understand that funds on the order of $2M may be available for this effort. One approach would be to scope a demonstration to this level of funding. In this case a comprehensive demonstration could be conducted toward the end of 1984, assuming a start sometime late in 1983. This would provide for a complete treatment of the improvements to design approach as focused through the common, centralized database, and a significant demonstration of the computer-aided graphics representation of the man/tool/machine interface.

An excellent demonstration of the basic approach and benefits could be conducted for substantially less; and, of course, more depth could be covered with more funding, especially if the time period were extended somewhat to permit the design to develop in more detail. The best route would probably be to follow the middle road discussed above and look toward a more distant follow-up effort to be defined later.

A possible schedule might start in October 1983, with 6 months of demonstration planning followed by 6 months of demonstration implementation, culminating in a demonstration in Novemenber of 1984.

AREA: Logisitics Support Analysis Methods
CONTRACTOR: Northrop, Aircraft Division
PROGRAM: F-20
R&M TO BE DEMONSTRATED: Airframe LSA
COST: $150K
SCHEDULE: 16 Months

COMPUTER AIDED ENGINEERING APPLICATION TO IMPROVE WEAPON SYSTEM SUPPORTABILITY

The Northrop Corporation, Aircraft Division has been actively developing Computer Aided Design and Manufacturing (CADAM) capabilities to aid in the design engineering and manufacturing of the current product line of tactical fighter weapon systems (F-5, F-18, and F-20). The recognized benefits in terms of quality and productivity are the primary incentive in obtaining this capability. Simultaneously, the Northrup product committment of effective, low ownership cost aircraft stimulated implementation of an aggressive Logistics Support Analysis (LSA) program for all development activities. Since the objective of the LSA program is to influence design to improve supportability, all opportunities to more closely relate engineering design effort with the LSA effort are explored. Hence, an IR&D project is currently on-going to define the utility of CADAM technology in the LSA process.

Preliminary results of the IR&D project indicate two areas of particular benefit to the LSA Process from CAE applications. The first involves the coupling of engineering and support analysis. Engineering data is evolving and still amenable to change. This is in contrast to the current system whereby support analysis effectively begins after drawing release, the design is in a somewhat stable state wherein the effort required to overcome the inertia of the system to cause a change is substantial. Essentially, through the computer aided engineering process the preliminary support analysis can be more effectively integrated to achieve the primary LSA objective of improving the suppportability through design.

The second area of identified benefit resides in the utility of the three dimensional display (NCAD) in visualizing the construction and packaging of components into the airframe. This visualization, and the ability to rotate the display, can significantly improve the maintenance task analysis. This task analysis constitutes the basis for the assessment of support resources required to restore a failed element to serviceable condition and is therefore a key element in the support analysis process.

The current IR&D project will be complete in the fall of 1983. At the present time, no additional study is anticipated as the F-20 engineering development and LSA programs are essentially complete. A pilot project to demonstrate the feasibility of the CADAM application to LSA can be undertaken for the airframe maintenance plans for the F-20. Considerable engineering modification to the basic airframe to accommodate the manufacturing process is anticipated as the program moves into the production phase. Consequently, the airframe LSA was deferred - it is the single major element of the total weapon system LSA remaining to be accomplished. This pilot project could begin within the next two months and will require R&D funds to support approximately 1.5 man years of effort and the necessary hardware and software to implement the interface with the CADAM systems. The project would be completed in approximately 16 months given a start date of August 1983.

The pilot study would provide the necessary data to confirm the applicability of automated engineering processes to the LSA process and the benefit in terms of improved supportability which would derive therefrom. The next full weapons system development (the Advanced Tactical Fighter) would provide the opportunity for large scale implementation and demonstration of the procedures and techniques evolved from the pilot study on the F-20 program.

Boeing Figure 1

Attachment 1
Memo #2-3754-ECh

Thermal Management and Reliability Analysis Demonstration Program

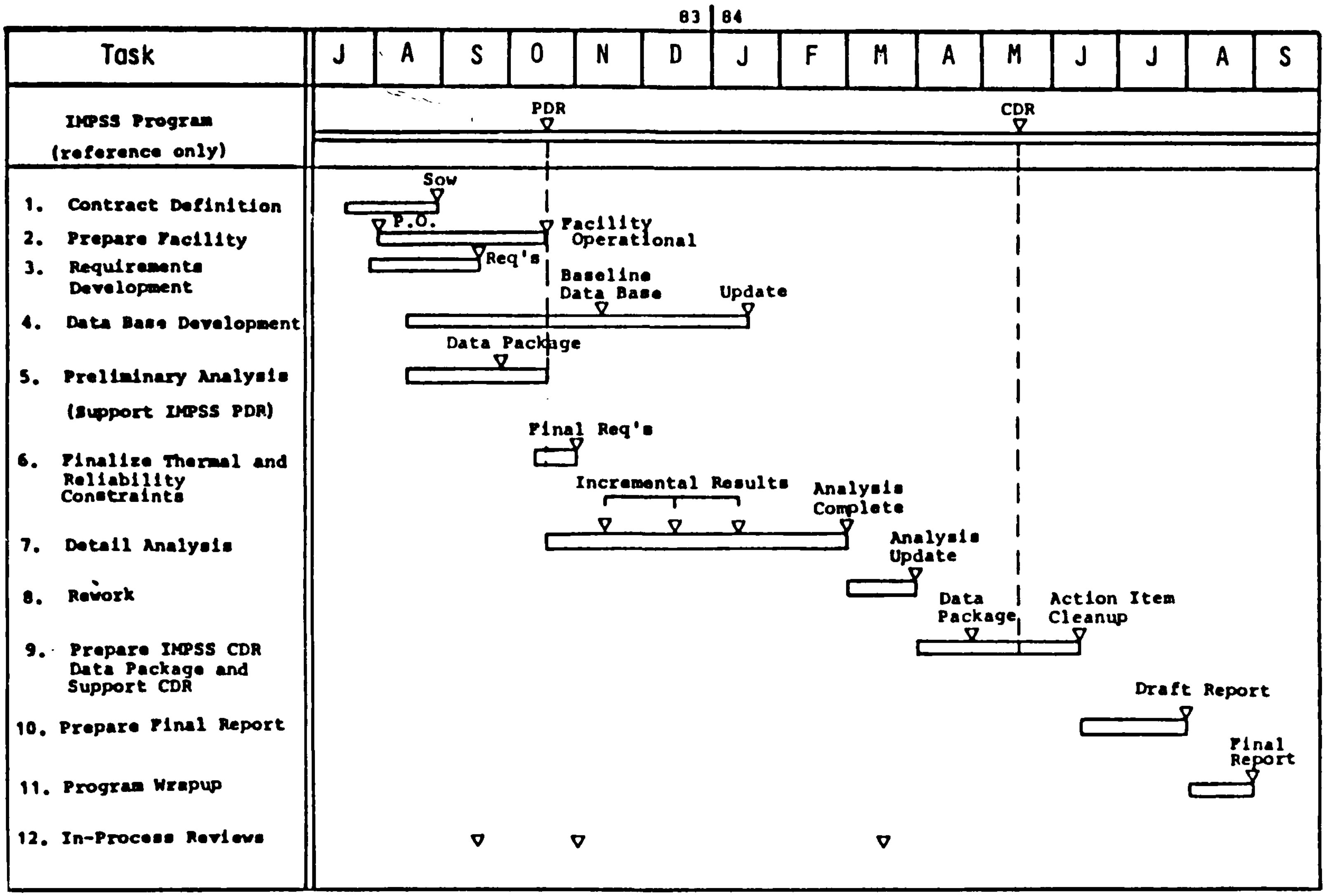


Figure 6.1 Program Schedule

Honeywell

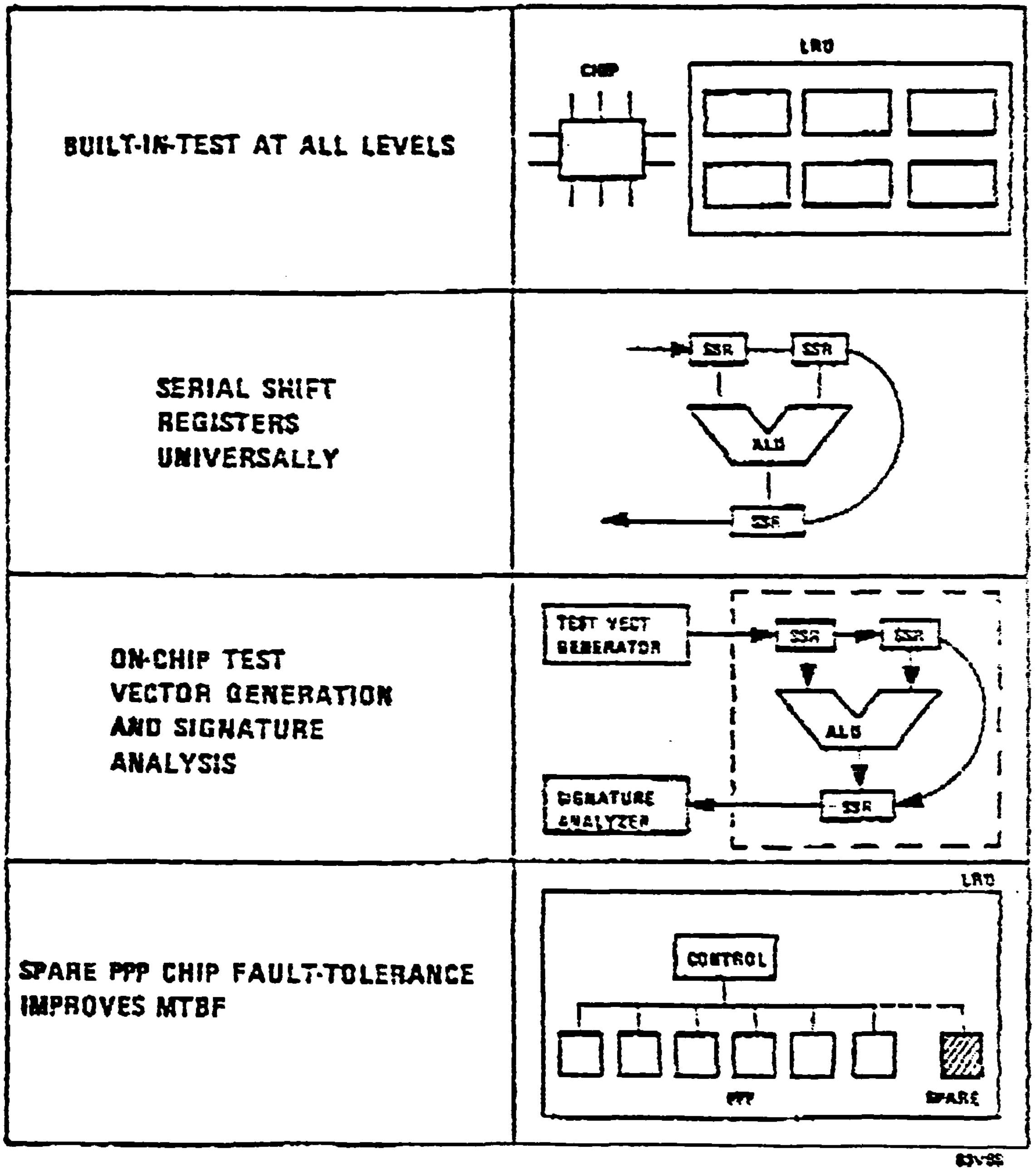


FIGURE 1. TESTABILITY AND FAULT TOLERANCE

HONEYWELL

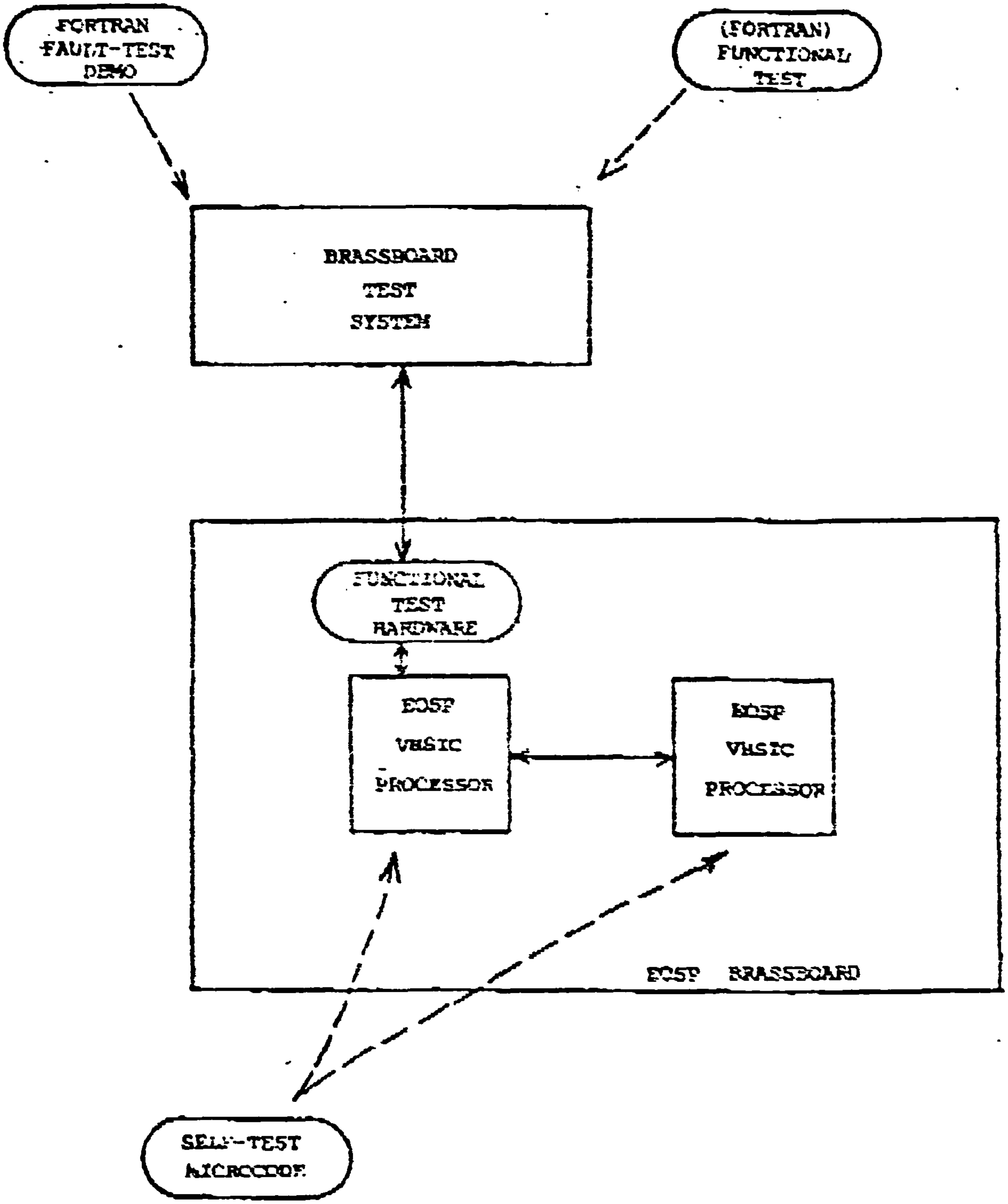


FIGURE 2. HONEYWELL DESIGN-FOR-TEST DEMONSTRATION

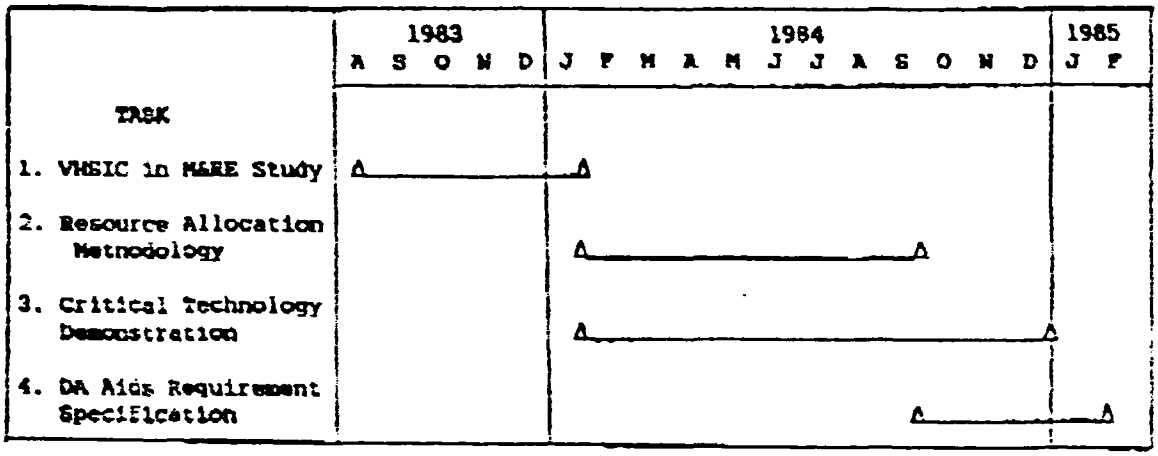
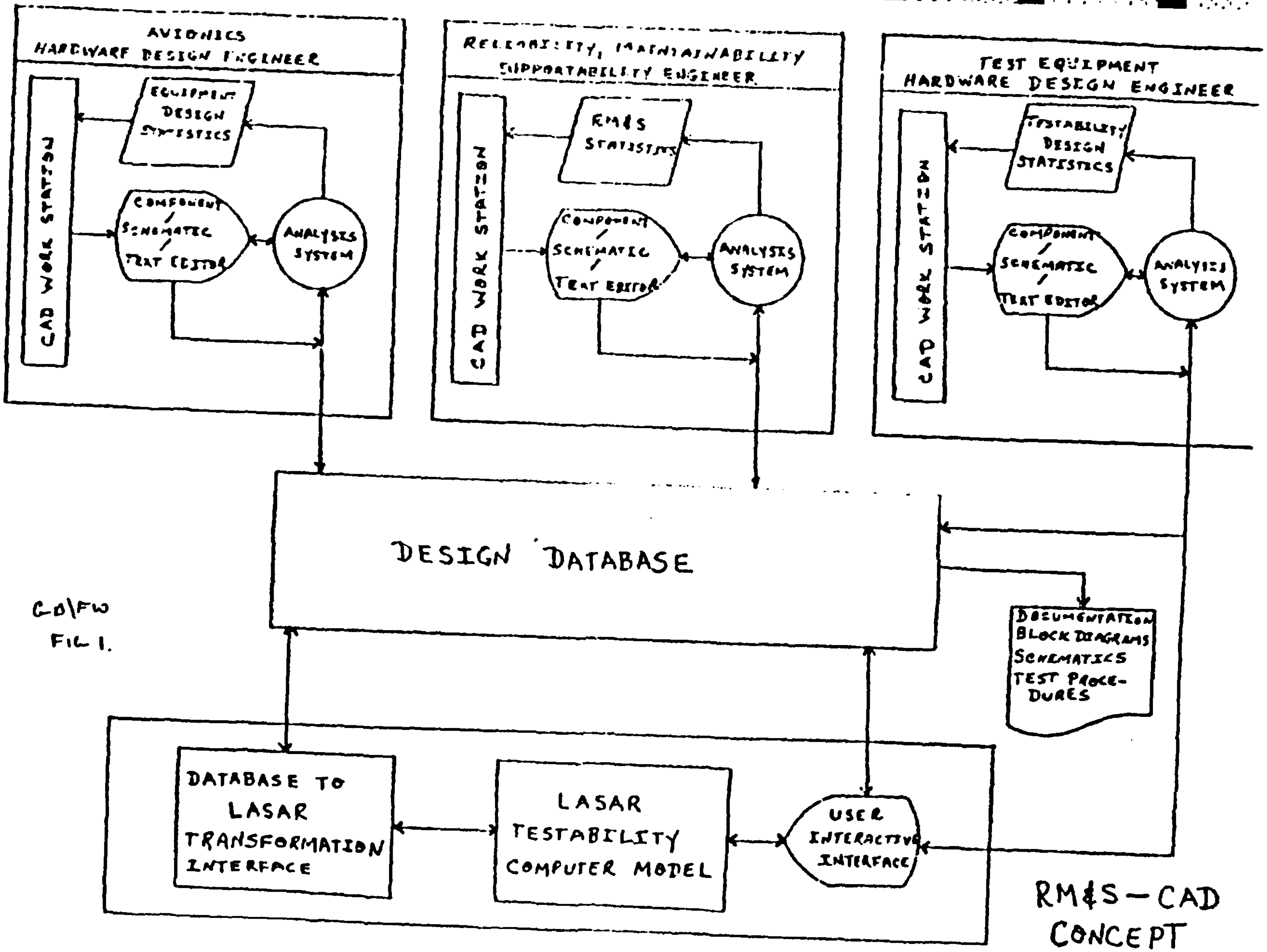


FIGURE 3. PROPOSED PROGRAM SCHEDULE

TABLE 1. MANPOWER ESTIMATES

		MAN HOURS
Task I	VHSIC in M&RE Study	1100
Task II	VHSIC Resource Allocation for Field Maintenance	2300
Task III	Critical Technology Demonstration	6500
Task IV	DA Aids Requirements Specification	2100
	Total	12000

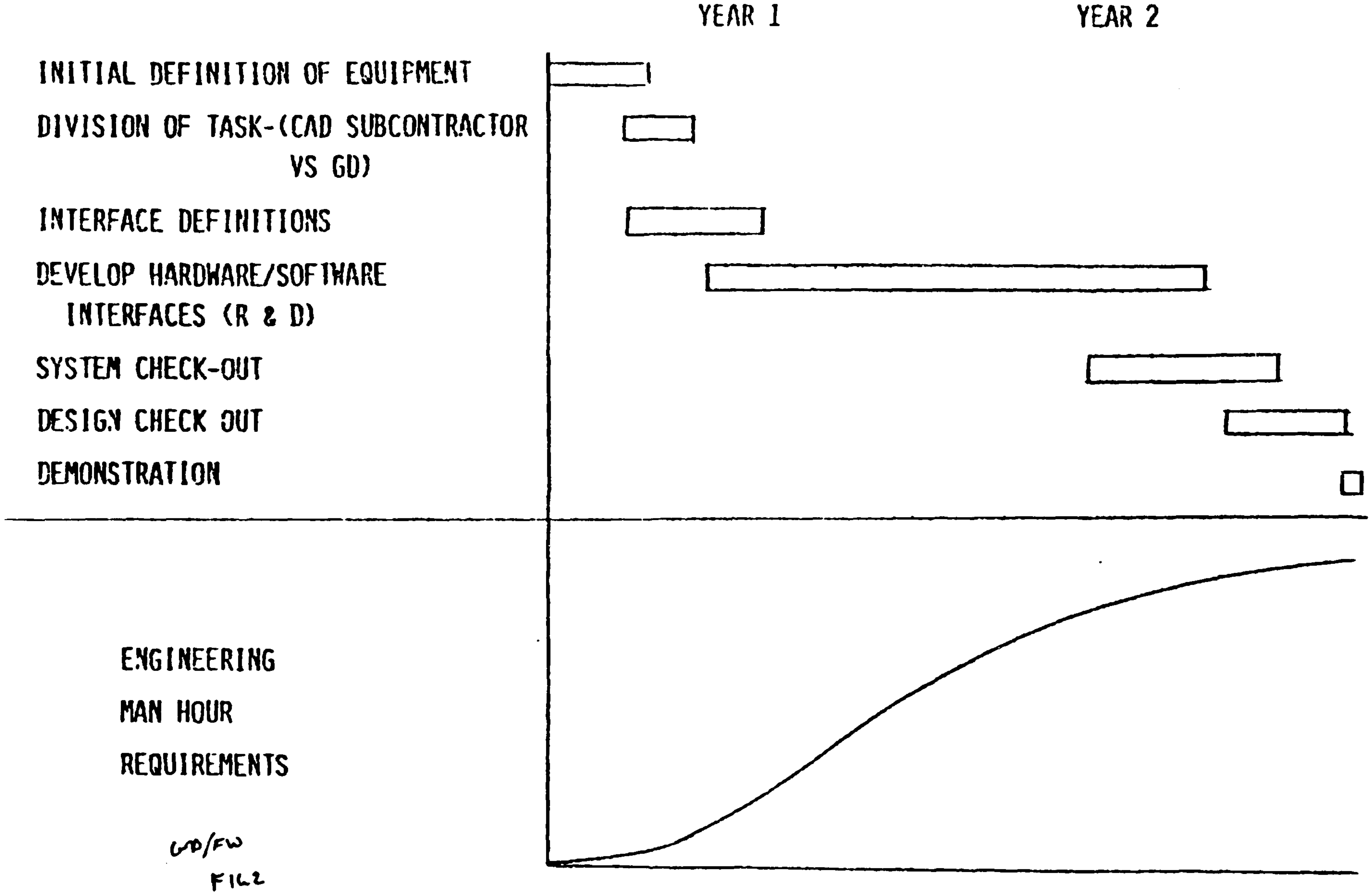
HONEYWELL



RM&S—CAD
CONCEPT

CD\FW
FIG 1.

DEVELOPMENT TASKS



GD/FW
FIL2

INTEGRATED SUPPORT SYSTEM DESIGN (IDS)

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PROBLEM STATEMENT:

A modern aerospace vehicle is a complex integration of sophisticated technical systems manufactured to the exacting standards required for mission performance, safety and economy. The complexity of both the design and manufacturing processes has increased significantly as a result of the high technology employed. Traditional methods generate enormous volumes of information which must be managed manually today. This task is manpower intensive and results.in a substantial loss in productivity. The application of computer technology has produced improvements in the engineering disciplines. These improvements have only partially exploited the potential for computational efficiency and automated data communication. They have concentrated on isolated elements of vehicle design and not on the integration of the overall design process.

Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) technology have both matured to the point where it is now possible to design and build an integrated-system.

Currently there are a number of programs addressing the integration of manufacturing technology. Principal among these is the Air Force Integrated Computer Aided Manufacturing (ICAM) program. In fact the Air Force is looking beyond ICAM, to the concept of the Factory of the Future, which will maximize the impact of computers on Aerospace Batch Manufacturing.

There is however, no unified approach to integrate the application of computer technology to the Aerospace Design process. NASA's Integrated Program for Aerospace Design (IPAD) is addressing the development of an Engineering Data Base Management System, and the Air Force Integrated Thermal Avionics Design program (ITAD) is developing an electronics design system for printed circuit boards. There is, of course, an abundance of "Turn Key" systems on the market today, calling themselves CAD systems. However, they are actually Drafting, not Design systems.

Today all major aerospace companies are using computer based CAD systems to assist their engineers in the creation of drawings - reducing the time required to produce geometry and related data by factors of as much as 12 to 1.

CAD tools could make design data available to other groups participating in the design process. But current studies of this idea indicate that there are deficiencies in this approach. Too many components of Design have not been brought into "computer age compatibility". That is, either they have not yet been computerized or if they have been programmed, the software cannot be linked up or "Integrated" without considerable and expensive rework. This then is the general weakness of todays CAD approach, the lack of integration between the various design disciplines and between the design function and the balance of manufacturing.

TECHNICAL SOLUTION:

The IDS program is a concept for improving productivity in Aerospace Design. It consists of a combined technical and management plan, designed to integrate the aerospace design process, primarily through the systematic application of advanced computer technology. Since a major portion of the design activity is concerned with the communication of information, two of the primary components of

IDS are a central engineering data base and a highly efficient data base management system. The various technical disciplines such as structures, aerodynamics and propulsion, together with their associated management functions will then be integrated through this common data structure. The entire design activity, from conceptual design to final detailed design will be included in the program.

The program begins with the establishment of a generic framework, or architecture for the design process, through which an integrated application of computer technology would proceed in the form of modular subsystems to computer assist and tie together the various design disciplines, resulting in a comprehensive management and control system for the design process.

The basic technology required to implement this program has been accomplished both in the areas of design and computer technologies. The basic technology advancement arising from this effort will be the integration of design capability and the demonstration of this integration concept through specially selected projects. These projects will consist of "Wedges" cutting across the spectrum of aerospace design and the demonstrations will be carried out in a production environment.

IDS's potential to provide direct engineering support to an emerging weapons system has been carefully studied. In addition, its capacity to reduce acquisition and life cycle costs has been determined. The B-1B has been selected as a prime candidate for application of this technology because of its large investment, limited procurement, wide fleet disbursement and strategic importance. Application of IDS technology to the B-1B will result in decreased downtime, reduced maintenance costs, and improved fleet readiness. IDS is a prototype design system specifically designed to achieve the following objectives. The program will serve as a technology demonstrator, operating in a production environment. The IDS development will provide the transfer and tracking of design data in manufacturing operations through the implementation of an integrated data base management system. This system will also significantly influence the establishment of a responsive sustaining engineering design data base. IDS development will further aid potential downstream activities by providing integration of critical design technologies with the use of a captured design data base.

BENEFITS:

Substantial benefits will result from implementation of the IDS system. IDS will not only improve our ability to design a system initially, but we also expect it to provide an order of magnitude improvement in our ability to redesign an existing system in order to meet changing mission requirements. IDS will enable an engineer to design or redesign components to meet expanded or new mission roles for weapon systems. The capability to communicate design data between design disciplines, from design to manufacturing, between prime and subcontractors and between contractors and the Air Force will be significantly improved. IDS will provide improved ability to perform sustaining engineering as a result of the design data being captured in a total systems data base. Configuration Management of an entire fleet by tail number will be possible since this same data base will accommodate fleet data, mission data, damage/repair data, and design modifications. The benefits to be derived from this aspect of the program will occur downstream in sustaining engineering/repair, modification and support wherein life cycle costs will be significantly reduced. Substantial productivity improvement can be achieved by implementing an integrated system in AFLC and field support/repair activities. Reduced aircraft downtime can be achieved through improved aircraft repair and logistics support, as a result of rapid availability of structural design and repair data. Availability of detail part manufacturing data into the

1990's, long after many aircraft component suppliers have gone out of business, is a real problem that can be overcome by having an interactive stored part design data base.

Intangible benefits include IDS's capability to maximize man's unique creative and decision making capabilities while assigning routine tasks to the computer. This will result in a significant reduction in schedule delays, costly errors and inefficiencies.

The driving force behind the development of an IDS system however, is still improved productivity resulting in reduced costs of weapons systems coupled with the increased efficiency and responsiveness of the aerospace industry.

COSTS:

The cost of the IDS program has been established at $17.4M dollars over a scheduled development period of six years.

IMPLEMENTATION:

It is recommended that the AFWAL's Flight Dynamics Laboratory be tasked to conduct the IDS program. FDL has been active in CAD since its inception in the late 60's and has worked closely with other large scale computer integration efforts such as the Integrated Computer Aided Manufacturing (ICAM) program currently underway in AFWAL's Materials Laboratory.

APPENDIX B

Discussion of an Example Configuration Management and Data Control Module

DMCS
Data Management and Control System
by
GE-CAE International

Background

The last decade was a time for radical technical innovations and significant cost reductions in computer hardware and associated terminal interface systems. In the 1970's, these trends led to the introduction of computer based design and manufacturing systems capable of automating complex functions at reasonable cost. The use of Interactive Graphics (IAG) systems to automate design drafting and manufacturing machine control functions is a well established case of productivity improvement through computer automation. The increasing use of packaged vendor software systems to automate engineering analysis functions and manufacturing planning functions has also resulted in significant productivity gains in both design and manufacturing organizations.

Today many companies are major users of both Interactive Graphics systems and other CAD/CAM packaged software systems. These CAD/CAM systems have resulted in both significant productivity gains and harder to measure improvements in product quality and product innovation through a synergism between man and computer.

However, as significant as these gains have been, they are primarily a result of automating specific functions through the use of an improved computer based capability. This approach is ultimately limited by both the nature of the automated function (e.g., by the degree of automation possible) and the interaction between functions in an overall design and manufacturing process (e.g., by the critical path through functions). To achieve a next significant level of productivity improvement, it is necessary to change the design and manufacturing process by integrating computer aided functions to better take advantage of common CAD/CAM information and computational capabilities.

Unfortunately, the full advantage of integration is only achievable when adequate mechanisms are established to safeguard product information and to control the distribution of this information between originating and using functions. Traditional storage and control procedures are based on the use of user readable standardized information (e.g., drawings, printed specifications, microfilm) in both engineering and manufacturing. Storage procedures often involve manual filing, search and retrieval of the user readable information. Control procedures often involve manual approval, release, update and change notification of the information. In many cases, the control scheme imposes an inflexible boundary between engineering and manufacturing organizations that either precludes overlap of naturally parallel functions or that encourages bypassing control mechanisms in time critical situations (e.g., redlining of drawings to meet a production deadline).

With the advent of large numbers and varieties of computer based engineering and manufacturing systems, an increasingly significant portion of the product information data base is being created in a computer system dependent digital format on a variety of storage media (e.g., tape, disk). Although this information requires significantly less physical storage area and can be searched or transmitted at electronic speeds, it is much more susceptible to inadvertent destruction or update. Even more serious is the context sensitivity of the data format which precludes sharing common data between two different systems and which can render the data meaningless each time the host computer hardware or application software changes (e.g., the well-known case of nine-track magnetic tapes replacing seven-track tapes).

An obvious approach to this digital information dilemma is to maintain parallel user readable data items (e.g., plot a drawing from an interactive graphics system data file). Then all the traditional control mechanisms apply. Although this is widely practiced, it creates the added problem of maintaining compatibility between the two different information forms; it precludes reducing labor intensive, error-prone manual control mechanisms; and it fails to address the strain placed on manual management and control systems by the increased rate of new information generated from the automated processes (e.g., a draftsman at an IAG console can interactively produce drawings significantly faster than a draftsman at a board). Also, certain computer digital representations, such as a 3D (three-dimensional) geometric model or a view of such a model, are incapable of complete representation in a 2D man readable form.

In summary, the full opportunity of the CAD/CAM revolution in engineering and manufacturing cannot be attained without development of systems which effectively manage digital CAD/CAM information and control the distribution of this information to the many machine and functional environments involved.

The following issues are representative of current CAD/CAM data management and control mechanisms for Interactive Graphics (IAG) system data.

- o Data from IAG systems and other application computer systems are often maintained on both magnetic tape and on plotted hard-copy images (e.g., drawings). Both the tapes and hardcopy images are manually filed and retrieved with adequate back-up and restoration to ensure safe storage (see Figure 1). The administration of storage, retrieval, and data maintenance is labor intensive, an information flow bottleneck, and a possible source of retention problems through human error. The administration problem is complicated by the many different related data types, IAG systems and other application computer systems. For example, a part geometry may be represented by various 2 and 3 dimensional forms in one computer system and associated with drawing images and various types of analysis data in other computer systems. The retention problem is compounded by organizations which must maintain usable data for 50 or more years (e.g., Turbine businesses).

MANUAL DATA ADMINISTRATION

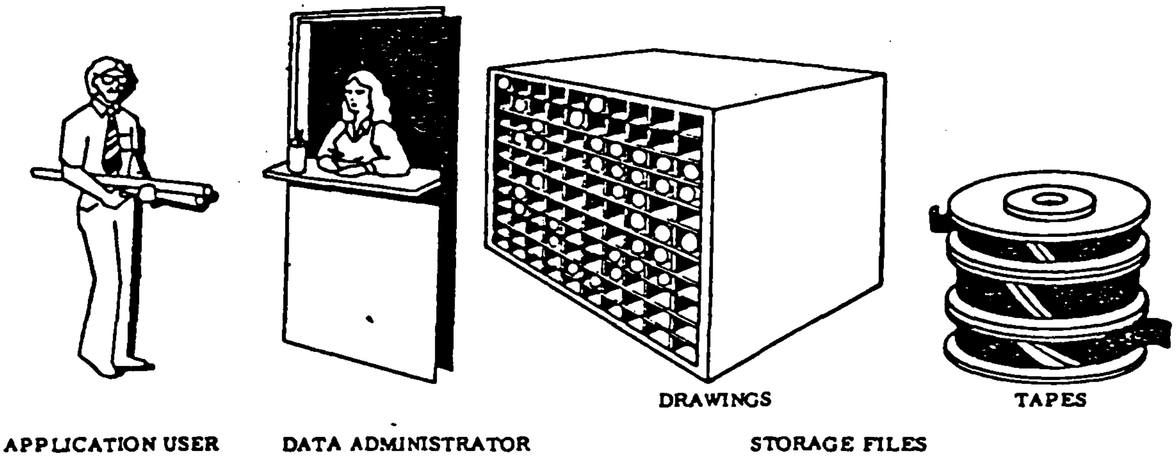


Figure 1

- IAG data is required by many different functions at various points in the product development cycle (see Figure 2). For example, a part geometry is used during engineering analysis to investigate mass properties, during detailed drafting to create various two-dimensional toleranced images, during manufacturing planning to create a numerically controlled machine's program and during quality assurance to create an inspection machine's program. Although the same data (e.g., a 3D model of a part) has multiple users, the manual control process often requires that data be transmitted by 2D drawing representations at well-defined release points and reentered at each computer-based function. The manual control mechanisms are labor intensive, restrict information flow to 2D user readable approximations, and as the number of users increases, becomes an increasing source of transmission errors and delays. Even with elaborate manual control mechanisms, situations where changes to an engineering drawing are not synchronized with a manufacturing drawing still too often occur with resultant scrap or rework costs.

- The diversified product environment and decentralized organization has resulted in a variety of CAD/CAM hardware and software systems (see Figure 3). Some operations have more than one type of Interactive Graphics system, a variety of application computer systems and various data communication links to both external mainframe computers and various networks This environment of different functional users within operations sharing data is coupled with a geographic separation of some engineering and manufacturing operations. The result is a distributed set of data repositories (one or more per CAD or CAM system) with system-unique data formats, data communication protocols, and data users. Also, the predominance of an organization's product and process data resides in non-digital form on drawings, computer output microfilm, cards, and various types of documents. This information is often related to digital data and these relationships must be managed and controlled. The variety of CAD/CAM data forms and environments requires labor intensive coordination of information flow, is conducive to bottlenecks at transfer points, and has significant potential for conversion and transfer errors.

SAME DATA, MULTIPLE USERS

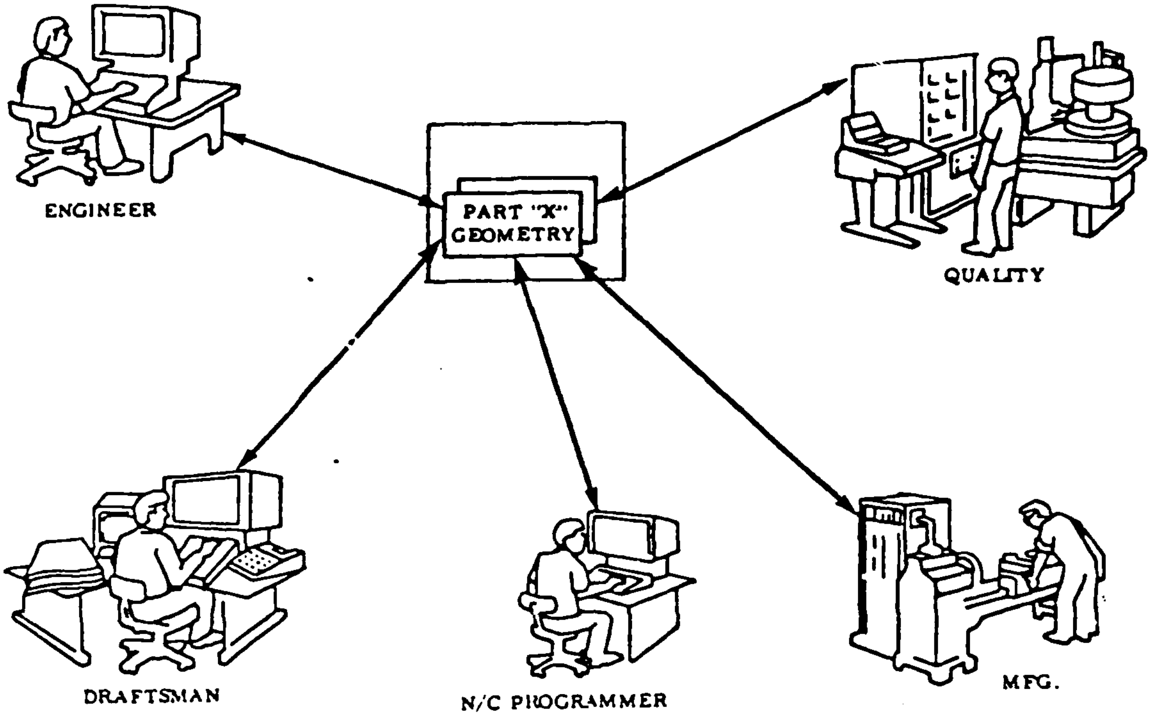


Figure 2

DATA SHARING

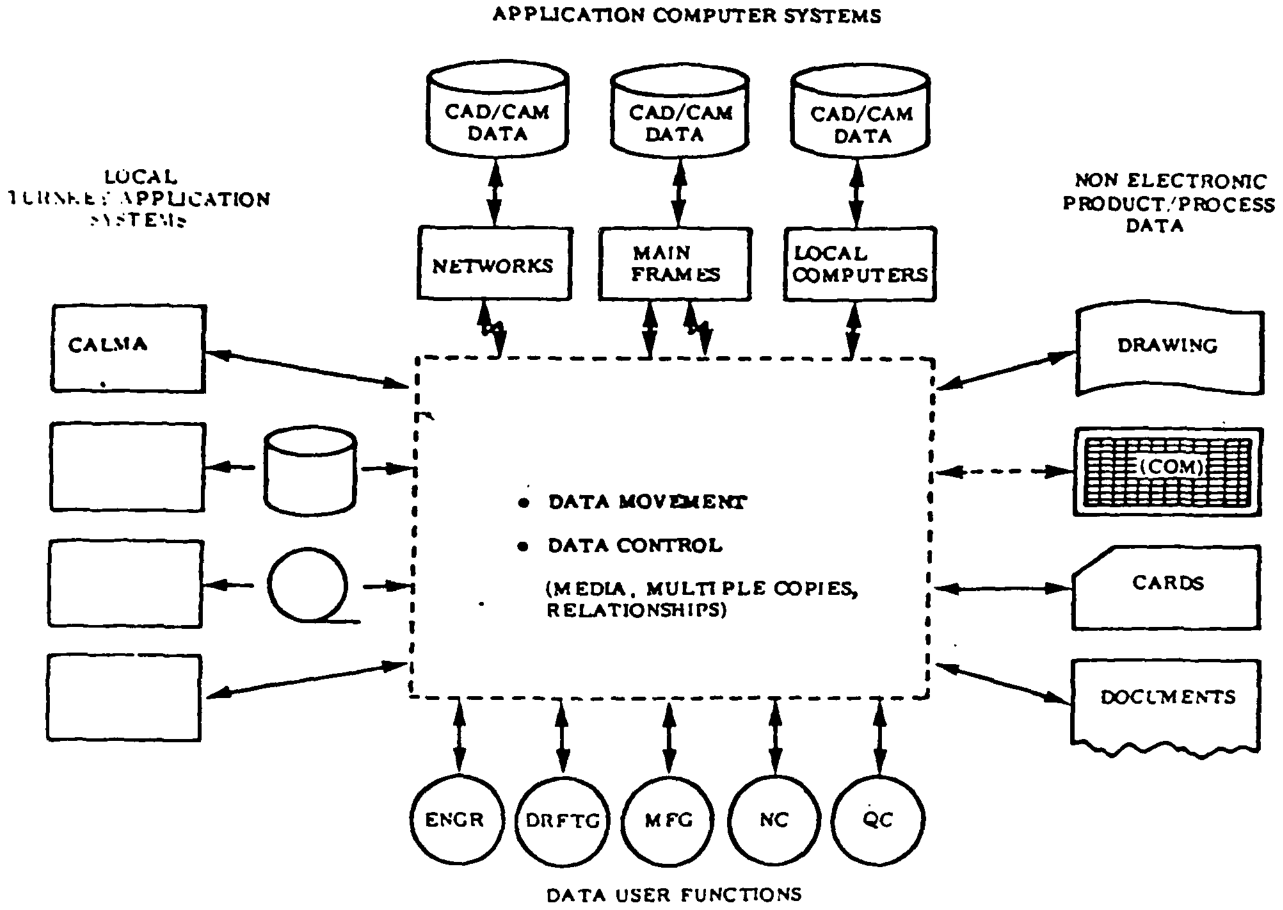


Figure 3

- CAD/CAM data management and control needs are increasingly urgent as the quantity of digital data increases (see Figure 4). Efforts such as more restrictive configuration management procedures or the use of computer programs to track digital and non-digital files are underway in operations to address emerging problems. This can result in parallel labor intensive development activities in different operations, unsupported "solutions", and continued risk to product data integrity if a solution is delayed or unsatisfactory.

In summary, current CAD/CAM data management and control mechanisms are tied to people oriented paperwork systems that predate the introduction of computer aided design and manufacturing systems. Although these paperwork systems have a long history of success they constrain the opportunities for computer systems to reduce cycle time and product/process development costs, and they tie up critical personnel resources.

DMCS augments these traditional paper oriented data management and control mechanisms with computer based mechanisms which offer improved response times, improved data security and integrity, wider user access to data, new capabilities to locate and apply data, and the ability to handle special computer data forms such as 3D models and software for computers embedded within many products.

MANUAL DATA CONTROL

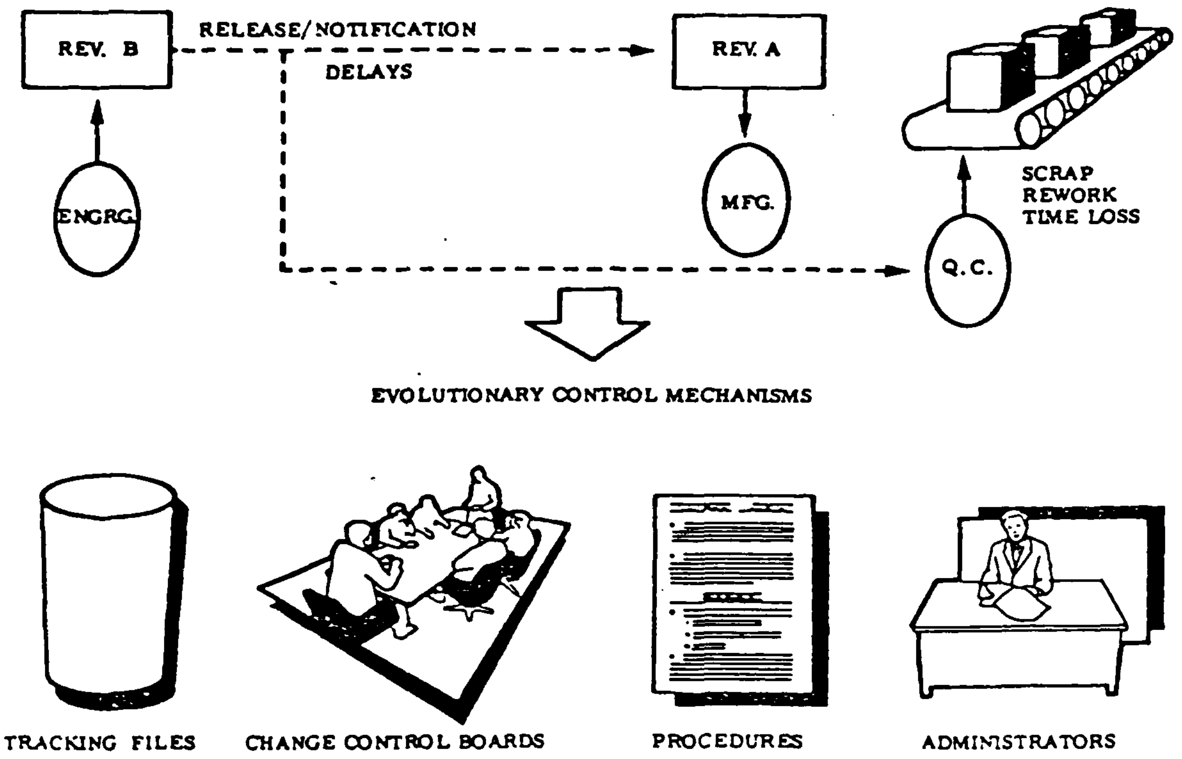


Figure 4

The introduction of computer-aided design and manufacturing (CAD/CAM) techniques in the 60's and 70's introduced a new variable that the established manual systems had to cope with: digital information such as part geometries and NC tool paths. This information was not standardized in format, was invisible to most users, and provided a flexibility that allowed more frequent changes in shorter periods of time. As a result, partially computerized systems began to appear in many companies. These systems tend to be based on the proven manual control methods: the digital information forms are first housed on tapes and disks, and then the tapes and disks are treated as the physical information form which is physically stored, identified, copied, tracked, and distributed. In many cases, an associated paper document is created to describe the content of the tape or disk and this document is used to provide accountability by signature and to serve as the element handled by the manual change control system. This computerized information, however, is still linked manually (and often incompletely) to associated product definition information. In general, the partially computerized approaches achieve the proven effectiveness of the manual approaches by significantly restricting the ability to access, update and communicate the much more flexible digital information form.

The current trend in industry is for both the number of CAD and CAM applications, and the associated volume of digital information to grow. By the mid-1980's manual systems and partially computerized systems in highly automated operations will begin to severely restrict product development cycle times and engineering productivities. The Data Management and Control System addresses the digital data related issues of storage,

control, release, on-line access, archiving, human visibility, long term integrity and security, and traceability.

So, the full opportunity of the CAD/CAM revolution in engineering and manufactiring cannot be attained without development of the distribution of this information to the many machine and functional environments involved. The Data Management and Control System was developed to manage and control the flow of engineering and manufacturing digital data, focusing on digital product and process definigion data being developed in interactive graphics systems and CAD and CAM applications computer systems.

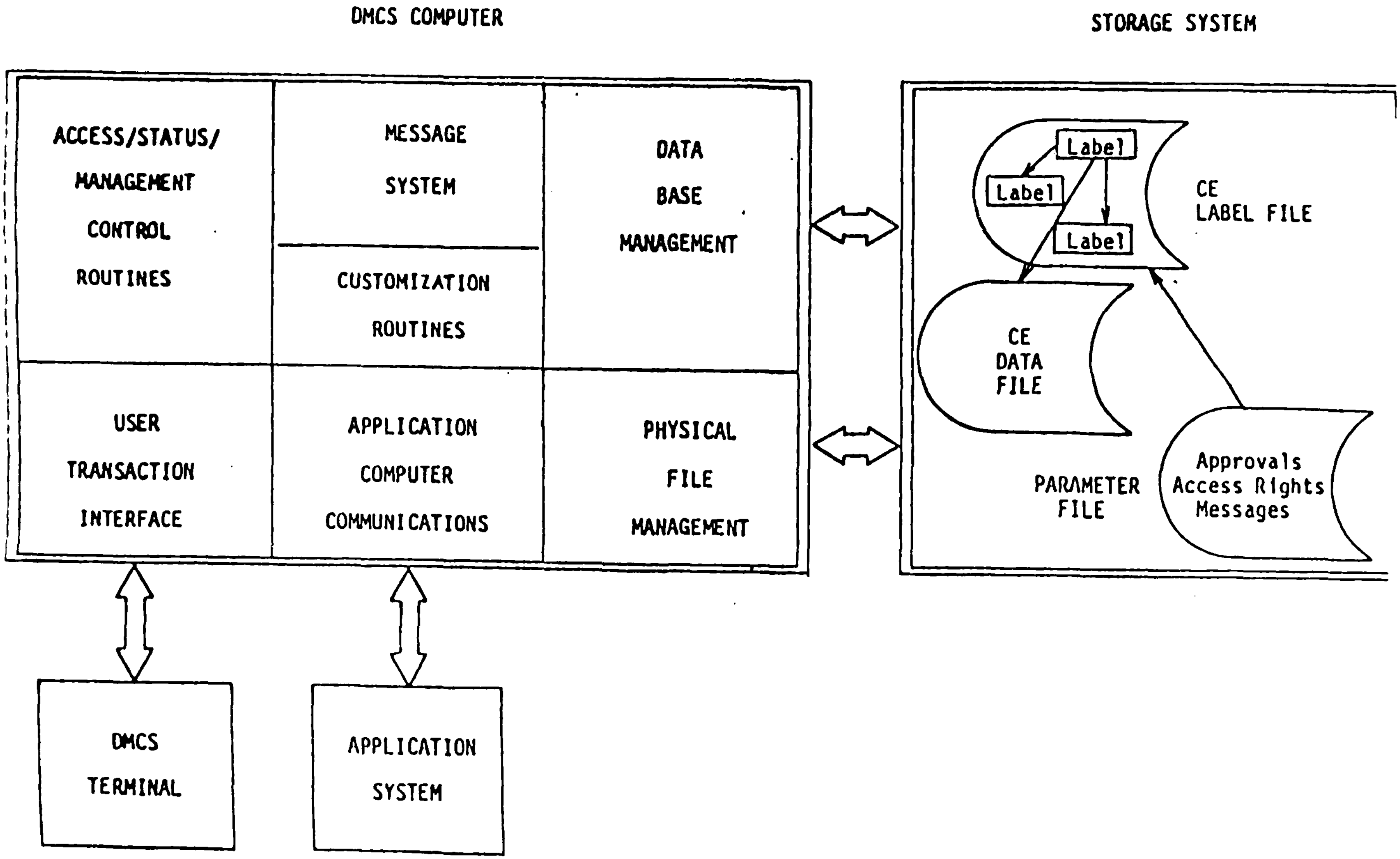
DMCS is a system for controlling computer stored information. Information is controlled in the form of digital data files called Controlled Entities (CE's) whose internal structure is unknown to DMCS. Engineering drawings, geometric models, and specifications are examples of CE's. Control of CE's includes storing of originals in a relatively safe environment, making copies available to authorized users, keeping accounting information on approvals which may be required, maintaining information associated with CE's such as other CE's it may relate to, and keeping records and producing reports and messages for system administration.

Certain terminology and administrative functions within DMCS may be established or "customized" at system installation, or periodically thereafter by a sub-set of DMCS users for whom this privilege is reserved.

DMCS includes the capability to invoke data communications to application computers which produce and use CE's. DMCS includes user terminal interfaces for user requests, messages, and administrative reports. The rate at which CE's and operator interactions are processed by DMCS is a function of the data communications rate between application computers, user terminals, and other DMCS equipment. Users may size data communications capacities to fit their budget and other needs.

The top level block diagram "DMCS architecture" shows the interrelationship of DMCS program modules. The following paragraphs present a functional description of those modules.

DMCS ARCHITECTURE



Application Computer Communications - Plug compatible communications hardware and software protocols for one or more attached application systems (e.g., turnkey IAG, NC controller, word processor, analysis machine).

The interface provides all required protocol translation to allow data to be received from and transmitted to one or more attached application systems. Buffering is provided to allow concurrent input and output operations. Data is error checked to ensure transmission integrity. User supplied routines can be activated to process files upon data receipt (prior to data storage) and after data retrieval (prior to data transmission back to the application system). The application computer communications interface will handle concurrent 9600 baud transmissions along with other DMCS activities.

Physical File Management - A set of system software for storing and retrieving files. Provides for on-command back-up, and for on-command archiving on attached disk and tape media. Sufficient information is maintained to ensure file integrity.

Data Base Management - Each CE stored by the physical file management system is identified by a user created label. This label contains information such as the CE identification, CE originator, time of CE creation, and type of data stored within the CE. The data base management routines support label creation and access, label association to a stored CE or to a record that identifies an external storage location, and relationships to other labels. The data base management system also maintains information such as access rights, notification directories, and user messages. The data base management routines support data dictionary functions, data base search functions, appropriate structuring functions, and utilities for data base creation and maintenance. Appropriate error checking is provided to ensure label and relationship integrity.

User Transaction Interface - Users communicate with DMCS via one or more attached terminals capable of communicating at up to 1200 baud. One or more users may access the system concurrently and user transactions are provided to prompt the user through all command sequences and to provide appropriate user reports. System activities are preceded by a user transaction that conditions the system to perform the activity. User transactions activate the application computer communications routines to receive or transmit data; the access status and management control routines to perform appropriate control system logic; the message system to transmit and generate user messages and to prompt user responses; the customization routines to enter or modify parameters that guide system operations; and the data base management routines to create or search for labels.

Access/Status/Management Control Routines - These routines are activated each time a label or CE related activity occurs to verify access rights to the associated CE via comparison between label and pre-stored table information; to support label searches for a particular identified data item or class of data; to provide status on data availability via checks of action item tables and stored label parameters; to provide where used reports based on label to label relationships; and to provide history reports on user access and updates.

Message System - The message system provides for message generation, transmission, availability notification, and reminder notification in response to either user or system activities. In particular, messages are generated when data is changed to notify appropriate users of the change and to request review of potentially impacted data to clear the data lock-up. Messages are also generated to indicate data availability after sign-off; to request sign-off of new or revised CE's; and to periodically provide reminders on outstanding actions.

<u>Customization Routines</u> - These routines are used to define label field constraints; access rights by individual user, collection of users, or organization; project/product relationships; CE types; CE states; CE sign-off requirements; authority for access to DMCS transactions; and reason codes for CE access and CE revision. Customization routines in effect create tables of parameters that are utilized to guide control activities by either conditioning the logic of transactions or by providing comparison data for use with label fields.

The storage system is configured to house labels, parameter tables and messages according to the structure required by the application routines. The system also provides storage for CE's and back-ups on both disk and tape media.

PRINCIPLES OF DMCS

DMCS is an interactive computer program which has the capability of being custom designed for each installation. The purpose of DMCS is to control data packets of electronic and nonelectronic data. DMCS does not create or modify data packets, but it does keep track of creation and modification of data packets.

The interface to DMCS is via terminals connected to the computer on which DMCS resides. Typically a user will log on to the DMCS host computer and then log on to DMCS by supplying his DMCS user id and password. After the logon procedure, the user interacts with DMCS by selecting picks from menus. Each pick results in another menu or a prompt for data. Keypad function keys provide additional controls.

All functionality of DMCS addresses control of data. "DMCS will be used to control data in digital form because the data are required in digital form by more than one application computer user and because the data are required in digital form a number of times during the product design--production-support life cycle ...." ... "DMCS shall provide aids for controlling files of digital data. Data defining product structure, or defining processes to produce products are planned for control."

Six general functions of DMCS are:

1. to identify data control entities with standardized labels
2. to control access to data
3. to monitor and control release and distribution of data
4. to notify users automatically upon the occurrence of predefined events
5. to maintain a historical log of the above
6. to grant or deny authorization of users to perform DMCS transactions

Functions

1. To identify data control entities with standardized labels. A data control entity is a digital file or other information packet which is of lasting significance to a product's development and over which control is desired. Control of data implies data security (access control), data integrity (no editing of control entities after issueing), and data reliability (assurance of having the most recent version of an entity).

A label is associated with each control entity (CE). All labels for an installation have the same standardized fields. The individual values in each field of a label describe the CE associated with the label. DMCS stores the labels for all CE's and allows the user to search or query for CE's which, according to the information in their label, satisfy the conditions the user has specified. Project ID, creation date, and creator are examples of label fields.

2. To control access to data. The concept of control, work, and aplication spaces is straight forward. Files in the three different spaces have different accessibilities. Control Space contains CE's only. CE's may not be edited. CE's may be copied for revision, but the original is never deleted. Only files which are of lasting significance and/or over which control is desied reside in Control Space.

Work Space contains files which have not become CE's and files which are copies of CE's. Work Space is a staging area for sign off (approval) of files. Not all Work Space files will become CE's.

Application Space contains all files which are not in Work Space or Control Space. Files are generally prepared and edited in Application Space. DMCS is not aware of files in Application Space.

3. To monitor and control the release and distribution of data. DMCS controls, according to rules defined by the users, if a data entity can be moved into Control Space, or if a CE may be copied from Control Space. When a CE is copied from Control Space, the user must indicate why he is copying the CE. DMCS keeps track of which users copied which CE's and for what reason they copied the CE. This information is then available when it is desired.

When an information packet becomes a DMCS Control Entity, it is "issued", and it is moved to Control Space. But the issuing of a CE must be "approved" by a predefined list of users. DMCS keeps track of each approver's "vote" for the issue process. If the issue is not appropriately approved, the data entity does not become a CE.

4. To notify users automatically upon the occurrence of predefined events. DMCS can be customized to automatically send electronic notification to users. Notifications are then generated upon the occurrence of certain predefined events, e.g., issue of a CE into Control Space or rejection of CE issue. The users to whom the notifications are sent are specified by the customizer. DMCS may be customized at any time to delete or add new notifications.

5. To maintain a historical log of DMCS control transactions. DMCS records control transactions such as CE issue and access history. The information recorded includes the CE label, the id of the user performing the transaction, and the type of transaction, e.g., approval or rejection of an issue or copying of a CE. This information is then available for later use.

6. To grant or deny authorization of users to perform DMCS transactions. Authorizations can be defined for individual users or groups of users. If a user is authorized for a particular type of transaction, e.g. making a copy of a CE, the menu pick representing that transaction appears on the user's menu, otherwise it does not appear, and the user is not permitted to make a copy of a CE.

Authorizations may be granted not only according to user id and transaction type, but also according to CE label. For example, a user may be granted the authority to make a copy of a CE, but only if the label of that CE has a certain value in the Project ID field, or for example, only if the lable of the CE has a certain value in the CE Type field. The user granting authorizations to other users specifies the "certain values".

As a result of effective control of data during a product development cycle, an organization should gain the following benefits:

1. flexible development systems or consistent levels of reliable communication between departments
2. single system which knows of the existence of all data
3. management tool for providing current status of a product's development or for providing a history of a previous product's development

1. Flexible development systems or Consistent levels of reliable communication between departments. Flexible development systems involve utilizing resources in an efficient manner. Resources in this context are organizational departments within a company, e.g., engineering analysis departments, prototype testing departments, or quality control departments. Using these product development resources in an efficient manner implies management and awareness of the state of the resources as well as management and awareness of the state of the data they produce. All to often a product development resource is wasted because of a lack of awareness of the states of other resources and their data. For example, when data from one resource is issued, it is assumed to be stable data, i.e., the data appear, as a result of all pertinent analyses, to be acceptable for all subsequent phases of product development. Inevitably, some packet of apparently stable data will become unacceptable. At this point, a modification of the previously stable data is mandatory. When the requiremnt to modify the data becomes obvious, it is vitally important that it be made known to all affected resources that the data, which was assumed to be stable and acceptable is no longer so. This notification to the affected resources is important because they have probably begun to use the previously assumed stable data in subsequent phases of the product development cycle. Since the previously assumed stable data is no longer acceptable, it cannot be used and resources using that data should immediately cease to do so.

Much of the inefficiency which results when resources use "apparently stable" data is a result of a lack of awareness of the states of other resources and their data. The degree to which this efficiency can be eliminated is directly related to the "agility" with which resources can become aware of the states of other resources and their data.

DMCS provides an "agile" notifications capability which eliminates lack of awareness. To this extent, the inefficiencies of using bad data are eliminated.

Notifications of the completion and availability of "good" data are equally as important as notifications of "bad" data. When one department completes generation of a data packet and approves its acceptability, the department(s) who will use that data next should be notified as soon as possible. DMCS provides automatic and immediate notifications of approval of "good" data packets, thus eliminating any time delays which occur as a result of handling the notification process manually. Also DMCS ensures that the "next" department gets the label of the correct data packet, and hence the correct data rather than some earlier or edited copy.

2. Single system which knows of the existence of all data. Each data packet which becomes a CE has a descriptive, standardized label. DMCS allows a user to search for a label which satifies the conditions he has specified. In this manner, a user may locate and retrieve a CE which may be helpful to him in building new CE's.

The proliferation of data during a product development cycle, particularly electronic data, has resulted in massive, unorganized, and undocumented accumulations of data packets. A situation often arises when the retrieval of an "older" data packet is desireable because parts of it may be used to build new data packets, e.g., new finite element models may be partially built from a part of a previous finite element model. If that previous model was used some time ago, it is often unlikely that a user will be able to find it, let alone be assured that the one he finds is the one he really wants (usually the latest version).

DMCS not only allows a user to locate and retrieve an "older" CE, but because it is a CE, the user will not mistakenly retrieve something other than the latest version.

3. Management tool for providing current status of a product's development or for providing a history of a previous product's development. A collection of CE labels with the same Project ID and the same Assembly ID represent the current status of a product's development. Other fields in the labels of these CE's indicate the completion and acceptability of the data packets with which the label is associated. A manager may request a collection of such labels periodically to determine his progress.

It is also desireable to retrieve "older" CE's to study the development of a particular product. A collection of CE's relevant to the development of a product represents a database of that product's development. With this database managers study previous product developments in an attempt to improve and streamline a development cycle. It is frequently not clear whether to have two development activities on the same product occur simultaneously or subsequent to one another. Which is the better choice depends on whether one activity may invalidate the data for the other activity. The degree to which this invalidation occurs can be chosen based on suspucions or gut feelings, but the best way to choose between simultaneous or subsequent activities is to review the development of similar products and accumulate statistics regarding how often one activity led to the invalidation of a data packet for the other activity.

APPENDIX C

Slide Presentation on Information Management in Factory Automation

With Script

SCRIPT FOR SLIDE PRESENTATION ON
COMPUTER-AIDED INFORMATION MANAGEMENT

Slide
Number

The overall problem that we are talking about has as its context 1,2
information management and with a specific focus on factory 3
automation. Factory automation can be defined in terms of four major
functional areas; product planning, design engineering, manufacturing 4
engineering and manufacturing. Traditionally we have broken design
engineering down into two subphases; concept engineering and detail
engineering.

Now in addition
to thinking of factory automation just as four functions, we need to
think of it as process. This slide represents the basic information
flow in factory automation and we have added the one main ingredient 5
that is missing, that is history. In principal, at least, if we make
a mistake or do something very good we learn about the process and we
learn how to do the process better the next time.

DMCS in one sense of explaining the product, is a traffic cop that
controls the flow of information along all of those arrows between all
of those different areas of the factory automation process. If we
look at one of the interfaces, any particular one, this happens to be
the interface between engineering and manufacturing, we see that it is
a pretty rough interface. In this slide we see a four foot high brick
wall covered with glass at the top and the design engineering staff 6
simply throwing the design over the wall to the poor manufacturing
engineering people. In most organizations the design folks don't
even bother to say, "Here it comes." But this happens to be an
example of a particularly well run interface. We really need to do
something to make that interface a little bit smoother and more user
friendly. Now if we talk about the requirements of doing that, that
is, what are the requirements to make the interface between any one of
those boxes a more effective interface. We realize that we need to
have effective data interchange, effective control, and useable data 7
so we have to take information across an interface with these three
fundamental attributes. We are going to look at each one of these in
a little bit of detail right now.

Looking first at data interchange. Historically data interchange in
the real world has been accomplished by people writing memos, notes,
talking on the telephone and having conferences. As we begin to 8
automate certain systems we tended to implement computer systems that
emulated the manual processes. The result of that is a varietal
spaghetti bowl of interconnected computer applications. Everything 9
talks to everything else almost, the level of difficulty associated
with adding a new application is extremely high because we must figure
out the impact of that application on all other applications. What we
really need in the future is a data interchange methodology that
avoids this tangle of interconnections and rather uses a common data 10
interface whereby modules that communicate with others do so in a
standard and well defined way.

If we look next at the attributes of control, again looking at it from

a historical point of view, in the paper environment people have
provided the data administration and control. We have on the left an
application user of some kind, it could be an engineer and or a
quality control person bringing a paper drawing to a data
administrator. The data administrator is responsible for filing those 11
drawings away in some sort of tracing vault or storage location and
for providing hierarchical copies on magnetic tapes or microfishe or
some similar medium. Now in the event that the application user walks
up to the data administrator and says, "Hey, I would like to have the
copy of drawing xyz123 and that user doesn't have the authorization to
pull that drawing out, the original out, the data administrator pulls
out her trusty 45 and shoots him dead. If on the other hand the user
has pulled out a blue line of the drawing and has marked it up and
puts that on the data administrator's desk and says "Hey, I would like
to update the tracing vault." The data administrator simply laughs
because everybody knows you make changes to the tracing and not to a
copy. Now in the computer environment neither of these two situations
exists. We have removed the data administrator from the equation and
replaced the drawing vault with a disk file. The drawings that we are
dealing with now are invisible and it is also impossible to tell a 12
copy from the original. So we have a situation in which the things we
are trying to control are indistinguishable from each other, at least
on the face of it, and with no person responsible for controlling it.
The havoc that can be caused in a design environment using this
approach can only be imagined but I would submit to you that it is
about the same as if you simply fired your current data administrators
and told all of your engineers that they could go into the tracing
vault anytime they wanted, pull any drawing they wanted, and do
anything they wanted to it. How long would your company last? What
we need in the future to avoid this problem today is some sort of data
management and control system that provides the same functions that
the drawing control administrator provides but in the electronic 13
environment. Furthermore, that data management and control system
needs to talk to that common interface that we talked about a few
minutes ago in order to make sure that the DMCS does not function in
isolation. That is, it needs to talk to systems like bill of
materials and master tracing control and other similar systems.

The third major criterion that we want to look at in terms of
interface is that of usability. Historically, we have a real problem
in the usability of electronic data and that is that we tend to store
an awful lot more information than we ever retrieve. This happens for 14
two reasons; 1) The information storage technology is so good that we
tend to store everything, we just as a default position file it away
so we have hierarchies that just go on and on forever. The second
reason we have more going in than coming out is much more serious and
that is we don't have good access paths for retrieving data. We often
times know the data is in there, but we can't figure out how to get to
get back out. 2) The second set of problems associated with
usability concerns media and volumes. Everyone is aware that if you 15
put data on a magnetic tape that after a certain time period anywhere
from 2 to 5 years, it is not there anymore. It simply faded away.
Similarly we have a fairly major problem in the area of data volumes.
The acre of disk syndrome makes life difficult for us. Finally, we

have a format problem. The same data on different machines is stored
in different formats. It becomes difficult to transfer information
from one place to another. We don't have the electronic analogue of
the 8 1/2 by 11 piece of paper. So what we need in terms of getting
usable data are common formats or at least common interchange
technologies between formats, new storage technologies to get us 16
around the acre of disks problems, a better organization of data so
that we know what we have and where it is and flexible access tasks so
that we can retrieve it easily.

Now, in saying all of these things of what we need in terms of access
control and the usability of data we have to recognize that we have
some challenges. The first that we have to look at is that some data 17
can not be well represented on paper. For example, this 3 dimensional
view of a robot manipulator arm, exploded view, simply can not be
represented on paper in terms of all of this information. We can take
a picture of this but we do not capture in this picture the full three
dimensional or textural information. Similarly, kinematic motion 18
analysis can not be represented on paper. We can make <u>a step</u> motion
but that doesn't describe the real motion. Many other types, for
example, stress outputs, simply don't show up well on paper when we 19
need to think in terms of three dimensional color and rotations. 20

The second major challenge that we have to deal with is massive data
storage. I alluded to that briefly a few minutes ago, but it is a 21
much bigger problem than most people realize. If we look at a typical
organization, this slide comes out of a survey of a very large US
company that did a survey of what they thought their on-line
interactive graphic needs were going to be through the year 1990.
This division felt that the number of IAG terminals would reach 2000
in 1990. What is even more impressive is the number of bytes of
on-line storage, 10 to the 14th bytes. Now when they added the other 22
types of electronically stored information to this number, that is
things like video images and text files and other things like that and
then allowed for a 10 to 1 data compression, they came up with 10 to 23
the 15th bytes of data on-line. Now, if you are like me, you cannot
comprehend that number. What I like to do is reduce that number to
comprehensible things. I really understand 500 megabyte disk packs, 24
that is about 4 or 5 pounds of data. That 10 to the 15th bytes means
2,000,500 megabyte disks. Now, to really bring that home, the machine
room that will house 2,000,500 megabyte disks is one mile on a side.
That is assuming that there are no access paths between the disks and
that the operator uses a catwalk to get out to the disks.

The third major challenge that flows right out of the second one is 25
backup and recovery. Can you imagen the operator of a one square mile
machine room trying to do a full back up or a full recovery of their
disk system. It is virtually impossible. However, there are some
helps coming in this area, for example, data base machines and major 26
disk storage systems. We also need to recognize some challenges in
the area of retention requirements and version control. Data
processing folks traditionally only understand one version, one
current version of the file and they only understand keeping a file
around until someone deletes it. We need to have the emulation of the

current retention and version control systems on a data processing side where in certain drawings automatically will get hierarchived 27 after a certain time period where we can have several versions of a file active and current at one time where the number of years of storage can approach 50 or even 100 years in similar requirements that are not addressed in traditional data processing systems. We really need to address that.

One of the methods that people use today to handle retension requirements and version control is the change control board. People 28 simply get together in a room and figure out what they are going to do as best they can. We should have an electronic system that emulates this change review board or at the very least speeds up this process. The whole focus of these challenges really can be summed up as a difference between information and knowledge. We have in the data 29 processing world an enormous amount of information, facts stored away on disks. It is not organized, however, or accessible in such a way to be useable and thus does not contribute very much knowledge. We 30 really need to maximize knowledge and not just pure information.

Well hopefully we have given you some things to think about in terms of this overall context of the problem. The next series of slides will be talking about some of the specific details of the problem with a focus on the relationships between data and the relationships of retention requirements and version control. Are there any questions 31 at this time?

We are now going to look at the specific problem with CAD/CAM data management and control. Remember that although we are talking about 32 CAD/CAM data management because the first version of DMCS is targeted at the CAD/CAM world, the set of problems that we are going to look at and the solutions later really apply across everyone of those interfaces that we talked about earlier. Back in the historical past 33 when people got together to talk about their designs and their work their didn't really need to be much in the way of formal control but as we move in to complex environments wherein there are many different organizations and different levels of data we really need to have sophisticated control.

Now the next series of slides talks about the relationships between data. The first relationship that we need to talk about is that of the level of the data and the communications requirements that that 34 implies. From a conceptual point of view we see three types of data and they are shown here as corporate, project and applications data.

A corporate data base would contain, for example, standard parts or external vendor lists, standard specifications, things that 1) don't change very often and that 2) require a very high degree of security for control because if they were changed inadvertently they would have a very large impact everywhere in the corporation. Corporate data bases tend to be characterized by fairly large retrievals at one time period but at fairly low speeds and they tend to communicate with other corporate data bases across some corporate network that may be world wide in scope. Now when we deal with a particular project especially in the design world we tend at the beginning of the project to collect all of the relevant information from corporate data bases. We would collect the designs of all similar items that had been accomplished in the recent or perhaps distant past. We would collect all of the specifications, all of the standard parts, vendor list, etc. and formally or informally create a project data base. Now in the paper world this is simply a set of tracings or copies of all of the important information in the electronic world that ought to be exact analogued, that is, copies of all of the data bases that apply to a particular project. We want to be free to modify these data bases within the scope of a particular project without impacting the corporate data base.

Now, the project data base also may interact with other project data bases usually on a local scope, this would happen for example if the particular project occuring was very large, say the design and building of a Triden nuclear submarine, and we had a large number of subprojects, say the electronics and the structural and guidance etc. that needed to communicate with each other. They would typically communicate on a project network level. Similarly to the relationship between corporate and project is the relationship between project and applications data bases. When a particular application, for example, the design of a finite element model is undertaken a copy of a certain amount of information is pulled out of the project data base and stored away in an applications program or in a local data base and then that application program works on the application data base. Typically, applications data bases require very low security since the security is physical, it is an operator working on a terminal. And it requires very high speed access to and from the data base and very high speed displays. Now we recognize that these distinctions are not absolute and that certain data may have existence at all three levels of this hierarchy at one time but from a conceptual point of view, in trying to provide storage control and access control we need to recognize these different classes of data.

The next relationship that we want to look at consists of the 35
hierarchy of data within a particular product. Now we have here a relatively simple product called product A and if you look inside of this hierarchy you can see a standard bill of materials breakdown. Product A to assemblies, to sub-assemblies to parts. Now the data hierarchy that goes along with this is much more complex than the bill of materials breakdown. At every level of the bill of materials breakdown we also have associated information. For example, in product A we have performance specifications, geometry and market data that somehow needs to be associated with this product. Now, in the paper world we associate by filing things under the proper filing folder and we have enough time to go searching for it, in the electronic world we need some method of associating these things in real time, so to speak.

Now, the other attribute of the relationships of data hierarchies consists of control of that product. If we take all of these squares or rectangles in this slide and we shrink them down into a little
bubble and call it just product A and then look at the ownership of 36

data we find that we must look at organizations. We have shown here a sample organization of the manufacturing plant that owns product A and you can see that in this example a particular unit owns manufacturing 37 release that is, the right to release a product to manufacturing. Some other unit owns the right to initiate a change request or to authorize a change another person, a manager in this case, owns the right to release specific drawings to manufacturing, and another individual, in this case an individual engineer, has the right to do prototype designs. Every level of the organization can own a different right about that product. Now if we look at the overall interaction between the previous slide and this slide we can see that control can come from any level of the organization to any level of the data hierarchy. This is in other words, a mini to mini relationship of a very high complexity. We must be able to associate data based on the organization that the people working on it are associated with the product data hierarchy and the project on which 38 the data is operational. We must be able to do that between any two boxes at whatever level in the project organization hierarchy. This, needless to say, requires some sophisticated data processing technologies and some very sophisticated and powerful control systems.

We know come to one of my favorite three slides in the presentation. It is a favorite of mine because it violates every principal of good slide in terms of the amount of information contained on it. But, if 39 you will bear with me I think I you will see why we put up such a complex slide. If we look at the product development cycle for this hypothetical problem 1 and just look at the bottom third of the slide, the sequence labeled Rev 1, we see that the information required to develop this product goes through a series of steps. We start out at step A, we do something there perhaps as a prototype design, and that information flows to different steps, steps B and G, and then we do something at steps B and G and we pass that information off from B to C and from G to H etc. until finally we end up with all the information required to build the product and those are represented by the bubbles J and F. Now, at each exit point from a bubble, we have the necessity for control. That is we must have some sort of control valve that prevents the person or organization working on A from simply sending off the information without regard to the rest of the system. In the drawing environment this is a review of some kind, it is the supervisor who reviews the drawing before it gets released or it is a change review board that approves or whatever. So we have to think in terms of a review point or a check point at each exit from one of these bubbles. Now, it is very common for the processing sequence to stay the same as time goes on. In fact, as we introduce new technology or simply re-organize we will find we do things differently. We have shown this in Rev 2 of this product design with 40 a different set of bubbles and arrows connecting them to represent a different information processing cycle and then similarly when we get to Rev 3 we have a third way of developing the product. It is the same product, it is a new revision. The way we get there is different. Now this slide is important because we must always realize, we must remember in the data processing world what the information process was historically. We must maintain an audit trail in the design cycle that allows us to reconstruct what the design process was for a particular revision. Again in the traditional data processing world we only know what the process was like in Rev 3. We don't have any method of reconstructing Rev 1 and Rev 2 methodologies. For legal requirements and for design verification requirements, however, we must be able to reconstruct the methodologies. Furthermore, we must be able to accomodate a shift in methodology right in the middle of a revision cycle, so it is a non-trivial problem that causes or requires an interaction between legal requirements, design requirements, and general revision control requirements.

Now, if we look at a second product, just for a second, this is
necessary in order to set up the third slide which is really my 41
favorite slide, this is the same concept applied to hypothetical
product 2. We have three revisions and a different information
processing methodology for each revision. Now I said a second ago
that coming out of each bubble is a requirement for a control valve,
that there is some method of stopping the release of information from
each bubble until it is proper to release it and I implied that the
information required for doing so is contained in this cycle.
Sometimes it is, but more often there is an interconnection between
the product development cycles of two products. We find that we
cannot release information from one step until we have information
released from a number of associated steps of different products. The
class example is the manufacturing release of an entire system. We do
not release the system to manufacturing until we have the associated
release of all of the individual subcomponents. This degree and
complexity of interaction really is a very small fraction of the true
complexity of interaction that exists in the design and manufacturing
environment. A data management and control system must be able to
handle this kind of interconnection of control requirements.

Come back now to a fairly simple concept but, an important one none
the less, in the area of data relationships. This deals with the time 42
with which we keep data around. That is, how long before we
hierarchive it or delete it? We should recognize that data is, in
terms of its retrieval with inherently hierarchical, in that
frequently accessed data should be stored near the user and as we find
that we use the data less and less often, we should put it into some
sort of intermediate storage and finally automatically send it to
hierarchival storage. We would like to see a system designed in such
a way that hierarchival storage is very inexpensive compared to
on-line frequently accessed data storage and yet the retrieval time
from hierarchival is measured in minutes as opposed to the current
days or weeks.

The next major relationship that we need to think about in terms of
understanding the overall control problem is that between Computer 46
Aided Design (CAD) and Computer Aided Manufacturing (CAM) data sets.
In the CAD arena we tend to have very large data sets. Megabytes at a
time is not at all uncommon as we look at a very complex finite
element model or the results thereof. These data sets tend also to be
fairly short lived so that there are a lot of them and they stay
around for a short period of time. We tend to have a very large

number of types of information, finite element models and stress analyses, many different kinds of information that tend to be highly variable in and of themselves, that is, we tend to change a finite element model very rapidly and very quickly as we don't like the results. The CAD world is also characterized by having a large number of what we call adhoc applications. That is, quick and dirty as the engineer would say. We simply run it once to find out how it works and then we throw it away. The CAD world needs to be very responsive to the engineering user, this is a place where the performance of the system is a major concern. The response time must be very rapid. There is a high degree of data sharing between engineers as they are designing new products frequently a design decision made by one engineer will simply invalidate something that is being done by another engineer. Finally, because this is a design environment the degree of update of the data sets tends to be very rapid. We have frequent updates as we have design changes and iterative design decisions. On the CAM side, (Computer and Manufacturing) side, we tend to have relatively small data sets, 10,000 bytes at a time, say a numerical control file to drill some holes, we tend to have a relatively small number of well defined and fixed data types. The applications are highly, that is, we know precisely what we are going to do, when we are going to do it and how we are going to do it for a long time in the future. In point of fact, the farther in advance the better. The responses of the system are often time critical, that is, we are dealing with numerical control machines, we had better respond almost instantaneously to an overheated condition or some similar response. We are dealing with real time response as opposed to fast reponse to a user. Fast response to a user might be 2/10 of a second, that might be an eternity to an automatic drilling machine. The access to the data tends to be very rigid and controlled. We allow a very small number of people to actually see the data and in terms of changing it or updating it there are many procedures that must be followed rigidly. Mainly because the consequences of an uncontrolled access of update can be the ruining of an entire run of the manufacturing process. The data interchange between CAD and CAM, most of the information really flows from CAD to CAM in terms of the data, things like, numerical control files, specifications, and testing plans, this sort of thing. Most of the change information comes back from CAM to CAD, that is, the manufacturing folks say that you can't build it that way and then the designers make a change to this design and the information that was changed flows back across the fat data arrow. In summary on this slide, we have on the CAD side a data base that is characterized by performance and time, that is, we will cheerfully pay a slight increase in cost if we can get a radical improvement in the performance of the system, how fast we can get a display, or the lead time to design a system. We will also cheerfully usually pay a slight degradation in quality, for example, a lower resolution on the video display, if we can get a much quicker response. On the CAM side the driving factors tend to be quality and cost. That is, we will usually spend a little bit more time making something if we can do it at significantly higher quality or significantly lower cost.

So if we talk now in summary about access control, how should we allow 45

access to data? The first thing we need to do is to make sure that
the user who has access has a job that requires access. We should
control access based on the job function. We need also to recognize
the type of data is important in controlling access. We don't want
necessarily to have a finite element model made available to the
quality control people, there is no need to have that data made
available. The status of the data likewise has an important bearing
on this. When a piece of information is in prototype design we don't
want it released to manufacturing. Similarly if we are talking about
something that has been released to manufacturing we don't give free 47
access to the design engineering staff, they are simply not allowed to
modify that data. And as I noted earlier, we need to take into
account the status of related data in order to release or to access
data in a packet or to insure that specifications etc. are available
to the appropriate people.

Secondly, we need to think in terms of degree of control and recognize
that different types of data require different degrees of control. It
doesn't make any sense in the military to control every piece of 44
information as top secret and in the same way it doesn't make sense in
the manufacturing organization to treat every piece of information as
highly sensitive and requiring a high degree of control.

In summary, we need to treat electronic data at least as well as paper
base data and we need to do so in these areas of validation security,
hierarchiving, duplication, etc. etc. if we think back to that top 43
slide where we had the drawing control administrator, we need to
provide all of those functions in the electronic world. Now hopefully
everything I have said at this point and time has given you an
understanding of the problem that we are trying to face. Are there 49
any questions at this time? 50

Well, the world's first computer, that is right. That is exactly
right. Historical overview, if we talk about again the problems in
the past and the methods of control back when stonehenge was done up 57
they obviously didn't have any CAD/CAM data management and control
systems to deal with. They managed pretty well and from an
engineering point of view, the degree of precision of placing of those 58
stones is still slightly better that we could do the same with our
normal engineering techniques. I suspect if we brought space age
technology to it and laser placement and such, we could probably equal
the placement today, but we are still not able to do better. Now, the
whole problem of data management and control really began when we
started to replace these drafting systems with electronically,
electronic analogues of them, such as this arbitrarily chosen Calma 59
graphics workstation. We will remember that the problem stems from
our inability in the CAD/CAM world to replace the manual data
administration system, which handles the manual environment, we simply
don't know today what we are going to do in the CAD/CAM environment, 60
or at least we didn't know until DMCS came around. Now we are going
to take a short digression here just in case there are any doubting
Thomases left in the audience who really don't buy this precept that 61
all of these problems are real and that the overall challenge is there
in terms of managing electronic data.

This is a highly confidential slide that I have obtained, and you may
not ask me how I obtained it, from the Albatraz Aerospace Engineering
Corporation of Albuquerque, New Mexico. This shows the preliminary
prototpye design of a generation of aircraft and as you can see the
wing group was primarily responsible for this design and it is a 62
rather radical design. Now, the problem was and this is why these
slides are confidential, unbeknownst to the wing group, the tail
assembly group was also working on this design and they thought that
they had the primary design role. Now, when the tail assembly group 63
and the wing group got together over lunch one day they began talking
about this thing and they both discovered that they had primary design
responsibility they really got upset. They decided they had better
have a meeting to resolve their design differences. They got together
and they started resolving their design differences and they were just
about finished when the chief of the power plant group walked by and
he said, "What are you guys doing?" They replied, "We are having this
design group on a new XY37 fighter." The power plant guy said, "Well
I don't understand because I thought I had the design responsibility 64
for that aircraft and this is the real design for that aircraft."
Well after a little bit of bickering back and forth they finally
decided if they were going to get this aircraft off the ground they
had better resolve these design differences. So they brought the
power plant group into this design review and they started working,
and working, and working, well days go by and they are just about
finished, in walks the President saying, "How are you guys doing, what
is going on?" They say, "Well, sir, we are just about finished here
is the new design of the XY37 fighter plane and we are really proud of
this." The President says, "Guys, I don't understand this I told the
stress group that they had the primary responsibility and they are the 65
ones who are designing the plane." Well that tore it, all the chief
designers resigned, there wasn't sufficient control in the
corporation. Now you understand why you have never heard of the
Abatraz Aerospace Engineering Corporation of Albuquerque, New Mexico.

Well, how is your company going to avoid the fate that I have just 66
described? Well, the answer is DMCS from General Electric. Before I
talk about the functionality of DMCS, I think it is probably
appropriate to talk about the history of DMCS. This product has its
roots in a task force that General Electric put together about 5 years 67
ago consisting of these major operations of General Electric. Now
this task force had as its goal, the definition of the problem of
control of electronic information. The task force went out and 68
interviewed a very large number of divisions inside of General
Electric to talk about what are their requirements that they see
coming in this area of CAD/CAM data management and control? In 69
addition to going internally to major divisions, they also went
outside to a number of very large manufacturing and associated
organizations. The result of all of this discussion, which by the way
took about a year and a half, was the CAD/CAM Data Management and 70
Control System Perspectus. This document was put on the street to 37
hardware and software and system house vendors, and these vendors were
asked to bid on the development of a system that would handle these
problems that were raised in this perspectus. Of the 37 vendors, 6

responded, and entered into subsequent negotiations. SDRC was chosen after a long series of negotiations to build DMCS for General Electric. As you know, SDRC is a 48% owned subsidiary of General 71 Electric.

Well, it is now time to talk about the Data Management and Control System itself. We have talked a lot about why we need one and what are the problems that we are going to solve, how we got to where we are, we are now going to discuss the system itself. .

This is, in a sense, a summary slide of all of the functions of DMCS. It is a system that will manage a product and process data in its most 72 generic sense, cross a wide range of functions and systems. In particular, DMCS provides for data sharing in the context of movement, conversion and coordination. DMCS will operate eventually on a large number of main frames, super minis, and mini computers, currently it only runs on a VAX, but we expect it to run on IBM shortly. The DMCS 73 system works across a number of different types of data, engineering, drafting and manufacturing data. DMCS is designed to interconnect to a wide variety of electronic systems, Computer Vision, Applicon, Calma, Gerber, Electronic Testing Systems or whatever, and it is also designed to handle a wide variety of non-electronic information such as drawing files, computer output microfishe, cards, documents, and whatever. DMCS is a generic data management and control system that 74 can apply in a heterogeneous environment. By heterogeneous environment we mean that it handles multiple types of data, running on multiple vendors of machines, stored in multiple data formats, using multiple communication protocols. DMCS is the central integrator of this entire spaghetti bowl. From a functional point of view DMCS has 5 major classes of functions that a user of the system sees and 1 is a supporting function that typically a system manager sees. The 5 user functions are storage, management, access control, status control and message communication. Customization is a feature or a function that applies to all of the 5 user levels of functionality and basically allows DMCS to be configured in such a way that the system operates as you currently operate, that is, we can customize DMCS in such a way that we make DMCS conform to your mode of operation rather than making you conform to our mode of operation. Now I hope to talk quite a bit about customization and its attributes as I go through these different functions.

The first function that we need to look at is that of high volume 75 storage. Now, the central disk file indicates the on-line storage of DMCS itself. When DMCS is running on a host computer, for example, a VAX, it owns a certain amount of storage capacity. It owns as much as you care to give it. DMCS manages and controls information on the host computer, that is, if you try to access a file that is controlled by DMCS, you will find that the host operating system won't let you because DMCS is the owner, not you. In addition to being able to manage and control data on host, DMCS is able to manage data elsewhere. It can manage data on a CAD/CAM system, or on an hierarchival tape library or in a computer output microfilm or <u>apeture</u> card library either manual or automatic retrieval and in a paper drawing control system. Now you notice I said manage not manage and control, and that is simply because the DMCS host has no way of physically enforcing its decrees. A user sitting down at that drawing control system or the lower left hand paper system, can request of DMCS authorization to perform a particular transaction, for example, making a copy of a particular drawing for the chief engineer. DMCS can come back and say, no, he is not authorized to have that data, but DMCS has no way of making sure that that copy wasn't made anyway. So DMCS manages information on peripheral systems and manages and controls information on the host.

If we look at the second category of functions, that of management. 76 These are relatively common functions for any computer system, but none the less, important ones. We have two major classes, system functions and engineering functions. The top four functions, recovery, restart, integrity and protection really revolve around system management. We make that sure you don't lose files, that the files are adequately protected, that the files are copied correctly when they are copied, etc. If we look at the engineering management functions we need to know where files are physically located. This assumes a major degree of importance when we are talking about multiple CAD/CAM systems interconnected via a central DMCS. In terms of structure of the information, the structure of the information becomes important when we are attempting to handle a heterogeneous environment. It doesn't do any good to transfer a word processing file down to our <u>local</u> Calma system. The information is simply worthless. So, we need to understand at least the rudiments of the structure of the information that we are dealing with.

The query function allows the management to perform adhoc queries and searches on the data base and file usage functions let management know who has accessed what file, when they were accessed, and the reason for the access.

If we look at access control, all of the concepts that I talked about 77 at the beginning of this presentation for access control are covered or implemented in DMCS. We fundamentally provide extremely complicated, if you so desire, access control. Access can be allowed or denied based on a specific list of people associated with a specific file. It can be allowed based on the project that a user belongs to, the organization that a user belongs to, the type of data, that is the file type, the revision level and the status and any combination thereof. It is an extremely sophisticated and powerful access control subsystem. There isn't time in this presentation to go into that in detail, but if you would like me to discuss it further at the end of the presentation, I would be more than happy to do so.

The control of information as it goes from one state to another forms an intrical part of DMCS. It is important to note that these states 78 that we have shown here, concept, sketch, prototype, production and hierarchive are fully customizable, that is, you the user will tell us what these states are. You may have 2,000 different states into which you place data. Now, when I say you tell, you don't really tell us, you customize the system with our help at the beginning and you can change those states as time goes on.

Now, status control consists of a series of functions that monitor the change of state. For example, if we wish to move a particular drawing from prototype to production, that is a state change. DMCS, when someone requests a particular state change, will first verify that that individual is authorized to request the state change and then automatically notify all the people or organizations who are required to approve that state change. Once all those people who are required to approve the state change have signified their approval electronically, then the state change occurs under DMCS control. Now, the method by which DMCS allows state change approvals is fairly sophisticated in and of itself. We allow what we call series parallel state change approvals. That is, it is possible to have any number of people approve in sequence, one after another, and then to go into parallel approvals where a number of people are approving the drawing or the part simultaneously and after all of those approvals are made then we go back into <u>serial</u> or again into parallel approvals so that it is possible for example to have the engineering supervisor approve it, followed by the design department supervisor approve it, followed by a parallel approving of quality control, purchasing, material and stress and after all four of those have approved it, to go to the chief engineer for final approval. This tends to speed up the approval process rather enormously.

If we talk about communications, message communications, this function forms the backbone by which the approval process that I just talked about actually occurs. Any time a individual needs to approve a particular state change, a message is automatically sent to that person's terminal. Once that message arrives at the terminal, the user is notified and can perform a DMCS transaction that calls up the particular approval and then he either denies or accepts the particular state change that was requested. In addition to approval control or approval cycling the message communications system notifies people who need to be notified whenever something of interest happens. Now, as an example we may have a fixed distribution list that gets notified every time a particular part goes to a new revision number. DMCS will automatically notify that fixed distribution list upon the specific event Rev level change. In addition, DMCS maintains adhoc lists of people based on who has looked at a particular piece of information. As an example, we may have a part that gets accessed by 10 different people during the course of the year. DMCS will make a note that these 10 people accessed that part and then when a revision occurs will automatically notify those 10 people that that part has been revised. Now, the difference between this and the previous list is that this adhoc list is perged from the system when these people have been notified. So we have a fixed distribution list and a temporary notification list. In addition, it is possible to use this communication system as a very primitive electronic mail system and that it is possible to attach comments and messages to notifications and approval requests. 79

In terms of customization, virtually every aspect of the system can be tailored to the particular needs of an organization. We can define file types, whatever types you need. There is a 6 character file type 80

code and a 32 character expansion of that code so you could, for
example, define finite element model as FEM, you could define a vendor
parts list as VPL, anything that you chose as a file type DMCS will
accept. Status codes, again, you can define virtually any number of
status codes. Message codes are similarly defined organizations. You
tell us what your structure is. Access control codes, you tell us
what people or organizations can access what types of data and under
what circumstances. The system is customizable to an extraordinary
degree without doing any changes to the software itself. All of these
changes are done by changing tables in the relational data base that 81
DMCS uses to perform all of its access controls and other functions.
If we look now at some of the fundamental concepts of DMCS probably
the most fundamental is that of the label versus the content of the
file. DMCS understands what we call buckets of bits. A bucket of
bits is simply a binary file that DMCS controls. DMCS does not know
what is inside of that file. It could be a geometric form as shown in
this example or it could be a word processing file, or a <u>video</u> image
file. DMCS simply doesn't know what is in that physical file. It
takes it from either an application program on the host or an attached
computer system via a communication link and stores it away as
received in a file. Contrasting this the label information is known
totally by DMCS, in fact, DMCS constructs the label and places all of
this information inside of the DMCS data base. Now, imagen this to be
a drawing and down in the lower left hand corner we have a
distribution code typically. We have in the bottom center the
approvals, the actual approvals for that drawing. We have a title
block in the bottom right hand corner and we traditionally have some
sort of <u>revisioned</u> history in the top right hand corner. And then in
the body of the drawing we have the actual drawing itself, the data
itself, that we are dealing with. Now in a one sheet drawing this is
the way it would actually be, often times we will have multisheet
drawings and all the revision history may be on one sheet and all of
the title block and such may be on another sheet but it doesn't
invalidate the basic concepts. Now if I take a DMCS label, what I
basically do is take the scissors and I cut out all of this
information here, all of the title block and the control information,
I fold it up into a nice package, I stuff it in this pocket over here.
I take all of the other information, that is, the actual geometric and
design information, etc., and I stuff it in another pocket over here,
then what I do is I establish a pointer between the two. Now, all of
the stuff that went in this pocket, that is, all of the information
about who did it, the title blocks, the revisions etc., goes up into
DMCS labels and all of the information in this pocket, that is, the
actual drawing itself goes down to the geometric form. So we have
data about the data, that is <u>medidata</u> contained in the DMCS label and
we have the data itself, the product information itself, contained in
the bucket of bits.

Okay, some of the implementation considerations that really gated the 82
design of DMCS, first, was to provide a generic solution, that is, one
that a single system can go into a very complex organization and work
across all of the different divisions and departments through
customization. We are providing a system that is really a one system

CHANGE TAPE SIDES

We have found that in many organizations the release process to manufacturing is a very rocky one, to say the least. In some organizations 50% of the release packets to manufacturing contain errors. They'll be either incomplete, in that required drawings will not be present, or even worse, the wrong revision level of a drawing will be included in a package. Of course, manufacturing doesn't know this and so they go racing off and begin to manufacture something and discover later that the release was in error and that most of what they have done has to be thrown away. The third impact area consists of early change notification. Usually engineering does not want manufacturing to have access to their drawings because they are afraid manufacturing will change them or do something horrible. With the DMCS system we can give manufacturing read only access to files so that they can be notified that changes are coming and hopefully that will allow them to take appropriate action, such as, stopping the production run, for example of a system that they know a change is coming on in the next day or two. 83 84

The fourth impact area allows early design access by purchasing and manufacturing personnel. Hopefully, this will enable feedback to the design staff so that the designers will not be designing things that are inordinately costly or extremely difficult to manufacture. Now, these three areas correlate with the three savings areas, reduced labor, reduced <u>scrapinary</u> work, fewer hardware changes on the right. To give you an idea of the magnitude of this, we have talked to one Vice President of manufacturing who said, "If engineering would install DMCS that he would pay for it and also cut his scrapinary work budget by 50%." Now his scrapinary rework budget was a $5 million a year operation. So, at least this one person thought that putting DMCS in would give him a very significant cost savings.

Finally, because we are now controlling and tracking virtually every design change we have good information. It should be able to perform correlations between changes and the product quality. If we look at this data over time we ought to be able to improve the quality of our product and potentially reduce the cost of warranty. DMCS in terms of an overall system has as its goal the simultaneous access of data in an engineering data base at multiple levels from multiple different organizations using different kinds of machines. This is the data sharing concept in a heterogeneous design and manufacturing environment. 85 86

Data release and control is an example of how we might use DMCS in a design engineering environment. We start off with an engineer working at his own personal work station and simply designing, prototype design or whatever, using or working unissued data. Nobody else beside that engineer has control over that data. Once the engineer has finished with his/her operations, he takes it to his manager who then approves that piece of information or that drawing and initiates a formal approval cycle. Once that formal approval cycle has begun the file is placed into appending state. While in appending state nobody other than approvers can gain access to it. If during this 87 88 89 90

approval cycle one of the approvers rejects the drawing or the file,
then the file is automatically taken out of pending state and put back
into personal work space and the engineer who was working on it or
somebody else designated by the department manager must correct the
defect and then we reinstitute the approval cycle. Once all of the 91
approvals have been made, then somebody named the drawing control
administrator must make a formal transaction to release the drawing or
issue the drawing to the system. This process makes that drawing
available to other engineers working on the system and typically this
process results in what is called issued data. The difference between
issued and unissued data is that any engineer who has proper
authorization can gain access to issued data under the control of 92
DMCS, whereas the individual engineer controls unissued data. Now the
overall access for the purpose, for example, of making work copies or
reading usually will reside in a person called the product data
manager. Now, this person will control who actually gains access to
the issued data and under what conditions. This person is the one, 93
for example, who would say that purchasing is allowed to see prototype
designs, but not to see concept designs. Now, what happens if we need
to make a change to that? Well, we will, first of all, make a work
copy of the issued data so that some engineer, perhaps the same as
before, can begin working on that and the engineer responsible will
make modifications to the work copy. Unlike the paper environment, we
never modify the original file, we always make copies of it and then
make modifications on the copy. Once the modifications have been
completed we put that file back into the approval process in exactly
the same way that we approved the original unissued data file. When 94
the approval process has been completed we will automatically delete
the work copy and we will send automatic notifications of changes or
whatever to the appropriate people.

Additional:

Slides 1-20 are examples of CAE Technologies applied to a variety of products.

APPENDIX D

Examples of Computer-Aided Technologies In Use

Survivability Through Mobility
A Systems Engineering Challenge

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ABSTRACT

The theme of "Survivability Through Mobility" is certainly not new in military thinking. This concept has been applied to the design and use of tactical battlefield weaponry and support equipment for ages. Today, however, in light of the sophistication of modern weaponry, the concept is applicable not only to tactical equipment but also to strategic equipment. Thus, both the Government who is concerned with identifying needs and requirements and procuring solutions to those, and industry who is asked to provide those solutions, must appreciate just what kind of a challenge this concept presents in today's world.

This paper presents a synopsis of that "Systems Engineering Challenge", stressing the complexities of survivability to the threats that exist today. Topics addressed include a discussion of how mobility contributes to survivability, mobility systems requirements, and the role of systems engineering in smoothing out solutions to the complex mobile system requirements. Particular attention is paid to systems analysis with emphasis on structural dynamic analysis. Then, in more technical detail, one aspect of a structural dynamics consideration in shelter design is addressed.

An example of a coordinated test and analysis approach to obtain hardened mobile shelter design information is described. Simple shelter models and finite element analyses using NASTRAN were used to simulate the nuclear environment and predict design loads on shelter components. The particular components considered were shelter edge members. The shelters consisted of panels made of aluminum facing sheets and a paper honeycomb core. These panels were joined at the edges by complex joints made of aluminum extrusions, bolts, adhesive, and fiberglass.

The loads predicted for these joints were then used in laboratory tests of a twelve-inch slice of a shelter which contained two edge members. The tests provided design understanding and verification of structural and EMP integrity for the final design configuration. A great deal more insight into shelter component design was obtained from the test than could have been obtained by even the most elaborate analysis. And, since this testing effort spanned only two weeks and the combined testing and analysis took approximately one month, this example represents a practical design approach which can fit into a shelter design schedule.

The major thrust of this paper is to implant an appreciation with the reader that to achieve "Survivability Through Mobility" requires the application of sound systems engineering techniques to provide rather complex synergistic systems.

INTRODUCTION

Survival during warfare is essential for victory. If you don't survive you surely cannot win. How to survive is the age old question.

- Dig a deeper hole?
- Wear thicker, heavier armor?
- Hide where the enemy can't find you?

Each of the above is a potential solution, but a terrible impediment to successfully carrying on your mission, to say the least.

The most effective means of survival is MOBILITY. Get in, get the job done, and get out before the enemy detects you and can strike at your detected location. This obviously is no new military concept. From the day when the first caveman went into battle against others, he found out that one way to survive when things got too hot was to get out of there. Today's Field Artillery "shoots and scoots". The whole essence of the Horse Cavalry through today's Armored Cavalry is mobility.

Although mobility has forever been a key ingredient to survivability on the tactical battlefield, from the strategic standpoint, mobility has never been a crucial requirement for survivability. In the strategic arena, survivability has been taken for granted simply as a matter of geographics. The strategic war has been played from "behind the lines", a good comfortable distance from the "heat of the battle", maybe even separated from the tactical war by an ocean or continent. At a minimum, you could protect the strategic centers by piling up enough sand bags, or pouring enough reinforced concrete, or burrowing deep enough into a mountain, to counter any unlikely enemy destructive thrust. There just wasn't a real crying need to have our strategic command, control, communication or processing centers be mobile.

Today, however, is a different story. It's pretty difficult to tell where "behind the lines" really is. It's almost impossible to be out of range of the "spear throwers". The battlefield has become potentially global. Technological advancement in target detection and weaponry allows our foes to engage pinpoint targets. It has therefore become a driving requirement that operations, even located within CONUS be survivable.

MOBILITY AS A CONTRIBUTOR TO SURVIVABILITY

Mobility as we have said, can provide survivability. Through mobility, survivability even in nuclear warfare becomes reasonably achievable when the strategic operation, be it a command post, data processing terminal, communications terminal or other control center is packaged into a highly mobile and hardened configuration. Ideally these mobile electronic system packages could be deployed in locations where they would not be detectable. However it is, of course, pure folly to expect that the mobile terminal can be camouflaged from visual, IR and RF detection for any extended period of time if it has a high enough strategic value for the enemy to select it as a target. The arsenal at the enemy's disposal consists of high numbers of delivery vehicles, each capable of carrying multiple maneuverable warheads, any one of which can be programmed to target a particular mobile center.

Given that detection is inevitable, one must assume that the terminal will be targeted for nuclear engagement. Operations Analysis, therefore, must digest the threat scenario and determine the logical size (yield) of the weapon most likely to be used, the time necessary for the detection to take place, time to transmit locational information back to the threat launch site, time for reprogramming of the launch vehicle for new target location, launch time and finally, flight time to the target location.

The result of such a threat analysis then determines the time allowed for the terminal to close down operation and relocate before the weapon arrives at the previously targeted location. This obviously demands two major characteristics in the ground terminal:

> Extremely short redeployment time requiring little or no tear-down or set-up time and rapid mobility.
>
> Hardening to the extent necessary to withstand the anticipated blast, thermal and EMP effects likely to be experienced at the distance traveled from the previous location (the expected detonation location) within the determined time.

COMPLEXITY OF MOBILITY SYSTEMS

The complexities of packaging the terminal into a mobile configuration have been underestimated time and again in both the procuring community and the contractor community. Within the procurement package, for, say a mobile communications system, the transportation element is often treated as an incidental. Communication Contractors feel, perhaps rightfully, that the major problem is to put together the communications system; packaging it into a survivable mobile system is thought of as secondary.

Let's try to focus on what is involved in such a mobile terminal. First of all it involves the payload itself or, the electronic equipment that performs the mission. The payload can be comprised of existing commercial equipment, perhaps some Government furnished equipment and most likely some newly designed special equipment packaged into standard electronic equipment racks. The remainder of the terminal system is considered to be the transportation element. A typical transport element, as shown in Figure 1, consists of a tractor with 5th wheel, a semi-trailer with a shelter or shelters attached that house the payload, the power generation and distribution equipment, an environmental control unit with an air filtration/distribution system, crew amenities, storage space, fuel system and an overall transportation element status and control system.

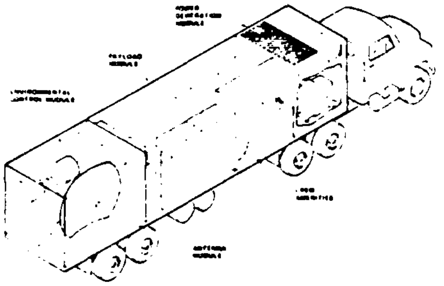

Figure 1. Typical Ground Mobile Electronic System

MOBILITY SYSTEM REQUIREMENTS

Typical requirements for such a system encompass:

1. Nuclear survivability from the nuclear effects of blast overpressure, thermal loading and electromagnetic pulse (NEMP).

2. Minimal tear-down or set-up time which more than likely will drive a requirement for a powered up status to exist at all times, even while mobile, to prevent the need for warmup time once the vehicle has arrived at the new location. Further, if the payload is powered up when mobile, the whole vehicle must be a self contained system, including power generation and environmental control equipment. This requires that relatively large fuel capacities be carried aboard the vehicle.

3. Rapid deployment from one location to another drives the requirement for a prime mover and trailer design to be capable of relatively high speed (equatable to commercial 18 wheel rigs) for rapid movement over primary highway networks either CONUS or OCONUS. This highway travel should not require procurement of special permits for highway operation. The vehicle should also have some limited off road capability because it most likely will have to pull off the road for mission operation.

4. The system should be electrically hardened to safeguard against the whole family of electromagnetic effects such as Tempest, EMP, EMI, EMC, TREE, Red/Black criteria when operating by itself or when interfaced with an external power source (commercial power).

5. Of course the system would need to withstand and operate in the whole family of rather standard natural environmental extremes of temperature, humidity, dust, sand, salt fog, wind, fungus, rain, sunshine, snow/ice and altitude.

6. Besides being transportable over roads by its own motive power, the system should be transportable by air. Aircraft relocation should require only minimal disassembly or reassembly for compatibility with standard military aircraft as shown in Figure 2.

7. Undoubtedly the system will demand that stringent systems effectiveness requirements be met. It will need to be safe to operate and maintain, it will have to be a highly reliable system with minimal mean time to repair, maximum mean time between failures and maximum system operational availability. Faults in system operation will identify themselves through use of BITE. Repair and maintenance will be simple, straightforward and easily achievable. The system will fulfill standard human engineering requirements during both operations and maintenance. The system will ideally have accommodations to support the operating crew for an extended period of time without resupply during the trans and post attack time frames. Noise levels will need to be kept acceptably low, and of course the system must be supply supportable.

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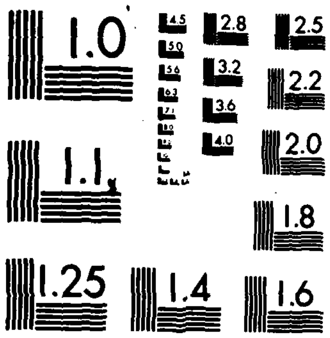


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

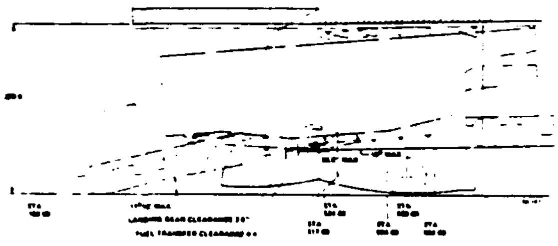


Figure 2. C-5A Loading Compatibility

8. To impede detection the system should not call attention to itself either during movement from one location to another or during mission operation. If the system blends in well or resembles other commercial tractor trailer rigs traveling the highways, the chances of delaying detection are considerably enhanced. Figure 3 is an example.

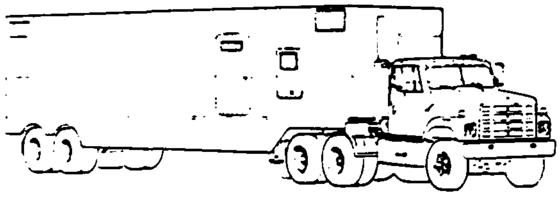


Figure 3. Example of Design For Inconspicuous Appearance

9. The operator, during mission operation or the tractor driver, during relocation operation should be able to determine the general status of the elements of the transport system and to control the operation of the power generation and environmental control equipment.

THE SYSTEMS ENGINEERING ROLE

While this list of requirements can be expanded, the above represents the more important requirements. Hardware to satisfy these requirements can only be produced with the exercise of sound systems engineering work. The integration of the system elements into a single system that satisfies interrelated requirements demands an integrated system design, analysis and testing activity.

For the benefit of the reader who is not entirely familiar with the complexity of true Systems Engineering activity, Figure 4 represents a method of iterative flow of systems analysis leading into an optimal system design. Figure 5 illustrates the same iterative relationship of system analysis and system design but in terms of hardware typical for a survivable Ground Mobile Electronic System.

Paramount in this mixture of system complexities is the structural dynamics problem. It is imperative that the payload survive the shock and vibration environments experienced during a nuclear overpressure event, during roadability operations, and during air, rail or sea transport.

The first difficulty encountered is the determination of the shock/vibration levels that the payload can tolerate. Given that data, the transport subsystem must then be designed to protect the payload to that level. However, there is strong tendency today to use commercial off-the-shelf electronic equipment or government furnished electronic equipment in payload design. Because the shock/vibration survivability threshold for such equipment is rarely available, it must be determined by analysis, test or combination thereof.

Isolators for equipment racks are designed or selected to afford absorption of the relative motions between the racks and the shelter's walls, ceiling and floor. These isolators must avoid point loading of either the shelter surfaces or equipment racks.

This relative motion between the racks and the shelter is a function of rack design, shelter construction and isolation between shelter and shock/vibration cause. In the case of overpressure as a cause, the interface between cause and shelter is direct, with no further isolation present. In the case of roadability induced shock/vibration, the isolation will consist of several isolating devices in series between the road and the shelter. The tires, the trailer suspension system, the trailer frame itself and possibly the isolation between the frame and shelter floor will all afford a differing degree of shock/vibration protection. If the transport configuration requires removal of trailer running gear and suspension, then certainly an isolation system under the shelter will be required to protect the shelter and payload from transport environments.

Figure 6 illustrates the above series of isolators as a system of springs which cause the noted deflections and forces to occur in varying magnitudes dependent on the stimulating environment.

With very little in-depth observation of the above, it should be obvious that the transport element of this terminal design is a complex system problem. The design of any one of the sub-elements described above effects the total system's dynamic response to shock and vibration.

This discussion of structural dynamic system effects is only one representation of the complex synergism of a mobile electronic terminal, which must be designed as a system. The design must be controlled through all system interfaces, hardware integration must be performed as a system, and operation and maintenance scenarios must be created as a system.

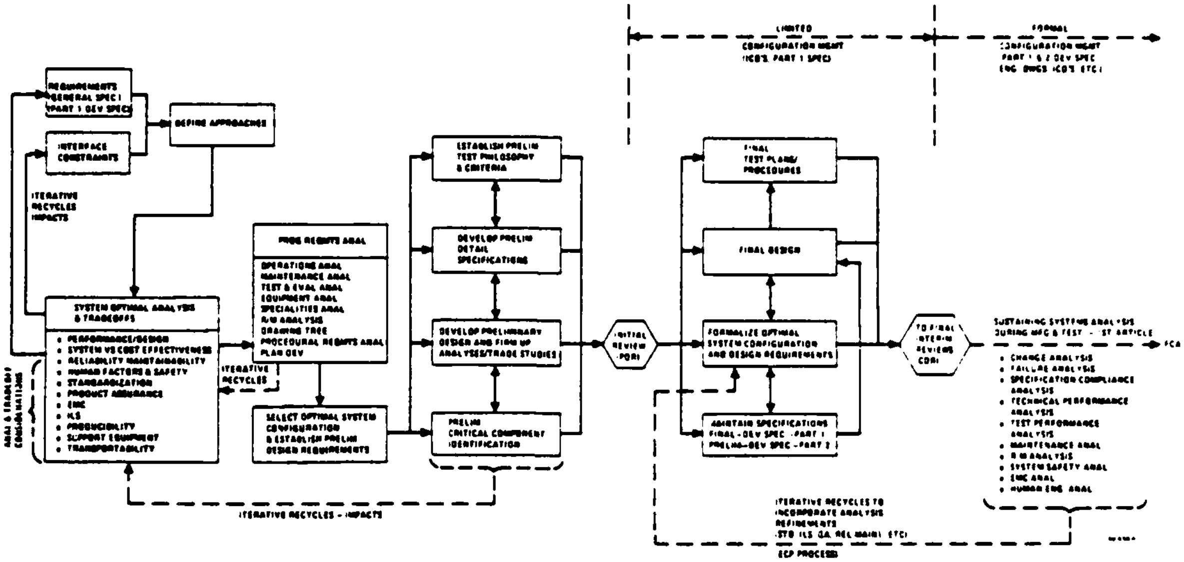


Figure 4. Iterative Method of System Analysis Yielding Optimal System Design

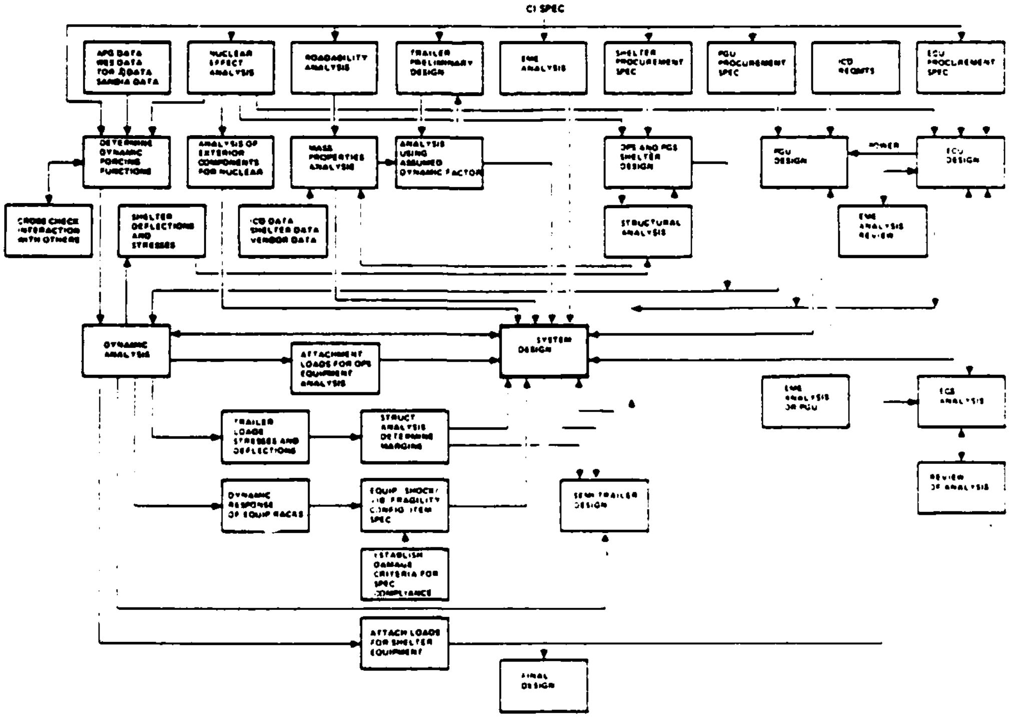


Figure 5. System Analysis and Design Iterations Relating to a Survivable Ground Mobile Electronic System

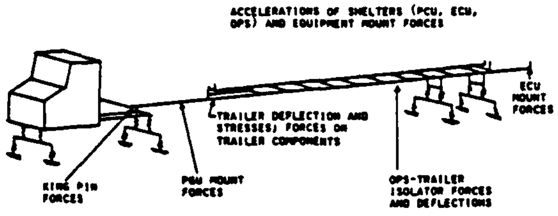


Figure 6. Component Dynamic Loads

COPING WITH THE STRUCTURAL DYNAMIC PROBLEM

During a recent design activity for a mobile electronic system, Brunswick procured services from Structural Dynamics Research Corporation (SDRC), San Diego.

Figure 7 shows how the SDRC structural dynamic analysis integrated into the total system analysis. Figure 8 is a block diagram depicting the general type of structural dynamic analysis performed by SDRC. Figure 9 is formatted as a status chart but through its matrix format we can see the extent of the dynamic analysis performed.

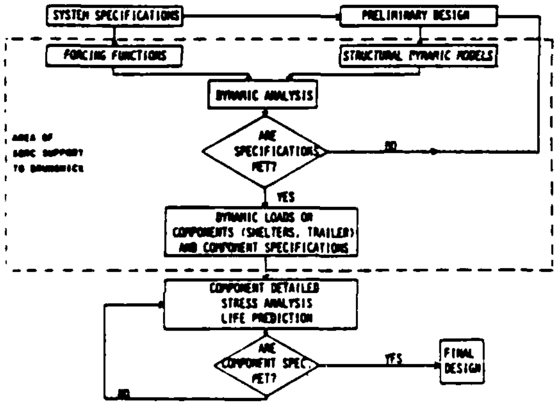


Figure 7. Design Analysis Flow Chart

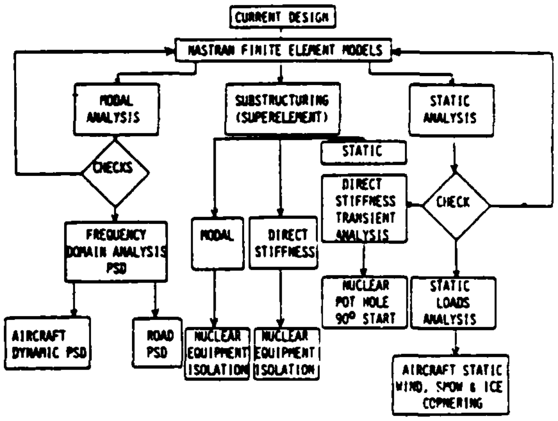
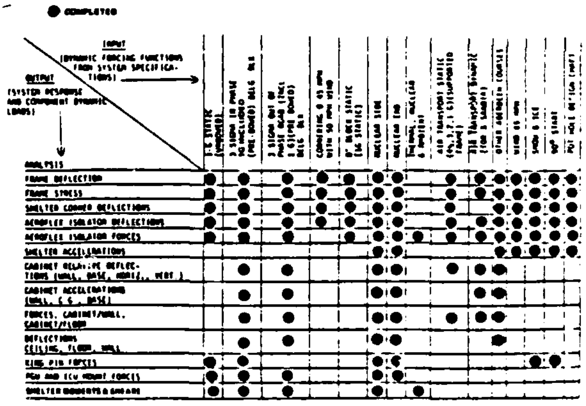


Figure 8. Structural Dynamic Analysis Block Diagram



● COMPLETED

OUTPUT (SYSTEM RESPONSE AND COMPONENT DYNAMIC LOADS) / INPUT (DYNAMIC FORCING FUNCTIONS FROM SYSTEM SPECIFICATIONS) / ANALYSIS	1-G STATIC (UNBOWED)	3 SIGMA IN PHASE 5G INCLUDED (PRE-BOWED) DELG [illegible]	3 SIGMA OUT OF PHASE ROAD (INCL 3 G)(PRE BOWED) DELG [illegible]	CORNERING @ 45 MPH WITH 50 MPH WIND	0" BLOCK STATIC (1G STATIC)	NUCLEAR SIDE	NUCLEAR END	THERMAL, NUCLEAR & AMBIENT	AIR TRANSPORT STATIC (4½, 3, 7, 1.5 G)(SUPPORTED FRAME)	AIR TRANSPORT DYNAMIC (FOR 3 SANDIA)	OTHER ABERDEEN COURSES	WIND 65 MPH	SNOW & ICE	90° START	POT HOLE DESIGN [illegible]
FRAME DEFLECTION	●	●	●	●	●	●	●		●	●	●	●	●	●	●
FRAME STRESS	●	●	●	●	●	●	●		●	●	●	●	●	●	●
SHELTER CORNER DEFLECTIONS	●	●	●	●	●	●	●		●		●	●	●	●	●
AEROFLEX ISOLATOR DEFLECTIONS	●	●	●	●	●	●	●		●	●	●	●	●	●	●
AEROFLEX ISOLATOR FORCES	●	●	●		●	●	●	●	●	●	●	●	●	●	●
SHELTER ACCELERATIONS						●	●				●	●	●	●	●
CABINET RELATIVE DEFLECTIONS (WALL, BASE, HORIZ., VERT.)		●	●			●	●		●	●	●				
CABINET ACCELERATIONS (WALL, C.G., BASE)		●	●			●	●			●	●				
FORCES, CABINET/WALL, CABINET/FLOOR		●	●			●	●		●	●	●				
DEFLECTIONS CEILING, FLOOR, WALL		●	●			●	●				●				
KING PIN FORCES	●	●				●	●						●	●	
PGU AND ECU MOUNT FORCES	●	●	●			●	●								
SHELTER MOMENTS & SHEARS	●	●	●			●		●							

Figure 9. Typical Dynamic Analysis Matrix

SDRC contributed significantly to the success of the program design activity. The remainder of this paper, prepared by Dr. Mary Baker of SDRC is an example of this performance and should leave you convinced that design of a survivable mobile electronic system presents truly unique system engineering challenges.

INTRODUCTION

The most powerful design tools are well-integrated test and analysis efforts. Test can give validity to analytical assumptions while analysis can extend the understanding beyond that available from existing hardware and achievable environments.

For shelters which must sustain a nuclear environment, the design challenge is particularly great. The nuclear environment is so severe that overly conservative design practices cannot be tolerated in a transportable shelter. Also, the nuclear environment cannot be easily simulated for test purposes, so the understanding which comes from experimental data is costly and difficult to obtain. Finally, the shelter designs involve complex structural components containing many materials and glued and bolted joints which are very difficult to model accurately.

This paper describes a portion of a shelter design effort which involved successful, coordinated test and analysis. This effort provided a great deal more understanding for shelter design than could be obtained from either test or analysis alone. Moreover, because it was completed in less than one month, it represents a practical design approach. This description is being presented as an example of ways to overcome the severe constraints placed on the designers of hardened mobile shelters.

In general, the approach described here is to use analysis with simplified structural finite element models to translate the specified nuclear environment into dynamic forces transmitted to shelter components. These loads can then be used in a simplified test easily performed in the laboratory on a component or portion of a shelter. With this added understanding, higher performance components and shelters can be designed and their structural integrity verified.

This work was performed jointly by Brunswick Defense, Costa Mesa, California; Brunswick Defense, Marion, Virginia; and Structural Dynamics Research Corporation (SDRC), San Diego, California, in June and July, 1982. The shelter design discussed is a patented design belonging to Brunswick Defense of Marion, Virginia.

DESIGN REQUIREMENT

The objective was to design and verify shelters for use in a survivable ground mobile electronic system. This system consists of a highway tractor trailer shown in Figure 1. In addition to mobility loads and air transport forces, this mobile shelter must sustain a specified nuclear environment. In general, this nuclear environment consists of a thermal pulse followed by a pressure transient impacting all surfaces of the shelters. Figure 10 shows a pressure pulse shape for two surfaces—facing the blast (windward) and opposite the blast (leeward). These pulses were derived (Reference 1) using the specified overpressure and guidelines in Glasstone and Dolan, The Effects of Nuclear Weapons (Reference 2).

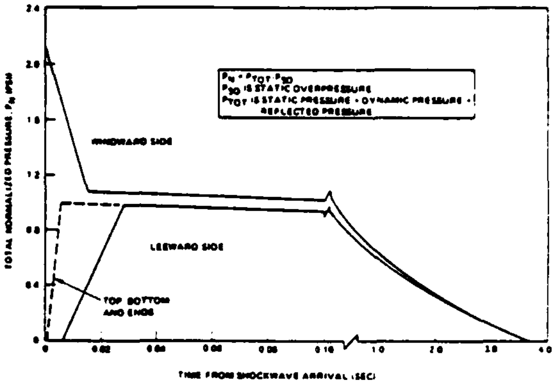


Figure 10. Nuclear Blast Overpressure Characteristics Trailer Side Oriented Toward Blast

All loads, and particularly the transient pressure pulses, force a complicated dynamic response of the whole tractor trailer. This response which significantly impacts the vehicle design includes rolling motion of the whole vehicle, of the trailer relative to the tractor, and of the shelters relative to the trailer. In addition, dynamic ringing of the trailer beams and all the shelter panels occurs. The main design drivers for the shelters and the trailer are loads resulting directly or indirectly from the nuclear pressure pulses. For the shelters, the design requirements are particularly severe because not only must the structure survive but the protection against the electromagnetic pulse (EMP) must be sustained as well.

The description of the complete design program is beyond the scope of this paper. The only portion of this work which is included here is the coordinated testing and analysis performed to complete the design and verify the shelter edge members which are critical for the EMP protection.

The shelters considered in this example are constructed of panels with aluminum facing sheets with Hexcel paper honeycomb core. The payload shelter is of most concern because it has the longest span. The dimensions of this shelter are 320 inches x 90 inches x 86 inches. The panels are joined at the edges by patented members shown in cross section in Figure 11. Also called out in Figure 11 are the different materials included in these joints. The variety of materials—including adhesives, fiberglass, aluminum, and paper, in addition to bolts, welds, and screws—illustrates the difficulty in performing a detailed analysis to predict the response of these edge members. Once the uncertainties are included for welds, bearing points at bolted joints, stiffness of all materials at temperature, and strength or yield limits of all materials, the validity of the results becomes questionable for either design decisions or design verification. Besides, an analysis which accurately included all these phenomena would take much more time than the design schedule allowed.

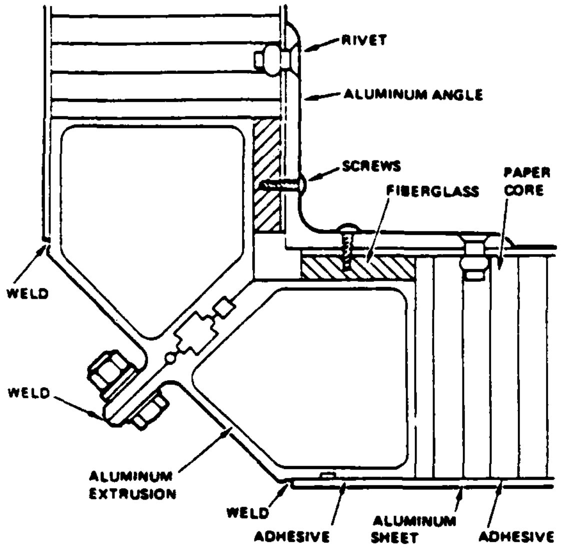


Figure 11. Cross Section of Edge Member Showing Materials

A traditional approach would have been to select the most conservative values and assumptions. However, the challenge of designing to an environment as severe as nuclear blast does not leave room for extreme conservatism in a mobile shelter. Therefore, the problem is to realistically predict structural response for design purposes and to verify structural integrity and preservation of EMP seal for the specified nuclear environments.

SHELTER BLAST RESPONSE ANALYSIS

The approach to achieving the needed design information was first to understand what the thermal and pressure pulses did to the shelters. Previous simulations of blast loading (Reference 3) had been performed on the whole tractor-trailer configuration. From this work, it was clear that the shelter loads occurred on a much shorter time scale than the overall vehicle response and therefore could be studied independently of the whole vehicle. This assumption allowed the use of simple finite element models of an isolated shelter. Since the objective was to find the design loads, much of the shelter detail was eliminated by selecting only the worst case. In this way, the shelter was assumed symmetric, and a half model was used. Figure 12 shows the simplified finite element model of the shelter created using these assumptions.

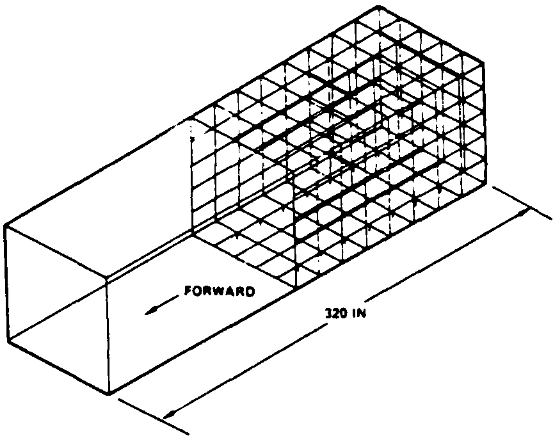


Figure 12. Payload Shelter Model Dimensions

Because the edge member characteristics do affect the shelter dynamic response, they had to be included in this simple model in order to correctly predict and understand the shelter panel responses to the pressure pulses. Previous test results (Reference 4) had shown that these edge members were more flexible than two panels would be if analytically connected directly. Figure 13 shows the previously measured nonlinear relationship between the moment exerted on an edge member and the angle of rotation. From this figure, edge rotational stiffness is 50,000 in-lb/in/rad and is linear to approximately 900 in-lb/in of moment. Based on this data, springs simulating this moment-rotation curve were used in the simple models. Nonlinearities were included when forces exceeded reasonable limits of linear behavoir.

The restraint conditions on the shelter finite element model were springs to ground with stiffnesses and locations matching those of the actual isolation mounts with which the shelter was mounted on the trailer. The basic assumption allowing an analysis of the shelter independent of the trailer is that the overall shelter rigid body motion occurs on a much longer time scale than the motions which strain the shelter panels and load the edge members. This assumption implies that the shelter tie-down springs are not important to this analysis, which was verified by comparing results with and without springs to ground and finding negligible differences.

The initial conditions for the shelter blast simulation were determined by the thermal conditions. Since the work described here was designed to determine the design loads on edge members, thermal conditions were selected which represented the worst edge member loads when combined with overpressure loads. The worst case thermal condition is extreme cold outside (-40°F) with interior heated (80°F). This condition, shown in

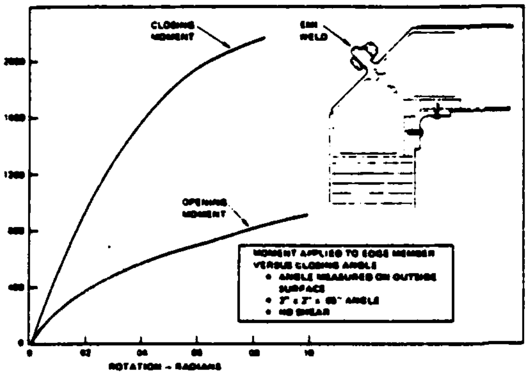


Figure 13. Data for Pure Moment vs. External Angle Measurement for 1" x 1" x .05" Angle

Figure 14, has a panel facing the blast heated from -40°F to +29°F and the roof heated to -3°F by the blast radiation. This set of temperatures causes the most severe edge member moments. The differential temperatures between the exterior and interior of the shelter wall causes the panels to deform inward as shown in Figure 15. This deflection adds to the deflections caused by the blast pressure pulse. The extremely hot day plus blast thermal radiation causes a bowing out of panels which counteracts the blast inward pressure and results in a lower overall edge member load.

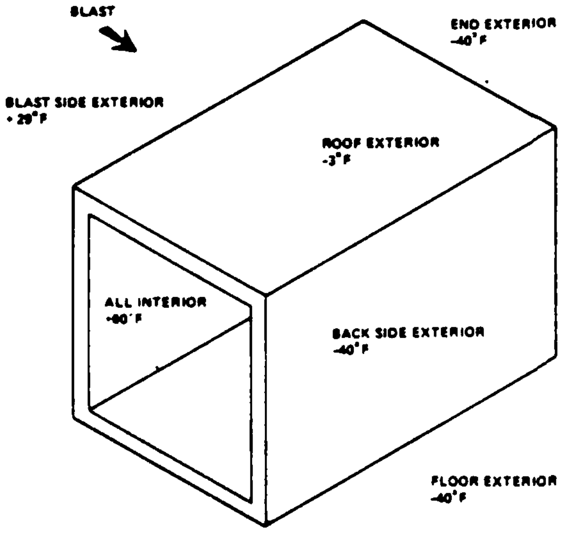


Figure 14. Payload Shelter Surface Temperatures for a Nuclear Blast on a Cold Day

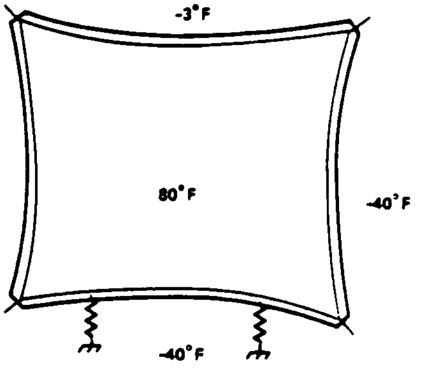


Figure 15. Cold Day Thermal loads and Resulting Deformations

The results from the thermal analysis included moments and shear forces carried by the edge member springs. The moment loads are shown in Figure 16 distributed along the edge of the shelter. Note that even these static thermal loads are slightly greater than the linear limits of the edge members. For this static thermal analysis, nonlinear springs were not used directly; however, the moments and deflections were adjusted to yield an equivalent strain energy moment deflection point on the actual nonlinear curve.

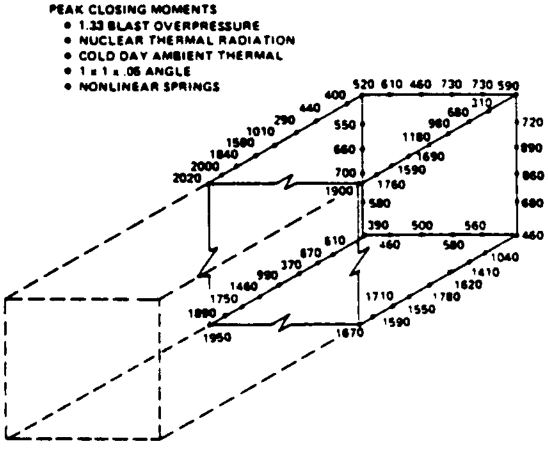


Figure 16. Edge Moments With 1 x 1 x .05 Angle $\frac{\text{in-lb}}{\text{in}}$ Due to Cold Day Ambient and Blast Thermal Loads

Using these thermal loads as initial conditions, the dynamic simulation was performed using the NASTRAN computer program and transient analysis to apply the pressure transients and predict the shelter responses. This dynamic simulation used the actual nonlinear spring moment rotation curve shown in Figure 17. Note that a closing rotation offset was used on these curves to account for thermal initial conditions.

The blast pressure transient (using 133% pressure to allow for 33% margin) produced panel resonances which are shown in Figure 18. This plot shows edge member moments as a function of time. Note that, even though the pressure pulse is a shock load which occurs in 10-20 milliseconds, the load due to nuclear blast which is delivered to the edge members by the panels is a harmonic oscillation at the panel natural frequency. This oscillatory load does not go below zero. Therefore, the edge moments are always closing moments. It is this oscillating load, or the peak values reached by this oscillating load, which must be simulated in the laboratory to study the shelter edge member structural capabilities. A direct shock pulse, as might be assumed for a nuclear blast load, is not appropriate. This result is important since it eliminates the need to be concerned about edge member resonance or dynamic amplification within the edge member itself. Peak edge moments are given in Figure 19, shown as they are distributed on the shelter. In addition to the moments, histories of shear loads at edge members were also obtained. Peak values for moments and shears delivered to edge members are 2020 in-lb/in moment and 240 lb/in shear for 133% blast pressure on a cold day.

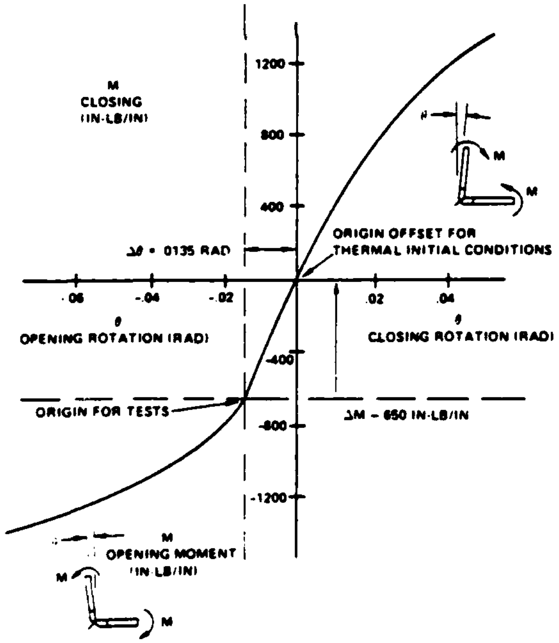


Figure 17. Nonlinear Moment-Deflection Curve for Corner With 1 x 1 x .05 Angle, Offset for Cold Day Thermal Initial Conditions

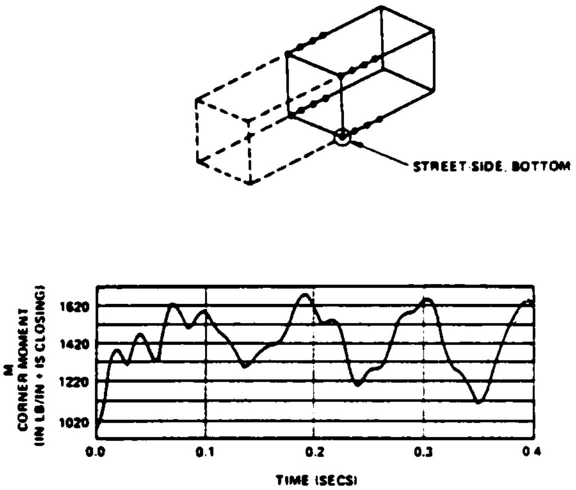


Figure 18. Corner Response Histories for a Curb-Side Nuclear Blast (1.33 on a Cold Day With a 1 x 1 x .05 Angle)

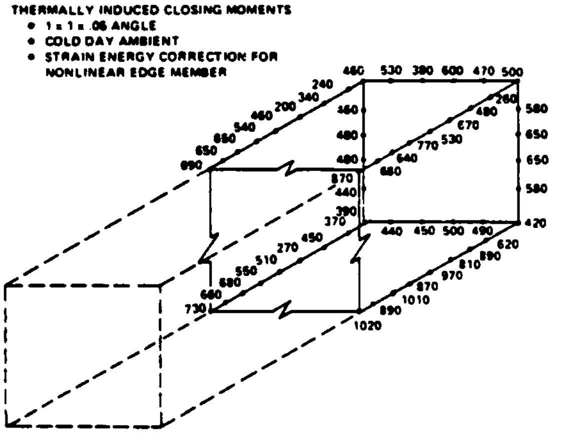


Figure 19. Peak Edge Moments $\frac{\text{in-lb}}{\text{in}}$ for Blast (1.33 and Nuclear Thermal for Cold Day Thermal Conditions with 1 x 1 x .05 Angle)

EDGE MEMBER TEST

Since the above loads can be easily simulated in the laboratory, the detailed edge member design evaluation was continued by test. Recall that the design requirements of the shelter edge member included the preservation of EMP seal. The edge member shown in Figure 11 has three welds: two connect the aluminum facing sheets to the aluminum extrusions of the edge, and the third is outside the bolted joint which joins the two extrusions. These welds provide a continuous metal shield which constitutes the EMP seal. Because the edge member stiffness curves in Figure 13 showed nonlinear moment-rotation curves, any loads beyond the linear limit caused concern for the structural integrity of edge members in general and for the welds in particular. Although edge member extrusion yielding could be tolerated, no yielding at or near a weld was considered acceptable since weld cracks and therefore breaks in the EMP shield could result. For design understanding, therefore, edge member tests were performed with the following objectives.

- understanding nonlinear behavoir of edge members
- determining shelter edge member capacity
- determining strains under worst case design loads
- identifying and understanding any extrusion yielding
- locating any potential weld damage under worst case loads.
- evaluating performance of edge member with design change consisting of different internal angle dimensions

The test article represented a 12-inch slice out of the center of the shelter containing one side wall and two edges with 36-inch portions of the roof and floor. Since shelter longitudinal forces were not significant, it was assumed that such a slice would accurately simulate the shelter edge member response. The original test set-up shown in Figure 20 was designed to independently control shear and moment loads and to allow a static or dynamic load application. For the results presented here the test was simplified from this original test plan to include only static loads. The justification of the assumption that edge member dynamics are not important is that the load delivered to the edge is not a shock pulse, but a relatively low frequency harmonic oscillation. Since the edge member will not have any modes of vibration as low as this frequency, the static loads equal to the peak dynamic loads can be used to predict all aspects of structural behavior except fatigue. Fatigue was not directly considered but, for the blast where only a few cycles occur, several applications of the static equivalent load are adequate to determine structural integrity of the joint.

As a further simplification of the test, the configuration shown in Figure 21 was used to emphasize moment loading, thus dropping the objective of simultaneously and independently controlling shear forces. The reason for this is that the shear forces are mainly carried in the core and the available samples did not have the correct core. This fact did not substantially hinder the test result because the moments are the most important for the design question being considered. Closing moments are carried by the facing sheets and by the bolted external connection. Since the welds at the facing sheets and at the bolted joint are of particular concern, the simplification of applying a moment and only the minimum shear is acceptable. The last important assumption used in the test is that the actual temperatures of the edge members will not severely alter material strengths. A review of the material properties and predicted temperatures justified this assumption. Therefore, the tests were conducted at room temperature.

The test configurations in Figures 20 and 21 contain an angle-measuring device that monitors relative rotation of the external surfaces with a highly repeatable accuracy of .001 radians, more than adequate for the

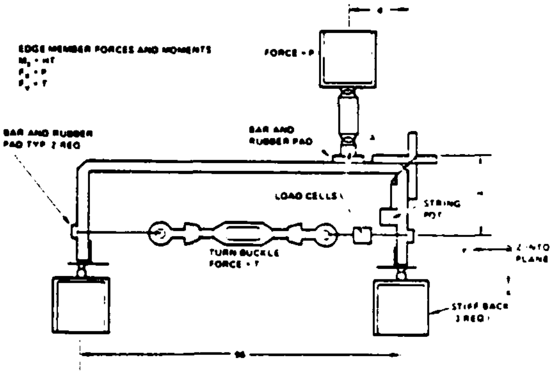


Figure 20. Initial SDRC Test Configuration

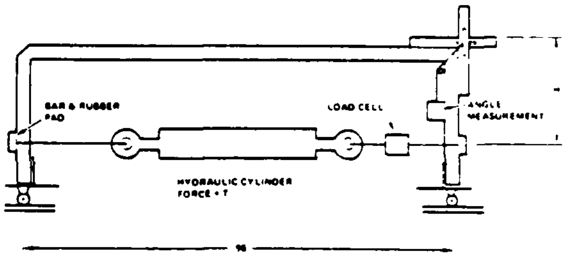


Figure 21. Test Configuration for Moment vs. Angular Deflection Measurements

expected angular deflections, which range in increments from .0045 to .18 radians. In order to monitor the detailed response of the edge members as loads were applied, five uniaxial strain gages were positioned on the extrusion as shown in Figure 22. These gage locations were selected to monitor strain close to the welds to detect any yielding (gages 3 and 6) and in the area of the extrusion where the most load was anticipated (4, 5, and 7). The purpose of using both gages 4 and 5 was to compare the strains at these two locations and, therefore, to detect any pulling apart of the extrusions between bolts.

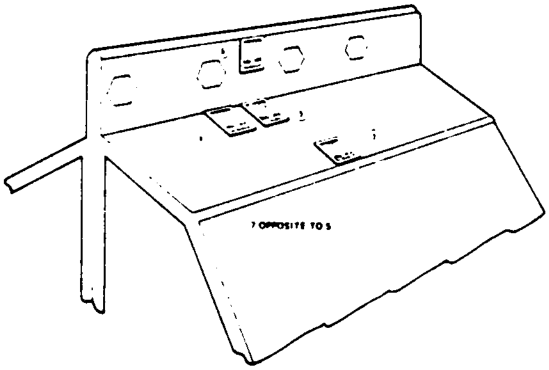


Figure 22. Strain Gage Locations

Two edge member design variations, shown together in Figure 23, were tested. The two designs differ only in the size of the interior angle used. The first tests, on the edge member with the smaller angle, showed no damage at the welds but exhibited core failures before reaching design loads. These core failures were apparently due to deformation near the interior angle of the edge member, which then initiated core damage and joint failure. Because of this response, the testing was shifted to the design with the larger internal angle.

The moment-versus-rotation results from testing the edge member with the larger angle are given in Figure 24. A great deal of information is represented by this curve. First, the moment angular deflection information is different than used to predict loads. This new moment deflection curve was therefore used to repeat the analysis and to obtain the new set of loads, which are 2400 in-lb/in moment and 240 lb/in shear. These values include 133% overpressure (33% margin) and cold day thermal loads. Therefore, the desired design point moment to achieve with this edge member is 2400 in-lb/in. This figure also shows the edge member's sustained loads significantly above the design load. Failure did not occur until 3540 in-lb/in, and then only after the third application of load above the design

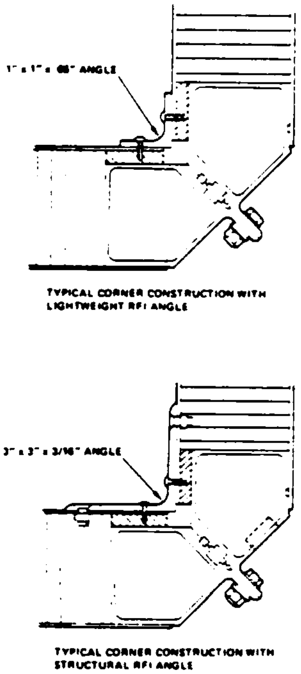


Figure 23. Two Edge Member Design Variations

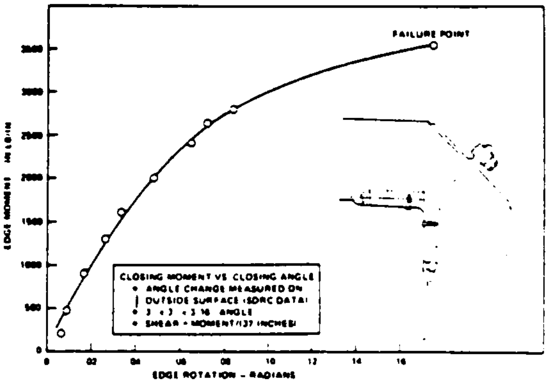


Figure 24. SDRC Moment vs. External Angle Measurement for Minimum Shear (V = M/37")

point. This edge member design could clearly sustain required blast pressure pulse and thermal radiation.

Additional design understanding was obtained from the strain histories shown in Table 1 and Figure 25. Strain gages 3 and 6 are adjacent to welds. These gages actually remain in compression! This is very significant since weld cracking or fatigue was of concern before testing began. Clearly, no load from closing moments is carried through any of the welds. Gages 5 and 7 do not deviate significantly from gage 4, indicating that the bolt spacing is adequate to provide a uniform load dis-tribution. Gages 4, 5 and 7 do show strain beyond the elastic limit. In addition, yielding in the ductile aluminum, away from welds, is quite acceptable. Figure 26 summarizes these results on a cross section of the edge member. Although no strain measurements were made on the internal angle, independent measurements by Brunswick, Marion showed linear moment rotation response to 2400 in-lb/in, indicating no yielding in this region.

Further verification of weld integrity after repeated loading beyond the design point was obtained by dye penetration tests of the welds. These tests demonstrated that no cracks existed in the welds.

CONCLUSIONS

The blast simulation analysis provided an opportunity to perform relatively simple laboratory tests which gave a great deal more insight into shelter edge member design than ever could have been obtained by even the most elaborate and lengthy analysis. In particular, the design configuration with a smaller interior angle failed—not because of extrusion, bolt, or weld failures, but apparently from a subtle interaction between the extrusion deformation on the inside of the joint and the core material. This phenomenon became clear experimentally but would not likely have been predicted by an analysis.

The larger internal angle improved the load path between the facing sheets of the two panels joined by the edge member and made the joint behave more nearly as designed. Moments were then carried in the facing sheets independent of the core. Testing this configuration to a very high moment loads demonstrated that a shelter closing moment could not damage EMP welds. Strain gages and dye penetration tests verified that even loads so high that the edge member was severly deformed did not begin to load welds. The verification provided by this test of the structural and EMP seal integrity of this final design configuration was much more conclusive than could be obtained with analysis alone. And since this testing effort spanned only two weeks and the combined testing and analysis effort required approximately one month, the example presented here represents a practical design approach which can fit into a shelter design schedule.

Moment	Gage No.	3	4	5	6	7
225 in-lb/in		250(C)	550(T)	500(T)	75(C)	00(T)
450 in-lb/in		500(C)	1250(T)	1200(T)	200(C)	1250(T)
900 in-lb/in		500(C)	2750(T)	2500(T)	175(C)	2575(T)
1100 in-lb/in		500(C)	3450(T)	3150(T)	250(C)	3250(T)
1300 in-lb/in		400(C)	4250*(T)	3875(T)	250(T)	3875(T)
1600 in-lb/in		300(C)	6000*(T)	5200*(T)	300(C)	5325*(T)
2000 in-lb/in		250(C)	9700*(T)	8350*(T)	425(C)	8850*(T)
2400 in-lb/in		250(C)	16200*(T)	14200*(T)	600(C)	15000*(T)
3540 in/lb/in (Failure)		0	(Gage Failure)	(Gage Failure)	1950(C)	(Gage Failure)

Test Condition: Load applied 37 inches from edge member

Maximum load: 1150 pounds

Table 1. Sample No. 3, Edge "A" Micro Strain Levels

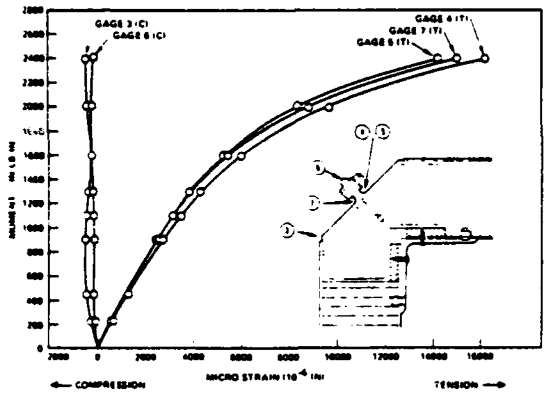


Figure 25. Moment vs. Micro Strain SDRC Data Specimen with 3" x 3" x 3/16" Angle

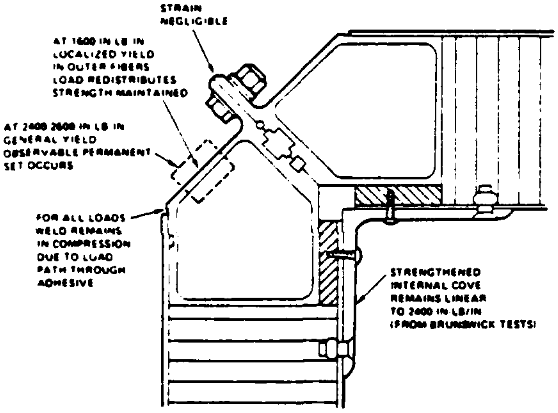


Figure 26. Strain Gage Conclusions

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BIOGRAPHIES

Mr. Paul L. Smet is a Senior Program Manager for Brunswick Corporation, Defense Division, Costa Mesa, California. He is engaged in New Business Development of a product line for survivable, mobile, electronic, ground systems. Following an extended period of active military service as an Army Officer, Mr. Smet has per-formed over the past twenty years in roles of Systems Engineering, Marketing, Engineer Management, Manufacturing Management and Pr n Management. He has been involved in the desig development, test and production of missile sys , marine systems, photo optical systems, simula systems and transportation systems as well as commercial construction products. Mr. Smet h Bachelors Degree in Physical Science and a Ma Degree in Management from the University of S California.

Dr. Baker directs technical aspects of analytical, testing, design and software activities within the Western Region of SDRC. Since joining SDRC in 1977, she has obtained the following direct project experience: buckling and elastic-plastic analysis of cryogenic transport arm; strain and fatigue predictions due to acoustic pressure and random vibrations in space shuttle components; static and dynamic analysis of impeller and fans; system simulation of fan/foundation installations; ride quality predictions using system simulation of highway tractor/trailers; heat transfer and thermal stress analysis for structural design of a ramjet; seismic qualification of nuclear power plant auxiliary equipment; finite element analysis of com-ponents made of composite materials; dynamic simulation of mobile communication systems; and shock and vibra-tion isolation of electronic equipment.

Prior to joining SDRC, Dr. Baker worked in the continuum mechanics area doing numerous modeling of geographic materials and explosive source function calculations at System Science and Software (S^3). Until 1975, Dr. Baker was employed in the Advanced Technology Department of Rohr Industries, Inc., where her main efforts were in structural dynamics and vibration and stability analysis of transportation vehicles and turbo-machinery components. In 1972, Dr. Baker was a staff member in the Systems Programming Department of IBM Research Center.

Dr. Baker received her Ph.D. and M.S. degrees in Applied Mechanics from California Institute of Technology for experimental and theoretical studies of the fluid mechanics of blood. Her B.S. degree from University of Wisconsin was in Engineering Mechanics.

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Design Automation for Integrated Circuits

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Summary. With the ever-increasing complexity of integrated circuits, manual design methods have become intolerably slow and error-prone. The use of computers to automate some or all of the design process is necessary to minimize both design time and error incidence. In this article are discussed the design and fabrication of integrated circuits, selected techniques of design automation, and the problems associated with such automation.

The complexity of integrated circuits is constantly increasing and the physical size of their individual components decreasing; for commercially available integrated circuits the complexity doubles every year (*1–3*). Like any rapidly expanding field, microelectronics is experiencing "growing pains" because some of its areas are not keeping pace with the rest of the field.

In the progression from idea to integrated circuit, the first phase, design, encompasses all tasks up to manufacturing. The second phase, fabrication, deals with the physical creation of the integrated circuit. Of the two phases, design is by far the more expensive and time-consuming. For example, to design a microprocessor chip containing 60,000 to 70,000 transistors can require dozens of man-years and millions of dollars. But, after the initial setup of the manufacturing process, fabrication of such a chip can take just weeks and cost thousands of dollars. Progress in integrated circuit development may be slowed or halted by the time- and cost-intensive design process unless help is forthcoming (*1–5*). For this help, designers are turning more and more to computers.

Computer-aided design (CAD) has been in use almost since the inception of integrated circuits (*3*). In CAD, computers analyze circuit and system behavior and designers use the results for guidance in correcting or enhancing their designs. Thus the role of the computer in CAD is one of an assistant to the designer, who carries out the actual design tasks by making decisions based on the CAD results.

In design automation, not only the analytical but also many of the synthetic design tasks are performed by computers. Computers carry out a given design task by performing a series of iterations and are guided by the analytical results of each iteration to improve the design until the desired specifications are met. Thus in design automation using a form of artificial intelligence, the computer decides what actions to take and carries out the design tasks with little or no human intervention.

Design automation is in a relatively primitive state compared to CAD, and represents one of the last frontiers in cutting design time, cost, and errors. Several reviews (*3, 6–8*) of the status of design automation are directed to specialists in the field; this article will provide an overview of design automation for scientists and technologists who are not involved in integrated circuit design.

A brief introduction to integrated circuits and their fabrication may be helpful in demonstrating the necessity for streamlining the design process. For simplicity, throughout this article we confine our discussions to digital circuits.

Integrated Circuits and Their Fabrication

An integrated circuit is a circuit contained on (or in) a continuous piece of solid material (usually silicon) called a die or chip. Components and wiring are fabricated simultaneously onto an integrated circuit. (In contrast, discrete steps are required for placing components and wiring onto a printed circuit board.) The circuit itself is usually specified by a logic diagram, which is an interconnection of logic gates.

Digital (binary) logic is composed of logic circuits. A logic circuit is realized with logic gates, each of which has inputs and outputs and performs a logical operation. In such an operation a set of variables having the complementary values 0 and 1 are treated as "false" and "true," respectively; translated to electronics, a 0 is usually implemented with a low voltage (around 0) and a 1 is usually implemented with a relatively high voltage (around 5 volts). Addition, subtraction, storing, counting, controlling, and many other functions are achieved by specific interconnections among logic gates.

Figure 1 gives names, symbols, and truth tables for some simple logic gates and their corresponding operations. A truth table shows the inputs on the left of a vertical line and the outputs on the right. Thus the truth table for the AND gate shows that the output, Y, is 1 only if both inputs A and B are 1; the output is 0 for any other combination of inputs.

The binary logic of digital circuits may be implemented by transistors, which act as switches. By connecting transistors in different ways, any desired electronic circuit function can be realized. Integrated circuits, commonly 0.25 to 1 square

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centimeter in area and about 1 millimeter thick, owe their compactness to this basic circuit element. Today, an integrated circuit may contain from ten to hundreds of thousands of transistors, each measuring about 150 square micrometers.

The complexity of an integrated circuit is described by the number of transistors it contains. In small-scale integration (SSI) a chip contains up to 100 transistors. Subsequent levels of complexity include medium-scale integration (MSI), with up to 1000 transistors; large-scale integration (LSI), with up to 10,000; and very large scale integration (VLSI), with more than 10,000 transistors. An integrated circuit is three-dimensional and can consist of up to 12 layers, each layer being composed of a semiconductor, a conductor, or an insulator.

The semiconductor is usually silicon to which small, controlled amounts of an impurity (called a dopant) have been introduced to provide carriers for current. Semiconductors are of two types. In an n-doped semiconductor, a group V element (for example, phosphorus) is the dopant and provides electrons as current carriers. A p-doped semiconductor contains a group III element (for example, boron), which provides positive, electron-deficient regions called holes as current carriers. Larger amounts of doping produce higher conductivities; the substrate, or supporting material for the circuit, is usually lightly doped with either type of semiconductor. Electrodes of transistors are made of semiconductor material, but usually contain more dopant than the substrate.

The conductor may be a metal (for example, aluminum) or polysilicon, a polycrystalline form of silicon that has been heavily doped. Strips of conductors form electrical connections within and between circuit elements. The insulator is usually silicon dioxide and is used to separate conducting regions where no connections are desired.

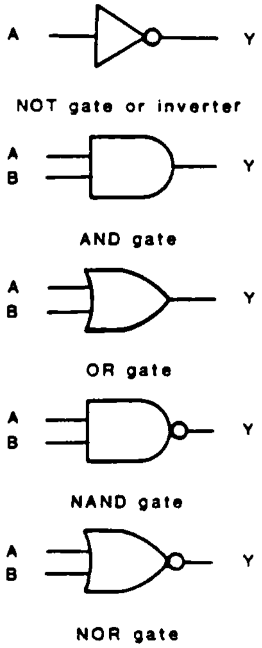
Integrated circuits contain several layers of various combinations of differently doped material, interconnections, and silicon dioxide. In the fabrication of integrated circuits, the layers are added one at a time. A template called a mask determines the pattern for each layer; 12 masks would be required to make an integrated circuit with 12 layers. Fabrication takes place by various multistep combinations of oxidation, mask protection, etching, diffusion or ion implantation, and vapor deposition. The whole cycle can take 4 weeks to several months on a commercial production line.

At various stages the chips are checked for possible defects, and thorough functional testing is done after their completion. Because of the integral nature of integrated circuits, a defective chip cannot be repaired; it must be discarded. Defects have two origins: manufacturing and design.

Manufacturing defects are random and will affect a certain percentage of chips on a statistical basis. The yield, the number of good chips divided by the total, decreases as the active chip area (the area occupied by components and wiring) increases. For a chip 0.2 inch on a side, doubling the active chip area causes a nearly sixfold decrease in yield (9).

A design defect is traceable to one or more of the masks and will, of course, affect all chips in that fabrication series. Some design defects are detectable early in the fabrication process; if a design defect is found, the process can be halted and the defect corrected. In some cases a second iteration of design and fabrication is needed to correct design defects in the first-pass chip.

Two economic reasons dictate that redesign and refabrication be held to a minimum. First, design and production of an integrated circuit are extremely expensive. Second, delay in getting the chip to the marketplace results in lost sales and loss of a potential share of the market. To minimize the necessity for redesign and refabrication, the design process must generate a valid set of masks.



A	Y
0	1
1	0

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

Fig. 1. Names, symbols, and truth tables for some simple logic gates and their corresponding logical operations.

General Design Procedure

The mask set that begins the fabrication process is the goal of the design process. To design an integrated circuit means to transform a functional specification into masks that are ready for fabrication.

Integrated circuit design can be partitioned into two major tasks: logic specification, in which the goal is a logic diagram that accurately represents the desired electronic function, and physical specification, in which the goal is an exact description of the physical locations of all circuit elements and their interconnections on the chip. The design tasks are carried out by continuously iterating between synthesis, the creative act of constructing a given part of a design, and verification, determining whether or not the design will perform according to specifications. That is, a designer creates part of a design, verifies it, uses the results of the verification to modify or correct (recreate) the design, reverifies it, and so on until, much later, the entire design is completely synthesized and verified.

Often a hierarchical approach is taken in which a total design is decomposed into several simpler, functional modules, each of which may be broken into submodules, and so on until the submodules are simple enough to implement. (Hierarchy has the effect of reducing a large, unsolvable problem to several smaller, solvable problems.) Figure 2 illustrates hierarchical levels of an integrated circuit. At the highest level, the circuit itself can be partitioned into functional modules. At lower levels, each functional module can be decomposed into logic gates which, in turn, are represented by interconnections of transistors. At the lowest level, the transistors and their interconnections are described by physical structures.

At each level, each submodule and its interconnections with other submodules must be specified. Both synthesis and verification are performed at all levels, and verification is always needed when going from one level to another in either direction in the hierarchy.

In the era of SSI, a circuit could be verified by physically constructing it from discrete circuit elements on a circuit board and submitting it to exhaustive electronic testing. A major problem was that the discrete circuit elements often introduced extraneous electrical effects not reflective of the integrated circuit. With increased levels of integration the circuit board approach soon became impractical, and it is in this verification category that much of the existing CAD tools have been created. In particular, simulation, in which the operation and performance of a circuit or system is predicted by a computer program, is now widely used by designers.

Figure 3 presents an overview of the design process, fabrication, and testing. Steps *(a)* through *(h)* constitute the tasks necessary for logic specification: normally many iterations are needed before a successful first-pass specification is obtained. At *(a)* a functional conception of the desired system is generated (synthesis). As a first approach to verification, a functional or system-level simulator *(b)* can check for satisfactory communication among functional blocks in a total system. Next, at *(c)* each block is expanded into smaller modules that go through a complex cycle *(r)* of synthesis and verification and can be added to a library *(d)* for reuse in future designs. A part of the designer's input is a net list, which specifies the modules and how they are connected. These modules can be retrieved from the library *(d)* or newly constructed if they do not already exist. At *(e)* a logic simulator can check the design for correct function (verification); if the verification fails, then the designer modifies the specification [back to *(c)* or *(a)*]. Next, a timing simulator *(f)* can determine whether the performance speed requirements of the circuit will be satisfied and can detect the critical paths (the paths whose speed limits the performance speed of the chip). Timing simulators also indicate whether expected delays of the circuit elements will cause undesirable circuit behavior, such as racing (an error that occurs when a device receives conflicting inputs at nearly the same time). The design may again be modified until acceptable results are obtained.

An activity usually performed in parallel with the design is the creation of a set of test vectors *(g)* that will be used to test the chip after fabrication. Test vectors are sets of values that, when applied to the inputs of an integrated circuit, generate outputs whose values are known for a properly working circuit. An ideal set of test vectors thoroughly exercises all parts of the chip and detects all faulty circuit elements. At *(e)* an initial set of test vectors was created to be used for the logic simulation; usually the results of the simulation indicate changes to be made in the design and in the test vectors. The modified set of test vectors is used next in the timing simulation, and perhaps is modified again. In practice, a set of test vectors covering all possible faults may require too much testing time; a compromise subset of test vectors is often selected, and a fault simulator *(h)* can determine whether the subset is good enough to test the finished device. Often, further design modifications may be needed if fault simulation indicates that some possible key faults cannot be detected because they are buried too deeply in the design.

At *(i)* physical specification begins with layout, which determines the exact locations of the transistors on the chip and specifies a wiring pattern that will interconnect them. This phase of the design involves translating every element and its interconnections into a physical description and assigning it a location. [The average number of transistors that can be manually laid out per person per day lies somewhere between 3 and 40, depending on the regularity of the configuration *(10)*.] Next, more verifications *(j)* must be performed to make sure that design rules (rules pertaining to width, length, and spacing imposed on the geometrical features of an integrated circuit by the process technology) and electrical rules (for example, each element must be connected and there must be no shorts between power and ground) are obeyed. Software tools currently available for these tasks are the design rule checker (DRC) and the electrical rule checker (ERC). If the design violates any rules the layout must be modified until all rules are obeyed.

When a satisfactory layout has been obtained, yet another verification is

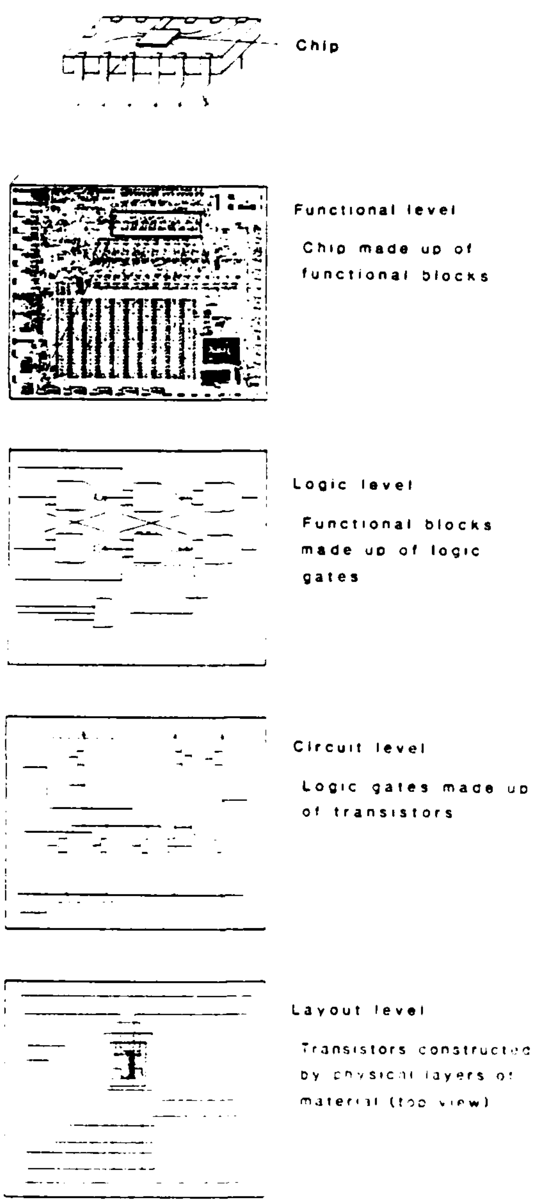


Fig. 2. Hierarchical decomposition of an integrated circuit into functional, logic, transistor, and physical levels.

needed. Up to this point, timing simulations had been based on approximate delays between circuit elements, because their exact locations were not yet known. Exact delays depend on the length and composition of the conductive paths: a signal takes longer to attain its final value through a long polysilicon path than through a short metal one. Now that all locations and path lengths are known exactly, this information is used to extract exact delays (*k*), which are fed back into the timing simulator (*l*). If any timing errors or unacceptable delays are found, the layout or the design must again be modified and the DRC and ERC again used.

When a satisfactory layout is obtained, a program decomposes all geometrical data into rectangles and generates a pattern generator tape (*m*). The pattern generator tape contains all topological information about the layout and is used in a mask-making machine to generate the mask set for fabrication. In the test vector loop a program generates a test vector tape (*n*) that will program the tester.

Finally, the chip is fabricated (*o*), tested (*p*), and packaged (*q*). Figure 3 presents a simplified view of the design process: in actuality many iterations are needed between synthesis and verification.

On the right of the flow chart the characterization of the small modules (*r*) follows steps similar to those in the left part of the flow chart. First the module is represented by a logic diagram and verified with timing simulation. The next step in the hierarchy is the circuit diagram, followed by circuit simulation (not used in the left part of the flow chart). A circuit simulator fine-tunes the design of the module by simulating the behavior of the individual transistors and their interconnections. Next, custom layout manually defines all physical devices. After design rule checking, circuit extraction, and resimulation the module has been completely characterized and is ready to be used in the circuit or added to the library.

Total design automation, in which the desired circuit behavior is specified at one end and a set of masks comes out the other is, as yet, seldom realized. However, computer programs that automate portions of the design process have been and are being written. Because the layout phase is currently the most time-consuming and error-prone stage of integrated circuit design and because relatively simple decision-making algorithms are needed here, the first efforts in design automation have focused on this phase. Existing design automation programs use various structured approaches to the method of design (called the "design methodology").

In a "full-custom" chip, transistors are manually placed one at a time, requiring the full fabrication process for each design (other methodologies to be discussed allow some degree of prefabrication). Although hierarchical design can reduce time and cost to some extent, the full-custom chip has the longest turnaround time and highest cost of any methodology. Still, in some applications this is the methodology of choice. Manual placement by human beings is the best (albeit the slowest) way to achieve the most efficient packing of transistors and, therefore, the smallest size (smaller size results in lower manufacturing cost and higher yields). If a very large number of identical chips are to be fabricated, the design time and cost of full-custom design can be amortized over all chips sold. Also, applications in which high performance (speed and power) is critical may require the full-custom design process.

Established Design Automation Methodologies

At present, only two methodologies enjoy widespread use: standard cells and gate arrays. In the standard cell (or polycell) approach the designer, instead of constructing a circuit "from scratch" out of transistors, uses a library of cells that represent predefined logic functions, usually at the logic gate level. These cells have been constructed from individual transistors, and the cell dimensions, performance, and electrical characteristics have been optimized and recorded.

To use the standard cell approach, the designer first constructs the design by using logic functions represented in the standard cell library. The next step is to give the computer information telling what logic functions are in the design and how they are connected. Design descriptions are entered into a computer system by one of two methods:

1) *Graphics schematic entry*. The designer "draws" the schematic onto a monitor with a set of graphic symbols that represent logic functions. A computer program translates the graphic symbols into a machine-usable description of the circuit. Of the two methods, this one is easier for the designer to use but requires more hardware and software.

2) *Hardware description language*. The designer translates the design into a hardware description language, generating a written description similar to a computer program. This description is in turn translated into a machine-usable circuit description (as in graphics schematic entry). The method requires less hardware and software than graphics schematic entry, but the designer must learn a specialized language. The possibility of creating hard-to-detect discrepancies between the schematic and its description is a major drawback of the method. Also, the danger of introducing errors during design revision has doubled because changes in the design must be made both to the schematic and to the language description.

The circuit is then verified by simulation, using the known, predefined characteristics of the cells in the cell library. The next task is placement, in which cells are laid out in rows with spaces reserved between the rows for wiring channels. Connection points for input and output, called bonding pads, are placed around the periphery of the chip. Cells having many connections in common are placed close to each other, and those that connect to bonding pads are placed near the edge of the chip. In some design automation systems, placement is done automatically by the software; in others, the designer specifies the placement; in still others, software placement is done initially with designer intervention if difficulties or special cases arise.

Most successful placement algorithms are heuristic and use directed forces, vectors representing the direction and distance between interconnected blocks. In most placement algorithms the criteria for success are minimization and uniformization of the crossing count (the number of wires crossing each terminal position in a cell row) and minimization of the combined wire length of all connections (*11*).

Two major groups of placement algorithms are constructive placement and iterative improvement of placement. The constructive placement algorithms include the epitaxial growth algorithm, in which manual placement of a few modules is used to start the process. The algorithm finds the next unplaced module with the maximum number of connections to the placed modules. Then it moves the module into the best available position, finds the next unplaced module with the maximum number of connections, and so on, until all the modules are placed. The best position for a module is found by trying all available positions and minimizing the length of the connections or by placing the module into a zero-force position. [For every module there is an equilibrium position where the total pull from all other modules is zero. A zero pull is equivalent to the minimum length of the wire for all connected signals (*11*)].

The placement improvement group makes small local changes, such as pairwise exchange of modules, in an attempt to improve placement. After one exchange the crossing count or wire length is recalculated. If the exchange improves the placement it is retained. Some schemes accept some interchanges that worsen the placement in order to improve routability; others accept interactive placement by users.

Following placement comes routing, in which wiring paths among the cells are defined. Routing is done by software that attempts to minimize wire length or follows other optimization criteria. In standard cells the width of each wiring channel is varied to accommodate the wires it contains at the most populated point. In some software systems algorithms are used to iterate between placement and routing to optimize the total wire length and critical path length.

The channel router has been the main routing algorithm for standard cells for many years, and is designed for routing where the points to be connected are in parallel rows. Routes are wired by using horizontal tracks on one layer and vertical tracks on another layer. The variable channel width guarantees that all connections can be made.

In Fig. 4 the layout of a typical standard cell is compared with that of another methodology, the gate array. In the standard cell the width of the wiring channel is variable; wiring is clustered toward the center of the wiring channels, with some wasted space toward the outer ends.

Advantages of the standard cell methodology are:

1) *Rapid design turnaround time.* If everything is done with software, layout of an LSI circuit of around 10,000 transistors may be accomplished in a few months instead of a year or more. Logic specification, layout, optimization, and characterization with regard to delays, drive capability, and loading are all established when the cells are added to the cell library, and these operations do not need to be repeated at the cell level for each design.

2) *Flexibility.* Designers can handle special functions by creating new cells, characterizing them, and adding them to the library. And this flexibility is self-propagating: the larger the library, the greater the flexibility for future designs.

Disadvantages of standard cells are:

1) *Wasted chip area.* The area occupied by the wiring channels can easily exceed 50 percent of the total chip area. Because channel width is variable, the width of a wiring channel must accommodate its greatest requirements. Some designs may turn out to be impossible for the computer to place and route within the area restrictions of the chip. If a great deal of designer intervention is needed, the advantages of automation are lost.

2) *No savings in fabrication time.* Each chip must go through the complete fabrication process.

Fabrication time can be saved by using a programmable array, which contains repeated cells independent of any particular circuit implementation and which can be customized by modifying specific mask layers. Programmable arrays are partially prefabricated chips; that is, large volumes of identical arrays are manufactured and stockpiled. Then, when a designer wishes to implement an integrated circuit, the interconnections for the particular circuit are specified in the final layer or two.

The most common programmable array is the gate array (also called a master-slice or uncommitted logic array), a

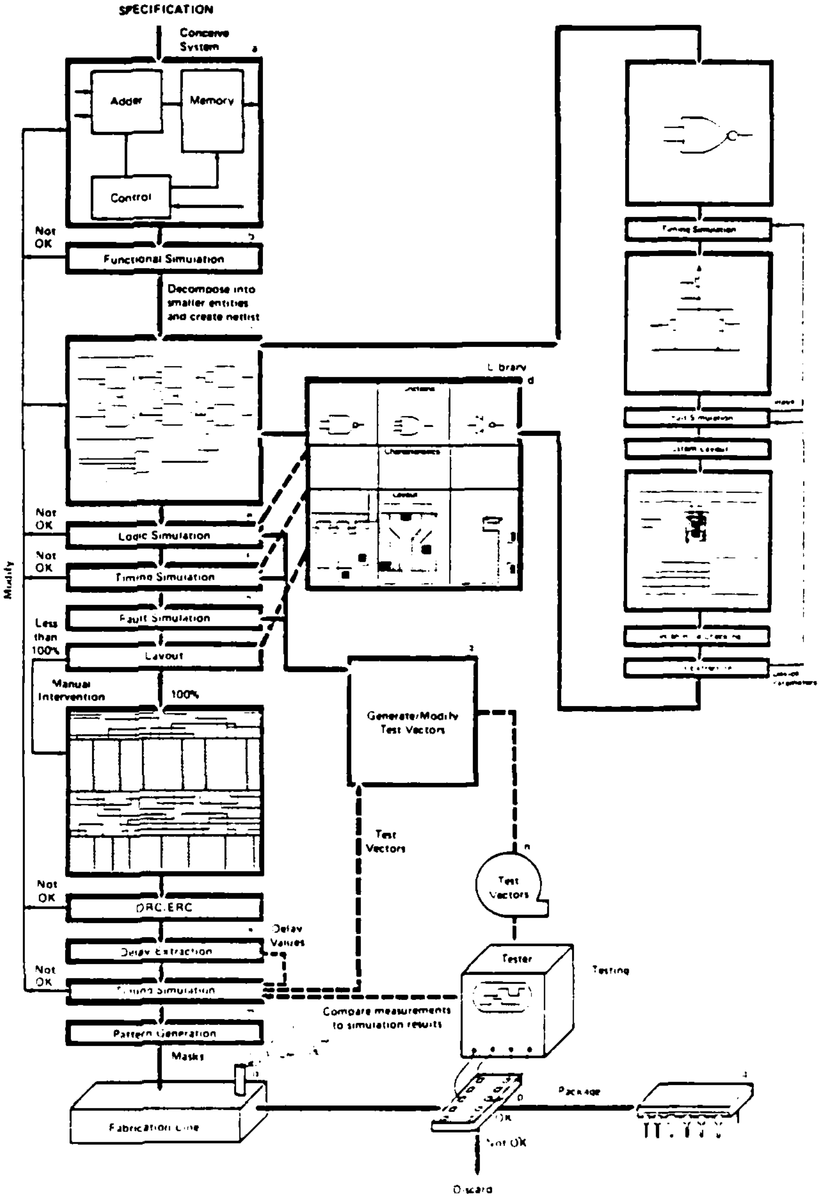


Fig. 3 Design and fabrication of an integrated circuit. A procedural flow is followed that iterates between synthesis and verification. Solid lines mark the flow of the design itself; the dashed lines indicate the transfer of information.

two-dimensional matrix of identical cells, each containing a fixed number (4 to 20) of uncommitted (unconnected) transistors separated by wiring channels (12). A circuit is constructed by specifying the interconnections among the transistors within and between cells on the final contact and metallization layers.

From a user standpoint, gate arrays are like standard cells. Gate array designers construct their circuits by using a cell library (sometimes called a macro library) of predefined logic elements, and use graphics schematic entry or a design language to enter the schematic into the computer system. The task of placement is similar to that with standard cells.

Routing of a gate array may be started with a channel router and then "cleaned up" with a Lee or line search router. The Lee (grid expansion) router works on a grid and is based on expanding a wave from one point to another. At each step, grids on a diamond-shaped wave front are expanded one step further, avoiding obstacles and previously used grid points. Each grid point through which the wave passes is marked with a code that stores the direction to the source of the expansion. Once the target point has been reached codes are followed in reverse order to yield the shortest path.

Table 1. Comparison of design methodologies.

Characteristic	Gate array	Standard cells	Full custom
Design time	Short	Short	Long
Fabrication time	Short	Long	Long
Chip area	Large	Intermediate	Small
Cost	Low	Intermediate	High
Versatility	Low	Intermediate	High
Turnaround time for minor redesign	Short	Intermediate	Long

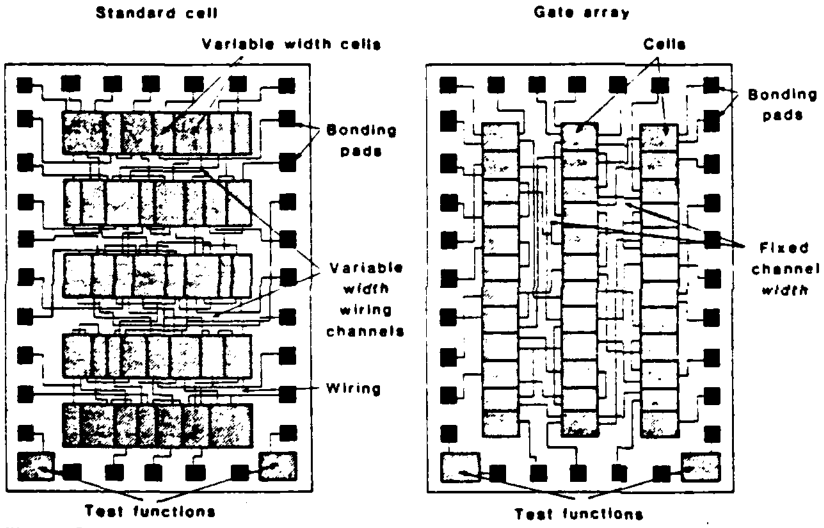


Fig. 4. Comparison of standard cell and gate array methodologies. The standard cell has variable cell and wiring channel width, whereas both are fixed in the gate array.

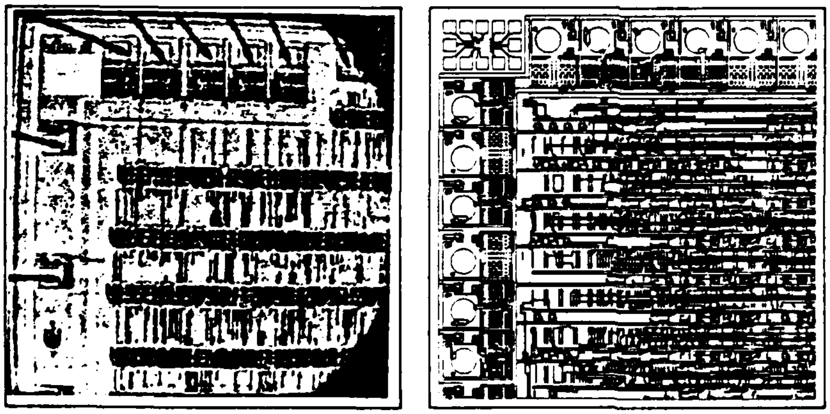


Fig. 5. Completed integrated circuits. On the left is a photomicrograph of a portion of a circuit implemented in standard cell technology. On the right is a computer-generated graphics representation of a routed gate array circuit.

The line search algorithm is gridless and finds a connection through a maze of obstructions. It runs vertical and horizontal expansion lines from the two points to be connected. If any line encounters an obstacle, the router takes a perpendicular path until a line parallel to the original one can pass by the obstacle. Two expanding nets are thus created and the process is terminated when expansion lines from both nets intersect, creating the desired connection. Although this algorithm does not yield the shortest path, it requires substantially less computer memory and runs faster than the Lee algorithm in most cases.

Because of the restrictive wiring capacity of gate arrays, either of the two routers may not always achieve 100 percent routing, and user intervention may be necessary.

One major difference between standard cells and gate arrays is in the construction of the logic elements. Whereas a standard cell logic element is custom-built from individual transistors, a gate array logic element is defined by connecting transistors already contained in array cells. A second major difference has already been mentioned: whereas the width of the routing channels is variable in the standard cell, the array cell's routing channels have a fixed (but not necessarily uniform) width (Fig. 4).

Advantages of the gate array methodology are:

1) *Rapid design turnaround time*. The savings in design time are the same as in the standard cell methodology.

2) *Low cost*. By prefabricating the chips the cost advantages of mass production can be realized for low-volume production.

3) *Short fabrication time*. Since only the final metallization layers need to be made, fabrication time is drastically cut.

Disadvantages of gate arrays are:

1) *Wasted chip area*. Gate arrays typically waste more area than standard cells do because the individual positions of the transistors cannot be optimized; in fact, some transistors may go unused. Also, 10 to 30 percent of the gate array cells may be wasted because wiring channels may run out of space if more than 70 to 90 percent of the available cells are occupied.

2) *Decreased flexibility*. Fewer circuit

functions can be realized than in standard cell or full custom methodologies (for example, analog functions are difficult to implement optimally on a gate array).

3) *Possible wiring restrictions*. Because of the fixed wiring channel width, a particular design may contain too many logic elements to be routable. In that case the recourses are (i) use of a larger array if one is available, (ii) designer intervention and hand-routing of difficult interconnections, (iii) partitioning of the device onto more than one chip, or (iv) reverting to the standard cell methodology.

Figure 5 shows parts of a wired standard cell design and of a gate array. The photograph on the left is of an actual standard cell, while the photograph on the right is of a plot of a gate array obtained with an interactive graphics system. Notice the differences in wiring channel width between the two methodologies and the amount of space devoted to interconnections and bonding pads.

The difficulties of placement and wiring may limit both standard cells and gate arrays to the LSI level of circuit complexity (*3*). On the other hand, the difficulties encountered in the layout of VLSI chips may require that automation be used for large designs. At the present time both the standard cell and gate array approaches provide designers with quicker, less expensive alternatives to full-custom chips. Also, designers in either standard cell or gate array methodology need not be "silicon sophisticates." Table 1 compares the gate array, standard cell, and full-custom design methodologies.

Programmable Logic Arrays

Another programmable array that is established but not as universally applicable as gate arrays is the programmable logic array (PLA). It consists of two rectangular arrays of gates called AND and OR planes. The gates in both planes can be customized by connections in the final metallization layers.

Any desired logic function may be realized by combinations of AND and OR functions and their complements. In a PLA, ANDing is done first by entering the inputs into the AND plane along parallel connections. The results of the AND operations are then entered into the OR plane perpendicularly long parallel connections. The results of the OR operation are output on parallel connections and can be fed back into the AND plane for another set of operations if needed to perform the desired function. Area reduction of the PLA is achieved by logic minimization, folding (permutation and splitting of rows and columns), and partitioning (*13*).

Programmable logic arrays represent almost completely automated design—in areas where they are applicable. To use a PLA the user specifies the logic functions to be implemented. After being processed by logic simplification software, logic equations are used to program the PLA for the desired function. The regular structure of PLA's makes it possible to go directly from the simplified equations to the mask set without placement, routing, or any other intermediate steps. Often the design cycle is shortened further by mapping into a prefabricated PLA structure, thus requiring a single masking step. PLA's, however, have limited applicability; they are poor for many logic functions, especially where timing is critical. PLA's find the most use as specialized parts of other chips (for example, control logic of microprocessors). In addition, field-programmable logic arrays are available that can be customized electrically by the user.

In addition to the global design methodologies already mentioned, several shortcuts are being developed to optimize various steps in the design process.

Design Shortcuts

Symbolic layout. Designers describe transistors and their interconnections and locations in a particular circuit by using predefined symbols on a cathode-ray tube terminal. Once stored, a symbolic layout may be called up and automatically implemented in a particular technology; thus the same design may be adapted to changes within a technology without changing the layout description. Thus, when an existing technology is scaled down (dimensions are reduced by some factor), only a few key design rules need be changed in the stored layout description; a new layout is not required. In one symbolic layout system, designers represent their designs on a floating grid by manipulating shapes and lines, mapped one-to-one with transistors and interconnections (*3*). Compaction programs exist that attempt to condense the layout to improve chip area use.

Bristle blocks. In bristle blocks functional circuits are defined as rectangular modules having specific interconnections ("bristles"). These modules have been predefined and presimulated, and are ready to be connected to one another by "intermeshing" the bristles. The claimed advantage of the bristle block approach is that there are no routing paths needed outside the blocks; all the necessary connections are made automatically at the edges. However, a major limitation is that each block must interact only with its immediate neighbors. Because of this limitation, bristle blocks may find the most use in computer-type chips, where all blocks are organized around a common data path.

Conclusions

Chip design is a long, complicated, and expensive task, and even the smallest error can be fatal to a project. As circuit complexity increases to VLSI, design tasks are becoming astronomically expensive, time-consuming, and error-prone, and manual implementation is impractical or unfeasible. A constraint that design automation will always face is that of solving problems of the next generation with tools of (at best) the current generation.

Design automation remains the hope of VLSI designers for getting their chips to the marketplace in a reasonable amount of time and for obtaining a competitive price. Design automation not only saves money by reducing design and fabrication time, but also helps the community of systems and logic designers to work more effectively and innovatively. A coherent, user-friendly, completely automated system of integrated circuit design that requires little or no human intervention has yet to be realized by many design institutions. Improving and integrating existing design automation software packages and inventing algorithms will continue to occupy industrial and academic institutions for many years to come.

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MANAGEMENT ISSUES IN COMPUTER AIDED ENGINEERING

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Introduction

Engineers have been on the leading edge of using computer technology in analysis but, bewilderingly, we have not benefited from the CAD/CAM revolution. The reason for being lost in the backwater of computer usage is that we have traditionally been a slave to the monolithic corporate computer and the batch environment. Our only reminder that there is a revolution out there is the ubiquitious green storage tube display devices which allow us to display finite element models and graphical output.

We learned, at the First Chautauqua on Finite Elements(1), that the drafting department was creating a data base of geometric information that was potentially useful for analysis. And we also learned that the turnkey CAD/CAM vendors were starting to recognize the potential market for systems which supported not only drafting but also other design functions such as solid modeling, analysis, and simulation. This recognition lead almost immediately to the need for more computer power than could be obtained from a 16 bit minicomputer, and in the two years since the First Chautauqua we have seen all of the major turnkey vendors move to incorporate 32 bit processors in their systems.

The evolution of turnkey CAD/CAM systems which incorporate application software, an ergonomic man/machnine inferface, and high resolution color raster graphics has given the engineering manager the potential of increasing the productivity and quality in the engineering office. However, with the new technology comes a new set of issues for management to understand and to deal with.

In trying to satisfy a local need for increasing productivity by using computers it quickly becomes obvious that the issues are global in nature rather than being local issues that sucb-sector managers can deal with autonomously. These global issues include corporate economic policy, possible revolutions in corporate organizational structure, and labor relations, in addition to the more tractable technical issues. Those issues that we will address in this paper are as follows:

- The meaning of productivity
- The role of CAE in Computer Integrated Manufacturing
- The state of the art of turnkey CAD/CAM
- The interface between design and analysis
- Application software fo engineering analysis
- Education and training

To a large extent these issues were addressed by participants at the Second Chautauqua on Productivity in Engineering and Design(2) which was held in November 1982. In discussing the issues I will rely liberally on ideas which were discussed at the Second Chautauqua.

What is Computer Aided Engineering (CAE)?

Before discussing the issues of CAE it's worthwhile to make sure we all agree on what Computer Aided Engineering entails. We are talking about a subset of all corporate activities; the subset that has been traditionally called engineering. These activities encompass all of the functions that lead to a set of design documents which are then used by manufacturing to create a product. The process of creating the design documents has traditionally been associated with the following activities

- Conceptual design
- Testing
- Analysis
- Detailed design and drafting

The CAD part of the CAD/CAM acronym has been taken to mean several things. However, since the turnkey CAD/CAM systems have, at least until this time, been viewed primarily as automated drafting systems it seems consistent to consider CAD to be the drafting and documentation subset of Computer Aided Engineering. It is also of interest as we talk about the Alphabet Soup of Computer Aided Everything (which was described by Jack Conaway in his keynote address at the Second Chautauqua) to note that the use of the acronym CAE has been used by some organizations to refer to only analysis tasks such as finite element modeling and kinematics.

Productivity

There seems to be a growing awareness that productivity can mean much more than the myopic idea of increasing the number of units produced in a given time. The use of computer aided tools throughout the organization means better communication between individuals, departments, and divisions; it means a consistency in performing mechanical tasks, and an increased quality in the "product", whether that product is a finite element analysis, an engineering drawing or a robot-controlled weld. The issue of productivity means jobs and survival for many segments of American industry. There's a real issue here on productivity. Management defines productivity from a macro view point whereas labor defines it from a micro view point. On a recent talk show on the Public Broadcasting System which was discussing the relationship between labor and management the moderator asked each of the panelists if the the "American Worker" was the most productive worker in the world. Two of the panelists who were part of the labor movement were adament in saying "yes, American workers are the most productive in the world...When it come to putting three nuts on three bolts, we can do the job as well as anyone." They both went on to put the blame for any price advantage that foreign companies might have squarely in managements lap for failing to make the capital investment in productive tools. However, in the very next breath, labor decried the movement by several large manufacturing organizations to automate production because that threatens labor jobs.

The use of computer aided tools to increase productivity requires attention at the very highest levels in the corporation. Bella Gold(3) so aptly pointed out that the criteria which management uses to choose among alternative proposals has lead to serious under estimations of prospective benefits for technological innovation and to unduly slow rates of adoption. Gold suggests that the present methods are unsuited for evaluating the acquisitions of CAD/CAM systems because they tend to share certain common incorrect assumptions:

1. That the equipment will operate as an "Island of Automation".
2. That the technological fallout associated with the capabilities of the equipment are well known and will not change after installation.
3. That the productivity of the new "Island of Automation" can be estimated to within reasonably close margins.
4. That sub-sector managerial and technical specialists are best able to judge the advantages and limitations of the prospective acquistion.

Dr. Richard Hartung(4) also noted the problem associated with developing "Islands of Automation", and suggested that companies need a high level Czar to successfully implement computer aided tools throughout the organization. This CAD/CAM Czar must be above all operational user organizations and must have an understanding of all of the technological and management issues and have the power to develop and implement the corporate plan. Hartung and Gold are suggesting the same thing...we can't continue to do business in the same way. Organizations will have to change, and one change will be to define a new line management position, "Vice President of Survival".

Technology of Computer Aided Engineering

The technological foundations which are required to support the activities of Computer Aided Engineering and to tie design into the rest of the corporate activities are more-or-less available. These basic building blocks are

- Low-cost high performance computers
- Interactive operating systems
- Computer graphic displays
- Effective computer/user hardware devices
- Computer networks
- Data base and data base management software
- Third generation application software
- Software interface standards
- Distributed training and education

Low Cost Computers

Jack Conaway(5), in a futuristic projection, suggested that we would see an engineering workstation on the market by 1985 that would include

- A 32 bit computer on a chip with the power of the Digital Equipment Corporation's VAX11/780
- High resolution color raster scan graphic display device
- A digitizing tablet and a rational (non QWERTY) keyboard for communication with the computer
- A videodisc unit for interactive computer based documentation and training
- Lots of highspeed mass storage
- At least a megabyte of high speed memory using 64K chips

Sound familiar? These are the features that are available today on several announced products (perhaps minus the videodisc and the non QWERTY keyboard) such as the Apollo Domain, the Massachusetts Computer MC500, the recently announced Hewlett Packard 9000, the WICAT Systems: System 100, (and who knows what the rumored IBM professional computer will support). These computers together with superminis such as the VAX11/780, the Prime 850, the IBM4341, etc., provide the end user with the power of yesterday's mainframe in an interactive environment for about $10,000 per seat.

Does that seem high? Should engineering managers be preparing to spend $10,000 per engineer for computer hardware? Let's look at that question a couple of ways. First, let's take a look at productivity, and let's suppose that the availability of computer resourses (never mind what they do at this time) will save our engineer four hours per week. That's 200 hours per year and, at a rate of $50 per hour, we have paid off the hardware investment in one year. Now, let's approach the $10,000 in a more irrational fashion. My first industrial position was with AiResearch in Phoenix and was in the pre-computer days. But we did have mechanical calculators, rooms full of them. Almost symbol placement, and they cost about $200 at a time when Volkswagens cost $100 . Now VW's cost at least $6000 which establishes a ratio of 60-to-1 as a reasonable inflation index. In other words that investment in a $200 calculator which AiResearch made in the late 50's is now worth $12,000.

My point is that powerful computers which can support local computational needs are now available in the marketplace. And the cost of the hardware is within the budget of all companies who want to be among those that survive over the next five years.

Integrated CAE Systems

The hardware and softwear bits and pieces do marvelous things, but they don't communicate very well. On the hardware side there seems to be some hope, but on the application software side we have seen little or no progress. At any rate almost any marketing manager from either a hardware or software company can describe your company's CAE future by using the Comuter Integrated Manufacturing (CIM) Wheel of Fortune which is shown in Figure 1. This implies that each of the functional areas involved in manufacturing and design has well defined application software that is tied together through a corporate data base and which allows all sub-sectors to communicate with each other. The Wheel thus raises several issues.

- The state-of-the-art of application software
- The concept of a corporate data base
- Interface standards between hetergeneous hardware and software systems

Current CAE systems generally only satisfy the local needs of sub-sector groups. This is shown by Figure 2 as unconnected islands of automation which have been identified as

- Geometric modeling
- Finite element modeling and result display
- Finite element analysis
- Drafting and documentation

In order to interface these islands we need communication networks that allow computers to talk to each other and software interface standards to allow the various application programs to execute effectively on the same data base. The interconnection of these islands will then eliminate the regeneration of common data such as the geometric representation of a design.

The need for software interface standards has been recognized both in the United State and Europe and has lead to a proposed or accepted standards for both the hardware and the software/software interface. The software/hardware interface such as the SIGGRAPH Core and the Graphic Kernal Standard (GKS) are generally of interest to the developers of proprietary software whereas the software/software standards are of interest to the end user organizations who are attempting to integrate all of the bits and pieces.

The software/software interface that has received the most attention in the CAD/CAM areas is the Initial Graphic Exchange Specification (IGES) which provides a standard for exchanging geometric data between dissimilar systems. This standard is limited, at present, to only simple geometric entities such as points, lines, and arcs. However, even this modest capability allows geometric data, in wire frame form, to be captured on a turnkey CAD/CAM system and then to be transferred to an analysis processor such as FEMGEN or PATRAN-G where it serves as the basis for developing a solid three dimensional representation of the entity.

At present there is no standard representation for a finite element model (and I suspect that the proprietary vendors see no need for one). The pre-and post processor programs must therefore resort to some sort of neutral file for input and output. The vendors of pre and post processors generally support the interface between their own neutral file and the world class proprietary programs such as ANSYS and MSC/NASTRAN, but leave it to the system integrator to interface "OWNCODE" to the pre and post process. One might comment on the inefficiency of this approach but if or until the proprietary vendors agree upon a standard we will continue to clog the communication channels with thousands of card images which require excessive computer resources for generation, storage, and transmission. Perhaps it's time for us all to reduce the data representation down to Hofstader's "Golden Braid"(6) and transmit only the data kernal together with the name of the algorithm which is required to produce the expanded input data for a target analysis program...but better yet, why not eliminate the intermediate conversion of data by agreeing on a standard software interface.

The hardware vendors seem to be way ahead of the application software vendors when it comes to interfacing computers. There are a number of techniques such as

- Terminal emulation
- Local area networks
- Proprietary networks

with interconnection devices called "routers" for interconnecting homogenerous local networks and "gateways" for commumicating with heterogeneous systems.

As far as the needs of CAE are concerned I think we can eliminate the old work horse of the engineering department, terminal emulation, which allows access to remote (generally centralized) computers over standard telephone lines. The issue here is the rate of information transfer which is directly proporational to the range of frequencies (the bandwidth) that is supported. Voice grade lines are only good for about 4000 Hz which means that while they might be acceptable for batch computing they cannot support color raster devices that require megabits of information every 1/30th of a second.

Transmission media such as coaxial cable, which has a bandwidth of 300 megahertz, or fiber optics with bandwidths in the gigahertz range are more appropriate for the needs of computer aided engineering. These media are then used to couple computers together in some sort of network topology where the ring, star, and bus topologies are finding wide use in CAE systems.

The last issue in our Wheel of Fortune is related to the concept of a corporate database. As Hartung told us as the Second Chautauqua, there never has been a corporate data base and there probably never will be. As a matter of fact, the advocates of the corporate data base are exactly the same people who have advocated the single large corporate mainframe computer (or at least the centralization of all computer resourses). The introduction of low cost superminis lead to the demise of the centralized computer but for some reason we still have adherents to the corporate date base and the Wheel of Fortune.

The more modern view of Computer Integrated Manufacturing is shown by Figure 3 which represents a networked data base. In this view each island of automation can develop autonomously but all islands can, and will, be connected together to allow indirect access to all functions and organizational units. This approach will allow each island to develop and then gently bump into the adjoining islands by use of appropriate interisland interface standards.

In the networking approach to automation the Computer Aided Engineering Island can be viewed in more detail as shown by Figure 4. In this view we see the application tasks associated with CAE talking to each other over the network (shown here as a bus). However, even in this local island the global data base does not include EVERYTHING, it just contains the input to an algorithm which in turn can create EVERYTHING on demand. This NICE software and the concept of the local data base have been developed by Fileppa and his coworkers at Lockheed(7), and were reported on by Zumsteg(8) at the Second Chautauqua.

Education and Training

Everyone's an expert about education and training because it's an experience we've all had and we have formed definite reactions to that experience. We are moving into an era in which all of our background and our pre and misconceptions about education will do us little or no good. We have spent 25 years training the one million or so of us in the engineering workforce but now, staring us in the face, is the need for retraining more-or-less the entire engineering work force in the remainder of this decade. How can we accomplish this task using traditional prehistoric methods that do a questionable job of educating approximately 30,000 engineers who graduate from our engineering schools each

Let me give you some more perspective on the problem. First, my thesis is that college graduates per se will not be a factor in satisfying our need for engineers who are qualified to use CAE tools. I say this for two reasons, first, it takes approximately two years to teach a new engineer "the ropes" and secondly the numbers entering industry from the universities over the next five years will only be the proverbial drop in the bucket as far as the requirements are concerned.

Accepting the fact that we will not abandon the present labor force to be replaced by Apple toting college graduates, what kind of numbers are we really looking at? Well, industrial analysts such as Tom Kurlac of Merrill Lynch Inc. have suggested a growth rate of 30-40 percent in the turnkey CAD/CAM market(9). Using this compound growth rate we find that the number of users five years from now will be five times greater than those involved in CAE today. This means that, on the average, we must train as many people to use the new technology of CAE each year as are currently involved in CAE.

In order to expand the market for, and therefore the use and benefits of CAE (and all of the islands of CIM for that matter), we must develop new techniques for training and educating the users. The only alternative that I see is the use of computers to help people understand computers.

Computer Assisted Instruction is not a new idea; its an idea which has had advocates such as Norris of CDC and Bork(10) of the University of California for the last two decades. However, at this time there is only one delivery system for CAI which can satisfy the needs of distributed CAE. That product, called PLATO, is marketed by CDC and was developed, according to Time Magazine for $900 million (that sounds high, the accepted figure is only $700 million). The need is there but we have one small problem. There are no software entrepenures who are out developing courseware because there is, at present, no established market for the product.

In Closing

The field of CAE which people like Ed Wilson, John Swanson and myself have been part of for two decades is in its infancy. For example, Kurlac noted in his latest CAD/CAM report that the move to 32-bit processors will "enable users to design faster and more accurately". He noted further that "solid modeling and finite element analysis are two such tools which are gaining popularity...". There are many technological, social, organizational, and political issues that must be understood and dealt with effectively to enable it to grow to its potential. However, none is a big as the issue of educating and training the practioners of tomorrow.

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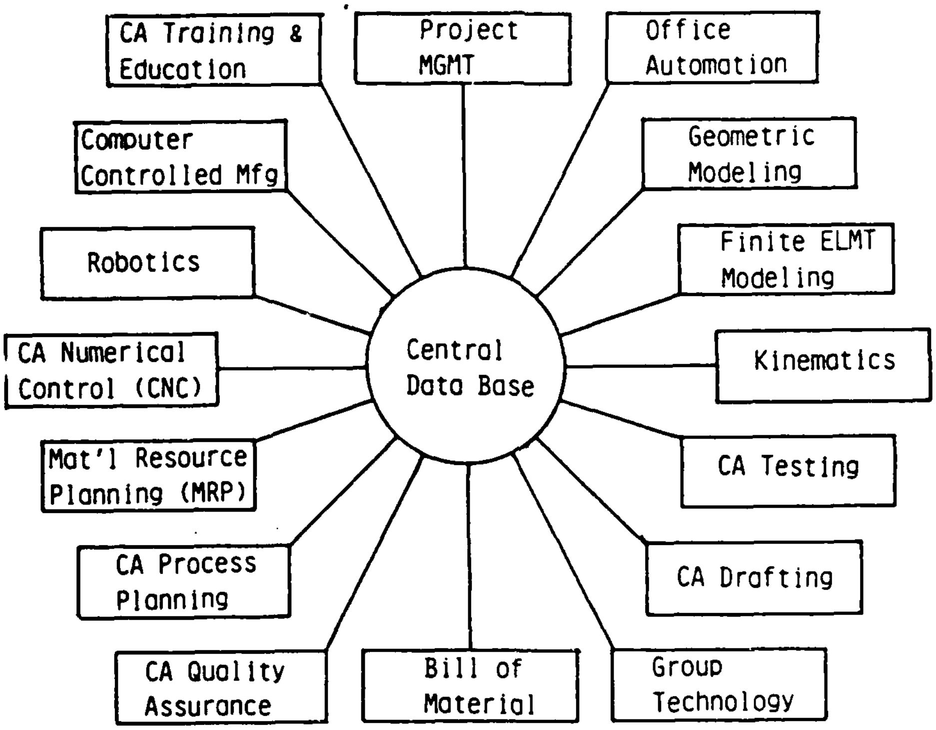

FIGURE 1 - Computer Integrated Manufacturing Wheel of Fortune

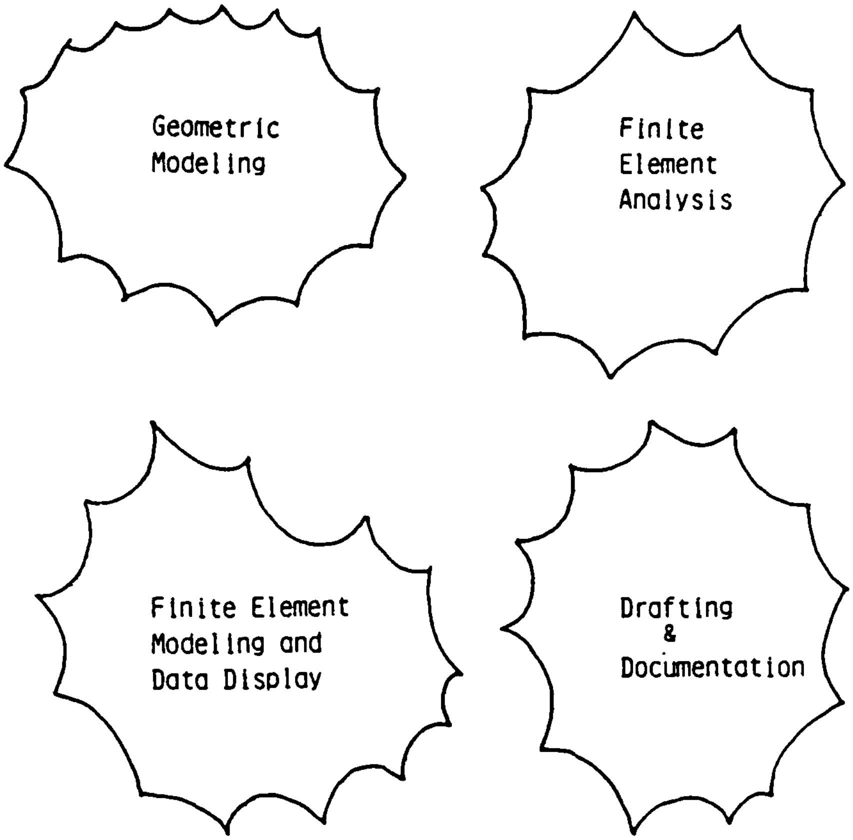

FIGURE 2 - Islands of Automation

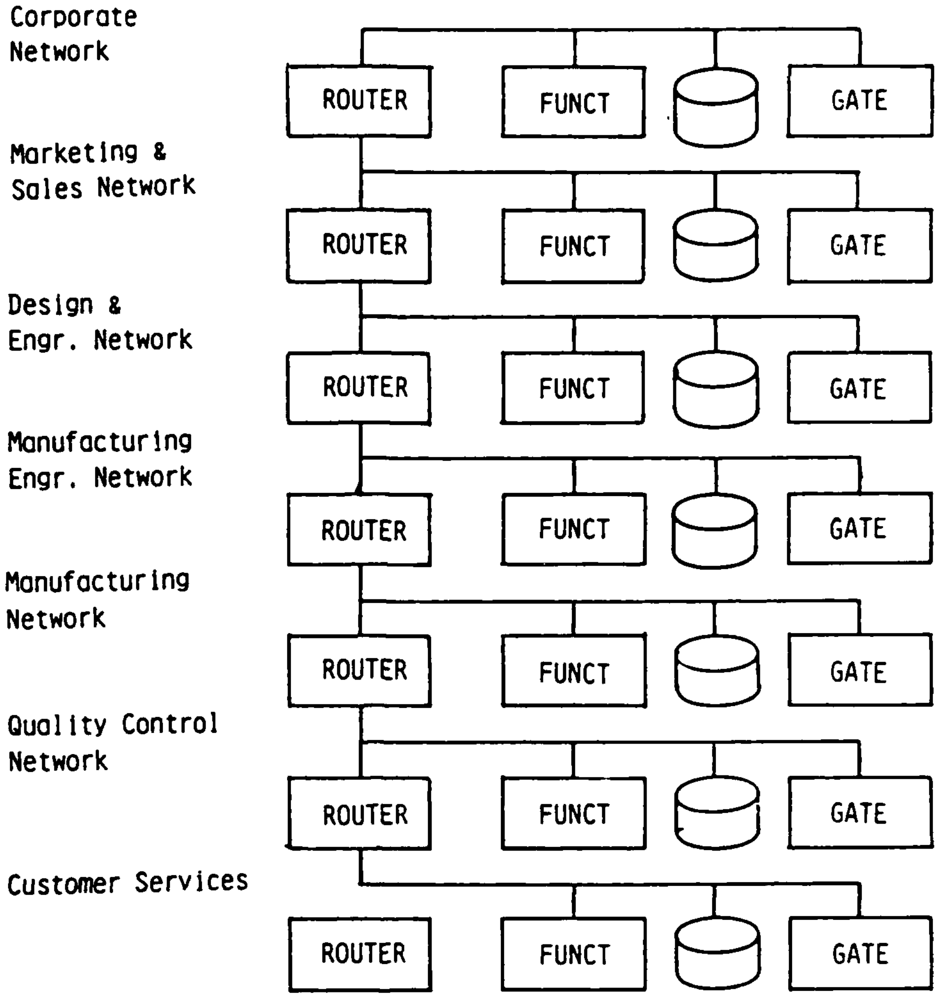

FIGURE 3 - Computer Aided Manufacturing - A Realizable Approach Using Local Networks

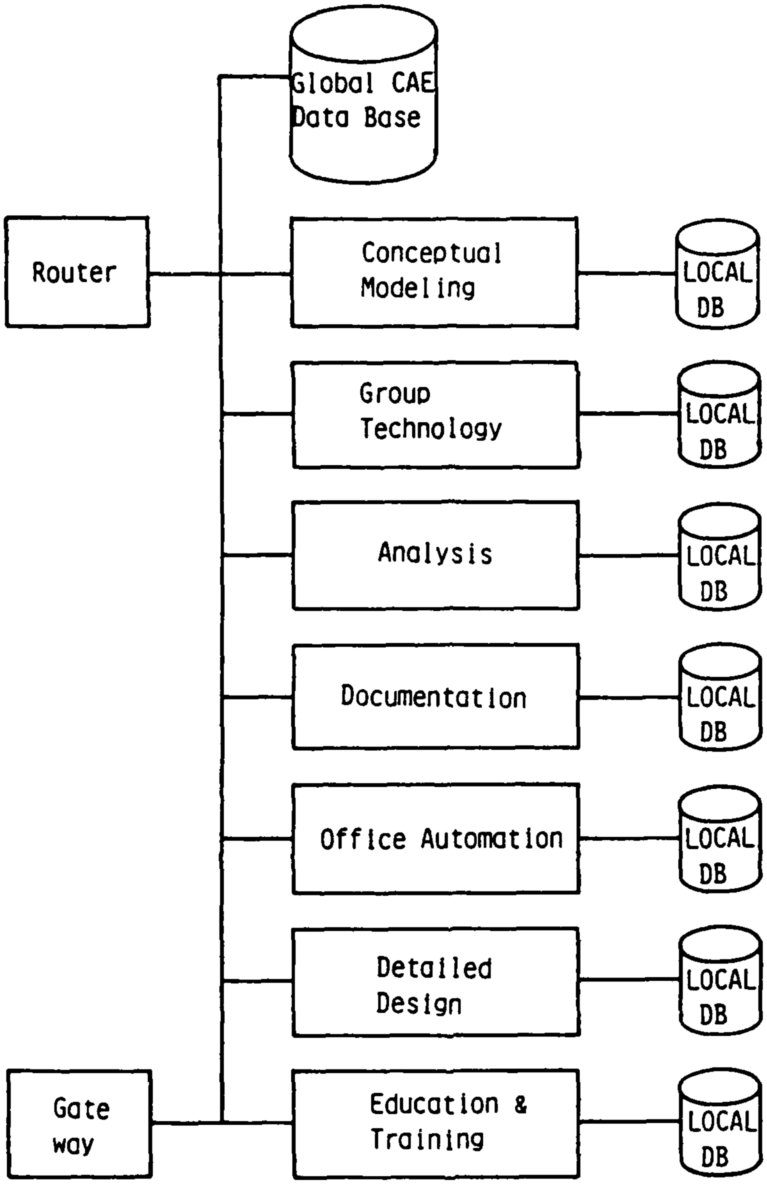

FIGURE 4 - Computer Aided Engineering Local Network - An Expanded View of Functions

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APPENDIX E

Reference Materials

(documents retained in IDA R&M Project Library)

FILM

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