

N O T I C E

THIS DOCUMENT HAS BEEN REPRODUCED FROM
MICROFICHE. ALTHOUGH IT IS RECOGNIZED THAT
CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED
IN THE INTEREST OF MAKING AVAILABLE AS MUCH
INFORMATION AS POSSIBLE

NASA CR-132671

APPLICATION OF IPAD TO MISSILE DESIGN

by

J. E. Santa
and
T. R. Whiting

April 1974

(NASA-CR-132671) APPLICATION OF IPAD TO
MISSILE DESIGN (McDonnell-Douglas
Aeronautics Co.) 393 p HC A17/MF A01

CSCL 16D

G3/15

N80-11120

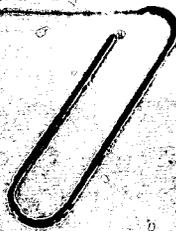
Unclas
40565

Prepared by
McDonnell Douglas Aeronautics Company
Huntington Beach, California 92647

for the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Langley Research Center
Hampton, Virginia 23665
and for
THE U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809



NASA Contract NAS1-12436-Task 4



ABSTRACT

The application of an Integrated Program for Aerospace-Vehicle Design (IPAD) to the design of a tactical missile is examined and an evaluation made of the feasibility of modifying a proposed IPAD system for aircraft design work for use in missile design. The tasks, cost, and schedule for the modification are also given.

The basic engineering design process is described, explaining how missile design is achieved through iteration of six logical problem-solving functions throughout the system studies, preliminary design, and detailed design phases of a new product.

The study recommends that IPAD be used to perform all routine data-handling tasks in design, many of which are now done manually by the design engineer. The functions of problem definition, synthesis, and system selection should still be performed by man, aided by IPAD in retrieving and displaying supplementary design information.

An analysis of the prospective benefits of IPAD discloses that the total engineering design time on a typical missile development program could be cut by an estimated 50%, and design costs lowered by nearly 25%, based on the productivity achieved in other integrated missile computer programs with terminal on-line interactive graphics now in use. Additional benefits of IPAD include: (1) improved design quality; (2) increased reliability and accuracy of design; (3) level manpower loads; (4) greater design visibility and traceability, and (5) an enhanced creative environment.

Existing computer codes used in various engineering disciplines are evaluated for their applicability to IPAD in missile design. The findings are that aerodynamic codes used in aircraft design can be incorporated in an IPAD system for missiles, but that codes used for aircraft in most other fields are not suitable for missile design. The effort of incorporating new codes into IPAD can be minimized by using a common language and storing data definitions in the computer.

Descriptions of known computer codes used in the various engineering disciplines and proposed codes are also given.

ORIGINAL PAGE IS
OF POOR QUALITY

PREFACE

This report was prepared by the Flight Mechanics Department of McDonnell Douglas Astronautics Company (MDAC) as Task 4 under Contract No. NAS1-12436 with the National Aeronautics and Space Administration (NASA), Langley Research Center, Hampton, Virginia. The study was funded by the U.S. Army Missile Command under MIPR No. A3168Z-33-7146 to the NASA Langley Research Center. The work was administered at MDAC under the direction of R. H. Christensen, head of the System Design Studies (Structures) Program. The work was monitored by J. R. Hall, Head of the System Design Studies Program, NASA Langley Research Center, with R. E. Fulton serving as Technical Advisor for the NASA Langley Research Center and Richard Eppes, Jr., serving as Technical Advisor for the U.S. Army Missile Command.

The authors wish to thank the following individuals who supported this study: D. J. Fischer, sensors; J. W. Robinson, propulsion; H. G. Timmer, aerodynamics; D. R. Hender, thermodynamics; E. H. Gillis, structures; H. C. Valette, guidance and control; A. J. Goodwin, costing; H. C. Thompson, armaments; O. D. Jordhal, flight mechanics; W. S. Kowalik, systems; and C. Melton and T. D. Lory, programs.

CONTENTS

1.	INTRODUCTION	1
2.	ANSWERS TO STUDY QUESTIONS	3
3.	THE MISSILE DESIGN PROCESS	13
3.1	Engineering Design Methodology	13
3.1.1	Program Phases	13
3.1.2	Logical Problem-Solving Functions	16
3.1.3	Dimensions of the Engineering Design Process	19
3.2	Tactical Missile Systems	19
3.2.1	Tactical Missile Description	21
3.2.2	Tactical Missile Subsystem Classes	21
3.3	Functions Performed in the Missile Design Process	25
3.3.1	System Studies Phase	28
3.3.2	Preliminary Design Phase	34
3.3.3	Detailed Design Phase	40
3.3.4	Production Phase	43
3.3.5	Operations Phase	43
4.	ANALYSIS AND EVALUATION OF THE EXISTING MISSILE DESIGN PROCESS	48
4.1	System Studies Phase	48
4.1.1	Aerodynamic Design	48
4.1.2	Thermodynamic Design	51
4.1.3	Flight Mechanics Design	51
4.1.4	Structural Design	56
4.1.5	Propulsion Design	58
4.1.6	Sensor Design	63
4.1.7	Guidance and Control Design	64
4.1.8	Costing Design	67
4.1.9	Armament and Ordnance Design	71
4.2	Preliminary Design Phase	75
4.2.1	Aerodynamic Design	75
4.2.2	Thermodynamic Design	78
4.2.3	Flight Mechanics Design	79
4.2.4	Structural Design	85
4.2.5	Propulsion Design	85
4.2.6	Sensor Design	93
4.2.7	Guidance and Control Design	93
4.2.8	Costing Design	99
4.2.9	Armament and Ordnance Design	105
4.3	Detailed Design Phase	108
4.3.1	Aerodynamic Design	108
4.3.2	Thermodynamic Design	112
4.3.3	Flight Mechanics Design	112

CONTENTS (Continued)

4.3.4	Structural Design	115
4.3.5	Propulsion Design	115
4.3.6	Sensor Design	126
4.3.7	Guidance and Control Design	128
4.3.8	Costing Design	131
4.3.9	Armament and Ordnance Design	136
4.4	Deficiencies in the Missile Design Process	140
5.	ANALYSIS AND EVALUATION OF THE IPAD SYSTEM FOR MISSILE DESIGN	147
5.1	Recommended Missile Design Functions for IPAD	147
5.2	Evaluation of Computer Programs Used in Missile Design for IPAD	148
5.2.1	Existing Aerodynamic Computer Programs	148
5.2.2	Existing Thermodynamic Computer Programs	156
5.2.3	Existing Flight Mechanics Computer Programs	157
5.2.4	Existing Structural Computer Programs	159
5.2.5	Existing Propulsion Computer Programs	168
5.2.6	Existing Sensor Computer Programs	171
5.2.7	Existing Guidance and Control Computer Programs	173
5.2.8	Existing Cost Computer Programs	176
5.2.9	Existing Armament and Ordnance Computer Programs	178
5.3	Undeveloped Computer Programs Proposed for IPAD	180
5.3.1	Undeveloped Cost Computer Programs	180
5.3.2	Undeveloped Sensor Computer Programs	183
5.3.3	Undeveloped Armament Computer Programs	183
5.4	Distribution of Effort and Cost in the Present Design Process	185
5.4.1	Distribution of Creative and Noncreative Functions in the Design Process	185
5.4.2	Distribution of Costs and Time in the Design Process	188
5.5	Productivity of On-Line Interactive Graphics and Integrated Computer Programs	197
5.5.1	Graphic Interactive Drafting System (GRID)	197
5.5.2	General Missile Sizing Program (GMSP)	199
5.5.3	Computer-Aided Design and Drafting (CADD)	203
5.6	Projected Time and Cost Savings with IPAD	206
5.6.1	Mathematical Model of the Engineering Design Process	208
5.6.2	Application of the Model to the Missile Design Process	217
5.6.3	Benefits Gained by Using IPAD	217
5.7	IPAD Design Features Appropriate to Missile Design	221
5.7.1	Description of IPAD System	221
5.7.2	Evaluation of IPAD Design Features	227

CONTENTS (Continued)

6.	WORK, COST, AND TIME TO EXTEND THE IPAD SYSTEM TO MISSILE DESIGN	231
	REFERENCES	241
Appendix A	AERODYNAMIC COMPUTER PROGRAM SPECIFICATIONS	243
Appendix B	THERMODYNAMIC COMPUTER PROGRAM SPECIFICATIONS	261
Appendix C	FLIGHT MECHANICS COMPUTER PROGRAM SPECIFICATIONS	264
Appendix D	STRUCTURES COMPUTER PROGRAM SPECIFICATIONS	269
Appendix E	PROPULSION COMPUTER PROGRAM SPECIFICATIONS	331
Appendix F	SENSOR COMPUTER PROGRAM SPECIFICATIONS	344
Appendix G	GUIDANCE AND CONTROL COMPUTER SPECIFICATIONS	350
Appendix H	COST COMPUTER PROGRAM SPECIFICATIONS	364
Appendix I	ARMAMENT COMPUTER PROGRAM SPECIFICATIONS	369
Appendix J	UNDEVELOPED COMPUTER PROGRAM SPECIFICATIONS	377

Section 1 INTRODUCTION

The engineering design approach utilized in the aerospace industry has developed in a random manner subject to human errors, which had led to serious deficiencies in the design process. Many large design projects do not provide the engineers working in various disciplines with a quick way of sharing raw data with each other. The flow of technical and management information is frequently interrupted, depriving the engineer of continuity in creating a design. In addition, routine data-handling activities the engineer must perform, which could be done faster and more accurately by a computer, reduce the engineer's time for creative design.

The Skylab launch failure has been traced to inadequacies in the design process. On May 14, 1973, after a \$2 billion development program spanning several years, the Skylab space station was launched into Earth orbit. During atmospheric flight, a thin, cylindrical micrometeoroid and thermal regulator shield wrapped around the space station was torn away by the airstream. As the shield left the vehicle, it caused severe problems with the two stowed solar array panels that were to generate power while in orbit. One solar panel was ripped off because of its premature deployment, and the other was jammed, preventing its deployment in orbit. Although the jammed solar array panel was later deployed, partly salvaging the project, it cost \$3 to \$4 million to solve the electric and heat energy problems, and it appeared at the time that the entire Skylab mission would have to be abandoned at a loss of \$2 to \$5 billion (ref. 1).

An investigation disclosed that a lack of communications among the engineering disciplines was a primary cause of the trouble. If the micrometeoroid shield had been treated by the design team as a complex subsystem involving several technical disciplines rather than as a mere piece of structure, the Skylab failure may well have been prevented.

The concept of an Integrated Program for Aerospace-Vehicle Design (IPAD) would provide timely interdisciplinary communication of technical and management information to all participants in the design process. It would allocate design engineering tasks between man and computer in an optimum manner by computerizing routine data-handling activities. Moreover, it would improve the quality of design by use of integrated models through data-management software and by removing the obstacles to creative efforts.

The feasibility of developing IPAD for use in aircraft design has already been studied (refs. 2 and 3). This report presents the results of a study to investigate the application of the above proposed IPAD concepts to missile design.

Section 2 provides questions and answers to address the fundamental issues in relating IPAD to missile design. Section 3 defines the functions performed in missile engineering design in the various program phases. A typical Army tactical missile is described by subsystem to permit a realistic evaluation to be made of the computer programs used in missile design.

A more detailed view of the engineering activities, by discipline and program phase, is presented in Section 4, with an indication given as to whether or not each activity can be automated. The design process is then appraised, and deficiencies in the process are noted.

The design tasks are related to the IPAD concepts (refs. 2 and 3) in Section 5. Existing computer programs are evaluated to determine their suitability for use with IPAD, and new programs that could be developed within the state of the art are identified. Savings in design cost and time by using IPAD are then projected. The IPAD systems investigated for aircraft in references 2 and 3 are next evaluated for their application to missile design, and the benefits of IPAD for this purpose are assessed.

Section 6 provides cost and schedule estimates for extending an IPAD system for aircraft to include the capability to design Army tactical missiles.

Computer codes are described, by discipline, in the Appendixes.

Section 2

ANSWERS TO STUDY QUESTIONS

This section answers certain questions posed by NASA to provide greater understanding of the missile design process and to determine the applicability of the IPAD system to missile design.

The questions were:

1. How can IPAD be used to support the missile design processes?
2. If it cannot, what modification can be made to make it usable?
3. Is a separate approach to design of missile systems more practicable?
4. What different disciplines should be involved?
5. What disciplines are already adequately represented by existing codes? Which ones are missing?
6. What disciplines have to be represented primarily by experimental data?
7. How should experimental data be handled in the system operation?
8. What aspects of the design are not quantifiable and what impact do they have on the design process?
9. What should be the IPAD level of application?
 - a. Preliminary design?
 - b. Detailed design?
 - c. Final analysis?
 - d. Can all be included in the system as a natural progression of the design process?

10. What are the cost or product benefits that can be achieved through use of this program (e. g., simplicity, reliability, economy . . .)?
11. Are some existing data bases (e. g., materials data bank) practical to fit into an IPAD missile design system?

Only general answers are presented in this section. Details are given in appropriate sections on the results of the study tasks.

QUESTIONS AND ANSWERS

Question 1. How can IPAD be used to support the missile design process?

The engineering design process consists of the following logical problem-solving functions: problem definition, system synthesis, system analyses, system optimization, system selection, and documentation. The process is iterative, with designers having brief periods of creative activity in selecting and modifying goals and synthesizing and selecting elements and form, followed by lengthy periods of noncreative activity. The noncreative work includes routine information-handling, such as data transmission, reformatting, and documentation. The effectiveness of the missile design process, whether it is aimed at quality design or lower-cost design, can be increased by applying the IPAD engineering design system which has an optimal interface between designer and computer. The design will allocate the noncreative activities to the computer, permitting the engineers to concentrate on the creative aspects of design.

Question 2. If it cannot, what modification can be made to make it usable?

The value of the IPAD system largely depends on the optimal interface between the designer and the computer and on the techniques represented by the technical codes in the library of the system. To enhance the missile design process, the system library must be extended to include technical codes of disciplines involved only in the design of missile systems. The detailed design phase of the missile can be further enhanced by extending the IPAD system so that it is a hybrid computer with digital and analog capabilities.

The IPAD system, as defined in references 2 and 3, performs routine data-handling activities required in the missile design process. But it must also be extended to include technical codes for all the missile subsystems, especially the sensor, guidance and control, propulsion, and armament subsystems. The design process can be further enhanced if technical codes for other missile segments are added, such as the acquisition and tracking subsystem, the command, control, and communications subsystem, and the launch platform.

If the IPAD system were developed into a hybrid computer using hardware subsystems, high-frequency control elements would be simulated on the analog instead of the digital computer. Certain tactical systems may employ very-high-frequency control actuator loops that would be amenable to simulation on the analog computer. Thus, IPAD might support the digital simulation with small analog elements controlled by electronic switches via the digital computer. The analog would then become a support function for digital computations in the IPAD concept.

An on-line support facility with the IPAD system may aid missile development efforts by uniting vehicle hardware subsystems (e.g., the electronics, sensors, and environmental subsystems) in a systems test. It is anticipated that this type of testing would be conducted predominately in the preliminary and detailed design phases. Computer coding would be required to interface the subsystem elements, conduct the test sequence, and evaluate the test results. This type of approach would be attractive on programs with a limited number of development flight tests. Much of the thermal and geometric environment could be simulated for subsystem elements, thereby demonstrating system integration and performance objectives with the IPAD concept. The demonstration of the integration and performance objectives, using an on-line support facility with IPAD, would lead to a reduction in the number of flight tests and their costs.

Question 3. Is a separate approach to design of missile systems more practicable?

The IPAD system is an acceptable engineering design system which can increase the effectiveness of the missile design process. It is probably the most practicable approach for performing missile design, since the executive control and data management functions required for data storage, retrieval, and control are part of the IPAD system. Also, many of the IPAD system technical codes can be used for missile system design. Consequently, no other approach is needed in the design process.

Question 4. What different disciplines should be involved?

First, the basic aircraft disciplines are involved in the design of a missile- aerodynamics, cost-estimating, electronics, flight mechanics, guidance and

control, mechanical, propulsion, reliability and maintainability, structures, thermodynamics, weights, and loads. Some of these disciplines such as aerodynamics, structures, and weights involve the same type of activities as in aircraft design. Others such as propulsion and cost-estimating involve quite different design activities because the classes of subsystems are different (solid rockets, thrust augmented, liquid rockets, etc.). In addition to aircraft disciplines, guidance, armament, and sensor technologies are needed in missile design. Further, any discipline which is strongly related to the design objectives and limitations of a particular vehicle should be considered.

Question 5. What disciplines are already adequately represented by existing codes? Which ones are missing?

Most of the disciplines listed in the reply to Question 4 are already represented by technical codes. However, there are no adequate codes for cost-estimating and control and sensor functions. Additional effort will be required in these areas to broaden the existing capabilities and to provide more detailed design capability.

Question 6. What disciplines have to be represented primarily by experimental data?

Experimental data are needed for most of the disciplines involved in the missile design process, especially in the preliminary design, detailed design, and testing phases. The principal disciplines using experimental data are aerodynamics, guidance and control, propulsion, thermodynamics, armament, propulsion, and structures.

The experimental data are used in the following efforts:

1. Propulsion design relies upon experimental data to generate nozzle performance and thermo-chemical data and ballistic relationships for candidate missile system.
2. Structural design requires experimental data to establish material properties used in all structural analyses and for analyses of candidate parts or assemblies which are too redundant or complex to analyze by computer simulation with a high degree of confidence. In qualification and acceptance testing, structural components representative of actual production components are tested to ultimate loads to ensure the adequacy of structural design.
3. Wind-tunnel tests are conducted to predict aerodynamic characteristics.
4. Thermodynamic design requires experimental data to determine methodology and material performance.
5. Armament design is dependent on experimental data to establish lethality conditions and kill probabilities.
6. Guidance and control requires experimental data to determine servomechanism performance and bending and sloshing modes.

Question 7. How should experimental data be handled in the system operation?

Experimental data are generated throughout most of the missile program. The data should be reduced to a usable form at the test facility and then stored in data blocks, with direct access provided by active technology codes, if desired. The experimental data should be easily retrieved and mixed with analytical

predictions to form a "best estimate" model to be maintained as the current data blocks. The mixing function requires human decisions which may involve some coding, but cannot be fully automated. The use of N-dimensional interpolation and weighted least-squares codes can help the mixing operation. Entry of the data via digitizing tablets would greatly reduce the work required for inputting experimental data.

Question 8. What aspects of the design are not quantifiable and what impact do they have on the design process?

Problem definition, system synthesis, and system selection cannot be quantified and yet they may have a major effect upon the quality of the design. These functions all require creativity, intuition based on experience, and human judgments. In each missile design phase, there are also logical problem-solving functions such as system analysis, system optimization, and documentation of results which are performed to various degrees of detail. These functions also require some creativity, intuition based on experience, and human judgment, and these cannot be completely quantified.

System analysts and designers must identify the design objectives and design limitations of a missile and establish their relative importance to satisfy the needs of a customer. Design variables are identified to be manipulated and to be constrained. Designers must then synthesize candidate missile systems before analyzing and evaluating them. In the initial design phases, synthesis consists of conceptualizing the missile characteristics from a set of characteristics; for example, the number of stages, type of propulsion system, type of control, or aerodynamic configuration. It might be theorized that the best

synthesized missile could be generated automatically, but all combinations would have to be enumerated and evaluated by the computer. This is not possible at this stage of design. As the design progresses, automatic synthesis becomes even more difficult because of the dimensionality of large complex systems. System selection is confronted by similar problems, since for simple, well-behaved small dimensional problems it may be redundant to optimize the system. But as the development and the dimensionality increase, formal methods may fail, and the engineer may rely more and more on his intuition and judgment. System analysts and designers must select design objectives to be modified or deleted when infeasible systems have been proposed, and set a course for generating other synthesized systems.

Question 9. What should be the IPAD level of application?

- a. Preliminary design?
- b. Detailed design?
- c. Final analysis?
- d. Can all be included in the system as a natural progression of the design process?

The IPAD system should be used in all missile program phases, including system studies, preliminary design, detailed design, testing, production, and operations. Since the design process is iterative, each activity builds on the previous activities. But since all program phases consist of both creative and noncreative activities, the IPAD system with its optimal interface between the designers and computer can be used to reduce the noncreative activities throughout the entire program.

Emphasis on problem-solving activities changes during a program with time or task. Results of a design problem in one phase set the design objectives and limitations for the other phases. The IPAD system would allow for this continuity in time and design activity through its data management capability in storing and retrieving missile characteristics and trade-study decisions. The system could also serve as a source of information to assist the project managers in determining progress.

Question 10. What are the cost or product benefits that can be achieved through use of this program (e.g., simplicity, reliability, economy . . .)?

In missile design, the IPAD system will decrease the routine, noncreative, data-handling activities of the designer, in effect reducing the program cost and time. Some of the designer's effort will be reinvested in performing more tasks. These tasks should result in a better-quality, higher-reliability product, and lower costs due to fewer engineering changes.

The IPAD system will also enhance the designer's creative activities because of its capability for near-real-time experimentation. The short response time should increase the designer's creative momentum, allowing him to synthesize more missile systems with greater continuity of thought in the iterative design process. The results will be a better-quality missile system.

Question 11. Are some existing data bases (e.g., materials data bank) practical to fit into an IPAD missile design system?

The existing data bases can and should be integrated into an IPAD missile design system. Some of the information which should be included covers material properties, propulsion data, aerodynamic data, armament data, and physical constants.

These data bases would greatly aid system analysts and designers to synthesize missile systems and perform analysis by helping in material selection, aerodynamic shape, propellant thermal chemical performance, and other factors. A materials property data base is almost a necessity for a missile design system. All existing material properties could be stored for instant retrieval and could be constantly updated as new materials and properties become available. A large amount of time is currently spent by the designer in searching for data on materials in handbooks, catalogs, and brochures when this information could easily be stored in data banks. Some data (for example, lethality data) may be classified and therefore may not be easily stored or found. The system design would have to provide for access to classified data.

Section 3

THE MISSILE DESIGN PROCESS

The missile design process can be defined by first determining an engineering design methodology, then identifying and describing the primary subsystems of a typical tactical missile, and next identifying and describing the primary functions performed.

3.1 ENGINEERING DESIGN METHODOLOGY

A concise overview of engineering design can be obtained, following the procedure described in reference 4, by considering three independent dimensions. The first dimension, program phases, represents the time element in engineering design, with each phase or time block separated by major milestones. The next dimension, the logical problem-solving functions, represents the logical steps which are taken to solve every engineering design problem. The third dimension, systems, represents the products that may be developed, such as aircraft, missiles, and buildings. In the missile field, the system blocks may be further divided into ground-to-ground, ground-to-air, air-to-ground, or other types of missiles. In combination, these three dimensions represent a methodology of the engineering design.

3.1.1 Program Phases

The time dimension may be described by the set of design activities performed in each program phase. These activities are separated by major product milestones which are the primary decision points in the life of a product. There are usually five program phases called (1) system studies, (2) preliminary design, (3) detailed design, (4) production, and (5) operations. These phases and their primary interfaces are shown in figure 1.

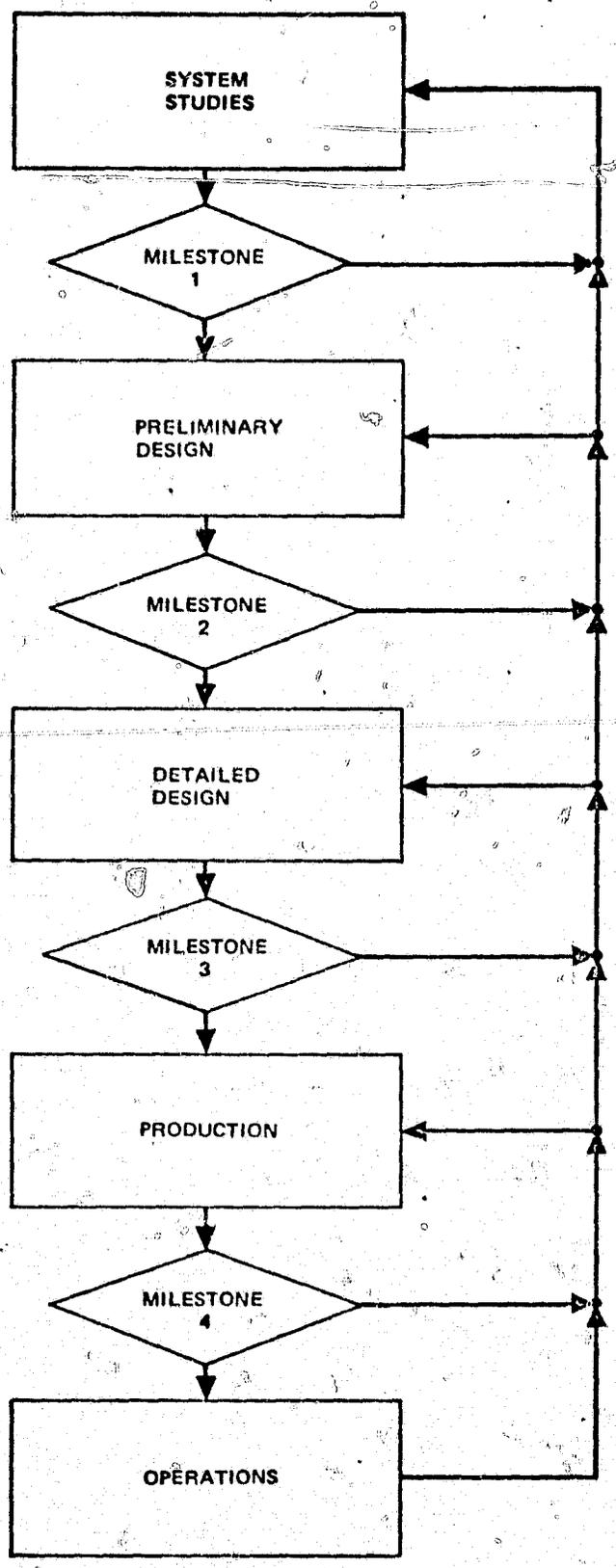


Figure 1.—Program Phases

The exact number of phases and their names may vary from product to product, but similar engineering design activities are always performed in development. Most of the engineering design activities occur in the system studies, preliminary design, and detailed design phases. As a product progresses in the phases, the engineering analyses becomes more complex.

In the system studies phase, systems of opportunity are chosen which the contractor believes will meet the needs of a customer. He performs a top-level, conceptual design on many systems to provide a technical description of the systems and program plans so that candidate systems may be selected for further study. This phase usually identifies one or more systems which the contractor hopes to pursue in the next phase, and defines the research activities required to support the system development. The system concept is selected in this phase and the objectives and requirements are defined for its subsystems. In the case of missile systems, this definition is generally made by a Government agency after a review of studies performed by contractors.

The system design is determined in the preliminary design phase, based upon some figure of merit and constraints. Unlike the system studies phase, the preliminary design phase concentrates on only one system. After the design is reviewed and a decision has been reached to develop the system, the project advances to the detailed design phase.

Detailed design is similar to the preliminary design phase except that the number of alternative systems has been greatly reduced. The activities performed in this phase, although basically the same as in preliminary design, are extended to a greater level of detail with emphasis on the design of subsystems and components.

In the production phase, the physical system is manufactured to the program and technical specifications which have been developed in the other phases. Engineering activities in production include determining the sequence, material flow, and floor layout for manufacturing operations, designing tooling and test jigs, and establishing a quality control program.

The objectives of the operations phase are to determine the best use of the system and to support the customer in the use of the system. These problems are usually integrated with the engineering design activities, since the design requirements depend on the operational activities.

3.1.2 Logical Problem-Solving Functions

The second dimension in the engineering design process includes six logical problem-solving functions: (1) perform problem definition; (2) perform system synthesis; (3) perform system analysis, (4) perform system optimization; (5) select system, and (6) document results. A flow chart of these functions is presented in figure 2. It should be noted that emphasis on a given function may vary with the different phases.

This dimension allows engineering design to be viewed as a process for generation and flow of information. The flow of information of these functions is multiplexed and is expressed in a given format at given times. Also, for large systems, many design activities will be performed in these functions, thereby increasing the complexity of the process.

The function "perform problem definition" defines the objectives and design limitations of the system. This function is usually initiated by a system specification or customer need. Since problem-solving is done in an iterative manner, objectives and design limitations are continuously changing. If candidate systems cannot be found to satisfy the problem as defined, then design objectives and limitations are modified or deleted. The objectives and limitations become increasingly detailed and gain greater confidence with iteration in the system analysis.

The "perform system synthesis" function identifies the candidate systems which are to meet the design objectives and limitations. The synthesized systems are the result of the problem definition and the select system functions. If the synthesized systems cannot meet the objectives or limitations

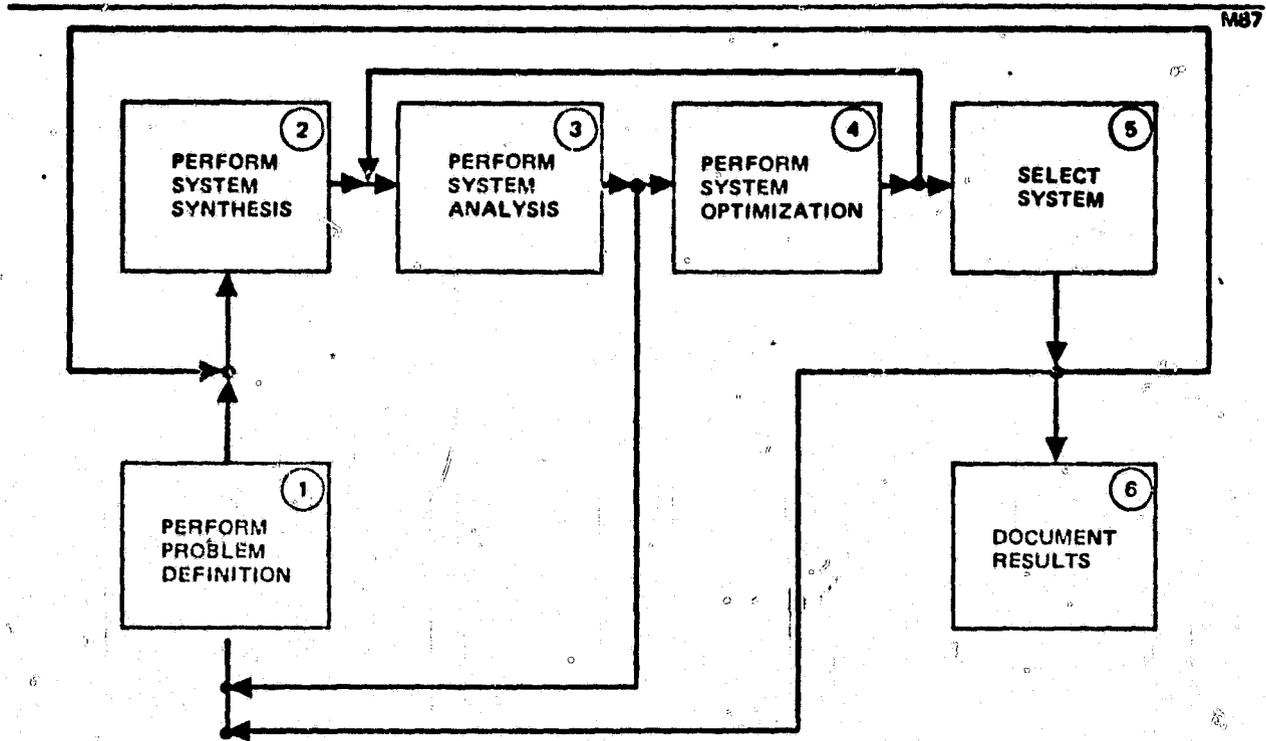


Figure 2.—Logical Problem-Solving Functions

or if their figures of merit are not considered "good," then other systems are synthesized. This cycle continues until the decision-maker judges that he has identified the best system.

The "perform system analysis" function determines the behavior of the system. The results of this analysis are used in subsequent iterations to define the problem in greater detail, utilizing the "perform problem definition" function. The analysis provides additional detailed design objectives and constraints for subsequent design problems that may occur in any program phase. The analysis is also used by the "perform system optimization" function, when optimization is desired. This function ("perform system optimization") changes the design variables so that design limitations are satisfied and the figure of merit of the system is extremized. System optimization is usually integrated with the "perform system analysis" function. Together, these two functions may be performed many times for a given design problem. They also add new details in the design problem.

The "select system" function is used to select the best system, to modify or delete certain system objectives and limitations, or to synthesize more systems. This function uses the information generated from the "perform system optimization" and "perform system analysis" functions. For optimization problems with a small number of variables, the "select system" function may achieve the same objectives as "perform system optimization." But as the dimensions of the problem increase, the possibility of other factors affecting the selection process increases and intuition and judgment are relied on more than formal techniques. If a system cannot be found to meet the design constraints, then the violated constraints must be deleted or modified or more candidate systems must be synthesized.

The "document results" function generates system specifications in the required formats. This is done so that design problem continuity is achieved and program plans can be made for the next phase. Planning includes the determination of schedules, allocation of resources, selection of performance measures for program evaluation, and development of techniques for program control.

3.1.3 Dimensions of the Engineering Design Process

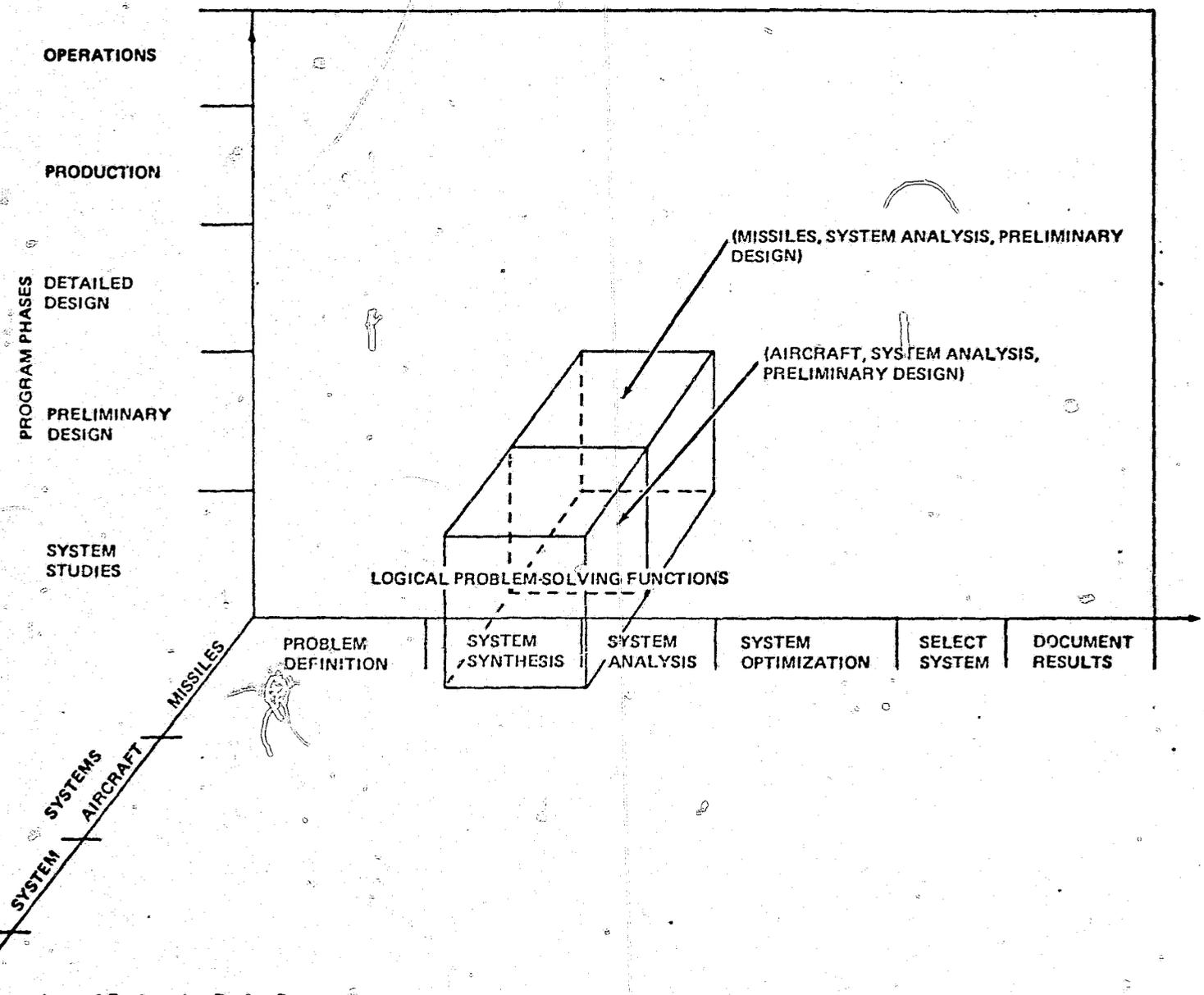
The three dimensions — program phases, logical problem-solving functions, and systems — may be combined as shown in figure 3 into a form which represents a model of the engineering design process. These three dimensions represent all the knowledge, facts, models, and techniques required for the development of engineering systems. A given coordinate or cube in the system engineering model establishes the system, program phase, and logical problem-solving activity. In many cases, there may be similarities in activities for different systems. For example, structural analysis of bridge systems and a structural design problem of missile systems may be similar.

In summary, the following primary characteristics of the engineering design process are important in analyzing and evaluating various engineering design systems (designers, computers, techniques, etc.) used in the process:

1. Engineering design may be viewed as consisting of three dimensions, program phases representing time, problem-solving functions representing logic, and systems representing products. The logical problem-solving functions apply to all systems and to all program phases.
2. Engineering design may also be considered a process for the generation, control, and flow of information. The information is generated, modified, and deleted in an iterative manner.
3. As a program progresses, design activities become more detailed.
4. The process employs formal techniques, intuition, and judgment.

3.2 TACTICAL MISSILE SYSTEMS

In this section, typical tactical missiles of the Army Missile Command are described to identify the primary disciplines involved in their engineering design. The subsystems and their various classes — for example, in the discipline of control, two classes might be thrust vector and aerodynamic control — are described to ensure that a complete missile computer program library can be determined.



20

Figure 3.—Dimensions of Engineering Design Process

3.2.1 Tactical Missile Description

A profile of a typical tactical surface-to-air missile is shown in figure 4, which illustrates two propulsion stages, the payload stage, and the primary subsystems and components. The missile shown has two solid-propellant rocket-motor stages and an infrared (IR) guidance seeker. It is assumed that the missile would be rail-launched, so launch lugs are also shown. Movable aerodynamic fins are assumed for control. The four control fins and four, fixed tail fins are shown in a conventional cruciform arrangement. Pitch or yaw control would be achieved by moving opposing control fins in unison. Roll control or roll-rate damping would be achieved by differential deflection of opposing fins.

The major subsystems and the primary physical disciplines involved in designing the typical missile are indicated in table 1. Other disciplines required in the engineering design process are cost-estimating, reliability and maintainability, and flight mechanics.

3.2.2 Tactical Missile Subsystem Classes

For each major subsystem of a tactical missile, various classes of subsystems may be selected and synthesized to form a missile system. In some design problems, the classes depend on the mission. They then become the object of the system analysis, optimization, and selection functions in engineering design. Consequently, their identification and the computerized models used in the design process are required to determine the applicability of the IPAD system to missile design.

The Army has three types of tactical missiles: surface-to-surface, surface-to-air, and more recently, air-to-surface. In the future, an air-to-air missile may also be developed for helicopter defense. For each of these missions, candidate propulsion, control, and guidance subsystems are identified.

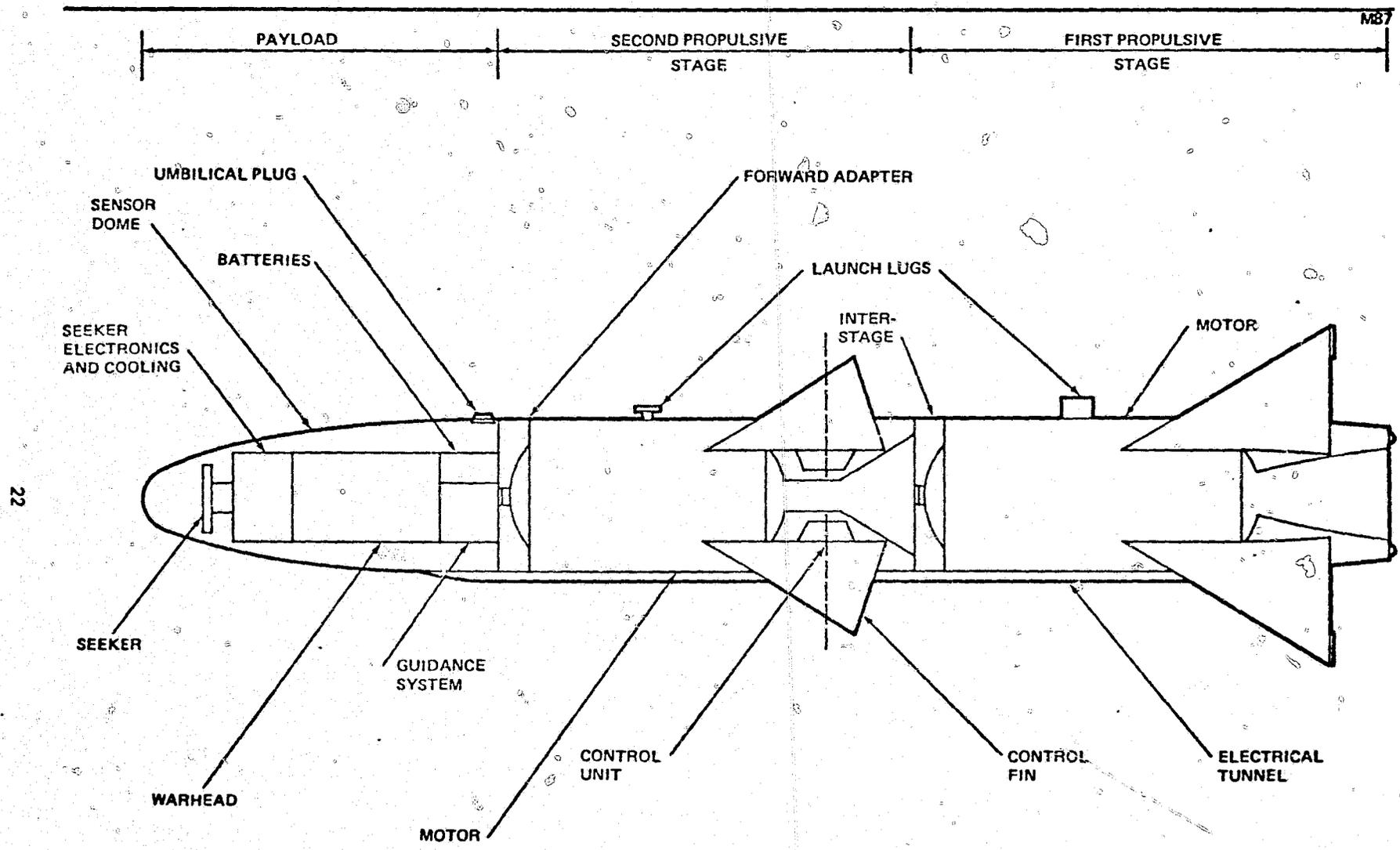


Figure 4.—Typical Tactical Missile Profile

TABLE 1
TYPICAL TACTICAL MISSILE SUBSYSTEMS

Subsystem	Description	Applicable Disciplines
PROPULSION STAGE		
Main propulsion	Includes primary propulsion unit, ignition system, safe and arming device, nozzle and blast tube, and air intakes if applicable. (These may include solid propellant motors, storable liquid propellant motors, air-augmented solid propellant motors, turbojet, turbofan, ramjet, or integral rocket/ramjet)	Propulsion Structures Thermodynamics Mechanical Electronics Weights
Launch lugs and/or rail provisions	Structural members of the vehicle used to guide missile off launcher	Structures Guidance and control Weights
Control unit and fins	Movable aerodynamic control surfaces which provide body axis control. Includes control surface actuating subsystem	Guidance and control Aerodynamics Thermodynamics Structures Mechanical Weights
Aft fairing/interstage	Load-carrying aerodynamic fairing extending from the motor aft skirt to the end of the nozzle (fairing) or to the forward end of the first propulsion stage (fairing/interstage)	Structures Thermodynamics Weights Aerodynamics
Separation system	Jettisons expended booster stage	Mechanical Structures Electronics Guidance and control Weights
Fixed aerodynamic fins	Maintains static aerodynamic stability and lift capability	Aerodynamics Thermodynamics Structures

TABLE 1 - Continued

TYPICAL TACTICAL MISSILE SUBSYSTEMS

Subsystem	Description	Applicable Disciplines
PROPULSION STAGE (Continued)		
Antennas and beacons	Antennas to receive commands or detect guiding beam; beacons to augment tracking by radar	Electronics
PAYLOAD STAGE		
Nose fairing and sensor dome	Provides environmental protection for payload section components and aerodynamic shape to minimize performance losses. Provides signal transparent window for sensor; e. g., optical dome	Structures Thermodynamics Aerodynamics Weights Materials (radome)
Seeker and seeker electronics	Includes sensor (e. g., radar, IR, TV, and microwave radiometer optics) for acquiring and tracking target and associated gimbaling mounts, torquing subsystems, and electronics	Optics (if applicable) Guidance and control Electronics Structures Weights
Seeker cooling system	Provides means of maintaining temperature of IR seeker detectors within acceptable signal operating resolution range (if applicable)	Electronics Thermodynamics Structures Weights
Warhead	Includes warhead, safe and arming, and fuzing devices	Structures Electronics Weights Armaments
Guidance system	Includes inertial reference unit, autopilot, guidance and control electronics and computer, transmitter, and receiver	Guidance and control Electronics Structures Weights
Power supply	Batteries or auxiliary power unit provide power and heating to electronics. Thermal battery initiates pyrotechnic warhead events	Electronics

TABLE 1 - Concluded

TYPICAL TACTICAL MISSILE SUBSYSTEMS

Subsystem	Description	Applicable Disciplines
PAYLOAD STAGE (Continued)		
Umbilical plug	Allows external power supply, sensor coolant supply, and missile checkout prior to launch	Electronics
Forward adapter	Aerodynamic fairing extending from the nose fairing to the forward connection joint of the adjoining propulsion stage	Structures Thermodynamics Aerodynamics Weights

The surface-to-surface missile covers the spectrum from the Dragon for antitank use to the Lance for battlefield support. Surface-to-air missiles range from the Redeye and Stinger to Hawk and SAM-D. The air-to-surface category is currently represented by TOW, Hellfire, and the air-defense suppression missile (ADSM) concept. There are no Army missiles yet designed for the air-to-air mission. However, this might be a secondary capability for, say, the Hellfire or Stinger missiles if they were carried on attack helicopters. This capability would provide a defense against enemy helicopters and tactical aircraft.

Candidate propulsion units that are most likely to be considered for each mission category are listed in table 2. When more than one propulsion stage is required, more than one type of propulsion option may be chosen. For example, the Nike Ajax employed a solid-propellant rocket booster with a liquid-propellant rocket interceptor stage. Representative subsystem classes and applications are presented in table 3.

3.3 FUNCTIONS PERFORMED IN THE MISSILE DESIGN PROCESS

The missile design process, as noted previously, can be divided into program phases, with each phase providing for a sequence of activities divided by major milestones. The major milestones are concept review, preliminary design review, and critical design review. The phases and their

TABLE 2

TACTICAL GUIDED MISSILE SUBSYSTEM CLASSES

Mission	Propulsion	Controls	Guidance
Surface-to-surface	Solid propellant rocket Liquid propellant rocket Turbojet/turbofan Ramjet Integral rocket/ramjet	Aerodynamic fins Thrust vector control Reaction control system (solid)	RF command Inertial TV and low-light-level TV Laser Forward-looking IR and IR Wire-guided Simplified inertial guidance system Dual-mode
Surface-to-air	Solid propellant rocket Ramjet Integral rocket/ramjet	Aerodynamic fins Jet interaction External burning	IR homing Radar homing RF command Dual-mode
Air-to-surface	Solid propellant rocket Liquid propellant rocket Turbojet/turbofan Ramjet Integral rocket/ramjet	Aerodynamic fins	RF command Radar Laser Inertial Forward-looking and IR TV and low-light-level TV Wire-guided Dual-mode
Air-to-air	Solid propellant rocket	Aerodynamic fins Thrust vector control	IR homing Radar homing Laser homing Wire-guided

major milestones are presented in figure 5. The functions performed in the engineering design process and in the different phases are presented in this section.

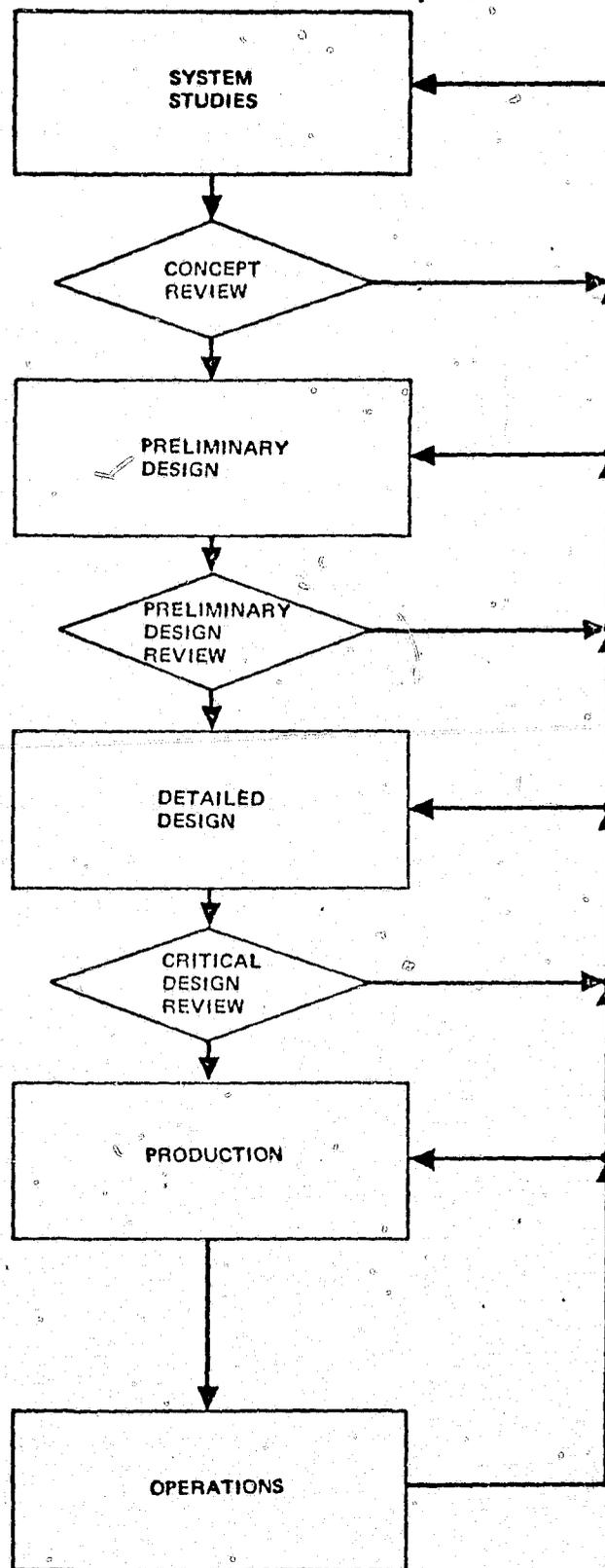


Figure 5.—Missile Program Phases

TABLE 3
SUBSYSTEM CLASSES AND APPLICATIONS

Subsystem	Subsystem Class	Application
Propulsion	Solid-propellant rocket Liquid-propellant rocket Turbojet/turbofan Ramjet Integral rocket-Ramjet	Dragon, SAM-D, Pershing Lance Harpoon, Turbo-Condor Bomarc SA-6 Gainful (USSR)
Control	Aerodynamic movable fins Thrust vector control Reaction control system Jet interaction External burning	Hawk Pershing Dragon UpSTAGE UpSTAGE
Guidance/Sensor	Infrared Radar Laser RF command Inertial Simplified inertial guidance system Wire-guided/optical	Redeye, Chaparral Hawk Hellfire, Stinger alternate Nike Hercules Pershing Lance TOW

3.3.1 System Studies Phase

The system studies phase generates program plans, conceptual design characteristics of missile systems, and selected missile projects which the contractor wishes to pursue. This phase produces the preliminary technical and program characteristics of the selected missile systems. Research activities are also identified and are pursued in this and the next two design phases. The first-level expansion of functions is presented in figure 6.

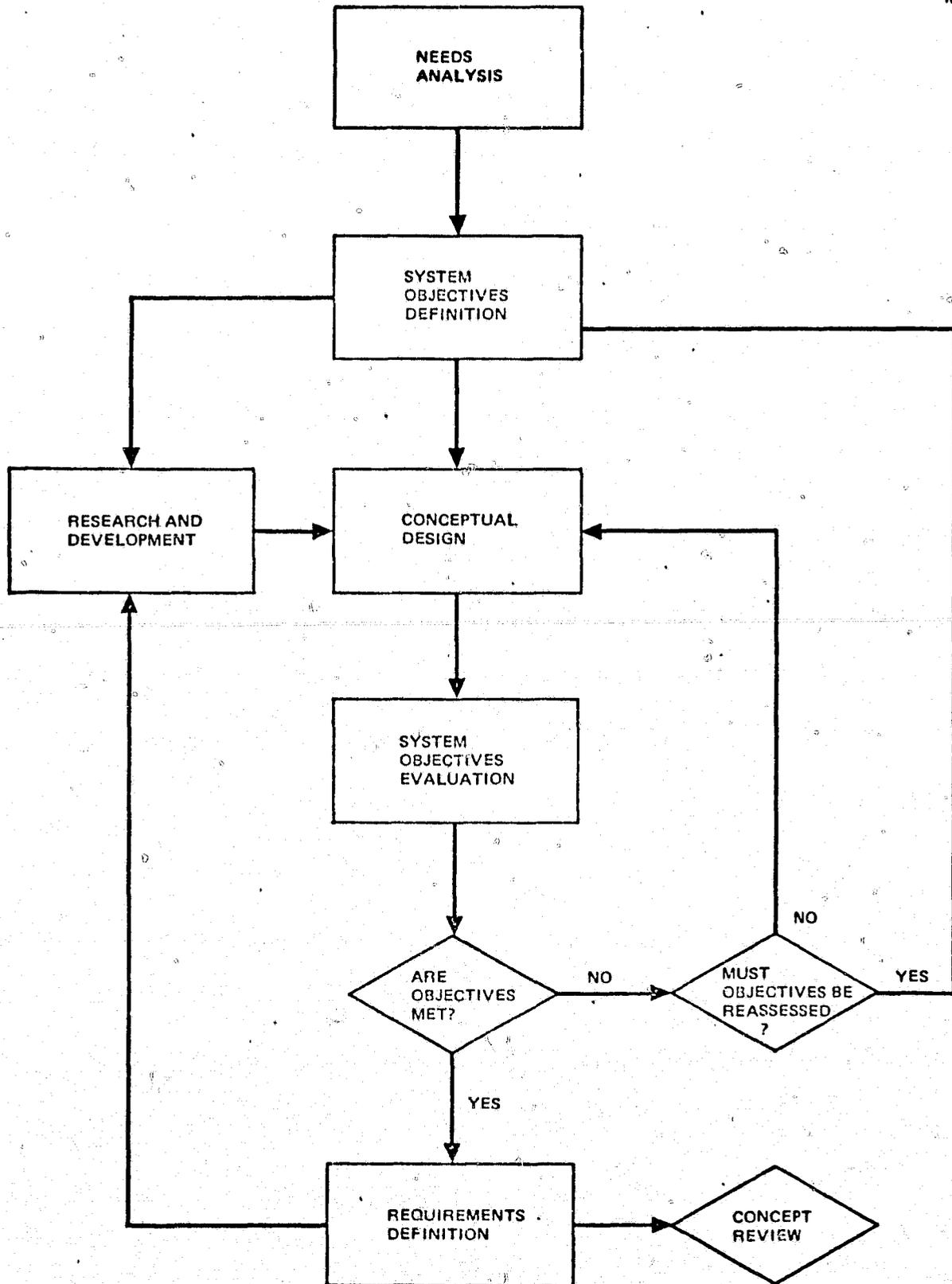


Figure 6.—System Studies

A "needs analysis" is conducted to identify the need for a new or improved missile system or to counter current or projected threats or enemy tactics. The initial identification is generally performed by a Government agency; however, in some instances, this function may be performed by a contractor for the appropriate agency. Based on a generalized preliminary definition of the needs, the contractor performs a capability evaluation in terms of manpower, facilities, technology, competition, or other factors to determine where he can provide the most effective service.

The "system objectives definition" function provides the definition of the missile system objectives and limitations, from which the requirements for the individual segments of the system are derived. This function includes the definition of the target, its operating and performance characteristics, its related defense systems (where applicable), and any other data which would affect the missile system requirements.

The type of launch platform and its environment, the target acquisition and tracking subsystem, and the command, control, and communications segment are also identified in this effort. This function is generally performed by a Government agency, but may also be performed by a contractor.

From these definitions, the requirements for individual missile segments are derived in terms of performance capability and gross operating conditions. In the definition process, areas may appear where advances in performance, analysis, and design would be needed to satisfy or enhance the missile system objectives. Identification of such areas provides objectives and tasks for supportive research and development work.

The definition function uses the results of other functions performed in the system studies phase, including evaluation of the system objectives of the conceptual design, human decisions made with respect to the designs, and modification of the design objectives and their limitations.

The "research and development" function represents the research and technological development work performed to advance the state of the art of

missile systems by advancing subsystem performance and analytical and design capability. The scope of this effort may be determined from the requirements identified in the "system objectives definition" function and through continuing contractor-directed research and development efforts. The effort may be aimed at advancement or improvement of control systems or material systems, development of smokeless propellants to avoid detection, or other purposes. The effort may also be directed toward the development of computer codes to enhance analytical capability and the performance of tests to obtain additional information about subsystems not easily analyzed, such as the performance of airfoil control configurations in the presence of a missile body. The results of these activities are provided for application in any or all of the missile program phases.

The "conceptual design" function synthesizes system concepts based on the previously defined design objectives and limitations. Trade studies are performed for each subsystem, providing a parametric data base for subsequent subsystem evaluations. For example, the number of powered stages and associated velocity staging ratios may be evaluated based on range and time of flight to the target.

Concurrently, types of propulsion systems, aerodynamic shapes, control systems, structural designs, packaging arrangements, and other factors are evaluated. The result is a base of parametric data on missile performance and configurations. Alternative missile configurations are subsequently evaluated in terms of compliance with the defined objectives and limitations. These sizing and trade study functions are currently computerized and the interdisciplinary trades are performed to obtain the optimum missile system based on the initial data. Evaluations are made of all major system segments and subsystems. Subsequent syntheses of total systems provide alternatives for evaluation of system performance and effectiveness without the need for additional major trade studies on subsystems. The results of the research and development activities, if available, are integrated into the conceptual design activities. Updated information is incorporated in the design as it becomes available and its effects are evaluated.

The "system objectives evaluation" function determines the performance and effectiveness of the candidate systems synthesized in the "conceptual design" function. The systems are evaluated using typical operational scenarios to assess each major subsystem's capability and to determine the impact of operational constraints or deficiencies on the total system capability. For example, a scenario might be used to determine whether various types of terrain impose adverse constraints on the tracking subsystem and therefore increase the missile circular error of probability on impact, thereby reducing the kill probability. The subsystem performance is assessed in relation to the defined objectives as a continuing part of the design effort.

The function "are objectives met?" determines the degree of system compliance with the established design objectives and limitations, and consequently identifies deficiencies in subsystem performance. This process is iterated until (1) a system is synthesized which fulfills the objectives, or (2) it is determined that all of the objectives cannot be met and some of them must therefore be deleted or modified. The function "must objectives be reassessed?" determines whether other candidate missile systems must be synthesized or whether system objectives must be modified or deleted. In addition, the reassessment function, at this point, results in a selection of the system. The selection is generally made by the contracting agency, with the contractor providing information on such topics as system performance, subsystem trade studies, and program data generated in this phase.

After the system objectives and limitations have been met, the technical characteristics or requirements of each major system segment are documented. Typical technical characteristics established in this phase are presented in table 4. These characteristics become requirements or specifications. They are usually prepared in sufficient detail to permit independent design efforts to be performed on the major subsystems. They are also the technical data base for the design objectives and limitations used in the next phase. But before the next phase begins, the contracting agency usually conducts a concept review.

TABLE 4

TYPICAL MISSILE SYSTEM REQUIREMENTS

Top-Level Requirements	First-Level Requirements
Mission objectives	Flight envelope Threat definition Range or time of flight to intercept point Circular error of probability Lateral maneuver
Warhead, or prime payload, or both	Target type Required system lethality Target vulnerability
Launch and handling environment	Operating temperature range Vibration and shock limits Type of launch (e. g., mobile ground launcher or aircraft)
Firing criteria	
Geometry	Size Launch or handling Signature (radar, optics, or both)
Reliability and maintainability	Probability of obtaining objectives

The second-level functions for the system studies phase and a composite of the functions are presented in figure 7. This figure summarizes the types of design activities which occur in this phase. An analysis is performed on the primary missile functions to determine the computer program library required for missile design (see Sections 4 and 5).

3.3.2 Preliminary Design Phase

The objective of the preliminary design phase is to increase the depth of the technical specifications and program plans for the missile system. Design objectives and limitations arrived at in the system studies phase are used to establish the missile system requirements. The design trades and system performance evaluations are established in greater detail than in the conceptual design function performed during the system studies phase. The first-level expansion of functions performed in this phase and their interfaces are presented in figure 8. This phase begins after the concept review and selection. It terminates with a preliminary design review by the customer, who checks the technical and program information to be sure the design will meet the missile requirements before the contractor selects the system.

The missile system requirements established in the system studies phase are used in defining the design objectives and constraints, which in turn are used to generate subsystem designs. They provide consistency in requirements for subsequent analyses and designs. An example of a design objective might be the desire to use an existing launch platform, which would place constraints on the launch lugs or locations of rail attachments, or on umbilical locations for ground support equipment. Whether this would affect the missile design would have to be determined.

The subsystem design objectives and constraints may be modified or some may be deleted as the design process continues. However, any changes in design objectives and constraints which affect other system segments such as the launch platform or the command, control, and communications subsystem must be communicated to the appropriate analytical and design groups of subcontractors concerned with these segments.

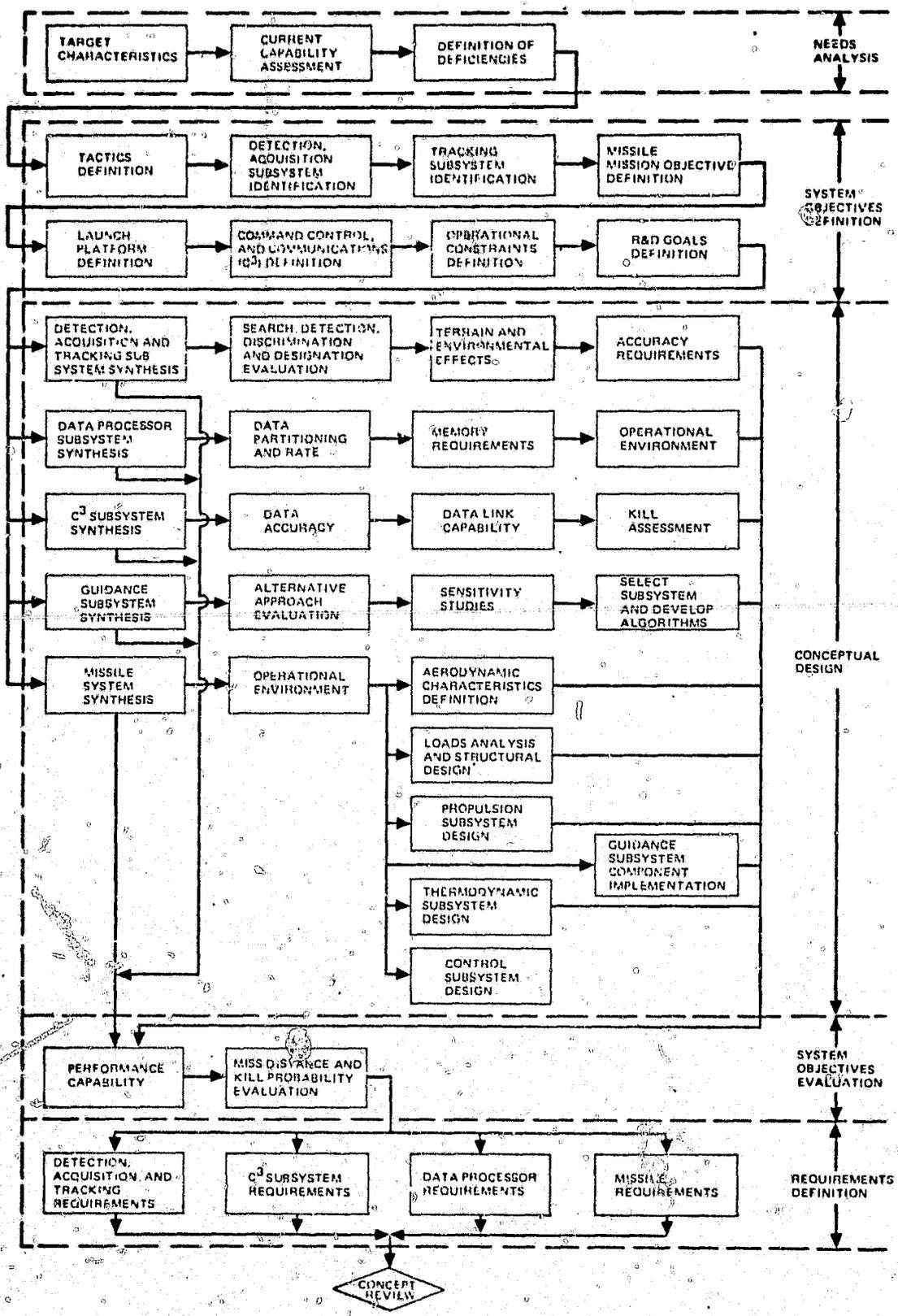


Figure 7.—Second-Level System Studies

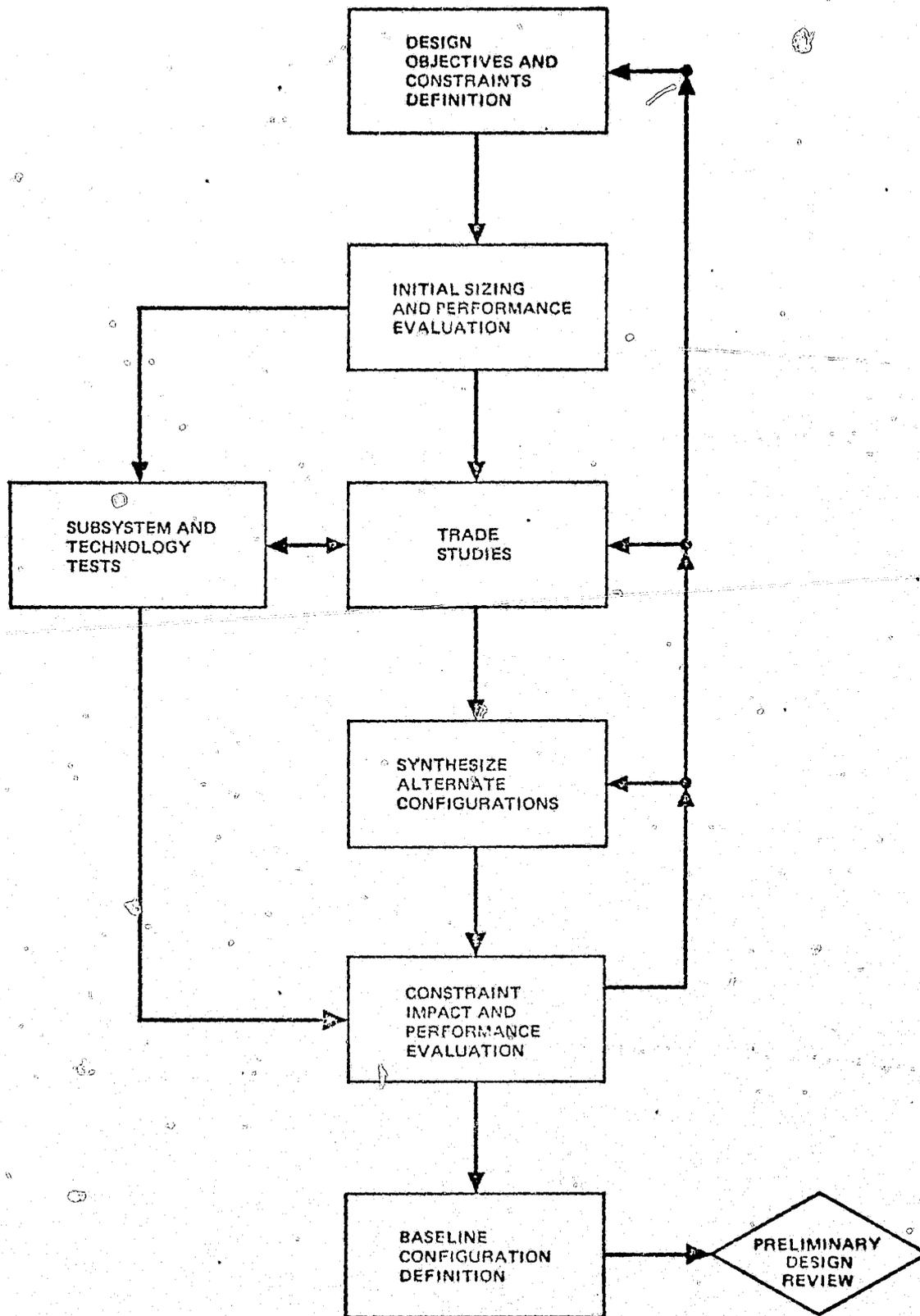


Figure 8.—Preliminary Design

An initial missile synthesis and a performance evaluation are made from the first sizing analysis. This is done from the best estimate of the subsystems selected, the conceptual design, and the performance requirements established in the system studies phase. They generate a reference configuration upon which more detailed analyses and design studies may be performed. The normal starting point is the final configuration synthesized in the system studies phase or a slightly modified version of the configuration resulting from an analysis of the design objectives and constraints. Some subsystem tradeoffs may be performed at the outset to provide a more definitive base for sizing. This effort may also point out the need for subsystem and technology tests to provide data for subsequent trade studies. Subsequent missile sizings and evaluations are performed in an iterative manner as required later in this phase.

In-depth trade studies are made in the technical disciplines identified as important in the system design. The initial missile configuration and performance data are used for these studies. A close communications link is maintained between the disciplines to ensure correct relationships and continuity of effort. For example, an initial flight kinetics study will be made to determine the number of propulsion stages and the optimum velocity staging ratio. The propulsion engineers must be in contact with the flight mechanics personnel so that the proper propulsion system is selected for each stage and the supporting trade studies justify the selection. While the intent of this effort is to provide an optimum design for each subsystem, it also provides a data base from which "off-optimum" subsystems may be selected to obtain an optimum design for the total missile. As the design process continues, other trade studies may be conducted.

The function "synthesize alternate configuration" identifies candidate missile systems for evaluation. These systems utilize selected subsystem and technical characteristics. The data base generated from the trade studies and the results of the performance evaluation are used to synthesize the candidate missile systems.

The subsystem and technology tests provide data to substantiate subsystem performance and serve to increase credibility in the subsystem designs. This function is tied to the trade studies and performance evaluation activities, permitting a maximum use of the technical data which is generated. These tests could include, for example, wind-tunnel tests and ablative materials tests.

The function "constraint impact and performance evaluation" determines the performance and evaluates candidate missile systems. This function provides an evaluation of the relationships among the various disciplines. For example, the shape and size of an aerodynamic airfoil may result in insufficient lift characteristics to meet the end-game maneuver requirements. If this happens, some of the individual design trades will have to be redone to obtain more appropriate subsystem characteristics. This process is continued until one or more viable designs which can meet the system design objectives and constraints are synthesized.

The objectives of the "baseline configuration definition" function are to select and document the preliminary design of the missile system. At this point, one or more missile systems have already been found to satisfy the design objectives and constraints. The selection may be made from a performance, cost, risk, or growth standpoint, or from a combination of these. This selection is generally made by the contracting agency during a preliminary design review, which must be completed before the next phase can begin. After the selection, the design is considered "frozen" and any subsequent change must be evaluated in terms of its effect on the total missile system.

The second-level functions for the preliminary design phase of a typical missile and a composite of the first- and second-level function are presented in figure 9. The figure summarizes the types of activities which occur in this phase. The actual activities, of course, depend on the missile system objectives. An analysis and an evaluation of the primary functions are presented in Sections 4 and 5.

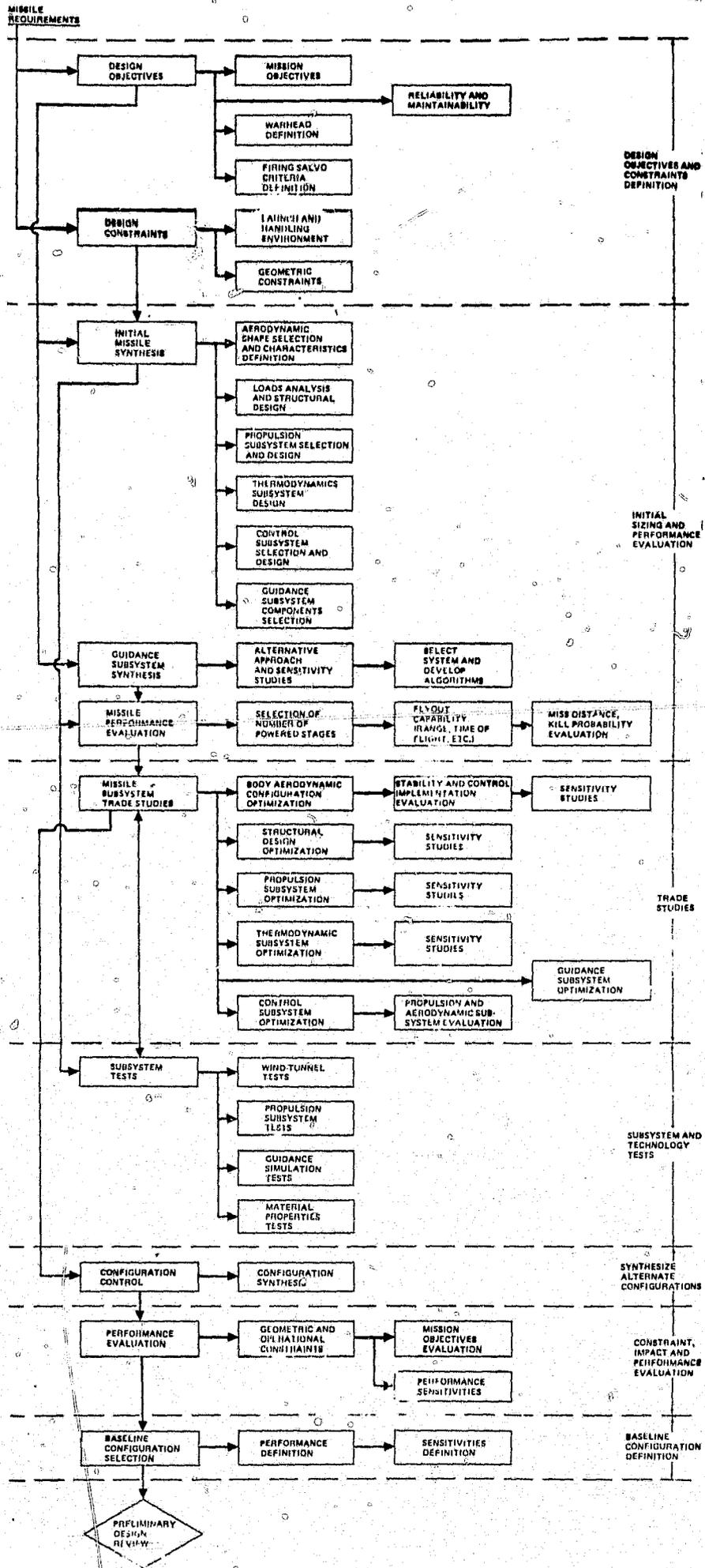


Figure 9.—Second Level Preliminary Design

3.3.3 Detailed Design Phase

The detailed design phase begins after the preliminary design review and terminates with a critical design review held before the design drawings are released to start the production phase. Detailed subsystem design and testing are performed for the missile system during this phase. The overall design, with a missile configuration and subsystem definition, is prepared before detailed design begins. The major subsystem tradeoffs have also been completed. In detailed design, the activities are concentrated on components and elements of each subsystem. The primary first-level functions and their interfaces for this phase are presented in figure 10.

Some limited trade studies may be performed in the detailed design phase; however, these studies are usually not the type that affect the missile design or its performance capability (e. g., interdisciplinary trades). The design activities are monitored by a configuration control board which ensures that proposed design changes will not have an adverse effect on missile performance. Once the missile configuration is "frozen" at the close of the preliminary design phase, this function provides the primary interdisciplinary link for the various subsystem designs. On completion of the subsystem detailed design, a critical design review is held by the contracting agency. The contractor's final design and the related performance and operating characteristics are reviewed to ensure that they comply with the total system objectives.

A detailed design is typically performed on the structural propulsion, thermodynamic, control, guidance, and sensor subsystems. On completion of the design effort, the subsystem component drawings and specifications are generated and released. These components and subsystems are subsequently manufactured and tested to validate the design and subsystem performance. Results of ground and flight tests are analyzed and evaluated in this phase to substantiate subsystem and system performance.

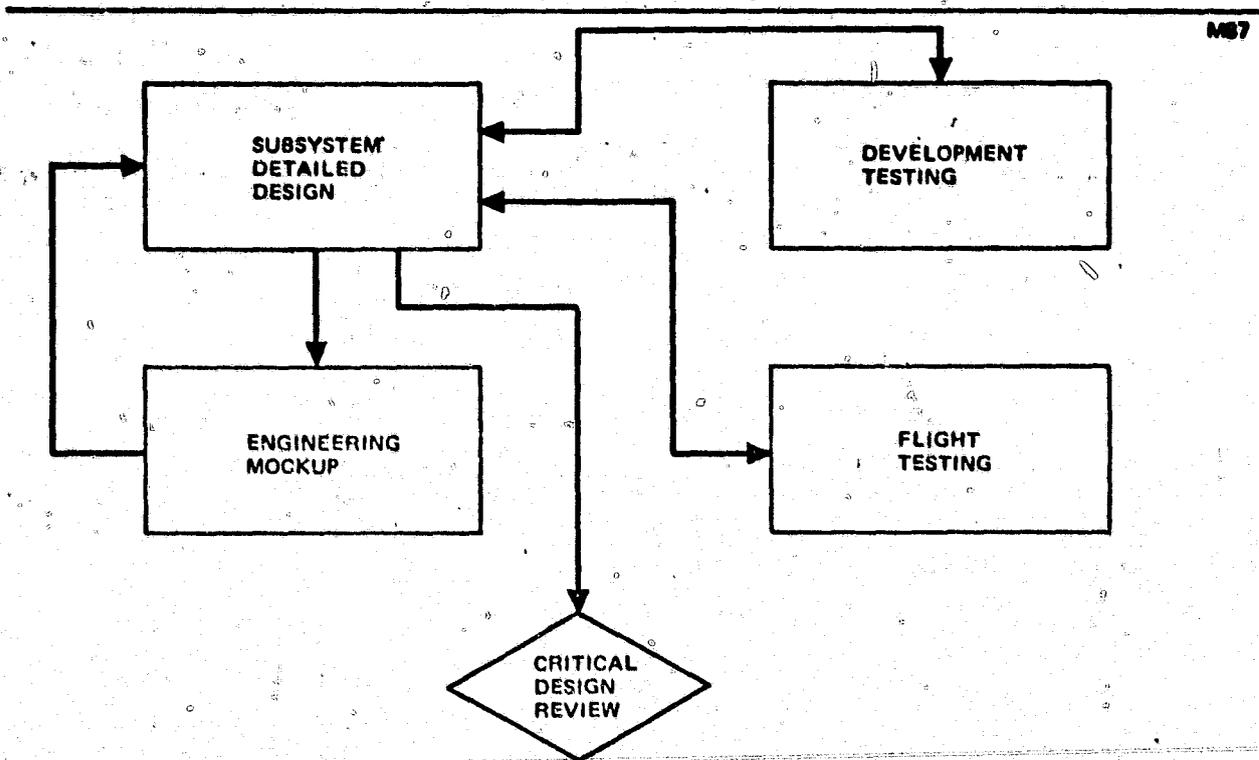


Figure 10.—Detailed Design

An engineering mockup of the total missile is made to assist in defining the final missile assembly process and to provide a method of checking out the subsystem packaging arrangements. The mockup is also used to determine the required lengths of electrical line and desired routing paths. Subsystem components or representative models are mounted as defined by the design drawings and provide a means for the technologist to verify his subsystem's packaging requirements. Discrepancies or improvements in the packaging design are fed back to the subsystem designers so that appropriate changes can be made in the final design drawings.

The "development testing" function verifies the subsystem design by evaluating its performance and qualifies the subsystem for the operational environment to which it will be subjected. For example, the propulsion subsystem will be initially static-tested to verify performance capability. This test will verify technical characteristics such as thrust, mass flow rate, and specific impulse. The subsystem will also be subjected to vibration and shock loadings and, perhaps, temperature-cycling and then tested for performance. This verifies the performance in a more realistic operational mode and further verifies the adequacy of the manufacturing operations. Tests will also be performed on the total missile, usually with a static launcher and target, to verify the flight and pseudo-engagement capability. These tests are conducted prior to the flight test rounds.

The "flight testing" function performs total system tests in a simulated operational scenario and provides for the initial training of user personnel. Some of this training will have begun in the latter part of the development testing effort. The contractor maintains responsibility for the test and training functions with appropriate support from subcontractors. The primary tasks are reduction and evaluation of flight-test data to ensure compliance with the design objectives and mission requirements. Variations from the desired performance or operational characteristics will be fed back to the subsystem detailed design function for correction or disposition.

The second-level functions for the detailed design phase of a typical missile and a composite of the first- and second-level functions are presented in figure 11. The figure summarizes the types of activities which occur in this phase. The actual activities, of course, depend on the missile system requirements. An analysis and an evaluation of the primary functions are presented in Sections 4 and 5.

3.3.4 Production Phase

In the production phase, the subsystems are manufactured into the complete missile. The primary functions and their interfaces are summarized in figure 12. The manufacturing process includes the production and assembly of tooling as well as the complete vehicle.

During manufacture, quality assurance methods and techniques are used to monitor the finished missile components and subsystems to detect discrepancies in the hardware from the drawings and specifications. Any discrepancies or deviations noted are flagged for engineering review and disposition. The sustaining engineering function reviews anomalies in production hardware and determines their effect on missile performance. If a redesign is the best answer to the problem, the data and redesign objectives are transmitted to the sustaining engineering function for the necessary action.

3.3.5 Operations Phase

The personnel assigned to the missile system are to remain ready and proficient during the operations phase. The primary functions required to accomplish this are summarized in figure 13.

BASELINE CONFIGURATION DEFINITION

M87

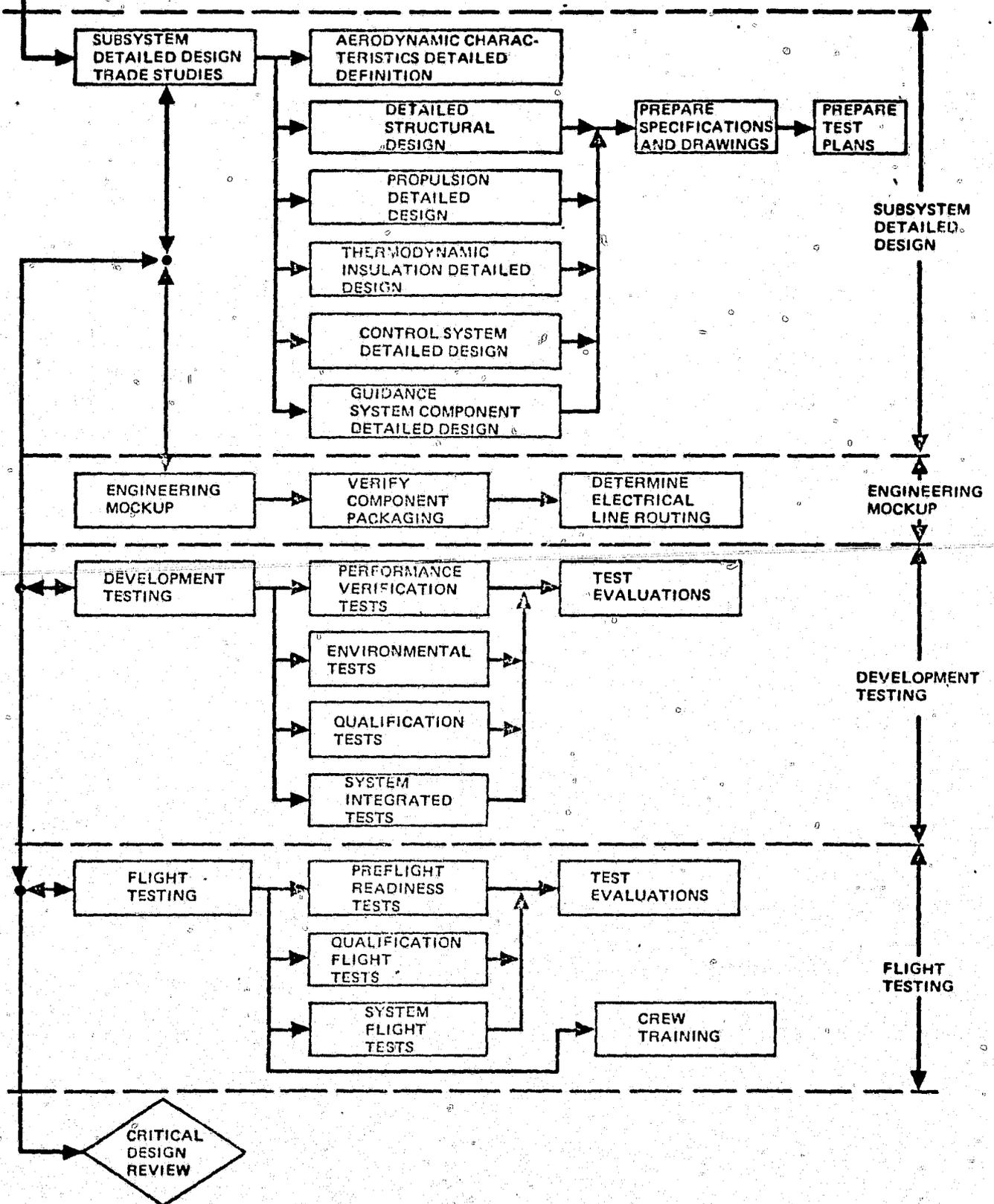


Figure 11.—Second-Level Detailed Design

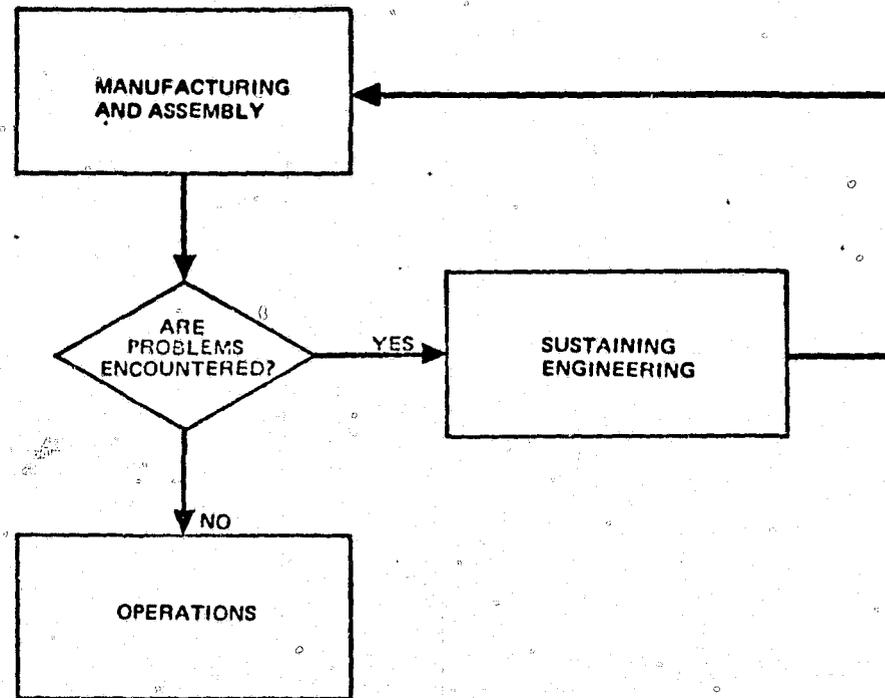


Figure 12.—Production

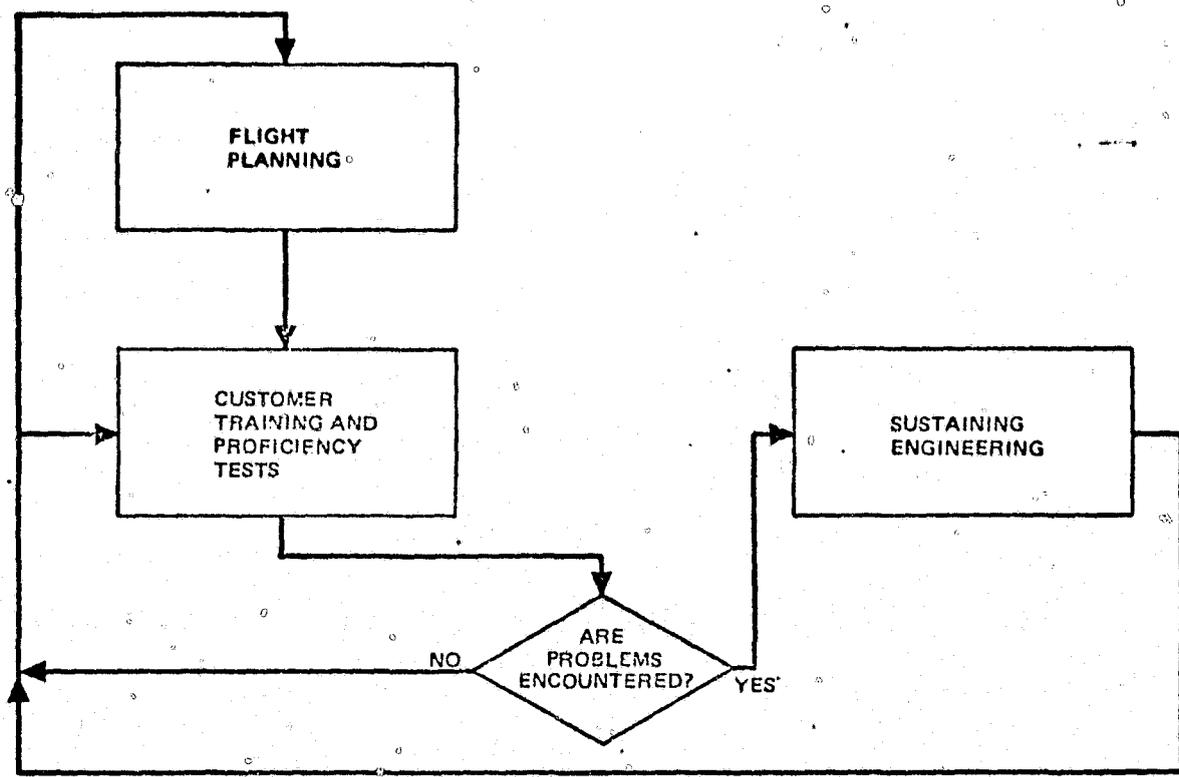


Figure 13.—Operations

The "flight planning" function supports the customer in any flight tests that may be conducted in the program. In addition to preparation of test plans, this effort may involve data analysis and evaluation to ensure that the missile system performance is adequate in all operational scenarios in which the system may be needed.

During the continuing activities of the "customer training and proficiency tests" function, problems may arise in the missile hardware. If problems occur, they are described and their effects on the missile system are determined for subsequent analysis and evaluation. Recommendations for possible redesign may be made by the sustaining engineering function.

Section 4

ANALYSIS AND EVALUATION OF THE EXISTING MISSILE DESIGN PROCESS

This section presents the results of an analysis and evaluation of the current design process for a typical tactical missile. Design activities are treated by program phase for each major engineering discipline in a typical missile program. Deficiencies are also noted in the current missile engineering design process.

4.1 SYSTEM STUDIES PHASE

The engineering objectives of the system studies phase are to determine research activities, conceptualize design characteristics of missile systems, and select missile projects which a contractor wishes to pursue. The design activities performed in this phase for a typical tactical missile are considered by discipline in the following text.

4.1.1 Aerodynamic Design

In the system studies phase, cursory studies are performed leading to the selection of a configuration which can meet the mission objectives and design constraints. The geometric parameters of the initial configuration selected may be varied in order to optimize the performance of the missile. Estimates of the aerodynamic characteristics are also provided to the pertinent technologies. This information is used to determine static margin histories and aft-to-drag relationships. The design activities require manual effort to synthesize and select configuration geometrics. The aerodynamic design activities in this phase are presented in table 5.

TABLE 5
SYSTEM STUDIES - AERODYNAMICS

Activity	Input	Output	Can Be Automated?
Select candidate configuration geometries	Mission performance requirements and constraints	Fuselage parameters such as length/diameter ratio, nose shape, air inlet location, and booster motor arrangement Wing and/or fin parameters such as aspect ratio, wing loading, leading-edge sweep angle, airfoil shape, and thickness ratio	No

TABLE 5 - Continued
SYSTEM STUDIES - AERODYNAMICS

Activity	Input	Output	Can Be Automated?
Generate aerodynamic force data	Configuration geometry Specification of the spread of Mach number and Reynolds number for the design flight envelope	Aerodynamic force coefficients for trimmed flight as a function of Mach number. (Components of forces may be resolved along body axes or wind axes)	Yes

4.1.2 Thermodynamic Design

Thermodynamic design is employed to control the temperatures of all critical components of a missile. In flight regimes where aerodynamic heating is not significant, the main task is to control payload and structural temperatures resulting from the propulsion subsystem and maintain a controlled environment for temperature-sensitive subsystems. In flight regimes with high Mach numbers (usually greater than 2), an exterior thermal protection subsystem may be required.

In the system studies phase, once the type of missile is known, an evaluation is made to determine the kind of thermodynamic design work needed. A methodology is adopted for alleviating aerodynamic heating, if necessary, and support is provided to the systems analysis group to allow tradeoffs to be made using generalized techniques. Guidelines are established for conceptual design to minimize the potential thermodynamic problems and to reduce the weight of the thermal protection subsystem. At the end of the system studies phase, design requirements are established for both the thermal protection and environmental control subsystems. These requirements are used in the preliminary design phase for performing more detailed analyses. The thermodynamic design activities are summarized in table 6.

4.1.3 Flight Mechanics Design

During the system studies phase, engineers specializing in flight mechanics compute parametric flight-performance data and first-cut trajectory parameters for various conceptual designs. In addition, the flight mechanics engineers may design target trajectories or flight paths for use in engagement analyses and in development of guidance laws. The design activities for flight mechanics are summarized in table 7.

Two-degree-of-freedom flight simulations are used to generate representative missile flight paths to, say, a specified intercept or impact point. Launch weight and booster burn time may be parametrically varied to yield a spread

TABLE 6
SYSTEM STUDIES - THERMODYNAMICS

Activity	Input	Output	Can Be Automated?
Evaluate missile category to determine type of thermal support required	Missile category flight velocity, altitude	Types of thermal problems to be anticipated	No
Assemble methodology to provide system conceptual design studies with equations, or data for initial tradeoffs Establish aerodynamic heating methodology, types of thermal protection systems to be used	Types of thermal problems for missile category, velocity, altitude, angles of attack	Preliminary methodology for type of aerodynamic heating, thermal protection, and environmental control subsystems	No

TABLE 6 - Continued
 SYSTEM STUDIES - THERMODYNAMICS

Activity	Input	Output	Can Be Automated?
<p>Establish guidelines for conceptual designs which minimize thermal problems</p> <p>Establish guidelines for trajectories and external configurations to reduce aerodynamic heating levels and weight requirements of the thermal protection subsystem</p>	<p>Methodology, typical trajectories, typical configurations</p>	<p>Thermal constraints</p>	<p>Partly</p>

TABLE 6 - Continued
 SYSTEM STUDIES - THERMODYNAMICS

Activity	Input	Output	Can Be Automated?
<p>Provide requirements for components of the environmental control subsystem</p> <p>Provide requirements for thermal protection</p>	<p>Conceptual design trajectory</p>	<p>Preliminary requirements for thermal protection and environmental control</p>	<p>Partly</p>

TABLE 7
SYSTEM STUDIES - FLIGHT MECHANICS

Activity	Input	Output	Can Be Automated?
System objectives definition	Customer requirements (category of missile)	Critical system design parameters - payload, range, velocity, and load factors	Partly
Conceptual design Optimum burn time Trajectory shaping Optimum staging ratio	Range, payload, velocity, load factor requirements, aerodynamics, propulsion, weight	Gross weight, propellant weight, burn time, preliminary point-mass trajectories, and staging ratio	Yes
System objectives evaluation Payload, time, performance evaluation	All of the above	Differences in customer requirements and concept capabilities. Assessment of feasibility of concept	Partly

of average velocity, intercept velocity, and launch acceleration. These trajectory studies provide the basis for sizing the motor and determining optimum staging ratios for multistage concepts.

After primary missile parameters are selected to define a conceptual design, a nominal two-degree or three-degree-of-freedom design trajectory is simulated. This trajectory provides data on variations of design variables with time, such as dynamic pressure, axial and lateral acceleration, angle of attack, and Mach number. These variables are then available for use by other disciplines.

After the initial design configuration is defined, maps of flight performance capability may be required. Two-degree or three-degree-of-freedom simulations can be used, for example, to compute launch and intercept zones. Flight limitations imposed by design constraints such as maximum lateral acceleration, maximum seeker look-angle, or aerodynamic instability are superimposed on the performance maps to define these zones.

4.1.4 Structural Design

In the system studies phase, the type of structural material and element sizes are initially selected based on experience and modified to meet any established design constraints. This permits the synthesis of a conceptual design of one or more candidate vehicles from which preliminary trajectories, operational environmental conditions, and flight loads are defined. The typical design activities are summarized in table 8.

TABLE 8
SYSTEM STUDIES - STRUCTURES

Activity	Input	Output	Can Be Automated?
Review new developments in structures state of the art	N/A	N/A	No
Recommend candidate structural concepts	Mission requirements and design constraints	Structural concepts for use in layout and weight estimates	No
Provide drafting and layout for conceptual design studies	Missile geometric configuration and physical constraints	Conceptual inboard and outboard profiles Auxiliary equipment sketches	Partly
Provide parametric weight estimation techniques and estimated configuration weight breakdown	Structural concept, configuration parameters, inboard and outboard profiles, subsystem list	Gross weight vs payload or performance parameters. Structural mass fraction and propellant mass fraction	Yes

Flight bending loads, launch loads, and handling loads are defined and shock and vibration criteria are established. Packaging studies are performed to define payload and missile envelopes. Subsequently, analyses are performed to define the size and weight of the structural components (e. g., skin thickness, frame size, and spacing) for the associated critical loading conditions. Material selections are updated where necessary as more definitive environmental conditions are obtained. Weight, center of gravity, and mass moment of inertia summaries are maintained and updated throughout the studies.

A great deal of the structural data is initially generated in a parametric manner. This permits configuration changes to be made from system synthesis and subsequent performance evaluations with a minimum effect on the structures technologist. After specific configurations of interest have been identified, these configurations are analyzed to provide a more detailed structural definition.

Research and development programs are surveyed and those which offer improvements for the missile design — perhaps in the design itself or in manufacturing techniques or cost — are identified. Areas where new research or redirection of existing research could provide desired improvement are also noted.

4. 1. 5 Propulsion Design

Through propulsion design, the propulsion subsystem is selected and propulsion performance data are generated for the missile system evaluation. The primary propulsion design activities are summarized in table 9.

The definition of system requirements and design goals become design constraints and performance requirements. Design criteria are prepared to satisfy these requirements. This activity involves engineering judgment to determine the characteristics of the technology required to satisfy the overall mission objectives. This is a nonhardware-oriented activity from which

TABLE 9

SYSTEM STUDIES - PROPULSION

Activity	Input	Output	Can Be Automated?
Propulsion subsystem objectives definition	Mission and customer requirements and restraints, environmental requirements, weight and envelope limitations, maximum gravity, etc.	Cost, weight, and performance target values Preliminary design objectives and constraints including total impulse, mission duty cycle, time to target, and dormancy	No

TABLE 9 - Continued
 SYSTEM STUDIES - PROPULSION

Activity	Input	Output	Can Be Automated?
Needs analysis - Propulsion research goals	<p>Current and planned technology programs</p> <p>Mission, vehicle, and propulsion subsystem requirements</p>	<p>Definition of adequacy of current and planned technology programs and additional programs required</p> <p>Data bank of propellant thermochemical and formulation data; propellant characterization and physical property data; and advanced hardware concept characterization</p>	Partly

TABLE 9 - Continued
 SYSTEM STUDIES - PROPULSION

Activity	Input	Output	Can Be Automated?
<p>Propulsion subsystem requirements definition</p>	<p>Mission duty cycle, total impulse, environmental limits, storage, size and weight requirements, etc.</p>	<p>Subsystem design requirements - propulsion subsystem design parameters (e. g., liquid or solid, thrust vector control, deflection angle, mass fraction, specific impulse, thrust-to-weight ratio, burning time and propellant weight). Envelope restraint and key operating parameters (e. g., chamber pressure)</p>	<p>Partly</p>

TABLE 9 - Concluded
SYSTEM STUDIES - PROPULSION

Activity	Input	Output	Can Be Automated?
Propulsion conceptual design	<p>Mission requirements and trajectory restraints</p> <p>Propulsion subsystem design parameters and subsystem requirements (such as specific impulse, thrust, burn time, propellant weight, and mass fraction)</p>	<p>Subsystem design data - parametric data, vehicle gross configuration, and performance optimization requirements</p> <p>Concept selection</p> <p>Stage hardware configuration, gross vehicle mass properties, size performance, and preliminary characteristics</p>	Partly

preliminary requirements for the propulsion subsystem are developed. System objectives such as maximization of performance and range and minimization of size, weight, and cost are defined.

Potential propulsion concepts are reviewed to determine whether it is possible to satisfy the system objectives. This effort involves evaluation of system objectives to confirm that propulsion concepts can satisfy requirements such as the specified time to reach the target or stepped thrust.

Design activities in the concept and definition function are aimed primarily at generating propulsion performance data and at selecting a propulsion concept. To choose a propulsion concept, the following must be determined: (1) the subsystem size and performance requirements (e. g. pressurization, storage, propellant-feed systems, and engines for liquid subsystems; and ignition, motor, nozzle, and thrust vector control; (2) the applicable subsystem elements (methods of pressurization, storage, propellant-feed systems, motor, packaging, etc.); and (3) the technology development required for candidate subsystems.

4. 1. 6 Sensor Design

Sensor technology plays a major role in design whenever candidate guidance schemes are to use some part of the electromagnetic spectrum to obtain data on target position or velocity. One of the first sensor technology tasks is to evaluate the targets to determine which region of the spectrum might be useful. In this evaluation, a quantitative estimate must be made of the target's physical characteristics and electromagnetic signature. The estimated signature will suggest whether or not passive homing might be feasible and if so, whether infrared, radar, TV, or microwave radiometer sensors might be preferable. If semiactive or active guidance schemes are considered, then the reflected signature—i. e., the cross section—must be estimated for, say, laser and radar illumination.

Candidate sensors that are found suitable from a target signature standpoint must then be evaluated against the mission scenario to establish the operational requirements of the sensor (e. g., day or night and all-weather operation). The requirements imposed by the specified countermeasures environment must also be assessed.

The operational requirements must then be translated into functional and performance requirements for the sensor design. For example, it may be convenient to identify the sensor functions needed in the prelaunch, launch, midcourse flight, terminal homing, and other mission phases. For example, the sensor lock-on function may be assigned to the prelaunch or midcourse phase. Or a narrowing of the field-of-view may occur between midcourse flight and terminal homing. Performance requirements must be established for such parameters as detection range, detection probability, and tracking rates. These performance requirements provide the basis for the first specification of seeker parameters. In addition, the sensor specialist coordinates his efforts with the thermodynamicist in the selection of the materials and shape of the radome or optical dome to maximize acquisition and tracking capability. Sensor technology design activities during the system studies phase are summarized in table 10.

4.1.7 Guidance and Control Design

In the system studies phase, potential guidance and steering designs are selected to meet mission requirements. This entails a review of guidance and steering functions through target engagements, launch, and midcourse and terminal phases. Using information on the target scenarios and desired miss sensor errors, launch aiming errors, cruise and guidance time, and missile peak-gravity capability, guidance laws are identified and evaluated. Guidance laws are then selected which achieve the desired miss distances with a given peak gravity. The relationship between launch errors and terminal corrections is also examined to determine which guidance laws provide the most satisfactory conceptual design.

TABLE 10

SYSTEMS STUDIES - SENSOR TECHNOLOGY

Activity	Input	Output	Can Be Automated?
Target evaluation and definition	Threat category tanks, armored personnel carriers, convoys, ammunition dumps, aircraft, emplaced weapons, radars, helicopters, etc.	Signature data	No
Establish mission-critical factors	Physical environment - meteorological, backgrounds, countermeasures (smoke, jammers, etc.)	Day/night/all-weather mission sensor operational requirements	No
Establish seeker design requirements	Mission objectives, target signatures, operational environment, weapons and tactics, operational requirements, countermeasures, circular error of probability requirement, guidance law	Functional requirements for launch, midcourse guidance, terminal homing Performance requirements - detection range, detection probability,	No

TABLE 10 - Continued

SYSTEMS STUDIES - SENSOR TECHNOLOGY

Activity	Input	Output	Can Be Automated?
Establish seeker design requirements (continued)		signal-to-noise ratio, sensitivity, frame time, field of view, resolution, tracking rates, size, weight	

General control system characteristics are also established in this phase and the type of control sensors that seem reasonable for the mission are determined. The dynamic environment associated with the target engagement is a starting point for system studies. From a knowledge of velocity, altitude profile, and mass properties, an estimate can be made of control moment and bandwidth required for the conceptualized missile. In addition, the type of control best suited to various flight regimes (e. g., aerodynamic, thrust vector, or reaction control) can be examined. Further estimates of maximum missile gravity and body rates will permit selection of suitable control instrumentation for this application. The guidance and control design activities are summarized in table 11.

4. 1. 8 Costing Design

The costing activity during the system studies phase can be divided into three parts. First, the cost of using various existing vehicles to perform the mission of the proposed vehicle is determined. This requires searching data banks and collecting estimated costs of vehicles that are similar to the proposed vehicle. Information is obtained on such items as first-unit cost, costs in various quantities, development cost, total hardware cost, operations cost, maintenance and repair experience, support equipment requirements, availability and capacity of manufacturing facilities, operational manpower requirements, and deployment facilities. This type of information could be stored on computer tapes for popular vehicles. The taped data would have to be updated periodically to reflect latest information. The vehicle quantities and other information would be input to permit estimating the cost of using the existing vehicles. The calculations involved in changing these quantities so they are compatible with the new system requirements could also be automated.

The second step in costing involves determining the development, investment, and operational cost of modifying existing vehicle hardware to perform the mission established for the new program. Inputs are prepared to describe the type and extent of hardware modifications in terms of the cost of the existing hardware. This type of estimating does not lend itself to

TABLE II

SYSTEM STUDIES - GUIDANCE AND CONTROL

Activity	Input	Output	Can Be Automated?
Select applicable guidance laws for launch, mid-course, and terminal phases	Engagement profile, missile peak-g, miss requirements, available guidance time, launch errors, sensor noise, cruise time	Guidance-induced g requirements, preliminary miss distance, select guidance law for various engagement phases (e.g., wire for boost, proportional navigation for terminal)	Partly
Establish control system characteristics	Conceptual missile velocity altitude profile, target scenario, and approximate mass properties	Control moment and bandwidth to meet mission requirements for launch, midcourse, and terminal phases Select types of control moment available during various flight phases, aerodynamic, thrust vector control, jets (RCS)	Partly

TABLE 11 - Continued
 SYSTEM STUDIES - GUIDANCE AND CONTROL

Activity	Input	Output	Can Be Automated?
Establish control system characteristics (continued)		Select type of autopilot altitude, rate, acceleration	
Determine available control instrumentation	Maximum g and body rates required for mission - i. e., launch g, peak-maneuver g for midcourse correction, altitude maneuvers	Select types of gyros, accelerometers, and altitude reference qualified for mission	Partly

automation because the type and locations of the modifications are different for each vehicle considered. Additional inputs are required to quantify the impact of these hardware modifications on program costs, including such data as changes in the number of vehicles, changes in operational cycles and schedules, changes in support equipment, and changes in manpower. After the modifications are identified and quantified in an acceptable manner, the actual calculations can be automated, but they are only a minor part of this effort.

The time involved in these first two activities varies considerably, depending on the type of detail expected in the output and the extent of the hardware modifications required. If an existing vehicle cannot be used or modified to be compatible with the proposed mission, this effort consists of only a few rough calculations to substantiate the unsuitability of existing models. On the other hand, the effort can be complex if the modifications are subtle and an attempt is made to provide more than top-level costs in the output.

The final portion of this effort is approximating the program cost of the proposed new vehicle. This involves selecting the appropriate cost-estimating relationships and algorithms for the particular vehicle and using these equations to calculate the program cost. The equations must be compatible with the type and magnitude of the known parameters of the vehicle. The selection of the relationships could be automated only if all the parameters were always provided in a never-changing, predetermined set of definitions, the state of the art never advanced, and the system remained the same as it was when the cost-estimating relationships were originally formulated. These conditions will seldom if ever prevail in a new missile design.

Cost-estimating relationships are used to obtain the top-level costs with the design parameters, such as weight, volume, pressure, material, size, type, and quantities, defined by other engineering disciplines. The program cost is arrived at with calculations of a gross research cost, a development, test, and evaluation cost, a representative first-unit hardware cost, an investment

hardware cost, other investment costs, and operational costs. These calculations could be automated. These design activities are summarized in table 12.

4.1.9 Armament and Ordnance Design

System studies related to armament and ordnance are conducted to establish the system operating boundaries. These boundaries, together with those established by other disciplines, will form the basis for selecting a desired missile configuration. For armament and ordnance, there are four primary design activities (see table 13) involved in producing parametric curves or tables of data defining the system boundaries for ordnance.

The first design activity evaluates mission requirements for the missile to determine types of warheads needed, and provides the basic sizing for the missile. In this activity, the weight and type of warhead and the miss distance of the missile are evaluated in terms of the effects on single-shot kill probability. This analysis generates the tradeoff information for the primary system. The computer programs used are relatively short and simple. Lumped-target vulnerability data are used. Missile size, encounter environment, and miss distance are estimated.

Once a tentative warhead weight and type have been chosen, secondary design activities can be started to yield tradeoffs for the estimated diameter of the missile, the quantity of missiles necessary for standard battle situations, and the overall warhead costs. The size will be determined by a simple calculation based on the weight and type of the warhead and material density. The calculation of quantities is rather sophisticated, requiring an estimate of the standard battle deployment, a firing doctrine, tactics and range, accuracy, and kill probability data. A computer program is currently being used for this calculation at Ballistic Research Laboratory and other Government installations. The results of this calculation can be used as input to a cost-quantity relationship to compute total warhead costs.

TABLE 12
SYSTEMS STUDIES-COSTING

Activity	Input	Output	Can Be Automated?
Evaluate existing vehicles	<p>Historical data on unit costs, life, maintenance, repair, replacement, etc.</p> <p>Program requirements quantities, transportation, support equipment, facility requirements</p>	Cost of using existing vehicles for the program	Partly
Modify existing vehicle	<p>Above plus modifications required. Impact on program requirements.</p> <p>Data bank of historical cost data</p>	Cost of providing modified vehicles	No

TABLE 12 - Continued
SYSTEMS STUDIES-COSTING

Activity	Input	Output	Can Be Automated?
Select cost-estimating relationships appropriate for this vehicle	Data bank of vehicle costs Vehicle parameters for proposed missile	Cost-estimating relationships for generating costs for this vehicle using available parameters	Partly
Calculate costs for this vehicle	Selected cost-estimating relationships Vehicle definition	Gross estimate of vehicle costs: 1. Development 2. First unit 3. Investment 4. Total program	Yes

TABLE 13

SYSTEM STUDIES - ARMAMENT/ORDNANCE

Activity	Input	Output	Can Be Automated?
Evaluate missile mission requirements to determine types of warheads needed	Expected target types, target vulnerability, encounter environment, estimated miss distance	Parametric curves of estimated kill probability as functions of miss distance, weight, and type of warhead	Yes
Estimate warhead size	Warhead type, missile diameter	Parametric curves of warhead weight as a function of warhead length and type	Yes
Estimate missile quantities required	Target deployment, tactics, locale, missile range, accuracy, and estimated kill probability	Tables of missile quantities required as a function of firing doctrine	Yes (for standard battle situations)
Estimate ordnance costs	Ordnance weight, production quantity estimate	Cost as a function of units produced	Yes

The warhead size and weight can be optimized by parameterizing the inputs to the last three design activities and obtaining system warhead costs as a function of warhead weight and type and system miss distance. These activities will define the desired warhead characteristics and will also define the effects of variations in parameters to help select an optimum system.

4.2 PRELIMINARY DESIGN PHASE

In the preliminary design phase, the depth of the technical specification for the missile system is increased. Most of the design tradeoff studies are performed in this phase. The design activities for a typical missile which are performed in this phase by the primary engineering disciplines are discussed in the following text. The functions required to accomplish preliminary design have been shown in figures 8 and 9.

4.2.1 Aerodynamic Design

The aerodynamic design activities for this phase are summarized in table 14. Most of them use a variety of computer codes. A parametric configuration study, for example, is usually performed with one or two appropriate computer codes. Experimental data are fed into the aerodynamic data base whenever possible. The amount of experimental data used depends on the scope of the effort as well as on the size of the existing data base. Thus, on large programs, an experimental wind-tunnel or free-flight test may be conducted.

For the configuration selection, aerodynamic controls are defined and the expected control effectiveness is predicted. Control sizing often represents a separate design activity which supplements the basic configuration selection exercise. The design activity may rely more on experimental data than on analysis.

As a configuration is developed, the aerodynamics group provides a force and moment model for use in more detailed trajectory calculations

TABLE 14

PRELIMINARY DESIGN - AERODYNAMICS

Activity	Input	Output	Can Be Automated?
<p>Conduct parametric configuration trade studies</p>	<p>Mission performance requirements such as desired range, speed, or maximum axial and lateral accelerations</p> <p>Design constraints such as maximum diameter, span, or weight</p>	<p>Baseline configuration optimized with constraints. May include definition of nose shape, wing and fin planform, booster configuration, and air intake location and geometry</p>	<p>Yes</p>
<p>Generate aerodynamic coefficients for flight performance calculations</p>	<p>Design flight envelope (e. g., Mach number, altitude, and angle of attack)</p> <p>Configuration geometry including nose, fuselage, afterbody, wing, and tail parameters</p>	<p>Trim lift and drag coefficients as a function of Mach number, angle of attack, angle of sideslip, roll angle, and control deflection angles</p>	<p>Partly</p>

TABLE 14 - Continued

PRELIMINARY DESIGN - AERODYNAMICS

Activity	Input	Output	Can Be Automated?
<p>Generate aerodynamic load distribution</p>	<p>Critical design point conditions; e. g., maximum dynamic pressure, angle of attack, and control deflection</p>	<p>Pressure distributions over nose, fuselage, wings, fins, and control surfaces</p> <p>Aerodynamic shears and bending moments corresponding to the pressure distributions</p>	<p>Yes</p>
<p>Conduct parametric wind-tunnel tests of promising preliminary configurations</p>	<p>Design flight envelope; e. g., Mach number, altitude, and angles of attack, sideslip, and roll</p>	<p>Comparative aerodynamic force and moment coefficients of various combinations of wing, body, and tail configurations</p>	<p>No</p>

involving refined guidance and autopilot simulations. These models are actually transmitted at all levels of design, but the source of the data generally varies from mostly analytical in the early phases to mostly experimental near the end of design. Detailed distributions of pressure and shear loads are also made for use by the structural analysis group. The load distributions are usually based on analytical predictions. The performance envelope is carefully screened to ensure that the predicted loads represent the worst-case design points.

Many design activities in this phase rely on information furnished by several other technology groups. The weights group provides an estimate of the mass properties with an accuracy compatible with the level of aerodynamic analysis being performed. The flight mechanics group supplies a baseline trajectory for preparation of an envelope of the flight environment. The thermal and structural response of the airframe to the environment also affects the final aerodynamic predictions.

4.2.2 Thermodynamic Design

At the start of the preliminary design phase, the system constraints on the thermal protection and environmental control subsystems are defined, as well as other requirements. Once these have been determined, the subsystems can be initially sized. Trade studies are begun, dealing with system effects on the size of these subsystems, their weight and relative cost, and the effect of various candidate materials and thermal protection or control techniques on the subsystems. Often, the cost and weight trade-offs need to be evaluated for the environmental control subsystem in terms of increasing the temperature tolerances on the subsystem while reducing its size.

During this phase, techniques, material performance, and thermal environments are investigated and ground tests conducted to provide data for the trade studies, as well as to reduce uncertainties in the preliminary sizing

of the thermal protection and environmental control subsystems. Finally, a preliminary design is established, with two subsystems defined for this design. The thermodynamic design activities during preliminary design are summarized in table 15.

4.2.3 Flight Mechanics Design

Based on the requirements and objectives defined in the system studies phase, an initial sizing and a performance analysis are made by the flight mechanics group. This analysis uses the best available estimates of the mission objectives and vehicle description - aerodynamic coefficients, thrust history, weights, and control policy. This activity determines the missile performance. The flight environment is given in the form of simulated trajectory histories - accelerations, velocity, dynamic pressure, aerodynamic heating, angle of attack, etc. - which are to be used by other technical disciplines.

During preliminary design, the missile sizing and configuration selection must be consistent with the requirement to fly optimum paths. These optimum profiles are determined by trajectory simulations involving various thrust profiles, staging ratios, guidance laws, and other data. An optimum profile might simply mean providing the required range or payload capability with minimum gross weight. Or the optimum profile might involve considerations such as minimizing the probability of detection or maximizing the single-shot kill probability. The flight profile optimization studies lead to the selection of a nominal trajectory on which to base the preliminary design.

Through trade studies, critical mission parameters are evaluated as functions of vehicle design parameters. Flight mechanics typically determine payload or range penalties (or gains) as functions of acceleration or aerodynamic heating. Trade studies can lead to design changes or to alternative designs. Finally, a baseline configuration is selected with which to enter the detailed design phase. The flight mechanics design activities during preliminary design are summarized in table 16.

TABLE 15

PRELIMINARY DESIGN - THERMODYNAMICS

Activity	Input	Output	Can Be Automated?
Establish system constraints and requirements for environmental control subsystem Establish system requirements for thermal protection subsystem	System study results, customer specifications	Thermal protection and environmental control subsystem requirements	No
Define preliminary concepts for environmental control subsystem, establish size requirements, provide data to designers	Methodology, configuration, trajectory, materials data, subsystem constraints, structural constraints	Thermal protection and environmental control subsystem size and weight requirements	Partly

TABLE 15 - Continued

PRELIMINARY DESIGN — THERMODYNAMICS

Activity	Input	Output	Can Be Automated?
<p>Define initial aerodynamic heating loads, materials, and thermal protection subsystem weight requirements</p>			
<p>Evaluate alternative designs, concepts for environmental control subsystem in terms of size, weight, cost, etc. Evaluate need for environmental control subsystem vs broader subsystem temperature tolerance</p>	<p>Methodology, configuration, trajectories, materials, subsystem and structural constraints</p>	<p>Thermal protection and environmental control subsystem trade study results for use in design and structural analysis</p>	<p>Partly</p>

TABLE 15 - Continued

PRELIMINARY DESIGN - THERMODYNAMICS

Activity	Input	Output	Can Be Automated?
Evaluate alternative materials, concepts for thermal protection subsystem in terms of weight, size, cost, etc.			
<p>Define, conduct tests on environmental control subsystems concepts, evaluate data to support trade studies and preliminary design tasks</p> <p>Define, conduct aerodynamic heating and materials performance tests to support trade studies and preliminary design tasks</p>	Configuration, design concepts, environments	Data, correlations, trade study input information	Partly

TABLE 15 - Concluded

PRELIMINARY DESIGN - THERMODYNAMICS

Activity	Input	Output	Can Be Automated?
<p>Establish preliminary design baseline environmental control subsystems, provide necessary data to system and subsystem designers</p> <p>Establish preliminary thermal protection subsystem, provide necessary performance data to other technologies, system designers</p>	<p>Methodology, baseline configuration, baseline trajectory, materials data, subsystem and structural constraints</p>	<p>Baseline thermal protection subsystem and environmental control subsystem structural temperatures design information</p>	<p>Partly</p>

83

TABLE 16

PRELIMINARY DESIGN - FLIGHT MECHANICS

Activity	Input	Output	Can Be Automated?
Initial sizing and performance estimation	<p>Design constraints</p> <p>Mission trajectory requirements such as range, speed, and maneuver capability</p> <p>Aerodynamic force coefficients and propulsion parameters. Estimated payload weight and structural mass fraction</p>	<p>Gross weight, propellant weight, and optimum staging ratios for baseline configuration</p> <p>Preliminary point-mass trajectories</p>	Yes
Parametric trade studies	Baseline configuration, desired payoff functions, and independent design parameters to be varied	<p>Sensitivities of vehicle and mission payoff functions to variations in design parameters</p> <p>Alternative configurations and/or mission profiles</p>	Yes

4.2.4 Structural Design

In the initial structural design activity, the vibration load spectra are established for all the critical ground and flight conditions which have been defined. Tank pressures are also defined. Factors of safety are defined for structure, propellant tanks (or motor cases), pressure vessels, and lines. Missile geometry is also defined. Drawings are prepared which show major dimensions of components, packaging of payload and equipment, and field and assembly joints. A weights analysis is made to obtain weights and centers of gravity of all components. Total weight, mass distribution, and moments of inertia are calculated, tabulated, and distributed to other technologies. Acceleration loads are determined. Differential-pressure aerodynamic loads and temperature distributions are obtained from the aerodynamicist and thermodynamicist for all critical ground and flight load conditions. Corresponding axial, shear, and moment distributions acting over the length of the missile are calculated. The various types of construction and materials are evaluated and selected. Methods of manufacture and cost are determined. The structure is sized primarily by means of preliminary stress analysis. Drawings or sketches are prepared with sufficient information and detail to permit trade studies and weight revisions to be made.

Material property tests are made where inadequate data exist. Tests are also made of structural components too complex to analyze with a high degree of confidence.

The trade studies result in optimization of structural components: they are usually optimized with respect to a figure of merit such as weight or cost. The structural design activities performed during the preliminary design phase are summarized in table 17.

4.2.5 Propulsion Design

Detailed propulsion design objectives and constraints imposed by the mission requirements are defined. These design objectives will complement the

TABLE 17
PRELIMINARY DESIGN - STRUCTURES

Activity	Input	Output	Can Be Automated?
Define load spectra for all critical conditions. Select factors of safety	Transportation and handling environment, launch environment, trajectory envelope	Load spectra: ground loads, prelaunch, launch, and flight loads	Partly
Lay out general arrangement	Conceptual design and design criteria (load factors)	Drawings showing major dimensions of components, packaging of payload and equipment, field and assembly joints	Yes
Calculate mass distribution and moment of inertia	Locations of structure, payload, and equipment from general arrangement	Tabulation of weight and center of gravity of individual components, total weight, center of gravity of vehicle, mass distribution, and moments of inertia	Yes

TABLE 17 - Continued
PRELIMINARY DESIGN - STRUCTURES

Activity	Input	Output	Can Be Automated?
Calculate envelope of axial, shear, and moment loads for all critical conditions	Load spectra: ground, prelaunch, launch, and trajectory loads. Mass distribution	Preliminary design of primary structure. Structure sized by preliminary stress analysis. Type of construction materials and methods of manufacture	Yes
Subsystem and technology tests	Test article duplicating material and/or structural configuration	Test results and interpretation	Partly

TABLE 17 - Concluded
PRELIMINARY DESIGN - STRUCTURES

Activity	Input	Output	Can Be Automated?
Trade studies	One or several component configurations, a set of loads or operating conditions, some fixed parameters and constraints	Relationships between several objective functions for changes in some design parameter. Optimized objective function and corresponding values of design variables	Yes
Synthesize alternative configurations	Candidate configurations, trade studies, and design constraints	Synthesized configurations	No
Evaluating impact of constraints	Alternative configurations, loads	Evaluation of impact of constraints	No
Define baseline	Results of constraint impact and performance evaluation	Baseline configuration	No

missile system preliminary design requirements. Constraints such as maximum thrust-to-weight ratio, stage diameter or length, and maximum dynamic pressure are also defined in this phase.

The acceptability of liquid or solid propulsion systems is determined considering storage, handling, duty cycle, and any other critical environmental requirements. Criteria are determined to establish the solid-motor or liquid-rocket optimization approach. Optimization is done in terms of total system considerations for one or more of the following figures of merit: (1) performance (payload or velocity), (2) cost (development, recurring, or funding level), (3) mission requirements, (4) growth potential, (5) facility implications, (6) availability, and (7) safety and handling. Gross characteristics of the propulsion subsystem are defined, including gross weight, dimensions, number of stages, burnout velocity, velocity staging ratio, total burn time, burn time distribution, subsystem weight, and subsystem gross dimensions.

The component characteristics which are defined include: (1) thrust-time history (nominal and extreme), (2) engine/motor chamber pressure-time history, (3) grain configuration and dimensions (solid motor only), (4) propellant type (solid, liquid, etc., physical and ballistic characteristics), (5) nozzle design and performance, (6) motor case or tankage design, (7) pressurization subsystem design (liquid propulsion system only), and (8) thermal protection insulation design.

The evaluation is used to verify the performance of the subsystem selected and the preliminary design, to change and improve the design where applicable, and to provide sufficient subsystem definition to permit estimation of the recurring and nonrecurring costs of the propulsion subsystem. After the preliminary design of the propulsion subsystem has been selected, sketches are prepared to determine materials and to resolve assembly and installation problems. A few strength calculations are made to ensure the feasibility of the design. Using the design requirements established in the system studies phase and the design sketches, preliminary layouts of the propulsion subsystem are prepared. Propulsion activities during the preliminary design phase are summarized in table 18.

TABLE 18

PRELIMINARY DESIGN - PROPULSION

Activity	Input	Output	Can Be Automated?
Initial sizing and design evaluation	Potential propulsion configuration and performance requirements, such as propellant type, number of motors (engines), and delivered specific impulse	Preliminary propulsion subsystem characteristics. May include maximum and nominal operational parameters of the components, design parameters and weights Basic layout and preliminary materials selection	Partly
Parametric configuration trade studies	Propulsion system optimization criteria Mission performance criteria Design constraints	Propulsion configuration optimized including hardware subsystems (e.g., thrust vector control, pressurization, nozzle type)	Yes

TABLE 18 - Continued
PRELIMINARY DESIGN - PROPULSION

Activity	Input	Output	Can Be Automated?
Parametric configuration trade studies (continued)		Performance optimization with constraints. May include thrust-time shaping, chamber pressure, and nozzle expansion ratio optimization Sensitivity analysis of critical design and preliminary specification control parameters	
Baseline propulsion subsystem definition	Vehicle and propulsion subsystem design requirements Potential propulsion subsystem configurations	Baseline propulsion subsystem configuration Propulsion subsystem performance characteristics (nominal and 3-sigma limits)	Partly

TABLE 18 - Concluded
PRELIMINARY DESIGN - PROPULSION

Activity	Input	Output	Can Be Automated?
Baseline propulsion subsystem definition (continued)		Propulsion subsystem data book (size, performance, weight, and cost)	

EC-2

4.2.6 Sensor Design

During preliminary design, candidate seeker configurations are defined and evaluated against the functional and performance requirements. Primary and secondary seeker parameters are selected, and they are parametrically varied in computer simulations. For each seeker configuration, the combination of parameters yielding optimum performance is obtained. Sensitivity of performance to off-nominal seeker parameters is also obtained. The one design configuration which best meets the requirements, including constraints on cost and maintainability and growth capability, is then selected as the initial configuration for guidance subsystem simulations.

The parameters of the initial seeker configuration are incorporated into computerized guidance subsystem simulations and into flight mechanics trajectory simulations. Seeker performance and its effect on overall missile system performance can then be computed throughout the mission envelope. The error budget - the tolerance on seeker component performance - is estimated analytically or obtained from historical data or from vendor tests. The effect of the significant tolerances on the overall system performance is then calculated.

If the performance simulations show that the seeker configuration is adequate, then the seeker parameters are translated into hardware design requirements, with functional diagrams, electrical schematics, and interface specifications. These design activities are summarized in table 19 for this phase.

4.2.7 Guidance and Control Design

The preliminary design of the guidance subsystem involves a conceptual missile design, type of target and seeker, basic signature data, accuracy requirements, and trajectory constraints.

Seeker design alternatives, along with the preliminary controls and maneuver performance data, are considered by performing engagement success

TABLE 19

PRELIMINARY DESIGN - SENSOR TECHNOLOGY

Activity	Input	Output	Can Be Automated?
Establish baseline seeker parameters	Functional and performance requirements	Seeker parameters: optical diameter, f/no., number of detectors, size of detector, spectral region, bandwidth, output format	Partly
Parametric analysis	Measures of effectiveness and cost Factors which relate seeker parameters, alternative functional requirements, and associated parameters	Cost-effectiveness model Optimum set of seeker parameters and performance parameters Sensitivities of performance to off-nominal seeker parameters	Yes

TABLE 19 - Continued

PRELIMINARY DESIGN - SENSOR TECHNOLOGY

Activity	Input	Output	Can Be Automated?
Performance analysis to evaluate seeker	Mission and functional requirements	Estimate of seeker performance throughout mission envelope Estimate of tolerances on seeker parameters	Yes
Specify design requirements	Functional requirements, seeker parameters, interfaces, performance	Design requirements and specifications, including functional diagrams, interfaces, and controls	No

88

analysis. This analysis evaluates the available guidance, control, and vehicle design options in terms of their overall mission capability.

During this design phase, options based on terminal accuracy are also evaluated. Design trades are made between miss distance effects such as target blooming, run range, and maneuver response, and accuracy requirements established based on types of targets or warheads.

The design activity for command systems in this phase is similar to homing systems except that missile tracking must be considered and missile command reception capability must be provided. Engagement success and miss distance analyses are similar, but they must be expanded to include design parameters for multiple engagements. The guidance design activities for this phase are summarized in table 4-20.

The preliminary design activities for the controls technology include development of control moment requirements from maneuver requirements in the conceptual design, selection of the required control measurements and actuation requirements, and the initial stability and response analyses.

Both aerodynamic fin-controlled and thrust vector control types of vehicles must be sized. For the finned vehicles, flight regime, maneuver levels, and aerodynamic characteristics are used to develop fin and wing sizes, locations, and deflection requirements. Static load requirements are also specified for design of actuators and structure. For vehicles with thrust vector control, the thrust profile gimbal angle trades and requirements must be prepared.

Selection of control measurement elements involves stability and performance analyses for various available sensor combinations such as accelerometers and gyros. It also entails preparation of data for preliminary instrument design requirements such as bandwidth, accuracy, and dynamic range. Further stability analyses in this phase define gains, shaping, and filtering, and evaluate major nonlinear elements. Analyses are conducted to evaluate integration of the controls and guidance into a

TABLE 20
PRELIMINARY DESIGN - GUIDANCE

Activity	Input	Output	Can Be Automated?
Determine tracking requirements	Engagement geometry, sensor configuration, velocity, altitude, and maneuver requirements	Sensor tracking and gimbaling requirements Tracking subsystem mechanization	Partly
Guidance loop stability analysis	Sensor characteristics, tracking loop dynamics, control subsystem dynamics, flight regime, loop nonlinearities	Guidance loop stability requirements in each flight mode Sample rate, bandwidth, unstable range	Yes

TABLE 20 - Continued

PRELIMINARY DESIGN - GUIDANCE

Activity	Input	Output	Can Be Automated?
Guidance accuracy analysis and selection	Sensor noise characteristics, tracking loop noise, control dynamics, target scenario, launch errors, guidance time, cruise time, maneuver capability	Miss distance Guidance law appropriate for each flight Noise and guidance loop filtering requirements Loss of track effects Fuzing requirements	Partly

subsystem. Data on vehicle response to steering commands in terms of attitude and time response, accuracy, and bandwidth are used to optimize the control subsystem design.

This design phase results in a selected configuration for the control subsystem. It includes design of control moment elements in terms of size, shape, location, loading, and gimbal and actuation requirements. It also includes the configuration of the measurement system sensor and the gains and shaping required for stability over the total flight regime and for vehicle response compatibility with the steering commands. These design activities are summarized in table 21.

4.2.8 Costing Design

During the preliminary design phase, the costing effort starts in support of the trade studies and ends with the final estimate of the lifetime cost of the missile. The trade study portion of the effort is divided into two parts. The first part consists of studies which are easily prepared to show which alternative is superior from the standpoint of cost. The data and analytical procedures are readily available and easily applied to the vehicle under consideration. For example, a trade study may be made to decide between liquid and solid propulsion systems or to choose titanium or aluminum as the major structural material. At times, the cost of one alternative is so excessive that the trade consists of little more than documenting an obvious conclusion.

This type of trade could involve a selection between a new and untried type of propellant with promise of higher specific impulse and a proven propellant of a heavier, larger vehicle. The trade could be partly automated and handled with a minimum of manual effort. Unfortunately, few trade studies fall into this category.

Most of the trade studies are more complex, requiring detailed investigation of special characteristics at a depth that is not normally considered during the design definition process. Once these characteristics are defined.

TABLE 21

PRELIMINARY DESIGN - CONTROLS

Activity	Input	Output	Can Be Automated?
Aerodynamic fin size	Maneuver requirements, aerodynamic coefficients, mass properties, flight regimes	Fin deflection, size, actuation bandwidth and location requirements, hinge moment	Yes
Size thrust-gimbal angle requirement	Maneuver requirements, aerodynamic coefficients, mass properties, flight regimes	Thrust-gimbal angle range, actuator bandwidth	Yes
Evaluate controllability	Maneuver requirements, aerodynamic coefficients, thrust vector control characteristics, flight regimes	Select flight control mode (bank to turn, cruciform, free roll, power on/off) Control sensor requirements	Partly

TABLE 21 - Continued
PRELIMINARY DESIGN - CONTROLS

Activity	Input	Output	Can Be Automated?
Evaluate controllability (continued)		Dynamic maneuver response at various flight conditions Preliminary shaping networks Refinement of actuator bandwidth	

they usually require individual cost-estimating relationships involving effort of both cost and design personnel. Typical trade studies determine the best pressure range for the hydraulic system, the optimum tank design and bulkhead shape, the most efficient voltage level, and the type of insulation.

This complex type of study not only involves quantification of special characteristics but also requires a special analysis to determine which characteristics significantly affect cost and which should be used as decision criteria. In addition, trade studies usually require data on a number of cost sensitivities such as the dollar value of additional performance or of an increase in reliability. By their very nature, these trades are tailored to individual programs and are unlikely candidates for automation.

Following the trade studies, the cost-estimating relationships that are used for calculating the cost of the vehicle must be reexamined, with equations revised as needed to reflect the decisions reached during the trade study, refinements made in techniques, and updated information.

Then, the total lifetime cost of the vehicle must be determined. This involves estimating the costs of research and development (some of which has already been done), testing and evaluation, first-unit hardware costs by major element, hardware cost for all quantities required, and operational costs. The estimate made at the end of the preliminary design phase is normally the last complete cost estimate made during the program.

This effort requires a complete preliminary definition of all hardware and programmatic factors, with costs obtained on such items as weights, power, pressures, thrust, sizes, materials, types, quantities, and maintenance and repair for all hardware. In addition, such factors as manpower requirements for design, test, and operations, facility requirements, support equipment, and off-the-shelf hardware must be quantified, and new or modified hardware described in terms of variation from existing hardware. The calculations involved in making this estimate can be automated. These design activities are summarized in table 22.

TABLE 22
PRELIMINARY DESIGN - COSTING

Activity	Input	Output	Can Be Automated?
<p>Make first cut on trade studies</p>	<p>Parameters describing alternative configurations (weight, material, etc.) Cost-estimating-relationships library Cost ceiling Data to permit calculating gross sensitivities (e.g., value of performance or reliability) Impact of alternative designs for a given system on other systems in the vehicle (e.g., propulsion on structure)</p>	<p>Cost of alternative configurations Identification of trades requiring more detailed investigations</p>	<p>Partly</p>

TABLE 22 - Continued

PRELIMINARY DESIGN - COSTING

Activity	Input	Output	Can Be Automated?
Prepare detailed trade studies	Above data refined for cost sensitivities. Information to permit formulating decision criteria. Special detailed system definitions. Extensive cost data bank	Costs in sufficient detail to permit selection or cost is not a factor in the choice	No
Refine and update cost estimating relationships	Output of cost trades, cost data bank	Cost-estimating relationships applicable to the particular vehicle	Partly
Determine cost of vehicle	Design definitions - weights, pressures, etc. Program definitions - quantities, schedules, quantification of new hardware in terms of existing hardware. Facility and manpower definitions. Test program quantities and manpower	Final lifetime cost estimate of hardware, new hardware, development, and operations	Yes

4.2.9 Armament and Ordnance Design

The armament and ordnance activities in preliminary design are summarized in table 23. These design activities use a variety of computer codes which are more complex than those used in the system studies and require more complex inputs in larger volume.

The parametric configuration trade studies provide the basic data used to optimize the missile warhead. The data are similar to the information obtained during the system studies, but they provide a better basis for the preliminary design. The basic data input represent rigorous descriptions of vulnerability for specific targets. The approximate location of the warhead in the missile is known, the warhead size limits are known, and the system miss distance goal estimates are known. Computer codes to perform these calculations are readily available. The basic vulnerability estimates are available for certain specific targets, and vulnerability data for new targets can be estimated by such Government agencies as the Ballistic Research Laboratory for major design efforts.

During this phase, tentative warhead drawings can be produced by using existing computer codes in a conversational mode between the designer and the computer. This activity can be partially automated. The drawings produced by the computer will be used to set the missile configuration and to serve as a basis for estimating lethality and costs, and for preparing specifications.

The warhead lethality cost data represent a first estimate for the preliminary design configuration. They indicate the efficiency of the design and the relationship of the design to the optimized design goal set in the system studies.

The preliminary costs and production schedules are also estimated on the basis of the configuration drawings. They can be automated to yield reasonably accurate cost data based on the same type of cost-quantity relationship or learning curve used in the system studies. The schedule can be based on a PERT or PERT-type code modified according to the engineer's judgment. *

*PERT is a detail scheduling technique with emphasis on the relationship between various tasks and activities and the estimated duration of each.

TABLE 23

PRELIMINARY DESIGN - ARMAMENT/ORDNANCE

Activity	Input	Output	Can Be Automated?
Trade studies	Target vulnerability estimate, warhead type, approximate location of warhead in missile, warhead size limitations. Estimated miss distance	Single-shot skill probability as a function of warhead type, weight, size, missile location, and miss distance	Yes
Warhead configuration drawings	Warhead type, missile geometry, warhead location, and weight	Drawings of estimated warhead	Partly
Warhead lethality estimates	Warhead type, estimated dimensions, target vulnerability, terminal encounter geometry, and miss distance	Single-shot probability of kill versus miss distance	Yes
Warhead cost estimate and production schedule	Estimated bill of materials, estimated quantities, and estimated milestones	Estimated production costs	Yes

TABLE 23 - Continued

PRELIMINARY DESIGN - ARMAMENT/ORDNANCE

Activity	Input	Output	Can Be Automated?
Design specification	Parameter data from trade studies, estimated configuration drawings, lethality estimates, and cost and schedules	Definition of tentative ordnance items required	Partly

Design specifications can be roughed out from the preliminary design information. No known computer codes are available for this purpose; however, it is possible to use the computer for this problem. Once the warhead type is set, there are certain implicit specifications that must be met and certain qualification tests to perform. These can be stored as part of the overall data bank and produced on demand in boiler-plate form. The boiler plate can then be updated automatically from the data bank.

4.3 DETAILED DESIGN PHASE

The detailed design phase is similar to preliminary design except that most of the trade studies have been completed and the activities in this phase focus on the design of components and elements. The design activities performed in this phase for a typical missile are summarized in the following text.

4.3.1 Aerodynamic Design

Aerodynamic design activities performed during detailed design are indicated in table 24. During this phase, the primary concern of the aerodynamicist is to design and conduct various tests and interpret the test data so that more accurate aerodynamic characteristics of the final configuration can be determined. The tests may be wind-tunnel tests, free-flight tests, or subscale or full-scale flight tests. They ensure that performance specifications will be met, demonstrate structural integrity under maximum flight loads, provide accurate aerodynamic coefficients for trajectory simulations, and verify adequate control response and flight stability. If the configuration is found to be aerodynamically inadequate in any way, the test data may be useful in determining modifications that will provide the desired characteristics.

TABLE 24

DETAILED DESIGN - AERODYNAMICS

Activity	Input	Output	Can Be Automated?
Flight test	Detailed test vehicle mass properties plus postflight trajectory data	Verification of lift, drag, and control effectiveness estimates with postflight analyses. Recommend aerodynamic modifications as required	Partly
Refine the aerodynamic coefficients for use in computer trajectory generation	Wind-tunnel and flight-test aerodynamic data	Improved estimate of aerodynamic coefficients including wing-body interference, base drag, and hinge moments which are difficult to estimate accurately	Partly

TABLE 24 - Continued

DETAILED DESIGN - AERODYNAMICS

Activity	Input	Output	Can Be Automated?
Refine local flow predictions	Wind-tunnel and flight-test measurements of pressure distributions plus local flow data obtained by Schlieren photos, tufts, infrared photos, etc.	Better estimates of flow separation characteristics, panel flutter stability, control effectiveness, peak heating regions, inlet efficiency, venting requirements, etc.	Partly
Analyze aerodynamic stability and control	Detailed wind-tunnel force and moment data	Static and dynamic stability derivatives (about three orthogonal axes) as a function of Mach number, control deflection and flow incidence, e.g., angle of attack and roll angle	Partly

TABLE 24 - Concluded

DETAILED DESIGN - AERODYNAMICS

Activity	Input	Output	Can Be Automated?
Plan and execute aerodynamic wind-tunnel or free-flight test program	Flight environmental envelope	Verification of aerodynamic prediction techniques. Optimization of aerodynamic components including nose shape, wing and tail planforms, boat-tail shape, etc.	No
Size the aerodynamic control surfaces	Same as above plus configuration of aerodynamic characteristics	Aerodynamic control geometry, balance requirements, control effectiveness, and hinge moments	Partly

A final area of aerodynamic effort might be called special flow-field considerations. Almost every new aerospace vehicle design raises new questions about the local behavior of the flow field surrounding the vehicle at some point in its performance envelope. These questions might result in such diverse activities as estimating the control force generated by a jet interaction control system or the state of the gas in the neighborhood of an antenna window. This kind of activity cannot be automated because of the highly specialized nature of each problem. Quite often, the tools for analysis do not exist until after the question has been posed.

4.3.2 Thermodynamic Design

In the detailed design phase, the design of the thermal protection and environmental control provisions is prepared for applicable components and subsystems of the missile. For each, thermal environments, system constraints and requirements, and techniques established during preliminary design are combined to provide any needed thermal protection or environmental control for the component. Verification testing is performed to ensure that the design is adequate. Instrumentation is devised for flight tests, and the resulting data are studied for possible improvements or excessive conservatism. Detailed designs are reviewed and on approval, they are released for production. Thermodynamic activities during the detailed design phase are presented in table 25.

4.3.3 Flight Mechanics Design

During detailed design, the flight mechanics discipline incorporates the latest subsystem descriptions (e. g. , aerodynamics, weights, thrust histories, and controls) to continually refine the estimates of flight performance capability and trajectories. This usually involves going from a three-dimensional point-mass to a six-dimensional finite-mass simulation with full guidance and control loop modeling. As the detailed design is finalized, the operational performance capability can be mapped, giving operational personnel the data necessary to fly the missile as required within its design envelope.

TABLE 25
DETAILED DESIGN - THERMODYNAMICS

Activity	Input	Output	Can Be Automated?
<p>Design environmental control provisions for each subsystem, as needed. Provide operational predictions of temperature response of critical subsystems</p>	<p>Methodology, configuration, structural design, materials data, subsystem, system, and structural constraints</p>	<p>Detailed thermal protection and environmental control designs, structural temperature response, system design information</p>	<p>Partly</p>
<p>Calculate thermal environment, both internal and external, for each component of the thermal protection device, calculate detailed thermal protection requirements and structural temperatures, incorporating all applicable data</p>			

113

TABLE 25 - Continued
DETAILED DESIGN - THERMODYNAMICS

Activity	Input	Output	Can Be Automated?
<p>Devise and conduct tests, evaluate data to verify detailed environmental control designs</p> <p>Devise and conduct tests, evaluate data to verify detailed design environments and detailed design of the thermal protection device</p>	<p>Environments, detailed designs</p>	<p>Verification of detailed design, operational data</p>	<p>Partly</p>
<p>Devise instrumentation, evaluate data from flight tests for critical subsystem environmental control</p> <p>Devise instrumentation, evaluate flight test data for impact on final thermal protection design</p>	<p>Flight test environment (pre- and postflight) detailed designs</p>	<p>Configuration of total environmental control and thermal protection</p>	<p>Partly</p>

114

A flight-test program generally requires considerable support from flight mechanics personnel. Nominal trajectories must be simulated for each stage of the missile. Software must frequently be prepared to support range safety functions, particularly for longer-range types of missiles. Trajectory dispersion studies may be required for unguided test flights or to predict the booster impact area. After each test flight, an attempt is usually made to simulate the actual trajectory as determined from radar, movie cameras, impact points, or other data. A postflight report is prepared with trajectory reconstructions presented and many flight anomalies explained. Flight mechanics activities during the detailed design phase are summarized in table 26.

4.3.4 Structural Design

Parts and assemblies are designed in detail to achieve structural integrity and ease of manufacture at minimum cost. Careful and often sophisticated structural analyses are performed for all static, dynamic, and fatigue design loads to ensure structural adequacy in the operating environments. Detailed drawings are made from which production parts and test articles are fabricated. The articles are tested according to qualification test specifications. If a failure occurs, the part or assembly is redesigned and retested until structural adequacy is proved. Mockup drawings are prepared from which a full-scale model of the entire missile is made, mostly of wood, duplicating the structure, payload, equipment, and all electrical fuel, hydraulic, and other lines in order to investigate space and structural compatibility problems. A number of flight-test missiles are fabricated and flown under the most critical flight conditions. Any parts shown to be inadequate are redesigned or modified. The structural activities performed during detailed design are summarized in table 27.

4.3.5 Propulsion Design

Propulsion design details for the configuration selected at the end of the preliminary design phase are generated in this phase. For a typical

TABLE 26

DETAILED DESIGN - FLIGHT MECHANICS

Activity	Input	Output	Can Be Automated?
Subsystem detailed design	Detailed mass properties - e.g., moment of inertia Aerodynamic coefficients. Guidance and control subsystem simulation, Thrust history	Design trajectory histories including velocity, Mach number, dynamic pressure, load factors Acceleration, control deflections, altitude, etc.	Yes
Operational performance mapping	Final design of vehicle and mission characteristics	Operational performance and flight environment parameters	Yes
Flight test	Specification of test objectives and type of trajectory	Nominal trajectory printouts for each stage for each test	Partly

TABLE 26 - Continued

DETAILED DESIGN - FLIGHT MECHANICS

Activity	Input	Output	Can Be Automated?
<p>Flight test (continued)</p>	<p>Test range constraints</p> <p>Tracking and instrumentation requirements</p> <p>Detailed computer program for trajectory simulation</p>	<p>Specification of launch and in-flight guidance and control requirements</p> <p>Range safety software, such as predicted look angles vs time for each tracking radar, and nominal and dispersed histories of instantaneous impact prediction</p> <p>Estimated flight and impact dispersions for each stage</p>	

TABLE 26 - Concluded
DETAILED DESIGN - FLIGHT MECHANICS

Activity	Input	Output	Can Be Automated?
<p>Flight test (continued)</p>	<p>Flight-test data, including onboard recordings, telemetry data, radar track data, launch conditions, and meteorological data</p>	<p>Postflight trajectory simulations to assess observed flight anomalies, dispersions, etc.</p> <p>Report on postflight analysis identifying causes of non-nominal flight behavior and reconciling observed trajectory with post-flight simulated trajectory</p>	

TABLE 27

DETAILED DESIGN - STRUCTURES

Activity	Input	Output	Can Be Automated?
Loads analysis	Baseline configuration Design criteria Aerodynamic load distribution and temperature distribution	Static, quasi-static and dynamic loads. Differential pressure loads, axial, shear and moment loads; acoustic and engine vibration loads; shock loads; test loads	Yes
Structure resizing	Baseline configuration, loads, and design criteria	Final design of parts and assemblies	Partly
Preparing detailed design and assembly drawings	Final structural configuration	Drawings for manufacture of test and production parts	Partly
Weights analysis	Detailed design drawings	Finalized estimates and/or measurements of	Yes

TABLE 27 - Continued

DETAILED DESIGN - STRUCTURES

Activity	Input	Output	Can Be Automated?
(Weights analysis (continued))		weight, mass distribution, center of gravity and moments of inertia	
Full-scale mockup construction	Detailed design drawings and assembly drawings	Full-scale model duplicating arrangement of actual structure and equipment	No
Ground testing	Test articles and test fixtures. Design load specifications	Demonstrations of structural adequacy or inadequacy	Partly
Flight testing	Test articles	Demonstration of structural design throughout in-flight load envelope	Partly

tactical missile, details are designed for the system and its subsystems and components, and ground and flight tests are conducted. An activities list of detailed propulsion design is presented in table 28.

Design activities are extensively automated in propulsion, performance, and system simulation. Many of these activities are similar to those performed in the preliminary design phase, but they are performed with updated information.

Formal layouts are made with all information required to prepare detailed production drawings. The layout activity includes strength analyses, tolerance checks, and other analytical effort and calculations. Based on updated component requirements, design sketches, and layouts, procurement specifications are prepared for all purchased parts and subcontracted parts. Detailed design drawings for production are prepared for all remaining parts. Assembly drawings of all components are prepared and drawings for prototype test hardware are generated as required for special development and flight-test hardware. Detailed analyses are made to design the parts and ensure that the components are compatible with environmental and functional loads and with interface requirements.

Propulsion engineers prepare drawings for an engineering mockup. Outline drawings that describe the external configuration of each component are prepared from formal layouts. An installation drawing is also prepared. When completed, the mockup is used primarily to (1) ensure that no assembly problems exist, (2) develop tube routing, (3) develop wire routing, and (4) verify that adequate clearances exist between components and the missile structure. The mockup is prepared in parallel with the formal layouts.

Research and development tests evaluate the degree to which a design under development meets system requirements. They generally begin with component selection and assembly tests, and progress incrementally through flight tests as the system is developed. The test demonstration logic for

TABLE 28

DETAILED DESIGN - PROPULSION

Activity	Input	Output	Can Be Automated?
<p>Propulsion subsystem detailed design</p>	<p>Vehicle design requirements</p> <p>System design requirements</p>	<p>System and subsystem characteristics and performance requirements</p> <p>Functional interface requirements, e. g., fluid or electrical</p> <p>Detailed layouts</p> <p>Assembly and installation drawings</p> <p>System thermal and performance analysis</p> <p>System simulation model</p> <p>Engineering mockup</p>	<p>Partly</p>

TABLE 28 - Continued

DETAILED DESIGN - PROPULSION

Activity	Input	Output	Can Be Automated?
<p>Propulsion component detailed design</p>	<p>Subsystem design data</p> <p>Component design requirements</p>	<p>Subsystem critical component specifications</p> <p>Subsystem performance characteristics</p> <p>Component interface and functional requirements</p> <p>Detailed design analysis</p> <p>Subsystem assembly drawings and procedures</p> <p>Thermochemical and ballistic analysis</p> <p>Test drawings and procedures</p>	<p>Partly</p>

TABLE 28 - Continued
DETAILED DESIGN - PROPULSION



Activity	Input	Output	Can Be Automated?
Element detailed design	Component and element design requirements, including interface and functional requirements	Material selection Component specifications Detailed design sketches and drawings Test drawings, requirements, and procedures Component design and performance characteristics Component weight and stress analysis	Partly
Ground testing	System, subsystem, and component test requirements and procedures	Component cold-flow characterization Engine subsystems performance and structural integrity demonstration	Partly

TABLE 28 - Concluded
DETAILED DESIGN - PROPULSION

Activity	Input	Output	Can Be Automated?
Ground testing (continued)	<p>Test articles and fixtures and instrumentation</p> <p>Qualification test requirements and procedures</p>	<p>Rocket performance demonstration</p> <p>Combustion instability demonstration</p> <p>Hardware reliability demonstration</p> <p>System and subsystem qualification</p>	
Flight testing	<p>Test articles and instrumentation</p> <p>Predicted flight-test operating characteristics</p>	<p>Verification and reconstruction of propulsion system delivered performance</p> <p>Residual analysis, propellant utilization</p> <p>Flight anomalies definition</p> <p>Failure methods evaluation analysis</p>	Partly

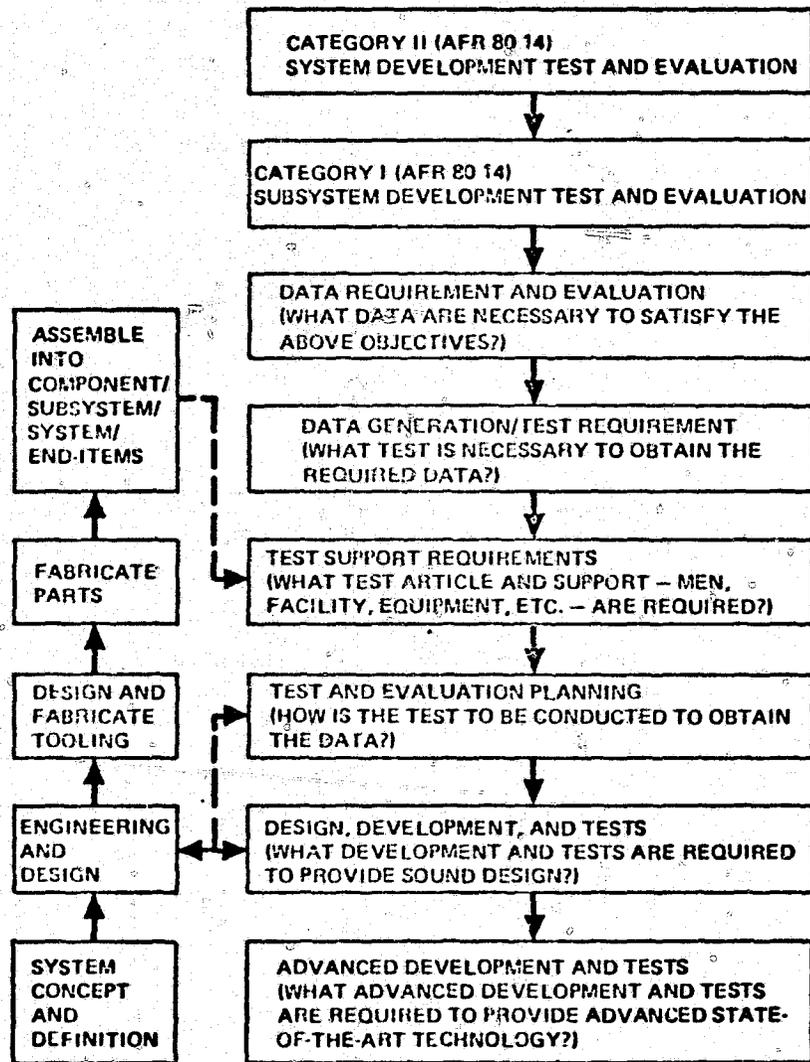
operational acceptance proceeds from advanced development through Category II total system testing (see figure 14). The relationship between the system design and testing is also displayed in figure 14. The end-items developed are used to verify or substantiate engineering analytical results obtained in advanced design-development and in the testing phase of the development cycle.

The end-item requirements are established through system engineering analyses (functional analysis, requirement allocation sheets, design sheets, etc.) conducted in the preliminary and detailed design phases. The engineering design is developed from these requirements and is tested to ensure compliance with them. The end-item drawings and specifications indicate the manufacturing and testing cycle. These items are then subjected to qualification tests and to the subsystem and total system tests in Categories I and II. Development testing plans are critiqued to determine the various levels and phases of testing needed. Development testing represents a significant portion of a missile program effort, involving engineering test support and testing documentation. Many procedures and requirements are prepared which may result in elaborate test conditions, data collection, data reduction, and similar effort. Design engineering identifies development-test requirements in terms of the type and scope of tests. These requirements are based on the materials, design margins, whether off-the-shelf hardware is available, the state of the technology, and operating environments.

4.3.6 Sensor Design

During detailed design, a sensor is designed, developed, and tested to achieve the performance called for by military specifications. The preliminary design configuration, trade studies, and component test data are used as a basis for iteration until the final design is produced. Each component, whether designed by a contractor or obtained through a supplier, must be compatible with the specifications. All the seeker elements such as the optics, electronics, and controls, are configured and their interfaces

DEVELOPMENT TEST AND EVALUATION PROGRAM REQUIREMENTS



127

M87

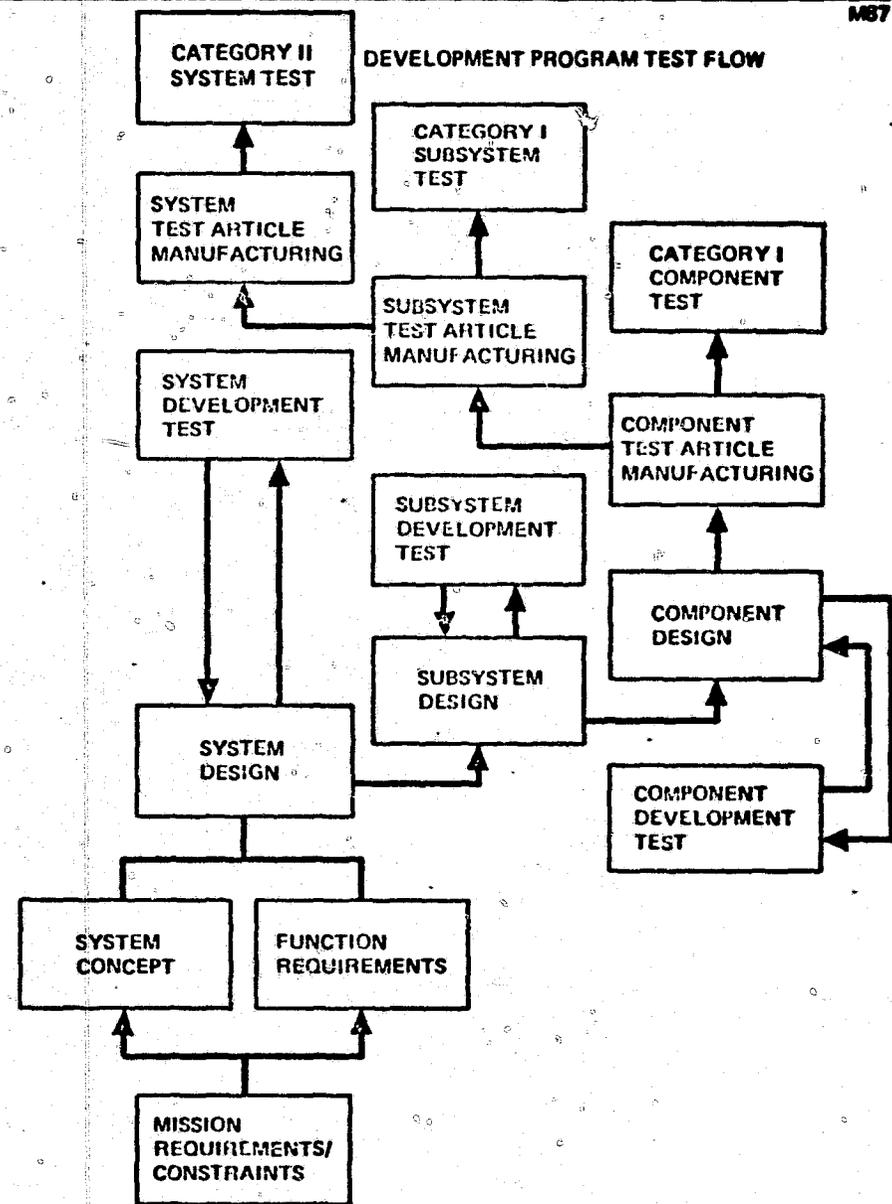


Figure 14.—Test and Evaluation Requirements and Test Flow

described. Critical components are identified for long-lead-time procurement or testing. Requirements for verifying performance of critical components are established and breadboard circuits or subsystems are constructed for verification testing of the critical components.

Test plans are prepared to verify that the final seeker configuration will meet all performance requirements and specifications. Various types of tests are devised, including environmental tests, captive firing tests, and flight tests. The appropriate instrumentation, facilities, and auxiliary test equipment are identified and acquired. Data recording, analysis, and reporting requirements are established to meet contractual, management, and engineering needs. The various tests are then conducted and the seeker design is evaluated. Design deficiencies are identified and corrected.

Sensor technology activities during detailed design are summarized in table 29.

4.3.7 Guidance and Control Design

In the detailed design phase, the guidance subsystem design activities are performed on the system configuration selected in preliminary design so that components and other elements can be designed. For homing and command systems, this involves designing elements such as the detector or receiver, gimbal and tracker, discrimination logic and circuitry, and command mechanization. Interface designs are generated for other subsystems such as the fuzing, power, controls, and launch subsystems. For inertial systems, the design activity also includes an inertial measurement unit, guidance software development, and targeting mechanization.

Simulation analyses are made to evaluate guidance performance when the guidance subsystem is integrated in the overall vehicle. Hardware elements are included in these simulations to determine the adequacy of the model and actual interface and performance characteristics. An on-line subsystem facility with the same computer simulation used in formulating the preliminary design is used in the detailed design phase.

TABLE 29

DETAILED DESIGN - SENSOR TECHNOLOGY

Activity	Input	Output	Can Be Automated?
Develop design compatible with specification	Design specifications	<p>Seeker design: optics, focal plane, processor, interfaces, etc.</p> <p>Critical component identification and verification of requirements</p> <p>Breadboard fabrication and verification of critical circuits and components</p>	Partly
Design performance verification test plans	Functional and performance requirements, sub-assemblies, interface and ancillary equipment	<p>Detailed test plans for environmental, qualification performance, captive firing, and flight tests</p> <p>Instrumentation, facilities, auxiliary equipment required</p>	Partly

TABLE 29 - Continued

DETAILED DESIGN - SENSOR TECHNOLOGY

Activity	Input	Output	Can Be Automated?
Design performance verification test plans (continued)		Data recording, analysis and reporting requirements, and procedures	
Evaluate design and performance	Detailed test plans Appropriate facilities, instrumentation, and auxiliary equipment	Various tests conducted, performance determined, seeker evaluated	Partly

As the design progresses and breadboard and prototype components become available, they are added into the simulation to verify the subsystem hardware design. These simulations aid in planning development and flight tests. Flight-test evaluation is also supported by this analysis in terms of a comparison of the expected with the achieved performance. The guidance subsystem design activities are summarized in table 30.

A detailed stability and performance analysis is made for the preliminary control subsystem configuration to create design specifications for manufacturing and flight testing.

Stability and performance analyses consider the total performance characteristics of the various components (sensors, actuators, etc.) as they become available from development and verification testing. System gains, shaping, and switching functions are specified.

Large-scale simulations are performed in this phase. These simulations allow evaluation of the compatibility of the control subsystem design with other subsystems, particularly guidance. Hybrid simulation is performed to evaluate the design in terms of component performance (sensors, actuators, etc.) and subsystem interfaces (seekers, command receivers, etc.).

These simulations are also used to plan critical-element tests as well as flight tests, and for desired performance verifications. The final activity during this phase is to use these simulation tools to support the flight-test program. The design activities are summarized in table 31.

4.3.8 Costing Design

The costing effort in the detailed design and later program phases is basically pricing or accounting rather than estimating.

TABLE 30
DETAILED DESIGN - GUIDANCE

Activity	Input	Output	Can Be Automated?
Tracker and boost subsystem design	Seeker and boost subsystem preliminary design, engagement scenarios, response requirements, boost requirements, winds, launch errors	Tracker subsystem response and subsystem performance Boost command electronics interfaces Tracker component design specifications (e. g., sensor control characteristics, gimbaling, power, component specifications)	Partly
Guidance accuracy and stability analysis	Guidance law and steering mechanization, control system model, engagement scenario, sensor and control measurement error models, tracking dynamics, target characteristics, fuzing subsystem	Guidance miss distance Fuzing interface with guidance and warhead Design specifications on guidance software and interfaces with control, launch, targeting systems Guidance shaping - required for stability	Partly

TABLE 30 - Continued
DETAILED DESIGN - GUIDANCE

Activity	Input	Output	Can Be Automated?
Development and flight-test evaluation	Development and flight-test data on seeker sensors, boost instrumentation, software modeling, target signature characteristics	Revised guidance component and subsystem models and guidance accuracy analysis exercised to upgrade performance estimates Guidance component and subsystem in-flight performance determined against simulated results	Partly

TABLE 31
DETAILED DESIGN - CONTROLS

Activity	Input	Output	Can Be Automated?
<p>Perform detailed stability analysis and design</p>	<p>Control system configurations for all flight modes, sensors, actuators, electronics dynamic characteristics, flight regimes, response requirements, detailed mass properties, and structural bending mode characteristics</p>	<p>Control stability defined in each flight mode and regime</p> <p>Control gains, switching criteria, and detailed shaping networks defined</p> <p>Nonlinearities and flexible structure effects evaluated on sensor placement and control margins</p> <p>Subsystem power requirements and design specifications defined (e.g., sensors, actuators, logic, electronics)</p>	<p>Yes (except for specifications)</p>

TABLE 31 - Continued

DETAILED DESIGN - CONTROLS

Activity	Input	Output	Can Be Automated?
Perform development testing	Control system hardware and software elements	Subsystem and component dynamic models updated for use in stability analysis Subsystem and component specifications revised	Partly
Analyze flight test data	Flight test results	Subsystem and component in-flight performance compared with predicted (simulated) performance Component and subsystem specifications and performance stability analysis revised with improved models	Partly

During the detailed design phase, subcontractor and vendor quotes and actual costs are obtained. These costs are documented and compared with the cost estimate made during preliminary design. The storing and summarizing of these costs can be automated.

One part of the cost-estimating procedure, the budgetary spreads of the cost estimate by accounting periods, may be continued during this phase; if so, it should be automated. Operating costs are also refined. Although this involves a large volume of data, the calculations and summaries could be automated. The characteristics of this activity are presented in table 32.

4.3.9 Armament and Ordnance Design

Ordnance and armament items consist of warheads, safety and arming mechanisms, explosive separation devices, explosive components, and missile destruct systems. All of these items require detailed design. The detailed design activities transform the armament and ordnance specifications into a complete set of drawings of qualified missile parts. The activity involves both design and testing, as well as a design demonstration and qualification of the item for missile operation by military forces. These design activities are summarized in table 33.

Test data are used to verify predicted fragmentation control and projection velocity and to determine aerodynamic coefficients of explosively projected particles. These data are obtained from warheads simulating the final design configuration; they are used to make primary and secondary modifications in the final design. The design testing activity is not considered suitable for automation because it involves special one-time tests. However, the projection velocity, spray angles, spray density, and other measurements taken in the tests may be automated. Other data such as a count of the fragments and fragment size distribution are not likely to be obtained by automation.

Final drawings of the various ordnance parts are also made. These drawings can be partially automated in the same sense as the preliminary design drawings; i. e., by a man using the conversational mode with the computer.

TABLE 32
DETAILED DESIGN - COSTING

Activity	Input	Output	Can Be Automated?
Monitoring and accounting for costs	Subcontractor costs Actual costs of research, development, test, and evaluation Vendor quotes	Actual R&D costs Actual test costs Hardware quotes Refined operational costs	Yes

TABLE 33

DETAILED DESIGN - ARMAMENT/ORDNANCE

Activity	Input	Output	Can Be Automated?
Design testing	Warhead size, function, detailed data requirement	Design data	No
Ordnance drawings	Missile size, ordnance location, material properties, test results	Complete set of drawings	Partly
Design demonstrations	Drawings of ordnance items and design specifications	Verification of design to meet overall requirement. Safe distance	Partly
Qualification to meet environmental requirements	Assembled ordnance items	Verification of design to meet environmental specifications	No

Design demonstrations furnish proof that the detailed design meets the specifications. The procedure is to take the first few production or preproduction items and detonate them to verify the design. This activity can be partially automated for measurement of velocities, spray angles, penetration, and aerodynamic coefficients or projected particles. It is not possible to automate the test setup and the judgment of damage level. Also, the judgment of safe distance based upon the test results cannot be automated.

In general, missile components are qualified for use by military forces when they pass the firing tests and are still in operational condition. For an ordnance item, the operational condition means that the item is detonable. Some individual qualification tests may be automated; however, test setups, especially for the firing test, and movement of the test article to the firing area require human judgment, particularly on safety matters.

The amount of testing will vary with the function and amount of explosive contained. However, testing will be required for all warheads and safety and arming mechanisms. These tests generally cannot be automated. Certain other tests, such as reliability testing of explosive cutting devices, can be automated on a go-no go basis where human judgment is not needed.

4.4 DEFICIENCIES IN THE MISSILE DESIGN PROCESS

The allocation of tasks in the current design process is presented in table 34, which also summarizes the characteristics of the current missile design process.

Many of the deficiencies in the current missile design process, as indicated in table 4-34, are caused by the incorrect allocation of tasks between man and the computer, and by man's use of computer codes. It is, of course, possible to hypothesize increases in performance and technological breakthroughs in the field of computer sciences, which might make it possible to reallocate tasks in a better manner. But only the present state of the computer technology was considered here.

Man is very inefficient in the current engineering design system. Most of man's efforts are concerned with routine data-handling operations, such as preparing data for computer programs, screening data, documenting results, and transmitting information. The system does not free man so that he can perform more creative activities. Moreover, most design activities do not allow man to interact with the computer and receive feedback information about the progress of simulations. This creates large gaps in time from the concept of a solution to the evaluation of results. The current system also does not allow man to readily acquire diverse types of supplementary design information. These factors reduce man's creative momentum.

The engineering design system utilizes both hand calculations and computerized information. For large-scale problems which are highly quantifiable, digital computers are primarily used. But analog and hybrid computers are also used primarily in the description of guidance, control, and sensor subsystems. The primary mode of operation is batch processing, but there are some terminal on-line interactive systems. These facts all add to the scatter-gun approach to missile design.

TABLE 34

SUMMARY OF CURRENT MISSILE DESIGN PROCESS

Missile Design Process Characteristics (Tasks)	Technique	Current Engineering Design System	
		Men	Computers
Search and evaluate the state of the art	Report on R&D activities, contractor brochures	Manual search and selection and documentation of data	Not used to perform this task
Search, evaluate, and select propulsion, cost, and other data from data banks	Report and prepare brochures summarizing cost and propulsion statistics	Manual search and selection and documentation of data	Not used to perform this task
Select concepts, configuration, and design criteria	Define design problems and identify subsequent measures to select design or solve problem	Selection of concepts configuration - performed by man, utilizing his creativity	Not used effectively - because of lack of data bank. Man's creative momentum is reduced

TABLE 34 - Continued

SUMMARY OF CURRENT MISSILE DESIGN PROCESS

Missile Design Process Characteristics (Tasks)	Technique	Current Engineering Design System	
		Men	Computers
Coordinate and exchange data between various disciplines; e.g., aerodynamics-structures, sensor-thermodynamics, or guidance-flight mechanics	Design problem and disciplines are not effectively integrated in the process. Most computer codes are not integrated, thereby increasing routine data handling	Man does most of the coordination and exchange of data among disciplines. These efforts increase the amount of non-creative activities which designers must perform	Not used in this task
Optimize the missile-many disciplines perform this task	Conduct a series of suboptimizations to arrive progressively at an optimal missile design	Some disciplines are in conflict over which one performs the suboptimizations. When formal methods fail, man uses judgment	Digital computers used primarily for batch processing, but some hybrid systems are used

TABLE 34 - Continued

SUMMARY OF CURRENT MISSILE DESIGN PROCESS

Missile Design Process Characteristics (Tasks)	Technique	Current Engineering Design System	
		Men	Computers
Develop design specifications and requirements for the system, subsystem, component, etc.	Develop design requirements and specifications in an iterative manner, progressing to more details	Generates and documents specifications. This effort does not involve much creativity	Not used
Some design activities are common in each of the engineering design phases	In many cases, only updated data are used	Modifies and updates information. This is a non-creative effort	Not used to modify and update information
Perform numerical calculations	Manual data input to computers to generate design information	Prepares the bulk of the input data. There is little opportunity for man to interact with the calculation process, which reduces man's creative momentum	Digital, analog, and hybrid computers are used, with batch processing being the primary mode

TABLE 34 - Continued

SUMMARY OF CURRENT MISSILE DESIGN PROCESS

Missile Design Process Characteristics (Tasks)	Technique	Current Engineering Design System	
		Men	Computers
Duplicate information generated and perform computations in computer codes	Computer codes often generate the same information, adding to the inefficiencies of the process	Some disciplines conflict on responsibility for information. The conflict results from use of non-integrated computer codes	Additional central processing unit time is required for redundant calculations
Use on-line subsystem facilities to support the design and verify performance	To increase the cost-effectiveness of some missile programs, prototype hardware is used in subsystem performance evaluation	Man is used in an on-line mode primarily in detailed design of guidance, control, and sensor subsystems	Hybrid computers are used in the on-line mode of operation

TABLE 34 - Concluded

SUMMARY OF CURRENT MISSILE DESIGN PROCESS

Missile Design Process Characteristics (Tasks)	Technique	Current Engineering Design System	
		Men	Computers
A seemingly random set of design activities with little management control	There are no universal design activities because each missile system is different	Management has little control and visibility of the status of design activities	Computers are not effectively used to manage design activities
Use full-scale engineering mockups for packaging and establishing routing lines for tubes and electrical lines	Physical models are used to design packaging and electrical and tubing routes	Most packaging and routing is performed by layout men, verified by the engineering mockups	Some functions are performed by the interactive on-line terminal
Prepare large volume of engineering drawings	Primarily non-automated procedures	Most of the engineering drawings are creative; they are prepared by draftsmen	Used to develop a few drawings

Many of the noncreative activities man now performs should be allocated to the computer. Certainly, routine data handling, preparation of large volumes of input for computer codes, and scanning and reformatting of output data could be done by computer to increase the total effectiveness of the missile design process.

Most of the computer codes used in design are not integrated; i. e., usually a computer code is written for one discipline. This forces man to perform data-exchange functions, which could be done by computer. The use of non-integrated software also promotes a suboptimization and increases the amount of redundant calculations performed in the process. If more integrated computer codes were used, it would be possible to achieve a global optimum and would reduce the number of computer codes by eliminating some of the redundant information.

Section 5

ANALYSIS AND EVALUATION OF THE IPAD SYSTEM FOR MISSILE DESIGN

The following analysis and evaluation of the IPAD system for use in the missile design process (1) recommends which functions of the missile design process can be performed by the IPAD system; (2) determines the availability and adequacy of the computer programs in the various disciplines which are known by McDonnell Douglas to be currently available for use in design as operating modules in the IPAD system; (3) identifies the areas of missile design where no known computer programs are available and recommends whether or not the current state of the art justifies development of computer programs at this time; (4) estimates the efficiency, time, and cost savings to be gained from performing missile design by the IPAD system; (5) assesses the benefits to be gained with the IPAD system; and (6) cites features from IPAD designs conceived by the Boeing Company and General Dynamics Corporation which will be especially appropriate in performing missile design.

5.1 RECOMMENDED MISSILE DESIGN FUNCTIONS FOR IPAD

Most of the deficiencies in the current missile design process, which are due to the nonoptimum allocation of tasks, can be eliminated or substantially reduced by using an IPAD system for engineering design.

Extensive cost-effectiveness studies will have to be performed in the preliminary design phase of any new engineering program to obtain specific desired component performance and the optimum task allocations. But some general recommendations can be made about which missile design functions should be performed by the IPAD system to increase the effectiveness of the missile

design process. This effectiveness may be achieved by increasing the productive efficiency or the design quality. The recommendations given here consider the functions described in the engineering design methodology and the results of the missile design evaluation.

Recommendations for use of the IPAD system in performing the general logical problem-solving functions are presented in table 35. The problem-solving functions which the IPAD system should perform have been selected to (1) reduce man's noncreative effort and thereby free him to perform more creative functions, (2) enhance man's creative momentum by allowing him to interact with the functions in real time, by having easy access to supplementary design information, and by giving him freedom to construct and test concepts, and (3) integrate computer codes to reduce redundancy and increase the mathematical relationships in the total system. The primary differences in current engineering design systems and the IPAD system are in these areas. But the following activities are common to both systems: development and modification of mathematical models.

The summarized characteristics or features of the current missile design process can be matched to components of the IPAD system, based upon the above three objectives. The recommended use of IPAD is presented in table 36.

5.2 EVALUATION OF COMPUTER PROGRAMS USED IN MISSILE DESIGN FOR IPAD

In this section, existing McDonnell Douglas computer codes are considered as candidate operating modules of the IPAD system. Additional computer programs that require development are also indicated for each design activity that can be automated. Each design activity is also evaluated to determine whether it can be performed by other known computer programs in private industry or owned by the Government.

5.2.1 Existing Aerodynamic Computer Programs

The computer programs evaluated for each aerodynamic design activity are listed by design phase in table 37. Similar computer programs that may be interchangeable with the other programs for some functions are also

TABLE 35

RECOMMENDED ENGINEERING DESIGN USE OF IPAD

Problem-Solving Function	Activities Performed	Present System	IPAD System
Perform problem definition	Establish design objectives	Man	Man/IPAD, IPAD supplies past system history and current requirements
	Establish design constraints	Man	Man/IPAD, IPAD supplies past system history and current requirements
	Identify relevant relationships to be considered	Man	Man
Perform system synthesis	Select system classes	Man	Man/IPAD, IPAD supplies past system history
	Identify design variables to be manipulated	Man	Man/IPAD, IPAD supplies past system history
	Initial design parameter sizing	Man	Man/IPAD, IPAD supplies past system history
Perform system analysis	Model development or modification	Man	Man
	Calculation	Computer	Man/IPAD, total model integration and man-IPAD interaction
Perform system optimization	Model development or modification	Man	Man
	Calculation	Computer	Man/IPAD, total model integration and man-IPAD interaction

TABLE 35 - Continued

RECOMMENDED ENGINEERING DESIGN USE OF IPAD

Problem-Solving Function	Activities Performed	Present System	IPAD System
Select system	Evaluate data	Man	Man/IPAD, easy access to supplementary design information
	Select system or solution	Man	Man/IPAD, easy access to supplementary design information
	Add, modify, or delete design objectives and/or constraints	Man	Man/IPAD, IPAD performs data-handling operations
Document results	Scan information	Man	Man/IPAD, IPAD used for scanning information
	Select information	Man	Man/IPAD, IPAD displays information in variable formats
	Record information	Man	IPAD, IPAD documents information

TABLE 36

RECOMMENDED MISSILE DESIGN FUNCTIONS TO BE PERFORMED BY IPAD

Missile Design Tasks	IPAD Use	Remarks on Use of IPAD
Search and evaluate the state of the art in the appropriate technology	No	IPAD would have to become a state-of-the-art information system
Search, evaluate, and select propulsion, cost, and other data from data banks	Yes	IPAD should have data on various subjects (materials, thermo-chemical, cost, etc.) stored in different bases and search algorithms to help design, search, and retrieve data
Select concepts, configurations, and design criteria	Yes	IPAD should have past missile system design characteristics stored, but easily retrievable
Coordinate and exchange data between various disciplines	Yes	IPAD should allow for total discipline coordination and data exchange
Perform total system optimization	Yes	IPAD should allow for all models to be integrated so that total system optimization may be achieved
Generate design specification and requirements	Yes	IPAD should have specification "boiler plate" stored and easily retrievable
Perform numerical calculations	Yes	IPAD should allow the designers to interact with the simulation and evaluation process in real time by using graphic displays
Utilize prototype hardware in on-line hybrid computations	No	IPAD should remain digital in initial development
Control and establish design activity visibility	Yes	IPAD should allow management to control design activities, provide visibility for decision making, and determine status

TABLE 36 - Continued
 RECOMMENDED MISSILE DESIGN FUNCTIONS TO BE PERFORMED BY IPAD

Missile Design Tasks	IPAD Use	Remarks on Use of IPAD
Establish, package, and route designs	Yes	IPAD should allow designers to perform packaging and routing tasks by using interactive graphics
Prepare engineering drawings	Yes	IPAD should allow designers and draftsmen to generate drawings by using interactive graphics

ORIGINAL PAGE IS
 OF POOR QUALITY

TABLE 37

AERODYNAMIC COMPUTER PROGRAMS USED IN MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing	Similar Computer Programs
Automated DATCOM (P3071)	X	X		Subsonic Wing-Body, Design and Analysis (Boeing, ARO-1) Calculation of Aerodynamic Influence Coefficients Matrix (Boeing, ARO-4) Analysis and Design of Wing-Body Combinations (Boeing, ARO-5)
Arbitrary Body Library (F218)	X	X	X	Supersonic Skin Friction Prediction (Boeing, ARO-12) Supersonic Drag and Pressure Distribution on Bodies of Revolution (Boeing, ARO-11)
Computerized Aircraft Sizing and Optimization (1915)		X		Subsonic Wing-Body Design and Analysis (Boeing, ARO-1)
Body of Revolution Aerodynamics (JA74)		X		Wave Drag and Supersonic Area Rule (Boeing, ARO-9) Calculation of Supersonic Drag due to Lift and Wing Nacelle Interference Drag (Boeing, ARO-10) Supersonic Drag and Pressure Distribution on Bodies of Revolution (Boeing, ARO-11)
Newman Potential Flow (JA40)		X		Potential Flow about Arbitrary Configurations (Boeing, ARO-3)

TABLE 37 - Continued
 AERODYNAMIC COMPUTER PROGRAMS USED IN MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing	Similar Computer Programs
Inviscid Flow Fields Program Complex (H292)		X	X	Supersonic Drag and Pressure Distribution on Bodies of Revolution (Boeing, ARO-11)
Inviscid Flow Fields Program Complex (H293)		X	X	Supersonic Drag and Pressure Distribution on Bodies of Revolution (Boeing, ARO-11)
Inviscid Flow Fields Program Complex (H294)		X	X	Supersonic Drag and Pressure Distribution on Bodies of Revolution (Boeing, ARO-11)
Multi-Jet Base Flow (P1319)		X	X	
Boundary-Layer Separation and Reattachment (P0748)		X	X	
Time-Dependent Blunt Body Program (H847)		X	X	
Equivalent Body Analogy Jet Interaction (H515)		X	X	
Conical Flow Program (P2151)		X	X	
Base Pressure Program (H579)		X	X	
Three-Dimensional Boundary Layer (H686)		X	X	

TABLE 37 - Concluded

AERODYNAMIC COMPUTER PROGRAMS USED IN MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing	Similar Computer Programs
Kutler Three-Dimensional Inviscid Flow Field (P2S71)		X	X	
Total	2	16	12	
Incremental computer programs	2	14	0	

listed in the table. The total number of computer programs required for each design phase is also indicated. A description of the computer programs is given in Appendix A.

Most of the state-of-the-art computer codes should be able to be used in missile aerodynamic design activities for the system studies and preliminary design phases with little manual effort. Once the detailed design phase has been reached, the function of several computer codes is replaced by experimental data.

There is a strong similarity between the aerodynamic computations required for supersonic transport design and for tactical missile design. Typical designs are not too dissimilar geometrically, and they both operate in roughly the same flight regimes. Consequently, many of the aerodynamic computer

programs used for supersonic transport design (ref. 2) should be applicable to a tactical missile design problem. The codes described in the Boeing Company's aerodynamic library of computer codes will be of considerable value, but they should be supplemented by codes from the General Dynamics Corporation's library (ref. 3).

A possible addition to the aerodynamic library is the DATCOM program (P3071) which was recently coded by McDonnell Douglas Astronautics Company-East under Air Force funding. This code is used to calculate the static stability characteristics of wings, bodies, wing-body, tail-body, and wing-body-tail combinations at angle of attack and in sidestep. However, the library may already have other codes that perform these calculations. The DATCOM code involves four boxes of cards, and running times and input-output quantities are not available. It has not yet been fully checked out.

The combined library of Boeing and General Dynamics appears to be deficient in "exact" numerical inviscid flow-field calculation codes. Inviscid flow-field codes must be considered as research programs, and their use would be restricted to the detailed design phase. They generally apply to the supersonic and hypersonic regimes and were formerly limited to two-dimensional or axisymmetric problems. Recent advances in techniques allow the codes to be used with problems of any geometrical form and they now offer angle-of-attack capability. Due to the advanced nature of these codes, it is very difficult to define their role quantitatively in design. They may be composed of from one to four boxes of cards and may have a running time of anywhere from 1 to 30 minutes for execution (assuming that the execution involves only a single Mach number and angle of attack).

5.2.2 Existing Thermodynamic Computer Programs

The thermodynamic computer programs used in design activities are summarized in table 38. The computer programs are described in Appendix B. There are no other known computer programs with similar capabilities for these design activities.

These decisions require judgments made after review of data from wind tunnel or flight tests. Once a missile system has progressed beyond preliminary design, many of the uncertainties have been resolved. During the detailed design phase, more of the design burden can be assumed by the IPAD system; however, a considerable amount of man-machine interaction is still required.

5.2.3 Existing Flight Mechanics Computer Programs

Computer programs for flight mechanics design activities are presented in table 39. Also presented in the table are similar computer programs that may be interchangeable with the other programs for some functions. The total number of computer programs required for each of the three engineering design phases is also given in the table. These computer programs are described in Appendix C.

TABLE 39

FLIGHT MECHANICS COMPUTER PROGRAMS USED IN MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing	Similar Computer Programs
General Vehicle Performance Analysis Tool (AB16)	X	X	X	Modular Simulation System. Three-Degree-of-Freedom Trajectory Simulation (AB60)
Performance Analysis and Design Synthesis Computer Program (P1511)	X	X	X	
Total Programs Used	2	2	2	
Incremental different programs	2	0	0	

TABLE 38

THERMODYNAMIC COMPUTER PROGRAMS USED IN MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing
Real/Ideal Gas Aerodynamic Heating and Ablation Program (JA70)	X	X	X
Three-Dimensional Heat Transfer (JA03)	X	X	X
Total	2	2	2
Incremental computer programs	2	0	0

From a thermodynamic standpoint, the IPAD system can be used to perform several analyses. Early in the system studies phase, when only gross concepts are being evaluated, general equations can be used to indicate relative levels of heating between trajectories or mission profiles, to determine the effects of some geometric features, and to identify kinds of thermal protection schemes which could be applicable.

In preliminary design, the IPAD system can be used for thermodynamics only after the methodology has been determined, materials and concepts for the thermal protection and environmental control subsystems have been investigated, and the preliminary design procedures for the type of missile being considered have been established. Thermal computer programs such as the Real/Ideal Gas Aerodynamic Heating and Ablation Program (JA70) and the Three-Dimensional Heat-Transfer Computer Program (JA03) can handle many of the design functions; however, experience has shown that each new missile design has features which require the development of new technology and computer codes. Probably, the decisions regarding methodology are least adaptable to automation; i. e., what heat-transfer method should be used for each particular area, what geometric approximations are necessary to use that method, and what is the local flow field at the location of interest?

Most of the flight mechanics design activities can be performed with the General Vehicle Performance Analysis Tool computer program (AB16). This program is modularized to allow for the generation of flight mechanics routines to any specified level of detail. Consequently, it can be used in all the engineering design phases. The Performance Analysis and Design Synthesis Computer Program (PI511) can also be used in all the phases for the same functions. This program can also generate optimal trajectories by using a calculus-of-variation solution.

Two other Government computer programs may satisfy most of the flight mechanics design activities. These programs are the Three-Degree-of-Freedom Trajectory Simulation developed at McDonnell Douglas Astronautics Company-West and the Modular Simulation System developed by LOGICON and used at the Aerospace Corporation. These computer programs are also described in Appendix C.

5.2.4 Existing Structural Computer Programs

For each design phase, computer programs applicable to structural design activities are presented in table 40 along with other computer programs that may accomplish the same activities. These programs are described in Appendix D. Other programs which may accomplish similar functions are described in reference 2.

During the system studies phase, various structural concepts for candidate missile configurations are defined with the aid of the General Missile Sizing Program (GMSP). Parametric weight estimation methods are augmented by estimates of center-of-gravity location, moments of inertia, and mass distribution obtained with the Computer-Aided Design and Drafting (CADD) system program. This program can also be employed to generate inboard and outboard profiles quickly for each conceptual design. In this phase, it may occasionally be necessary to produce estimates of missile-body shear, bending moments, axial loads, and deflections. These data can be obtained by using the Static Aeroelastic Load Analysis for Missile Bodies computer program (SA54).

TABLE 40

STRUCTURAL COMPUTER PROGRAMS USED IN MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing	Similar Computer Programs
Texas Grain Analysis Program (TEN GAP)		X	X	
Automated Viscoelastic Grain (G394)		X	X	
Transverse Acceleration Stress Analysis (P0777)		X	X	
Viscoelastic Grain Structure Analysis (P0781)		X	X	
Heat Conduction of Solid Propellant Rocket Motor Nozzles (P1050)		X	X	
SAAS III, Finite-Element Stress Analysis of Axisymmetric and Plane Solids with Different Orthotropic Temperature-Dependent Material Properties in Tension and Compression (P0307)		X	X	
Fatigue Analysis and Design (STR-5)		X	X	
A Computer Program to Design Conical Shell Structure (G554)		X		
Stress Analysis - Santa Program System (SA-86)		X	X	
SNASOR II, A Finite Element Program for the Static Non-Linear Analysis of Shells of Revolution (P1217)		X	X	

TABLE 40 - Continued

STRUCTURAL COMPUTER PROGRAMS USED IN MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing	Similar Computer Programs*
Axisymmetric Loading Compressible Solids of Revolution (SA-58)		X	X	
Static Aeroelastic Load Analysis for Missile Bodies (SA-54)	X	X	X	
General Missile Sizing Program (GMSP)	X	X		
Vehicle Mass Characteristics Determination (H523)	X	X	X	
Computer-Aided Design and Drafting System (CADD)	X	X	X	DSA-5
NASTRAN (P0730)		X	X	
DATRAN (P1874)		X	X	
BIGPIX (P2260)		X	X	STR-8
Missile-Rail Dynamic Response (SA-92)		X	X	
Rib Stiffened Shell Buckling (H312)		X	X	
BOSOR 2-Buckling and Vibration of Segmented Ring-Stiffened Shells of Revolution (P1146)		X	X	
FORMAT SA49		X	X	SDL-1, STR-6, STR-7, STR-9, STR-10, STR-11, STR-12, STR-13, STR-14

- *DSA-5 = Interactive Design - Structural
- STR-8 = Finite Element Structural Analysis - SAMECS Automated Plotting Program (SAPP)
- SDL-1 = Natural Vibration Modes
- STR-6 = Integrated Structural Analysis and Design (Finite Element) - ATLAS
- STR-7 = Finite Element Structural Analysis - SAMECS Structural Analysis System
- STR-9 = Finite Element Structural Analysis - SAMECS Data Checker Program (SAMCHK)
- STR-10 = Finite Element Structural Analysis - SAMECS Loads Transformation Program (LOADS)
- STR-11 = Finite Element Structural Analysis - SAMECS Merge Program (MERMAT)
- STR-12 = Finite Element Structural Analysis - SAMECS Superposition Program (SUPERPO)
- STR-13 = Finite Element Structural Analysis - SAMECS Deflections Back Substitution Program (DEFPU)
- STR-14 = Finite Element Structural Analysis - ASTRA (Advanced Structural Analysis)

TABLE 40 - Continued

STRUCTURAL COMPUTER PROGRAMS USED IN MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing	Similar Computer Programs
Plane-Strain Solution for Compressible Materials (SA-60)		X		
Axisymmetric Loading of an Incompressible Materials Solid of Revolution (SA-62)		X		
Plane-Strain Solution for Incompressible Materials (SA-64)		X		
Weight Optimization Program for Stiffened Cylinders (P2752)		X	X	
Thermal Stress Analysis under Asymmetric Loads (P0461)			X	
DEBACUL-Discrete Element Buckling Analysis for Cylinders under General Loading (P0608)			X	
Thermal Stress Analysis (H326)			X	
Weight Record Program (WT03)			X	
Weight Write-Up (WT05)			X	
Weight Write-Up File Translator (WT06)			X	
Call Number, Effectivity and Next Assembly (WT07)			X	

TABLE 40 - Continued

STRUCTURAL COMPUTER PROGRAMS USED IN MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing	Similar Computer Programs
Spin-Radius-Load (WT09)			X	
Weight Basic Decks (WT10)			X	
Alphanumeric Parts Listing (WT11)			X	
Functional and Sequential Code Control Book (WT16)			X	
Weight Section List (WT17)			X	
H-Arm Control Book (WT18)			X	
Weight Translation Program (WT20)			X	
Detail Weight and Inertia Distribution (WT21)			X	
Design Weight Statement (WT25)			X	
Weight Record Printout (WT30)			X	
Weight Write-Ups and Summary Line Totals per Vehicle (WT35)			X	
Selected Equipment Report (WT40)			X	
Detail Moments of Inertia (WT23)			X	
Span-Radius-Load Printout (WT33)			X	

TABLE 40 - Concluded
 STRUCTURAL COMPUTER PROGRAMS USED IN MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing	Similar Computer Programs
SABOR 5/DRASTIC V P (P0430)			X	
STACUSS I (P0579)			X	
SABOR CS-2, Finite-Elements Shell and Core Analyses (H841)			X	
Axis, Axisymmetric Large Deformation Elastic Plastic Dynamic Response Plate and Shell Analysis (P0494)			X	
Darts, Large Deformation Elastic Plastic Dynamic Response Ring Analysis (P0496)			X	
TDELTA			X	
TCURVE			X	
Total	4	26	49	
Incremental computer programs	4	22	28	

From the design objectives and constraints, the GMSP is used to design a number of candidate missile configurations. These designs are unrefined, using smeared thicknesses, but they can be compared to select the most likely candidates for refinement. Missile-body shear, bending moments, axial loads, deflections, and surface pressures are refined using SA54. Missile rail dynamic loads are obtained from the Missile Rail Dynamic Response program (SA92). Nose shroud designs of different materials and methods of construction are investigated using the computer program Design Conical Shell Structure (G554) for initial sizing and BOSOR 2 (P1146)

or SNASOR II (P1217) for refinements. Several possible designs of the transition section, aft fairings, and interstage using different materials and construction methods are analyzed with the aid of the Rib-Stiffened Shell Buckling (H312), BOSOR 2, or NASTRAN programs. Trade studies are made to compare weights, ease of manufacture, and costs of the several different structural designs.

The propellant grains and motor cases can be initially sized using AVGSAP (G394), which has design curves stored in memory for preliminary analysis. Trade studies can be performed using the same program. As the design progresses, more sophisticated analyses can be performed using the Axisymmetric Loading of Compressible Solids of Revolution (SA58), the Plane-Strain Solution for Compressible Materials (SA60), Axisymmetric Loading of an Incompressible Material Solid of Revolution (SA62), or the Texas Grain Analysis Program (TEXGAP) in conjunction with AVGSAP for a viscoelastic ablating grain analysis. The Transverse Acceleration Stress Analysis program (P0777) may be used for transverse acceleration (nonsymmetric) loading analysis. The Viscoelastic Grain Structure Analysis program (P0781) may be used for bond stress analysis and cumulative damage analysis. The rocket-motor nozzles can be analyzed using P1050 to obtain time-dependent temperature distributions in the nozzle, and SAAS III (P0307) for analysis of stresses, strains, and displacements. For structural members subjected to fatigue loads, the Fatigue Analysis and Design Program (STR-5) can be used in conjunction with other structural analysis programs to analyze fatigue failure. As the design progresses, the missile mass characteristics are calculated and updated using the Vehicle Mass Characteristics Determination Program (H523).

Having selected the first configuration in the preliminary design phase, the geometry can be refined and stored in memory using CADD. CADD can generate loft lines, create production drawings, and generate numerical milling tapes for production parts, as well as solve numerous design and space compatibility problems. SA54 is used to generate missile-body shear.

bending moments, axial loads, deflections, and surface pressures. Missile launch rail dynamic loads are obtained from SA92.

Equivalent fatigue loads are generated from the vibration load spectra by means of STR-5. The same program is used to perform fatigue analyses and to determine fatigue margins of safety for structures subjected to vibration loads. The nose shroud is analyzed using BOSOR 2 (P1146), SNASOR II (P1217), or NASTRAN (P0730).

The transition section, aft fairings, and interstage are analyzed using BOSOR 2, NASTRAN or, in the case of integral rib-stiffened structure, the Weight Optimization Program for Stiffened Cylinders (P2752) may be used to obtain an optimum design. The propellant grains and motor cases are analyzed using TEXGAP in conjunction with AVGSAP, P0777, and P0781. The rocket-motor nozzles are analyzed using P1050 and SAAS III (P0307).

Vehicle mass characteristics are calculated and updated using H523. Weight records are stored in data banks using the Weight Record Program (WT03) and the Weight Write-Up (WT05), Weight Write-Up File Translator (WT06), Call Number, Effectivity, and Next Assembly (WT07), Spin-Radius-Load (WT09), and Weight Basic Decks (WT10) programs. The Alphanumeric Parts Listing (WT11), Functional and Sequential Code Control Book (WT 16), Weight Section List (TW18), Detail Weight and Inertia Distribution (WT21), Weight Record Printout (WT30), and Weight Write-Ups and Summary Line Totals per Vehicle (WT35) programs are all used for reporting and retrieval of mass properties.

All of these programs will be used in any typical missile design. Additional programs described in Appendix D should be included in the IPAD system; some of them will be used in certain instances to supplement basic programs.

5.2.5 Existing Propulsion Computer Programs

The existing computer programs that perform propulsion design activities for solid-rocket motors are presented in table 41, and a description of the computer programs is given in Appendix E.

Figure 15 is a functional flow diagram for calculation of solid-propellant rocket performance, size, and mass. Propellant composition may be input to make possible trade studies to evaluate the influence of total solids loading determine percent of aluminum by weight and other factors on the propulsion subsystem and on the size and mass of the missile.

The propellant performance is calculated by a One-Dimensional Equilibrium Performance Program (H659) which contains a library of basic thermochemical data for the expected spectrum of propellant compounds. The propellant grain configuration options may be either radial-burning grains or end-burning grains. The radial-burning grain is simulated by a grain cross-sectional loading fraction coordinated with expected thrust levels or specified grain configurations in SRMAT (P3598). A pseudo burning rate can be calculated by specifying a design web fraction. Propellant ballistics are optional input for the end-burning grain since the burning rate will control length and thrust of motor.

A separate propellant ballistics program (PA08) may be used to confirm grain configuration and ballistics. Propellant temperature sensitivity inputs are required for calculating effects of propellant bulk temperature on motor and missile performance.

The SRMAT program (P3598) calculates case-wall thicknesses, blast tube, nozzle and case envelopes, and motor insulation thicknesses requirements called from the Equilibrium Surface Thermochemistry Performance Program (G508), the Charring Material Thermal Response and Ablation Program (G590), the Turbulent Boundary Layer Nozzle Analysis Program (H660), and the Three-Dimensional Heat-Transfer Computer Program (JA03). The output from this program is a motor configuration (length,

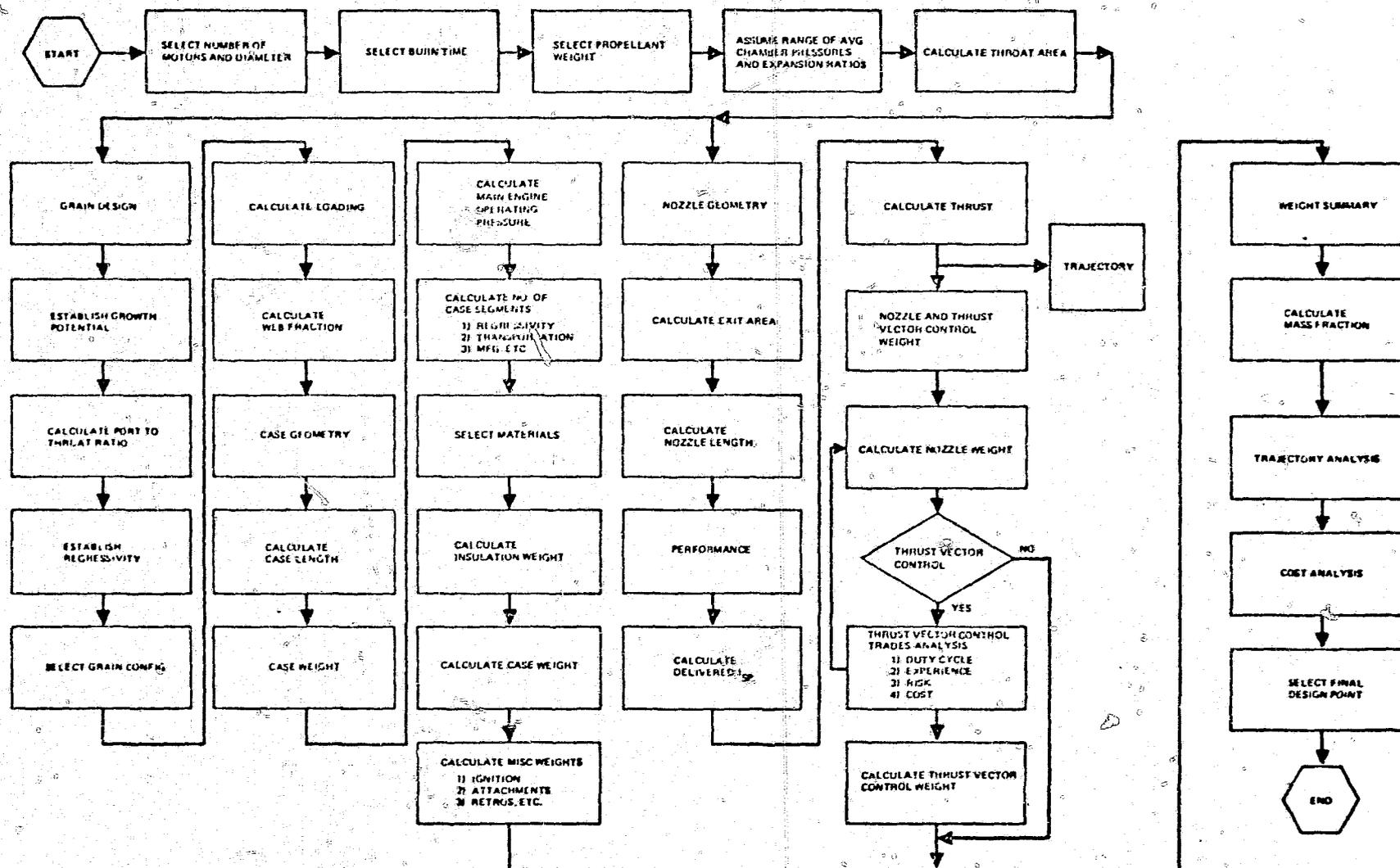


Figure 15.—Solid-Rocket Motor Design Function

TABLE 41

PROPULSION COMPUTER PROGRAM USED IN MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing
SRMAT-Solid Rocket Motor Analysis Tool (P3598)	X	X	X
One-Dimensional Equilibrium Nozzle Analysis Program (H659)		X	X
Grain Design and Internal Ballistics Evaluation Program (PA08)		X	X
Nozzle and Control System Preliminary Design Computer Program (H380)		X	X
Turbulent Boundary-Layer Nozzle Analysis Program (H660)			X
Three-Dimensional Heat-Transfer Computer Program (JA03)			X
Charring Material Thermal Response and Ablation Program (G590)			X
Equilibrium Surface Thermochemistry Performance Program (G508)			X
Advanced Thrust Vector Control Preliminary Design (AFN0Z)			X
Solid Propellant Motor Performance (P2002)			X

TABLE 41 - Continued
 PROPULSION COMPUTER PROGRAM USED IN MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing
Solid-Motor Ballistic Reconstruction Program (P1216)			X
Total	1	5	12
Incremental computer programs	1	4	7

diameter, weight, thicknesses, etc.). The wall thickness of the motor defined in the program is checked for minimum wall-thickness limits and for thickness compatibility with structural requirements from the structures programs. A simple grain stress calculation is incorporated in the program to check grain stress and strain associated with case deflections for a pressurized motor case. Stresses and strains can be calculated for a simple cylindrically perforated grain with a prescribed web fraction. The equations are not intended to provide a detailed verification of grain structural integrity, but they bring insight into grain stress criticality and marginal propellant physical properties.

For a thrust vector control subsystem, the concept code together with the force, angle, and duty cycle of the subsystem must be called from the Advanced Thrust Vector Control Preliminary Design program (AFNOZ). If a chamber-bleed concept is used, the decrement of motor performance is calculated and a weight of propellant is calculated to satisfy side-force impulse requirements. The thrust vector control models incorporated in the program include a gimbaled nozzle and flexible seal, with liquid secondary injection and chamber-bleed techniques. Ground and flight-test data can be analyzed and evaluated with a solid-motor ballistic performance program (P0833) and ballistic reconstruction program (P1216).

5.2.6 Existing Sensor Computer Programs

The computer programs used in sensor design are summarized in table 42. Descriptions of the programs are given in Appendix F. At the present time,

TABLE 42
SENSOR COMPUTER CODES USED IN MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing
FIR2	X		
TVACT	X		
RADTV	X		
Atmospheric Transmission	X		
UHF Data Link	X		
Total	5	0	0
Incremental computer programs	5	0	0

sensor design is not as highly automated as structural and propulsion design, and further computer program development is anticipated in this field.

During system studies, the atmospheric effects (attenuation due to absorption and scattering and background radiance) can be defined with the aid of the Atmospheric Transmission code. Given a baseline sensor design (optics, detectors, and processor), the FIR2, RADTV, and TVACT programs can be employed for conceptual design of an imaging infrared system and for passive and active low-light-level television. These codes provide the probability of recognition as a function of the scenario, the atmospheric effects, and the sensor characteristics.

During preliminary design, the performance of a missile seeker is defined in terms of the probability of acquisition. Where data from the missile are shown on a viewer display, the probability of acquisition is generally the probability of recognition; that is, the probability that an observer who views a display will recognize the desired target is about the same.

The Atmospheric Transmission, FIR2, RADTV, and TVACT programs can be employed to assess approximate system performance as a function of parameters of the following components: (1) optical device, (2) detector size and response, (3) preamplifier, (4) processor, and (5) display. In addition, various atmospheric conditions may be considered, including the meteorological visibility range, the relative humidity, temperature, particle size and distribution, and time of day. A parametric variation of these conceptual design parameters can be performed, yielding optimum subsystem parameters for preliminary design.

Computer codes are being developed by Xerox Electro-Optical Systems, Hughes Aircraft Company, Texas Instruments, Aerojet General Corporation, Westinghouse, the Naval Air Development Center, and the Army Night Vision Laboratory to assess electro-optical system performance where the measure of performance is the probability of recognition and signal-to-noise ratio at the display.

5.2.7 Existing Guidance and Control Computer Programs

The computer programs used for guidance and control in the various engineering design phases are presented in table 43. These programs are described in more detail in Appendix G. No similar programs have been found.

The guidance and control activity during the system studies phase relates objectives to the conceptual designs proposed. Broad design goals and objectives are evaluated to test potential concepts in conjunction with simplified dynamic and sensor error models of the subsystem elements. Paper-and-pencil analysis can be done using trajectory conditions to establish the preliminary control requirements (e.g., control moment and actuator bandwidth). Using simplified control and guidance formulations in the 3-D Terminal Guidance Simulation (E602) and End Game Simulation (G578) programs, preliminary performance can be evaluated.

TABLE 43

GUIDANCE AND CONTROL COMPUTER PROGRAMS
USE IN MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing
3-D Terminal Guidance Simulation (E602)	X	X	X
GVPAT (AB16)	X	X	X
End Game Simulation (G578)	X		
Vehicle Modes and Frequencies (DA02)		X	X
CEP Analysis Program (P1299)		X	X
Shaping Network Synthesis (P3175)		X	X
NUHYAP (P2286)		X	X
Hydraulic Actuation System Preliminary Design (H425)		X	X
Valve-Actuator Frequency and Transient Response (P2219)		X	X
Actuator Friction Analysis (FRICT)			X
Servo Activator Rate and Moment (RATE)	X	X	
Multiloop Linear Analysis (CA48)		X	X
Total	4	10	10
Incremental computer programs	4	7	1

In the preliminary design phase, programs are applied to evaluate the concepts carried over from the system studies phase. The emphasis in preliminary design is on improving the guidance and control subsystem models and exercising computer programs to develop trade study and control sizing information.

Control programs which will be used to generate actuator sizing include H425, FRICT, and RATE. These programs will be used to determine size, weight, power, bandwidth, friction levels, and response characteristics. Programs such as Multiloop Linear Analysis (CA48) will be employed to obtain loop stability data and DA02 will be used to get data on control transfer functions for flexible bodies.

The Shaping Network Synthesis Program (P3175) will be used to determine the shaping of network characteristics. Additional runs of Program CA48 will be made with shaping to verify stability margins and to identify potential advantages of the proposed actuator bandwidths and loop configurations. Guidance activity will be devoted to comparing guidance algorithms and improving the seeker and radar-tracking models. Guidance sensitivity analysis will be expanded in this phase to quantify the trade studies on guidance law, seeker mechanization, guidance instrumentation errors, and target characteristics. Programs such as E602, G578, and the CEP Analysis Program (P1299) will be employed to determine the accuracy of the end game and boost phase. Comparisons can be made concerning seeker mechanization, guidance-loop noise sources, guidance-loop stability (using CA48), and control mechanization impact.

Computer support will be used in the detailed design phase to identify and expand design and performance data on a selected concept. The controls area will utilize the Vehicle Modes and Frequencies program (DA02) with improved mass properties data to obtain design information on the flexible vehicle. In addition, development testing and design data fed into CA48 will provide improved control actuator and sensor models for use in stability analysis. Mathematical models prepared from test data for seekers,

detector errors, boost errors, and tracking system performance will be used to obtain improved performance and stability data using Programs E602 and CA48.

5.2.8 Existing Cost Computer Programs

Four typical computer cost programs used in design are given in table 44. The computer programs are described in Appendix H. No similar computer programs have been found. In costing, the normal procedure is to write a special program for each different design study. Frequently, a new program need not be written if minor revisions were made in an existing program, such as any of the basic programs cited in table 44.

A computerized cost model for missile design would contain the general characteristics of the programs listed in table 44, but they would be modified to incorporate more design options and alternate paths than are presently available in any single computer program. The model would combine many features of the basic programs into a single code.

It is appropriate that a single gross model such as the Light Area Defense Study (LADS) program be used during the system studies phase while a more complex version such as the Preliminary Surface-to-Air Missile Cost Model (SAMCOM) or even the System Cost Analyses - Life Cycle Estimate (SCALE) be used during preliminary design. This would provide flexibility and quicker response time by minimizing the detail input during the earlier stages of the study. At the same time, it would permit use of additional design details that become available as the study proceeds. The additional details would provide more accurate and lower-level breakdown of the costs.

Whenever a missile system uses new technology or new manufacturing techniques, the appropriate cost-estimating relationships must be changed or modified to obtain realistic figures. This modification must be done manually. It involves searching historical data banks, evaluating the impact of

TABLE 44
COST COMPUTER PROGRAMS REQUIRED FOR MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing
Light Area Defense Study (LADS)	X	X	
Preliminary Surface-to-Air Missile Cost Model (SAMCOM)	X	X	
Advanced Terminal Interceptor Technology Program (ATITP)	X	X	
System Cost Analyses - Life Cycle Estimate (SCALE)	X	X	
Total	4	4	0
Incremental computer programs	4	0	0

advances in the state of the art, and determining the appropriate equation to include in the computer cost model used in the changed design.

Early costing activities can be more meaningful if the cost data include an estimate of the range of probable costs and the likelihood of the actual value being greater or less than selected values in the quoted range. This type of information is particularly significant in early phases of a program and during trade studies.

In the detailed design phase, the pricing and accounting data include projections of the trend-to-date to predict the cost of the complete missile program. These projections are not presently automated, but they have been studied in sufficient depth to verify they could be automated.

5.2.9 Existing Armament and Ordnance Computer Programs

At the beginning of the system studies phase, the basic threat problem is assessed and parametric data are generated to use in war games. Program BRLSGP is used for surface threat estimates of lethality, and program BRLAAP is used where there is an air threat. Program ARM-G is the war game in which the missile and firing tactics are assessed against the new threat.

At the concept review which follows system studies, the results are evaluated and a decision is made to continue to preliminary design.

Preliminary design begins with the calculation of vulnerability data for the threat. Program J-71-7-2 is used to produce tables of vulnerability as a function of warhead type. Calculations of effectiveness in this phase use more sophisticated and more accurate computer programs than in the system studies phase. The measure of effectiveness has also changed. For surface threats, the lethal area program (J-70-6-1) is used for warhead optimization; for air targets, Program P5041 or P840 is used to compute the single-shot kill probability as the warhead optimization index. After having determined the optimum warhead configuration, structures program CADD is used in a conversational mode to produce drawings of the warhead. After obtaining drawings, a final estimate of the lethality is made using the applicable program.

Detailed design would utilize only the partial capability of IPAD. The design testing involves specific tests tailored to the warhead being used. It is necessary to make these tests in order to choose between design alternatives. This operation cannot be automated. However, the design drawings can be made using CADD. Parts are manufactured for the design demonstration test in which certain test data are required by specifications in order to prove the design. After the successful design demonstration test, the safe distance is set based on the design demonstration test data. The safe distance is a distance from the warhead at which it will not injure either personnel or material.

The design phase ends with qualification of the item for the environments specified in the MIL STD 300 series to prove the warhead safe to handle, transport, store, launch, and fly until armed and commanded to fire by the fuze.

Table 45 lists the known computer codes for ordnance design activities, and provides names of other codes with similar capabilities. No similar programs were found in the computer libraries of Boeing or General Dynamics. However, the Picatinny Arsenal, the Ballistic Research Laboratory, the Naval Weapons Center, and the Air Force Armament Laboratory each has its own programs for calculating lethal area and kill probability against personnel targets, a function also performed by Program J-70-6-1.

5.3 UNDEVELOPED COMPUTER PROGRAMS PROPOSED FOR IPAD

Some missile design activities currently being performed manually can be quantified and therefore automated. In these cases, the technology and physical relationships already exist so that automation can be achieved by development of computer programs. The areas that could be automated with additional software development are: (1) costing, (2) sensors, and (3) armaments.

5.3.1 Undeveloped Cost Computer Programs

Two kinds of computer programs can be developed in costing: those which enhance the value of the cost design activities, and those which automate manual activities. In the first category, the undeveloped program has been named RISK and in the second category it is known as COS-1. These programs are described in Appendix J.

During the system studies phase of a hardware program, the cost of several different systems is compared. In the past, the selection of the preferred system has been based on comparing the best estimate of the cost of each system. The RISK model provides the opportunity to select systems by comparing both the best estimate and the probability of each system overrunning or underrunning its best estimate as well as the anticipated magnitude of the overrun or underrun.

TABLE 4b
ARMAMENTS COMPUTER PROGRAMS USED IN MISSILE DESIGN

Computer Program Title	System Studies	Preliminary Design	Detailed Design and Testing	Similar Computers Programs
Missile Quantities Requirements (ARM-C)	X			
Salvo Gunfire Program (BRLSGP)	X			
Antiaircraft Effectiveness Program (BRLAAP)	X			
Magic Computer Simulation (J-71-7-2)		X	X	
Air-to-Air Terminal Encounter Simulation Program (P2308)		X	X	Air-to-Air Terminal Encounter Simulation (USAF, P840) (The Army Material Command and Army Missile Command have similar programs)
JMEM Anti- Personnel Lethal Area Program (J-70-6-1)		X	X	
Total	3	3	3	
Incremental computer programs	3	6	6	

The best estimate of the total program cost for any system is a summation of the best estimates of the cost of subelements of the system. All these subelements are not likely to conform to their individual best estimates at any one time. The RISK model recognizes this and randomly varies each subelement between its assigned high and low limits according to the likelihood of that subelement varying from its best estimate. Combining these random values for the subelements permits calculations to be made of the range of probable variation in the total system cost and the chance that the system will overrun or underrun. This information provides management with an opportunity to evaluate systems on the amount of risk involved. Two systems may cost approximately the same, but if one offers a high probability of increased costs and only a slight possibility of lower costs, management should be aware of this before selecting one.

The computer program COS-1 will predict the total cost of the missile program during the detailed design phase. This prediction will be based on a combination of actual costs-to-date and estimates of material costs, labor hours, labor rates, overhead ratios, and quantities. As quickly as actual costs become available, they will supersede the other data. Whenever new actuals are introduced, the model will project the impact of the data and compute a new prediction of total program cost. The new prediction will be compared with the budgeted cost for the program. This gives management a tool for tracking and controlling all costs of the program.

The ability of the model to predict the total program cost by combining actuals and estimates gives the model three types of secondary capabilities: (1) it can determine the cost of change orders that are incorporated in the program; (2) it can calculate the impact of schedule changes on the program costs; and (3) it can be used to predict the effect of proposed changes or adjustments in the program on costs.

In summary, this computer model will give information which will permit management to compare actual performance to budgeted goals. It will also permit management to predict the effect of changes in the program on costs and furnish information for decision making.

5.3.2 Undeveloped Sensor Computer Programs

Few computer programs have been developed for the design of missile seeker subsystems. A description of undeveloped sensor computer program is presented in Appendix J. Computer algorithms for the design, evaluation, and parametric analysis of electro-optical and infrared imaging systems are described in detail in references 5 to 12, and 13 to 16, respectively. Infrared reticle seeker design algorithms are available, but not in a coded form (ref. 17).

The Army Night Vision Laboratory, in Fort Belvoir, Virginia, and the Army Missile Command, in Huntsville, Alabama, have extensive digital and analog simulation facilities for electro-optical sensor design. No computer codes have been found for laser system seekers; however, detailed algorithms are readily available. Radar seeker algorithms are available, but no codes have been developed for seeker design, evaluation, and parametric analysis because of the unwieldy task in unifying the codes for antennas, transmitters, receivers, and signal processors. Microwave radiometer seekers are relatively new; algorithms are presently under development.

5.3.3 Undeveloped Armament Computer Programs

Several of the undeveloped computer programs which offer potential for design work in armaments are described in Appendix J. These programs have been named ARM-A through ARM-E, and could be used for a variety of purposes.

ARM-A would be a FORTRAN program similar to several existing MDAC programs for the system studies phase. ARM-A would have built-in algorithms to compute overall warhead parameters such as equivalent tons of TNT, number of fragments, fragment size, or projection velocity as a function of missile diameter and missile weight. The data would be preliminary, but would give an estimate of the expected warhead configuration for use in an air threat. ARM-B would use the results obtained from ARM-A, and would compute parametric values of lethality. Conversely, ARM-B could be used to establish a warhead size requirement for a given lethality, and then ARM-A

could be used to determine the required warhead parameters. It is believed at this time that the program would most often be used for the latter.

ARM-D, a modified PERT program, would be used in preliminary design to estimate warhead and other ordnance costs for cost-effectiveness studies. It would predict costs based on average cost-quantity relationships for the ordnance industry.

The ARM-E program would be used in an interactive mode to write detailed design specifications. It would contain all of the MIL-STD 300 and 800 series specifications, as well as MIL-STD 1316A and other standard ordnance specifications. These specifications would be stored on magnetic tape and cross-indexed. As each specification is called out from the keyboard, the corresponding specification and all of its cross-indexed specifications would be included in the output. Data to generate specifications would be obtained from the system data bank, as required, and the operator would intervene to include information on certain techniques (e.g., procedures for vibration, jolt, jumble, and other qualification tests per MIC-STD-300). Story boards could also be made up for special-purpose specifications not in the basic system files.

ARM-F would be a data-reduction program designed to work in conjunction with testing. Test data would be stored on magnetic tape as they were obtained during testing. ARM-F would then average, plot, and process the data as required to compare them with the desired results. This program would require continuous updated capability to make it useful on most ordnance tests.

5.4 DISTRIBUTIONS OF EFFORT AND COST IN THE PRESENT DESIGN PROCESS

This section provides distributions on cost, time, and efficiency in performing a missile design. The functions performed in each design activity are first identified and analyzed. Costs and schedules are then given for representative missile system segments and design activities.

5.4.1 Distribution of Creative and Noncreative Functions in the Design Process

Some of the logical problem-solving functions in engineering design can at present be accomplished only by man, while others can be accomplished by man, or by computer, or by both. To clarify the means by which the functions are accomplished, the logical problem-solving functions are combined and expanded as illustrated in figure 16. The problem definition and system synthesis functions are combined since they are accomplished by similar means, human intuition and judgment. The system analysis function is expanded into two functions, "develop or modify models," and "generate information." This function was separated because model development and modification is a major effort in many missile projects. The numerical activities of the "system analysis function" are combined with "system optimization" since these functions usually occur together.

The functions presented in Figure 16 involve man in noncreative and creative tasks. His noncreative tasks consist of routine data preparation for computer program input, documentation, and transmittal of data to other disciplines. The creative activities include defining the problem, synthesizing alternative solutions, developing and modifying models, and evaluating information. The mix between noncreative and creative tasks changes with each design activity and in each program phase. However, there is usually more creative activity in the earlier program phases than in the later ones, as shown in figure 17. This idea is expressed in reference 18.

A study was performed to determine the engineering time spent creatively and noncreatively for various design activities of the Thor/Delta launch

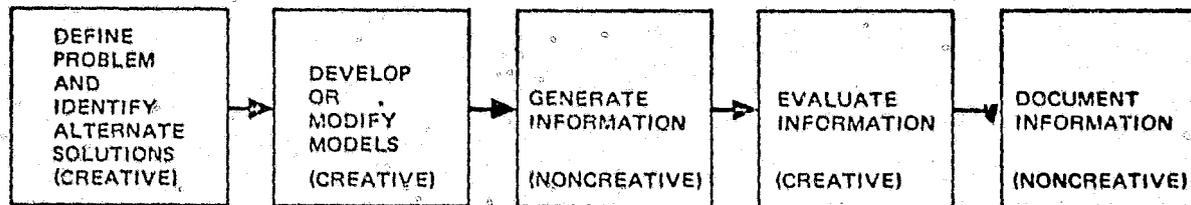


Figure 16.—Problem-Solving Functions in Engineering Design

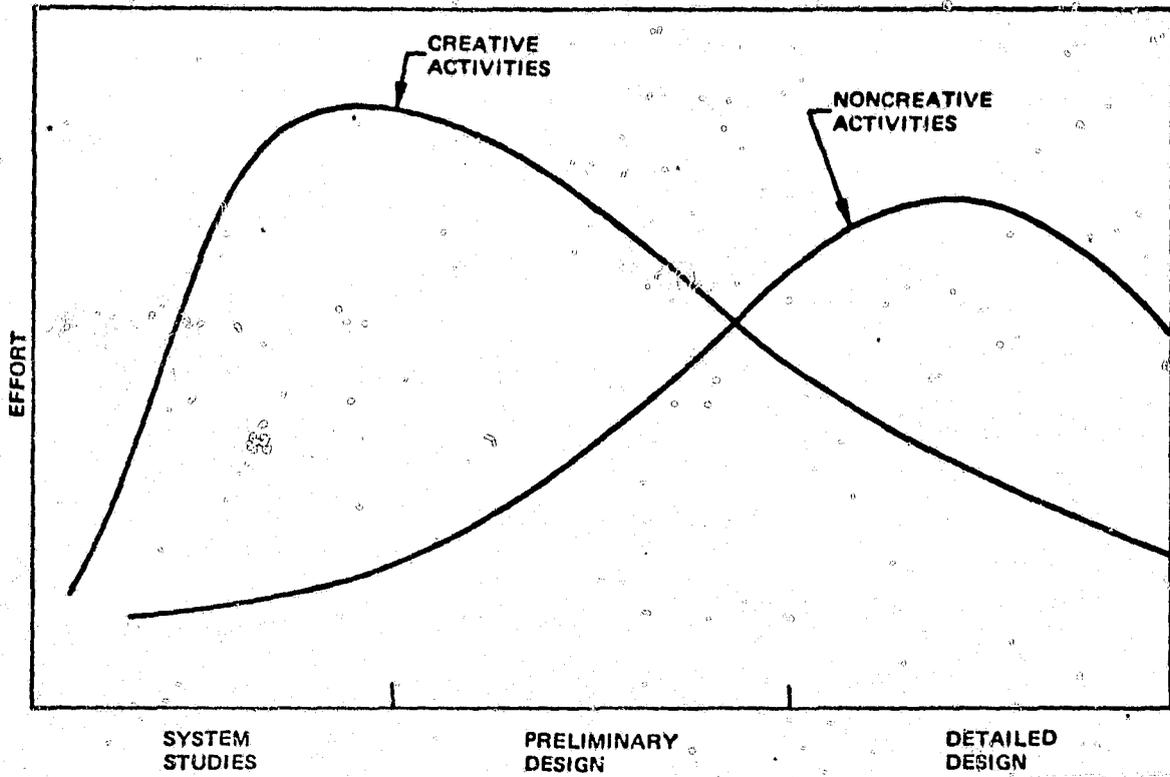


Figure 17.—Distribution of Creative and Noncreative Engineering Activities in Design Phases

vehicle program (ref. 18). The study evaluated the engineering effort expended in the preliminary and detailed design phases for the following types of design activities: (1) rigid-body dynamics analysis, (2) mission analysis, (3) ground track analysis, (4) design support, and (5) coupled modes analysis (ref. 19).

An example of the creative and noncreative effort is given in the following case of a rigid-body dynamics analysis for the Thor/Delta launch vehicle. The activities required to perform this analysis for preliminary design are indicated in figure 18. Similar activities were involved in analysis in the detailed design phase.

The results of the study are presented in figure 19 for the preliminary design phase and in figure 20 for detailed design. In preliminary design, 45 percent of the man-hours expended were for creative activities, while creative effort accounted for only 23 percent of the total man-hours spent in detailed design. The results of an evaluation of all the design activities in the study are presented in table 46.

In other cases, additional expenditures for creative activities are required to modify or develop computer programs used in design. Most of this type of activity occurs in the system studies and preliminary design phases of a program. In one missile program, the amount of man-hours spent in the system studies phase was about 70 percent of the total expenditure. Examples of various tactical scenarios are presented in table 47. In each scenario, modifications were required in the computer programs.

5.4.2 Distribution of Costs and Time in the Design Process

This section presents representative development costs and design cycle time associated with various missile projects. These figures are used in Section 5.6 to estimate the cost, time, and efficiency which may be achieved by using an engineering design system such as IPAD.

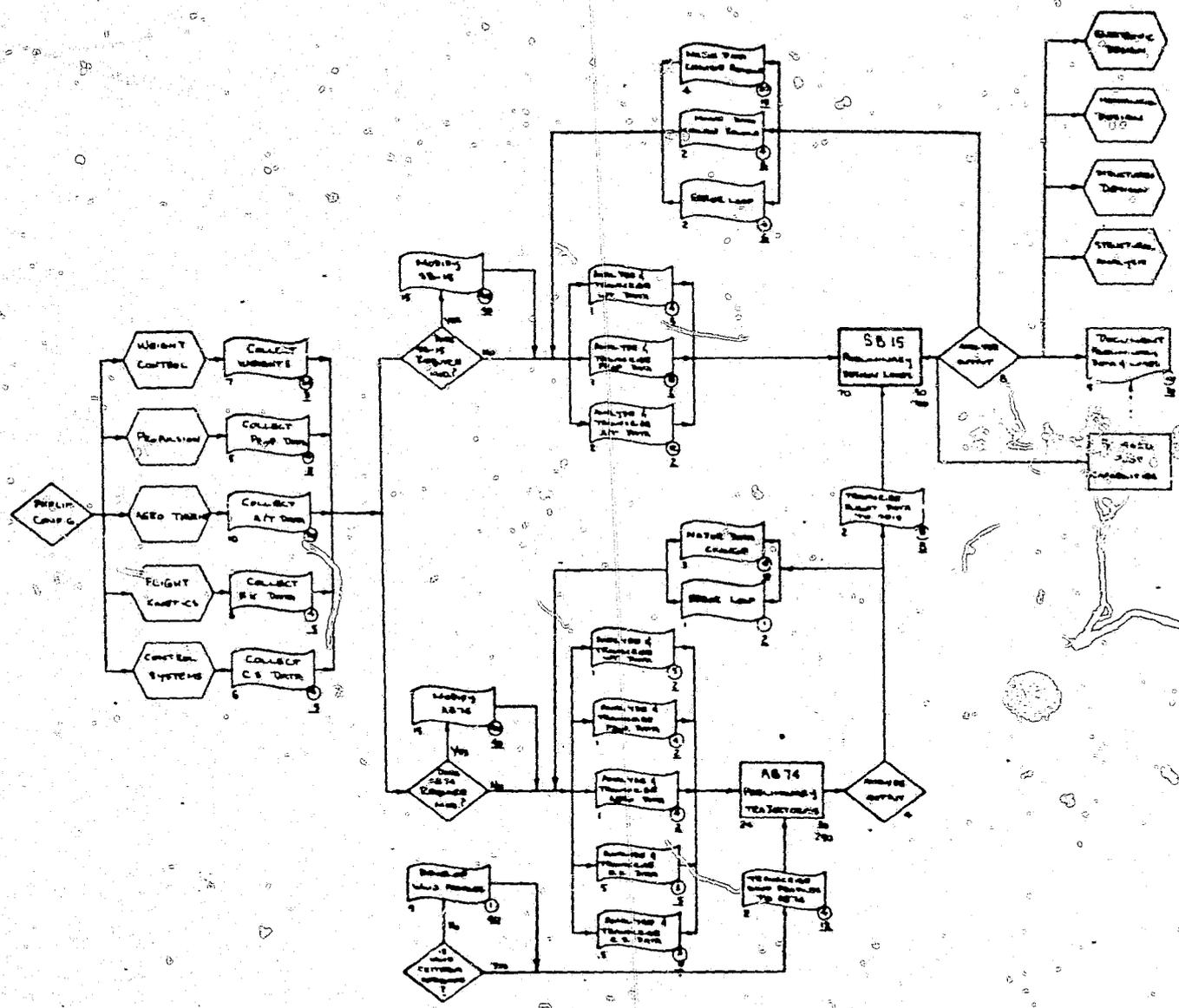
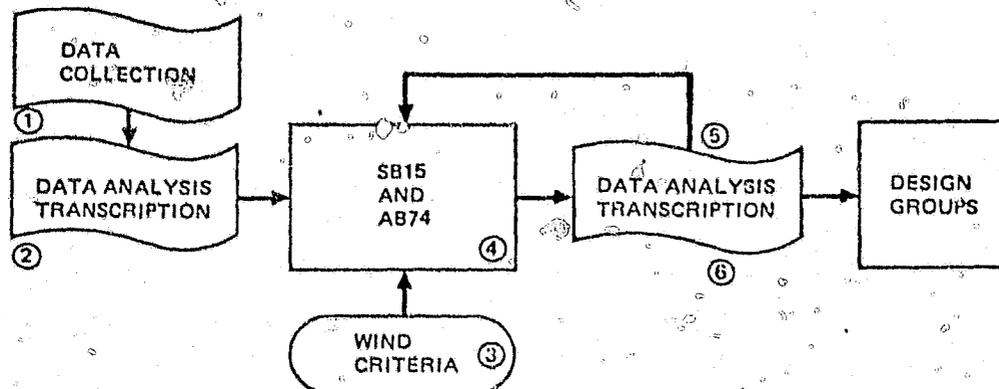


Figure 18.—Thor/Delta Use of SB15 for Flight Conditions in Preliminary Design

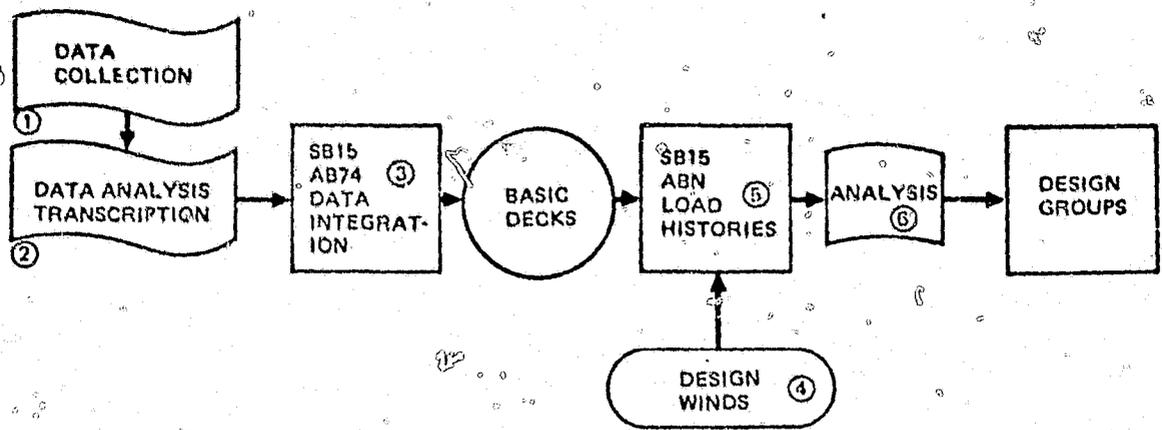
3



NOTE: SB15 - STRUCTURAL ANALYSIS COMPUTER PROGRAM
 AB74 - SIX-DEGREE-OF-FREEDOM COMPUTER PROGRAM

PHASE OF ACTIVITY	NONCREATIVE MAN-HOURS	CREATIVE MAN-HOURS	ELAPSED TIME (DAYS)
① INPUT DATA COLLECTION WEIGHTS PROPULSION AERO/THERMAL FLIGHT KINETICS CONTROL SYSTEMS	24.0 4.0 30.0 4.0 4.0	3.0 0.5 4.0 0.5 0.5	7.0 5.0 10.0 6.0 6.0
TOTALS - PHASE ①	66.0	8.5	10.0
② INPUT DATA ANALYSIS AND TRANSCRIPTION WEIGHTS PROPULSION AERO/THERMAL FLIGHT KINETICS CONTROL SYSTEMS	9.0 12.0 16.0 3.0 3.0	7.0 4.0 4.0 0.5 0.5	2.0 2.0 3.0 0.5 0.5
TOTALS - PHASE ②	43.0	16.0	8.0
③ DEVELOP WIND CRITERIA	1.0	40.0	5.0
④ ANALYZE AND TRANSCRIBE AB74 DATA TO SB15	8.0	8.0	2.0
⑤ INTERMEDIATE ANALYSIS AND TRANSCRIPTION	4.0	12.0	2.0
⑥ OUTPUT DATA TO TOTAL	-	12.0	1.5
TOTALS - CURRENT MODE 1 TO ⑥	122.0	96.5	28.5

Figure 19.-Engineering Effort for Thor/Delta Use of SB15 in Preliminary Design



NOTE: SB15 - STRUCTURAL ANALYSIS COMPUTER PROGRAM
 AB74 - SIX-DEGREE-OF-FREEDOM COMPUTER PROGRAM

PHASE OF ACTIVITY	NONCREATIVE MAN-HOURS	CREATIVE MAN-HOURS	ELAPSED TIME (DAYS)
① INPUT DATA COLLECTION WEIGHTS PROPULSION AERO/THERMAL FLIGHT KINETICS CONTROL SYSTEMS	40 16 21 4 4	8 2 41 4 4	60 60 100 150 60
TOTALS - PHASE ①	85	59	150
② INPUT DATA ANALYSIS AND TRANSCRIPTION WEIGHTS PROPULSION AERO/THERMAL FLIGHT KINETICS CONTROL SYSTEMS	1 8 252 2 1	5 8 5 14 3	1 2 17 2 1
TOTALS - PHASE ②	264	35	25
③ VERIFY DATA COMPATIBILITY	48	4	6
④ TRANSCRIBE WIND PROFILES TO AB74	16	4	10
⑤ TRANSCRIBE TRAJECTORY DATA TO SB15	8	1	1
⑥ OUTPUT DATA ANALYSIS	0	24	3
TOTALS - CURRENT MODE ① TO ⑥	421	127	150

Figure 20.--Engineering Effort for Thor/Delta Use of SB15 in Detailed Design

TABLE 46
MIX BETWEEN CREATIVE AND NONCREATIVE ACTIVITIES

Program Phase	Percentage of Noncreative Man-Hours	Percentage of Creative Man-Hours
Preliminary Design	49	51
Detailed Design	77	23

5.4.2.1 Cost

The cost of a missile system can vary significantly with the size, technology used, and the type of program. In a hardware program, the percentage of total program cost associated with engineering activities will be much lower than in a development program. Since the IPAD system is more effective when design engineering is the major effort, the cost statistics presented are for development programs.

Percentages of the various cost elements for a typical missile development program, an interceptor missile system, are presented in table 48. The cost of engineering analysis and design is 30 percent of the total development cost. The percentage of engineering cost is 5 percent in the preliminary design phase and 25 percent in detailed design. It is difficult to estimate percentages for the system studies phase because of the tremendous variation in program budgets in this phase. The amount is small, usually about 1 percent of development costs, and is therefore neglected in the study. The total program costs for an actual interceptor system may be on the order of \$132 million.

5.4.2.2 Schedule

The time to complete each missile design phase depends upon the type of missile system, its characteristics, and whether or not it is a variation of some existing missile system. For example, the NIKE, HERCULES, ZEUS,

TABLE 47
TACTICAL MISSILE SCENARIOS

Given Requirements	Design Trade Studies Required
<p>1. Target, defended range, warhead, and miss distance</p>	<p>Propulsion - Burn time, grain design, case material, performance</p> <p>Aerodynamics - Body shape, lift requirements</p> <p>Flight Mechanics - Trajectory shaping, performance evaluation</p> <p>Structures - Case material, fairings, etc.</p> <p>Guidance and Control - Search, acquisition, and track evaluation; end-game performance; command, control, and communications</p> <p>Mechanical - Pneumatics vs. hydraulics (movable fins, thrust vector control)</p> <p>Thermodynamics - Insulation materials</p>
<p>2. Target, defended range, family of warheads, and their characteristics</p>	<p>All of trades listed for Item 1 plus</p> <p>Armament - Miss distance vs. kill probability</p> <p>Others - Broaden scope of above trades to encompass multiple warhead choice</p>

TABLE 47
TACTICAL MISSILE SCENARIOS—Continued

Given Requirements	Design Trade Studies Required
<p>3. Target, defended range, warhead, miss distance, and propulsion package</p>	<p>Aerodynamics— Same as Item 1 except constrained by propulsion section. May require more work than in Item 1 to obtain desired lift</p> <p>Flight Mechanics— Same as in Item 1</p> <p>Structures— Probably one-fourth the effort of Item 1</p> <p>Guidance and Control— Same as in Item 1</p> <p>Mechanics— None if no movable fins are used; otherwise, three-fourths the effort of Item 1</p> <p>Thermodynamics— Same as in Item 1</p>

TABLE 48
TYPICAL PERCENTAGES OF ENGINEERING COST
ON A DEVELOPMENT PROGRAM

Activity	Percent of Development Cost
Production, Materials, field stations, etc.	40
Engineering, Laboratories, Logistics, and Systems Engineering*	60
Engineering Design (Flight Vehicle Hardware)**	30
Preliminary Design	5
Detailed Design of Vehicle*	25
*Excludes subcontractor costs. **Excludes ground support equipment, mockups, and field station equipment.	

and SPARTAN missile systems belong to the same family. In the area of launch vehicles, the Saturn S-IV is related to the Saturn S-IVB, which in turn is related to the Orbital Work Shop. In these cases, the time spent in preliminary design is relatively short since many of the trade studies were already completed for previous systems or because of system constraints.

Typical schedules for a new missile system are presented in table 49. For the four different missile systems considered, the time occupied in preliminary design is assumed to be the interval between receipt of the authority to proceed on a contract and the preliminary design review. The time occupied in detailed design is assumed to start at the preliminary design review and continue until 90 percent of the engineering drawings have been released, which usually occurs after the critical design review. For the systems presented, the average time spent in preliminary design was six months and the average time spent in detailed design was 11 months. This gives an average of 17 months for most of the engineering analysis and design activities.

TABLE 49
TYPICAL SCHEDULES

Program	Months in Program Phase		
	Preliminary Design	Detailed Design	Production
System 1 (reentry vehicle)	5	10	9
System 2 (cruise missile)	5	5	5
System 3 (ground-to-air-missile)	5	14	25
System 4 (interceptor)	9	17	21
Average number of months spent in program phase	6	11.5	10.6
Average percent of time spent in each phase	21	41	38

5.5 PRODUCTIVITY OF ON-LINE INTERACTIVE GRAPHICS AND INTEGRATED COMPUTER PROGRAMS

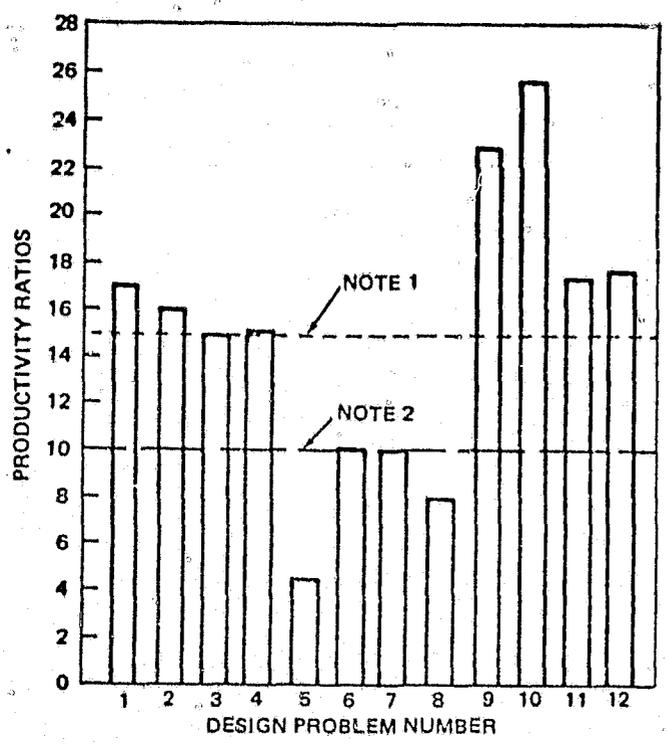
Three major computer programs used in the various companies of McDonnell Douglas Corporation have proved that integrated computer programs and on-line interactive graphics can increase the effectiveness of the engineering design process. These programs are: (1) General Missile Sizing Program (GMSP), (2) Computer Aided Design and Drafting (CADD), and (3) Graphic Interactive Drafting System (GRID). They have reduced the company's costs and time required to complete design activities. Similar savings are expected in the design of missile systems using the interactive graphics capabilities of IPAD.

5.5.1 Graphic Interactive Drafting System (GRID)

GRID was developed at McDonnell Douglas Aircraft for use in design and drafting on the F-15 fighter aircraft. Tests were performed on the system in June 1970 (see ref. 20). A summary of the productivity ratios, or the ratios of estimated manual time to interactive graphics system, is presented in figure 21. This test resulted in an average productivity ratio of 15 to 1.

The GRID program is now used principally to produce all the electrical drawings for the DC-10 commercial aircraft. These drawings are created or modified by an operator at a cathode-ray-tube console under the control of and aided by the software system. The user may call for drawings to be displayed on the tube for review and modification or creation. The console contains a light pen, alphanumeric keyboard, and programmable function keys. Once the drawing is created on the cathode ray tube, the user may store the drawing and request that it be automatically plotted using off-line equipment. The software aids the operator by allowing him to draw symbols, lines, and characters, and align, delete, duplicate, and move data.

Extensive tests have been conducted to measure the system's effectiveness. It has been determined that a new drawing can be created with GRID in 6.3 man-hours while it can be created manually in 25 man-hours. Drawings that



- NOTES:
1 - AVERAGE PRODUCTIVITY RATIO (15)
2 - PRODUCTION RATIOS OF 10 TO 1 OR BETTER HAVE BEEN ACHIEVED IN 10 OUT OF 12 CASES

Figure 21.--Productivity Ratios for the Design and Drafting On-Line Interaction Graphics System

take 8 man-hours to revise, require only 1 hour at the console. Over a period of 46 months, 27,000 drawings have been produced with GRID. The savings realized over manual methods amount to almost \$2 million.

5.5.2 General Missile Sizing Program (GMSP)

Integrated computer programs have been used at McDonnell Douglas Astronautics Company-West to increase productivity in missile design. On one new business proposal, seven men worked for three 60-to-80 hour weeks for a total of about 35 man-weeks. This group consisted of three propulsion engineers, two structures men, one aerodynamicist, and one flight mechanics engineer. The trade studies performed included grain design, vehicle configuration, and rocket motor-case materials. The payload, motor burn time, and burnout velocity were specified; therefore, no trades were performed in these areas. The equivalent effort performed by the integrated computer program, the General Missile Sizing Program (GMSP), would have been about five man-weeks plus computing time. The productivity ratio using the integrated computer program would have been 7 to 1.

GMSP was developed at McDonnell Douglas several years ago for the conceptual sizing of missile configurations to deliver a specific level of performance (see ref. 21). It is a rather large and versatile program that performs rapid and accurate sizing, optimization, and preliminary design of a missile configuration and its subsystems for a given performance requirement.

A brute force approach is used for the sizing process which assigns propellant weights to the respective stages, designs each of the subsystems, establishes the external geometry of the configuration, optimizes the performance, and iterates this process until the missile stages are sized to deliver the desired performance. The program is written entirely in FORTRAN IV and contains roughly 20,000 FORTRAN statements consisting of some 120 subprograms. Forty MDAC library routines are also utilized. The GMSP consists of a main program, referred to as the master control, and 14 modules, each module consisting of from one to 45 subroutines.

The GMSP represents a coalition of the analysis and design philosophies, techniques, and theories of every nonelectrical discipline involved in design of a missile. Each module groups together all the design and analysis functions for a particular subsystem or technology. For example, the propulsion module performs complete design, optimization, and weight and performance analyses for the propulsion subsystem. This activity includes the selection of type of grain design, the computation of the grain design details to produce the desired thrust versus time shape, the three-dimensional ballistic analysis, and the nozzle and motor-case design and optimization.

The GMSP may be operated in a variety of modes encompassing a considerable range in level of detail and computing speed. This capability permits the program to be used economically in each of the steps in the design process. The customary procedure of the GMSP in sizing and designing a missile configuration is indicated in figure 22. Three major iterative loops occur in the program: the initial design loop, the final design loop, and the performance loop. The initial design loop results in sizing a configuration to produce a specified impulsive velocity. The configuration design is based on the preliminary trajectory data generated in the preliminary performance module. This loop includes all the modules except the trajectory and results modules, and is completed only when the configuration's impulsive velocity, computed at the point labeled " V_I check," is equal to the desired value used in staging the configuration.

In the final design loop, thermal and structural design trajectories are generated for the initial configuration and its redesign to enable the vehicle to withstand the predicted environments. The structural design trajectory is used in the design of the airframe and control subsystems. When the design trajectories cause the impulsive velocity of the configuration to change significantly, the configuration is restaged accordingly. Thus, the final design loop is completed only when the configuration is designed to its own trajectories and possesses the proper impulsive velocity.

On completion of the final design loop, the trajectory module is entered to determine the maximum performance of the configuration obtained through

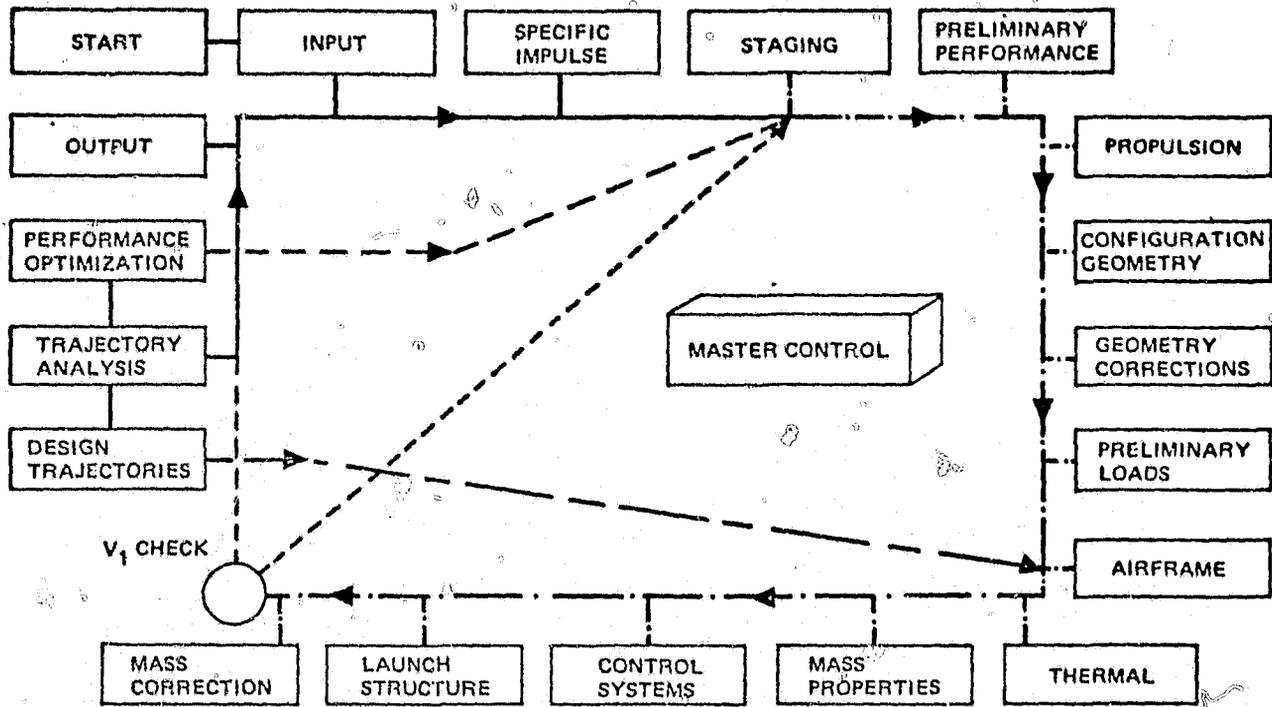


Figure 22.—GASP Block Diagram

trajectory shaping and to compare that performance to the input sizing requirement. When the achieved performance differs from the desired performance, a prediction is made for the impulsive velocity which will result in a configuration design with the correct performance. This value is used in restaging the configuration (in the staging module) and redesigning the configuration. This loop is iterated until the desired performance is achieved. When the performance loop is complete, the results module is entered to summarize and print out the final configuration characteristics and performance. The GMSP can, however, be used for quick answers in parametric tradeoffs between gross weight and performance and to examine the performance variation of a nominal missile across the intercept domain.

Computing time has been minimized in two ways: (1) by use of prediction techniques to reduce the number of iterations in the major iterative loops, and (2) by incorporating a learning capability where the results of sizing one missile configuration are used by the program to aid in sizing a subsequent configuration. Input requirements have been reduced so that as few as 60 input items are required to operate the program even though approximately 1,500 inputs are available. Over 90 percent of the available inputs either pertain to the hundreds of design options or are used to override internally stored data.

The same operations performed by the GMSP could be done by hand or by engineers operating specialized design or analysis programs, but more time would be needed and more errors produced. The major advantage of the GMSP is in the reduced design-cycle time and cost. With the GMSP, an engineer can produce a complete tradeoff study or a preliminary design in two to three days (including data evaluation), given only the missile performance requirement, the desired state of the art, and the payload. Or he can produce in a day the portion of the data required to select the performance, the state of the art, and the payload.

The cost advantage of the GMSP is considerable since the cost of an average configuration in preliminary design is only \$15 or \$30. Without GMSP, the cost could run up to \$10,000. Other advantages are conservation of manpower, accuracy, and a high level of detail. Even when the program is used

for a small task, such as to generate a parametric curve, the user is provided with a considerable amount of information on the characteristics of the missile configurations represented by each point on the curve.

5.5.3 Computer-Aided Design and Drafting (CADD)

The Computer-Aided Design and Drafting system (CADD) program is a computer graphics application which enhances the capability of design engineers in the execution of their daily work (see ref. 22). CADD is used by the designer to develop, manipulate, and analyze structural and mechanical design geometry faster and more accurately than possible with manual methods. The designer uses a graphics console in his own work area. It contains a display surface similar to a television screen, a set of control buttons (function keys), typewriter keyboard, and a light pen. The designer converses directly with the computer through the graphics console. Manipulating the various console control devices, he rapidly constructs a geometric model of his design objective. He uses a different set of function keys for varied applications. The lofting function keys perform different functions than the set of keys used in the layout package. In "drawing" a part on the cathode ray tube, the designer might typically touch a point on the tube with the light pen and tell the computer that he wants a vertical line there. He can proceed in this fashion, adding lines, rotating drawings, and in general he can manipulate the drawing in a most efficient manner. He can store and retrieve drawings as needed to solve his current problem.

Thus, the graphics console provides a means of communicating with the computer in the language of the engineer. He thinks the same way that he did at the drawing board, except that the computer does the tedious work for him. Many subroutines are available which enable him to take many short-cuts in drafting with his light pen and function keys. If he needs a hole pattern for rivets, he simply tells the computer how many equally spaced holes he needs from one point to another or at a certain distance from and parallel to a contoured curve. The cross lines for the rivet holes appear automatically in an instant.

Similarly, on a symmetrical design, the designer draws one half of the design to the centerline and tells the computer to finish it by repeating his design in reverse. If the design is nearly symmetrical, he still draws half, has the computer flip his drawing to complete it, and makes the small changes necessary by hand. Text and numbers are also keyed in at the terminal and appear where they were set up. The text may be moved en masse by indicating where it is to be placed.

By eliminating tedious effort, the system keeps the designer thinking and encourages his creativity. This is unquestionably one of the greatest benefits in terms of increased engineering productivity, although it is the most difficult to measure.

CADD allows the designer to iterate his tasks in a shorter time. In the past, if he needed accurate loft data upon which to base his design of aircraft structure or mechanisms, he had to send a request form to the lofting area where it was interpreted, the contours were manually developed, and an actual drawing sent back to him. The average time for this task was two weeks; the absolute minimum in a rush situation was two days, and there was always a question as to whether the data were completely current and accurate.

Now, the designer sits at a console in his work area and defines the plane in which he needs the contour. The system directly accesses the "surface" files in the computer, intersects the pertinent loft surfaces with the defined plane, and displays the resulting contour in a matter of seconds, even if this plane is a double-canted. It is displayed directly to the man who needs it, but if it is not what he wanted, he can reject it and immediately ask for the correct contour. Moreover, when that contour is needed again, it will be exactly the same, without any loss of accuracy.

This approach enables the designer to produce almost as fast as he can think. The power of the system is limited only by the creativity of the man using it.

The system was developed under the guidance of design engineers. As a result, the system is designer-oriented. A designer can think in the same terms as before and needs no reorientation of his past design experience. There is nothing he can draw on a board that he cannot draw on a console, and many things he can draw on a console much better than on a board. A designer can be taught to use the graphics system in two weeks and be brought to real proficiency in 50 hours.

CADD has been used in the design of the F-15 fighter aircraft. Over 15,000 hours have been logged on the system with approximately 60 designers qualifying as experienced operators. The system consists of IBM 2250 graphics consoles tied to an IBM 360 or 370 computer.

A measure of its productive effectiveness will not be presented. The data to be given indicate only the increased productivity in the design area by showing a ratio of the amount of work that can be accomplished using a CADD system versus a manual approach.

The estimates do not include many intangible advantages such as savings realized by creating a design in a much shorter time. They cannot show the benefit from the ability to complete "key" work and move onto other work. They do not reflect the savings achieved in manufacturing, planning, tool design, and quality assurance. These departments have access to the data on a display tube immediately upon completion of the drawing. They are able to interact with the computer to create their own instructions on use of the drawing. Therefore, the increased productivity figures shown below are very conservative.

Sixty-two design applications were reviewed to determine the productivity ratio. Some 326 console hours were used for these tasks and the mean productivity ratio was 10.8 to 1, even though the CADD package was used by relatively inexperienced operators. Individual productivity using the CADD system improves significantly with experience. The range of the productivity ratios actually experienced during this study extended up to 36 to 1.

to "see" while in the stowed position. The problem presented an extremely difficult layout for the designer since it called for data that show the blockage of seeker visibility produced by the aircraft and its stores for both inboard and outboard missile locations. Employing the graphics system, the task was initiated by taking sections cuts normal to the planview through the aircraft and stores mold lines in 10-degree increments using the missile seeker focal point as the center. Since the section cuts contained the basic aircraft mold line, the stores mold line, and the seeker focal point, the blockage angles and their locations with respect to a horizontal plane were readily constructed.

These data were then plotted on an Aitoff's sphere projection and simplified by additional section cuts. In all, the loft data file was accessed by computer graphics 80 times to obtain the complete plot for each missile location. The task was estimated to take in the neighborhood of 400 man-hours per missile location if attempted manually, but was accomplished using graphics with 28 console hours, along with a significant increase in accuracy.

5.6 PROJECTED TIME AND COST SAVINGS WITH IPAD

The effectiveness of the IPAD engineering design system can be determined by comparing it with the currently used engineering design system and applying it to the missile design process. The efficiency, cost, and engineering design cycle time can be estimated by considering primary activities performed by the system components. These are:

- A. Noncreative manual activities associated with data preparation, manipulation, documentation, and transmittal.
- B. Creative activities associated with problem definition, identification of alternative solutions, and data evaluation.
- C. Creative activities associated with model development and modification.
- D. Computations made to generate data.

These elements will be developed into a mathematical model of the engineering design process.

CADD has proven to be a very powerful and cost-effective design tool when applied to selected design problems and operated by qualified designers. Some examples of the effective use of CADD are given below.

During design and testing of the F-15 inlet subsystem, modifications were made at the wind-tunnel site which improve performance in the most critical inlet configuration. This information was relayed to the design group which then

1. Evaluated the difference between the original design and the wind-tunnel-revised subsystems for eight critical ramp locations.
2. Checked the compatibility of the revised linkage system with respect to the actuating system and obtained any increase in maximum ramp angles.
3. Laid out a minimum linkage and ramp structure configuration change with equivalent inlet ramp positions of the revised wind-tunnel model in each of the critical ramp positions.

Since CADD was used in the original design of the inlet subsystem, the ramp subsystem was readily retrievable. The above actions were completed and the results reported to the propulsion engineer who requested the work within a five-hour period, allowing the test to be continued with the new linkage system data. Upon verification of the improvement from tests, the structural modification layouts were made via CADD and incorporated in the present inlet subsystem. The fundamental advantages of a graphics system — accuracy, speed, and the ability to study alternative solutions rapidly — were clearly demonstrated in this example. Similar problems previously completed by trigonometric calculations would have taken about two weeks to solve.

Another study involved interspatial relationships with such items as positioning of external armaments through the full range of launch, release, and flight positions as well as their relationship to vehicle contours and moving landing gear systems. The missile-seeker visibility spectrum was investigated, and a missile mounted on a wing pylon was designed with the ability

5.6.1 Mathematical Model of the Engineering Design Process

The mathematical model of the engineering design process considered the four elements identified above and the missile system statistics presented in the preceding section. The model illustrates the primary relationships in the engineering design process, and therefore allows for a quantifiable approach to evaluating various engineering design systems. General conclusions about various systems can also be made. The model development is described in the following text.

Define the following parameters for an engineering design process that consists of many design activities and uses primarily nonintegrated computer programs exercised in the batch mode.

C_T = Total cost of a missile development program

P_1 = Percentage of total missile program cost spent in engineering analysis and design activities in the system studies phase

P_2 = Percentage of total missile program cost spent in engineering analysis and design activities in preliminary design

P_3 = Percentage of total missile program cost spent in engineering analysis and design activities in detailed design

P_4 = Percentage of total missile program cost not considered in P_1 , P_2 , P_3 . Therefore, $P_1 + P_2 + P_3 + P_4 = 1$

C_1 = Cost of engineering analysis and design activities spent in the system studies phase

C_2 = Cost of engineering analysis and design activities spent in preliminary design

C_3 = Cost of engineering analysis and design activities spent in detailed design

C_4 = Cost of missile development program not considered in C_1 , C_2 , C_3 . Therefore, $C_T = C_1 + C_2 + C_3 + C_4$

Let a prime (') denote the results of the engineering design activities being accomplished by a system of integrated computer programs operating primarily in the terminal on-line interactive mode with graphics (i. e., an

IPAD-type system). The missile program costs can be determined for each design phase for a given engineering design system by the following:

let

$$C_T = \sum_{i=1}^4 C_i \quad (1)$$

where the costs in each phase are defined by the following relationships:

$$C_i \equiv P_i C_T \quad i = 1, 2, 3, 4 \quad (2)$$

$$C_i \equiv P_i' C_T$$

For each phase, the cost is

$$C'_i = \left(\frac{C'_i}{C_i} \right) C_i \quad i = 1, 2, 3, 4 \quad (3)$$

Employing equation (2), and letting the total program cost, C_T , be normalized ($C_T = 1$), equation (3) becomes

$$C'_i = \left(\frac{C'_i}{C_i} \right) P_i \quad i = 1, 2, 3, 4 \quad (4)$$

Consequently, the change in program cost is weighted by the factor P_i ; i. e., a percent change in cost has a stronger effect in the design phase which has the largest expenditure of effort.

The total cost for each design activity can be divided into four cost elements, as indicated in equation (5).

$$e_{ji} = e_{ji1} + e_{ji2} + e_{ji3} + e_{ji4} \quad (5)$$

where

- e_{ji} = Total cost of the i^{th} design activity in the j^{th} phase
- e_{ji1} = Noncreative cost associated with routine data-handling for the i^{th} design activity in the j^{th} phase
- e_{ji2} = Creative cost associated with problem definition, synthesis, and data evaluation for the i^{th} design activity in the j^{th} phase
- e_{ji3} = Creative cost associated with model development and modification for the i^{th} design activity in the j^{th} phase.
- e_{ji4} = Cost of numerically generating data for the i^{th} design activity in the j^{th} phase

For the engineering design process which uses primarily nonintegrated computer programs operating in the batch mode, the cost elements are defined as follows:

$$e_{ji1} = R_D T_{ji1} \quad (6)$$

$$e_{ji2} = R_D T_{ji2}$$

$$e_{ji3} = R_D T_{ji3}$$

$$e_{ji4} = R_N T_{ji4}$$

where

R_D = The hourly rate (dollars per hour) of design personnel

R_N = The hourly rate (dollars per hour) for numerical computation

T_{ji1} = Time (in hours) spent in noncreative, routine data-handling activities for the i^{th} design activity in the j^{th} phase

T_{ji2} = Time (in hours) spent in creative activities associated with problem definition, solution synthesis, and data evaluation for the i^{th} design activity in the j^{th} phase

T_{ji3} = Time (in hours) spent in creative activities associated with model development and modification for the i^{th} design activity in the j^{th} phase

T_{ji4} = Time (in hours) spent in numerically generating data for the i^{th} design activity in the j^{th} phase

Substituting the set of equations (6) into equation (5) and summing for all design activities in the j^{th} phase provides the total cost of the j^{th} design phase. The total number of design activities is N_j .

$$C_j = \sum_{i=1}^{N_j} e_{ji} = R_D \sum_{i=1}^{N_j} T_{ji1} + R_D \sum_{i=1}^{N_j} T_{ji2} + R_D \sum_{i=1}^{N_j} T_{ji3} + R_N \sum_{i=1}^{N_j} T_{ji4} \quad (7)$$

Define the average times spent in each type of activity (creative, noncreative, etc.) as follows

$$\bar{T}_{jk} = \frac{\sum_{i=1}^{N_j} T_{jik}}{N_j} \quad \begin{array}{l} K = 1, 2, 3, 4 \\ j = 1, 2, 3, 4 \end{array} \quad (8)$$

Substituting equation (8) into equation (7) results in

$$C_j = N_j (R_D \bar{T}_{j1} + R_D \bar{T}_{j2} + R_D \bar{T}_{j3} + R_N \bar{T}_{j4}) \quad (9)$$

The costs for a design activity being performed by an engineering design system using integrated computer programs and operating in the terminal on-line interactive mode are very similar except in two respects:

- A. There is an additional cost for terminal operation.
- B. The engineering design process in terminal operation allows for greater efficiencies in both the noncreative and creative tasks associated with problem definition, identification of alternative solutions, and data evaluation.

The cost for the total number of design activities in the j^{th} design phase is

$$C'_j = N'_j (R_D \bar{T}_{j1} \eta_j + R_D \bar{T}_{j2} \omega_j + R_D \bar{T}_{j3} + R_N \bar{T}_{j4} + R_T \bar{T}_{j2} \omega_j \sigma_j) \quad (10)$$

where

η_j = Efficiency resulting from the noncreative, routine data-handling activities being performed by an IPAD system in the j^{th} design phase

$$\eta_j = T'_{j1} / T_{j1}$$

ω_j = Efficiency resulting from the creative tasks, problem definition, identification of alternative solutions, and data evaluation in the j^{th} design phase.

$$\omega_j = T'_{j2} / T_{j2}$$

σ_j = The percentage of creative activity performed with terminal on-line mode of operations

R_T = The rate (dollars per hour) for terminal on-line mode of operation with the IPAD system

N'_j = The total number of design activities being performed in the j^{th} phase by an IPAD system

The rate for terminal on-line mode of operation depends upon the IPAD system design; for example, on the type of host computer, type of terminals, and the number of terminals. It was assumed that the time a man spent at a terminal performing noncreative activities would be negligible.

The ratio of costs due to using the two different engineering design systems is required for equation (4). It can be obtained by combining equations (9) and (10). This results in the following:

$$\frac{C'_i}{C_i} = \frac{N'_i (R_D \bar{T}_{i1} \eta_i + R_D \bar{T}_{i2} \omega_i + R_D \bar{T}_{i3} + R_N \bar{T}_{i4} + R_T \bar{T}_{i2} \omega_i \sigma_i)}{N_i (R_D \bar{T}_{i1} + R_D \bar{T}_{i2} + R_D \bar{T}_{i3} + R_N \bar{T}_{i4})} \quad (11)$$

It is assumed that the costs associated with numerical computation can on the average be neglected with respect to the other costs. Reference 2 states that these costs are between 4 and 8 percent of the total engineering cost. Equation (11) therefore reduced to

$$\frac{C_i'}{C_i} \approx \frac{N_i'(R_D \bar{T}_{i1} \eta_i + R_D \bar{T}_{i2} \omega_i + R_D \bar{T}_{i3} + R_T \bar{T}_{i2} \omega_i \sigma_i)}{N_i(R_D \bar{T}_{i1} + R_D \bar{T}_{i2} + R_D \bar{T}_{i3})} \quad (12)$$

The above expression can be reduced by defining the following parameters:

θ_i = Ratio of terminal on-line interactive rate of operation to the effective designer rate

$$= \frac{R_T}{R_D}$$

μ_i = Ratio of time spent in noncreative activities to time spent in creative activities (excluding model development)

$$= \frac{\bar{T}_{i1}}{\bar{T}_{i2}}$$

ρ_i = Percentage of time spent on the development or modification of computer programs

$$= \frac{\bar{T}_{i3}}{\bar{T}_{i1} + \bar{T}_{i2} + \bar{T}_{i3}}$$

After substitution and some algebraic manipulation, equation (12) becomes:

$$\frac{C_i'}{C_i} = \left(\frac{N_i'}{N_i} \right) \frac{1 + \frac{\rho_i(\mu_i + 1)}{(1 - \rho_i)(\mu_i \eta_i + \omega_i)} + \frac{\theta_i \sigma_i \omega_i}{\mu_i \eta_i + \omega_i}}{\frac{(\mu_i + 1)}{\mu_i \eta_i + \omega_i} \left(\frac{1}{1 - \rho_i} \right)} \quad (13)$$

For assumed missile program statistics (ρ_i, μ_i, σ_i) a given ratio of terminal to designer rates (θ_i), and equal number of design activities ($N_i = N'_i$), the equation is a function of two unknowns, the creative (ω_i) and noncreative (η_i) efficiencies. A productivity ratio can be substituted for one of the unknowns by the following procedure. Let

τ_i = The productivity ratio for the i^{th} design phase when no model modification or development is required

$$= \frac{\bar{T}_{i1} + \bar{T}_{i2}}{\eta_i \bar{T}_{i1} + \omega_i \bar{T}_{i2}} = \frac{\mu_i + 1}{\mu_i \eta_i + \omega_i} \quad (14)$$

This definition of productivity is consistent with the reported productivity ratios presented earlier; i. e., the computer program or model was in existence and did not require development or modification. Eliminating the creative efficiency (ω_i) from equation (13) by using (14) results in:

$$\frac{C'_i}{C_i} = \left(\frac{N'_i}{N_i} \right) \frac{1 + \left(\frac{\rho_i}{1 - \rho_i} \right) \tau_i + \frac{\theta_i \sigma_i \tau_i}{1 + \mu_i} \left[\frac{\mu_i + 1}{\tau_i} - \mu_i \eta_i \right]}{\tau_i \left[\frac{1}{1 - \rho_i} \right]} \quad (15)$$

A similar model can be constructed for use in determining the savings in design cycle time. This model is:

$$D'_i = \left(\frac{D'_i}{D_i} \right) Q_i \quad i = 1, 2, 3, 4 \quad (16)$$

$$\frac{D'_i}{D_i} = \left(\frac{N'_i}{N_i} \right) \frac{1 + (\bar{\tau}_i - 1) \rho_i}{\bar{\tau}_i} \quad (17)$$

The parameters are defined as follows:

Q_i = Percentage of the total missile program time spent in the i^{th} design phase.

D_i = Time spent in the i^{th} design phase.

Some conclusions can be made about the effect of various engineering design systems on the engineering design process:

- A. Changes in the engineering design cost and design-cycle time are weighted by the effect of the engineering design phase. Consequently, a given percentage change will have its greatest effect in the design phase, which has its greatest effect on program cost and schedule.
- B. Savings in cost and design-cycle time can be reduced or even eliminated by a reinvestment of effort in performing more design activities.
- C. Savings in cost and design-cycle time can be reduced by modification and development of models which are common to all the engineering design systems. Consequently, these computerized models should be general so they can be applied to different design activities.

The ratio of upper to lower limits on cost and design duration, or efficiencies, for an engineering design process are presented in table 50. The range of the limits are

$$\frac{1}{\tau_i} \leq \frac{C_i'}{C_i} \leq 1 + \frac{\theta_i \sigma_i}{\mu_i + 1} \quad (18)$$

$$\frac{1}{\tau_i} \leq \frac{D_i'}{D_i} \leq 1 \quad (19)$$

TABLE 50
SUMMARY OF EXTREME ENGINEERING DESIGN PROCESSES

Types of Design Processes	Limits of Ratio of Cost $\frac{C'_i}{C_i}$	Limits Ratio of Duration $\frac{D'_i}{D_i}$
Design process which is primarily composed of model development and modification	$\lim_{p \rightarrow 1} \frac{C'_i}{C_i} \rightarrow 1$	$\lim_{p \rightarrow 1} \frac{D'_i}{D_i} \rightarrow 1$
No model modification or development ($p \rightarrow 0$); noncreative activities are performed with 100 percent efficiency ($\eta \rightarrow 0$)	$\lim_{\substack{p \rightarrow 0 \\ \eta \rightarrow 0}} \frac{C'_i}{C_i} \rightarrow \frac{(1 + \theta_i \sigma_i) \omega_i}{\mu_i + 1} = \frac{1 + \theta_i \sigma_i}{\tau_i}$	$\lim_{\substack{p \rightarrow 0 \\ \eta \rightarrow 0}} \frac{D'_i}{D_i} \rightarrow \frac{\omega_i}{\mu_i + 1} = \frac{1}{\tau_i}$
No model modification or development ($p \rightarrow 0$), very inefficient in performing noncreative activities ($\eta \rightarrow 1$), efficient in creative activities ($\omega \rightarrow 0$)	$\lim_{\substack{p \rightarrow 0 \\ \eta \rightarrow 1 \\ \omega \rightarrow 0}} \frac{C'_i}{C_i} \rightarrow \frac{\mu_i}{\mu_i + 1} = \frac{1}{\tau_i}$	$\lim_{\substack{p \rightarrow 0 \\ \eta \rightarrow 1 \\ \omega \rightarrow 0}} \frac{D'_i}{D_i} \rightarrow \frac{\mu_i}{\mu_i + 1} = \frac{1}{\tau_i}$
No model modification or development ($p \rightarrow 0$), very inefficient in performing noncreative ($\eta \rightarrow 1$) and creative ($\omega \rightarrow 1$) activities	$\lim_{\substack{p \rightarrow 0 \\ \eta \rightarrow 1 \\ \omega \rightarrow 1}} \frac{C'_i}{C_i} \rightarrow 1 + \frac{\theta \sigma \mu}{\mu_i + 1}$	$\lim_{\substack{p \rightarrow 0 \\ \eta \rightarrow 1 \\ \omega \rightarrow 1}} \frac{D'_i}{D_i} \rightarrow 1$

5.6.2 Application of the Model to the Missile Design Process

The model developed above is applied to missile design by using the two extreme engineering design systems described earlier; i. e., an IPAD-type system and a noninteractive graphics system using the batch mode of operation. A summary of the parameters used in the model is presented in table 51. It is assumed that the productivities which have been representative of past on-line interactive systems using a large, integrated computer program will also hold for the IPAD system. Also, the mix between graphics and alphanumeric terminals is such as to reduce the terminal charge to the point where it is almost negligible when compared with other costs.

The savings in the cost of a missile development program can be determined by applying the above model. The preliminary design cost is reduced from 5 percent of the total program cost to approximately 2 percent and the detailed design cost is reduced from 25 percent to 4.2 percent. This results in a total program cost saving of 24 percent.

Using the values of the parameters presented in table 51 and equations (16) and (17), the change in the average design cycle time for a typical missile program can be determined with the IPAD system. These results are also presented in figure 23. In a typical preliminary design phase, the time would be reduced to 6.5 percent of the total program from 21 percent and for detailed design, to 6.3 percent from 41 percent. The savings for the engineering design cycle would total 49 percent.

5.6.3 Benefits Gained by Using IPAD

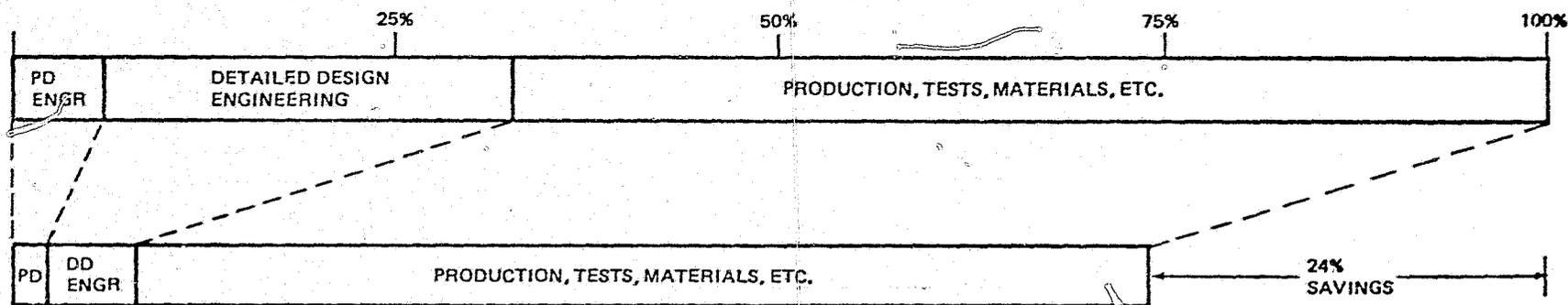
The current engineering design system has developed in a manner which has not resulted in an optimized interface between its components. The proper adjustment of design tasks to the components of the engineering design system would bring both tangible and intangible benefits to the design process. The IPAD system, with its primary features of integrated computer programs and terminal on-line interactive mode of operation, should enable these benefits to be realized. Some of these benefits are: (1) reduced cost,

TABLE 51

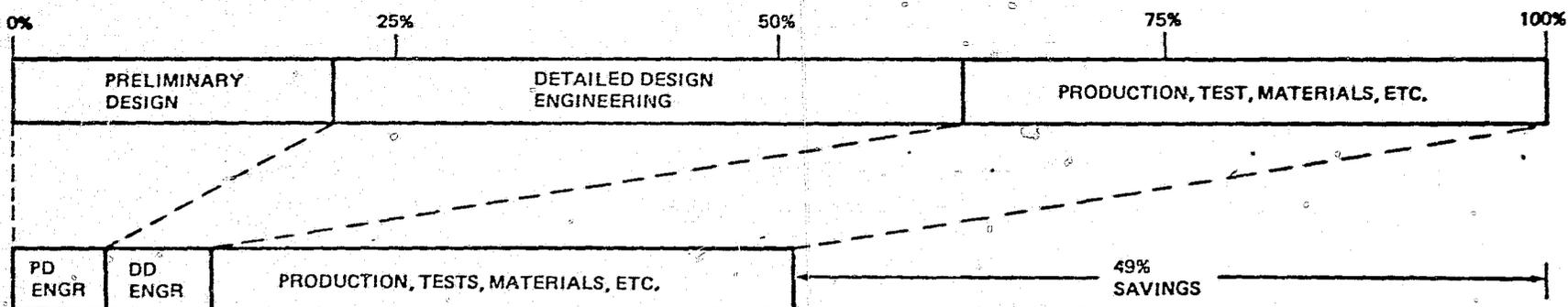
VALUES OF PARAMETERS USED IN THE ENGINEERING DESIGN PROCESS MODEL

Symbol	Definition	Preliminary Design i=2	Detailed Design i=3	Production i=4
P_i	Percentage of total missile program cost expended in engineering in the i^{th} program phase	5%	25%	70%
Q_i	Percentage of total development schedule spent in the i^{th} phase	21%	41%	38%
η_i	Efficiency resulting in performing noncreative activities in engineering design with an IPAD system	10%	10%	NA
σ_i	Percentage of creative activity performed with terminal on-line mode of operation	95%	95%	NA
T_i	Productivity ratio	7	15	NA
θ_i	Ratio of terminal on-line interactive operation rate to effective designer rate	0.06	0.06	
μ_i	Ratio of time spent in noncreative activities to time spent in creative activities	0.96	3.38	NA
p_i	Percentage of creative activity expended for computer program modification or development	20%	10%	NA

TOTAL MISSILE PROGRAM COST.



TOTAL MISSILE DEVELOPMENT SCHEDULE



LEGEND:

PD - PRELIMINARY DESIGN
DD - DETAILED DESIGN

Figure 23.—Program Cost and Design Cycle Savings

(2) reduced design-cycle time, (3) improved design quality, (4) increased reliability and accuracy of the design, (5) reduced manpower loads in design, (6) maximized design visibility and traceability, and (7) a more creative work environment.

As previously noted, an IPAD system can significantly reduce man's time in performing noncreative and creative activities. Manual, routine data-handling operations would be reduced or eliminated, and creative efforts enhanced for a given problem because of the easy access to supplementary design information and ease of interacting with design simulations.

The use of integrated design models will result in a larger, complex model with more accurate relationships. This in turn should result in improved design quality, reliability, and accuracy. Some of the effort saved can be reinvested in an increased number of design activities.

Manpower needed for different design phases will not fluctuate as much with the IPAD system. Historically, system design requires more noncreative effort in the detailed design phase than in preliminary design. The IPAD system, by reducing the noncreative manual efforts, will enable the manpower level in detailed design to approach the level of manpower in preliminary design.

The design visibility and traceability will be maximized by using the IPAD system because historical system design data will be stored as archives in the data files. The result will be better management of the engineering design process and elimination of redundant design activities.

An environment for performing more creative work will result from a more optimal interface between man and the computer. Since most of the noncreative efforts will be eliminated or greatly reduced, the total environment supporting the IPAD system will change, which in turn will affect man.

5.7 IPAD DESIGN FEATURES APPROPRIATE TO MISSILE DESIGN

5.7.1 Description of IPAD System

This section discusses some key aspects of both the General Dynamics and Boeing IPAD systems as they relate to missile design. In general, all features of the IPAD system as presented in references 2 and 3 will apply to design of missiles as well as other aerospace vehicles. But IPAD's applicability to missile design will actually depend upon the final form of the IPAD system. If, as suggested by both contractors, the system has considerable flexibility, then it should be applicable.

As envisioned by General Dynamics (ref. 3), the IPAD system consists of management and engineering capability software, IPAD framework software, operating system software, and computer complex hardware. The management and engineering software is viewed as being designed for the specific needs of one type of project. Therefore, the set of operating modules for aircraft design would be different than the set for missiles, although some modules might be common to many types of projects. The remainder of the software and the computer complex hardware are viewed as having the same capabilities for all users, but may differ from installation to installation.

The management and engineering software resides in a master data bank along with related data. The master data bank consists of one or more project-level data banks which are each divided into a disciplinary data bank and a user file. The project-level data bank, as the name implies, is related to one project. It contains utility programs which support all users and operating modules applicable to all users. The user may access operating modules which relate to his discipline and place them in his own disciplinary or user file. The project-level data bank also contains multidisciplinary data that pertain to one specific design. Data are placed in this file after they are verified by the designers. A data bank administrator would control data that are placed in or removed from the multidisciplinary data bank. This data bank must be controlled since it will represent the

approved design of the vehicle. An update file contains prospective data for the multidisciplinary data bank.

The disciplinary data bank contains utility programs, operating modules, and data that are used primarily by one group or discipline. Individual users may pull information and programs from this file to create their own user file. The design engineer uses this file in the design of a portion of an aerospace vehicle.

One of the most significant aspects of the General Dynamics study is its many references to the data base task group of the Conference on Data System Language (CODASYL). The General Dynamics report states that the data base management system, as envisioned by the CODASYL task group, is fundamental to the IPAD design. As General Dynamics created the IPAD design, it became apparent that most significant problems in IPAD centered around the data base. The study found that CODASYL's data base management system provided the capabilities that IPAD needed.

One area of interest in the IPAD framework software is the IPAD Executive (EXEC). The EXEC controls the interface of the user with IPAD and also facilitates his task by providing a more automated data setup and program execution capabilities.

The EXEC functions through the use of task control sequence files. A task control sequence is a set of commands needed by a user to perform a particular task. Once written and named, a task control sequence can be called by the EXEC to execute all specified steps automatically. A task control sequence may be written through the use of a utility called the interceptor, which is part of the EXEC. The interceptor creates a permanent task control sequence file of the commands as they are executed. A task control sequence can also be created using a text editor. To standardize format and to facilitate the creation of a task control sequence, other utilities such as the task control sequence skeleton and the skeleton expander are available. The skeleton is actually a task control sequence structured in the most desirable manner, and contains only common data for all sequences. The

skeleton also contains descriptive information to show what steps are needed to create the task control sequence. The expander would provide access to the skeleton and ask questions of the user in a step-by-step manner to guide him through the creation of a task control sequence.

The General Dynamics report indicates that languages associated with IPAD should be formulated by a CODASYL-like committee of potential developers, users of IPAD, and hardware vendors. Emphasis should be placed on simplifying the writing of computer instructions so that persons other than programmers can use IPAD. The results should be acceptable to CODASYL and the American National Standards Institute. With this involvement, the hardware vendors are more likely to implement the capabilities on their machines so that more software is written in these languages and is transferable.

The General Dynamics design recommends that the task control sequence skeleton be used to provide the interface with the operating system language for the IPAD user. The skeletons could be established for a given system, including detailed instructions to the user on his options. Once the user became familiar with the skeleton format, he would not have to refer to it to create his task control sequence, but he would be able to use it for reference. This seems to be a reasonable approach in that the task control sequences created in this manner would be standardized in format and recognizable by another needing to use the code.

The IPAD command language would also be used for EXEC commands in calling and creating task control sequences. The EXEC commands turn on the interceptor or cancel its action. The EXEC is also used to control the task control sequence skeleton expansion capability.

The General Dynamics design seems to be inconsistent in the area related to EXEC commands. The company's study indicates that the EXEC cannot be transferred from machine to machine because it must be different for each type of host computing system. The study also suggests that the higher-level languages are not suitable for use as an EXEC language because

all of them contain a weakness in some area or are not available on all types of machines. The study therefore recommends using the assembly language of each machine for EXEC coding. This seems to conflict with earlier statements recommending the use of an IPAD language for the EXEC.

A data description language is recommended for use in handling data. The language defines a data base and permits operating modules and utilities to interface with the data base. Again, reference is made to CODASYL's task group. Two types of data description languages are presented, Schema DDL and Sub-schema DDL. Schema DDL describes the data as they exist in the data base. The Sub-schema DDL does not describe the entire data base, but only those areas known to one or more specific programs. The data are presented in the form in which they are needed in the specific program. Thus, the user need be concerned with only that portion of the data base relevant to his program.

A data manipulative language provides the ability to interact with the data base. To accomplish this, the host language and data manipulative language are both used in an application program. The host language portion of the program manipulates data in primary storage. The data manipulative language portion of the program is the interface language with the data base. All calls to retrieve, add, modify, or delete data or data relationships are written in the data manipulative language.

The data description language and data manipulative language together allow the user to collect data needed for his task, reorganize them into a form acceptable to an operating module, and transform the output of the module into the form required for another operating module or the data base.

The General Dynamics design also proposes a query processor language which provides the IPAD user, who may not be a programmer, with an interactive access to the data base for interrogations, updates, and creation or restructuring of the data base. Their design specifies that the complete data manipulative language capabilities be provided for interactive use.

Boeing's IPAD feasibility study (ref. 2) disclosed that the design process for aircraft is similar to the process for missile design in that they both follow the same engineering design methodology. Virtually all of the key design features for aircraft will prove equally valuable in missile design. IPAD will be able to provide an organized method for the design of missiles and other complex aerospace systems.

Boeing's study stresses the need for continuity of the design process with task and time, particularly at the individual user level. This means that the individual should be able to work on a task in a continuous manner from initiation to completion, which is conducive to generating and sustaining creative momentum. When the task is interrupted for any reason, he should be able to resume his activities, with his task remaining the same as it was at the time of his interruption. The user may submit a job through the batch mode, and regardless of the results, make his next access either from the batch or from a terminal in an interactive mode. Thus, IPAD will leave an interrupted task in the same state for batch or interactive access. The user will also be allowed to leave the terminal when his task has an excessively long execution time. This frees the terminal for other users, and also allows the user to pursue other tasks. The user should be able to leave his task in an active state at the terminal and return later to continue it. After the task is completed, the resulting data should be placed in a common data base for use at a later date.

The IPAD data base in the Boeing design consists of community and subtask libraries. A community library is available to all users in a project. IPAD allows for more than one community library, since each project may have its own community library. The subtask library is oriented to one user. Data are transferred from the community library to the subtask library for use by an individual. This library will contain all of the data and application modules necessary to complete a subtask. When the subtask is inactive, the subtask library resides in the community library, but its contents are not available to the community library users until they are released by the user. This method of handling data bases would certainly be desirable for missile design since it makes data available quickly and in an organized and accurate manner.

The Boeing data manager is a collection of software responsible for information flow into and out of the IPAD data base. This software will be written in IPADL, a FORTRAN-based language, and will interface with software provided with the host computer system. IPADL is intended to be machine-independent, provided that the host computer includes software which supports a CODASYL-defined data management system.

In order to facilitate data-handling for users, the data management system has been organized so that data structure definitions are separated from programs that reference the data. Stored data definitions are supplied by the user to minimize their effect on an existing code and reduce the need to structure data in a single format. If data required by an operating module are not in the proper format, the module uses the proper stored data definition to put the data in the proper format.

Boeing's design recognizes that many existing application modules which were written in several different languages must be inserted in the IPAD system. To further complicate matters, even universal languages such as FORTRAN have many dialects and contain a code which is machine-dependent. Boeing recommends that IPADL be written as a machine-independent FORTRAN language and that the necessary utilities be written to translate existing programs into this language. This would allow a common input language and also minimize the problems of incorporating new operating modules into IPAD.

Hardware recommendations were made for IPAD based on Boeing in-house design experience and a survey of large computer manufacturers. The results of the Boeing survey indicated that approximately six manufacturers supply computers that would be adequate for IPAD. An IPAD hardware configuration was established using two of these, the CDC Cyber 74-18 and IBM 370-168.

The Boeing IPAD design stresses a multi-user, highly interactive environment. The recommended hardware includes teletypes, terminals for cathode ray tube display, and interactive graphics terminals.

5.7.2 Evaluation of IPAD Design Features

One of the most important design features of the system is to allow easy access, transmittal, and display of data. General Dynamics suggests the use of a query processor utility. Boeing, on the other hand, details a series of 15 user commands for data and code manipulation, transmittal, and display, but the company's report did not indicate how a set of programs would be executed automatically in an iterative sequence under its proposed system to perform some design function. The user commands defined by Boeing at first seem overly complex, but with proper tutorial aids they could be learned in a fairly short time so that a user could operate the system effectively.

From a programming standpoint, both companies' suggest designs using the data description language and data manipulative language processors proposed by the CODASYL task group. If these features become operational prior to IPAD development, they should suffice for data input and output to the individual operating modules in the missile design process.

Experience at McDonnell Douglas Automation Company indicates that the approach recommended by CODASYL's task group is a proper course of action in implementing a data base management system. McDonnell Douglas Automation is a heavy user of International Business Machine's information management system and has also designed its own data base systems. These data bases provide many of the features spelled out by the task group, and it is apparent how they might be modified to provide all the enhancements needed in IPAD. It therefore seems reasonable to use a CODASYL-type data base management system, especially since software is likely to be standardized using this approach.

With regard to data security, Boeing seems to rely on users with the proper passwords implementing changes themselves in the data base. General Dynamics recommends a data base administrator and Engineering Review Board approach to changes in the data bases. It is believed that both approaches have merit, but that the administrator-review board concept is

more desirable as it provides a forum for considering the effects of data changes on other users.

Boeing's design stresses the need for key word search capability to allow a user to interrogate the IPAD system to determine which operating module might do his specific task or subtask. This feature is definitely desirable. In missile design, there are often many programs that perform a similar technology function, and not all users of that particular technology are aware of all the programs.

Boeing commented in its report that IPAD should not allow user instructions to do arithmetic replacement or alter calculated values, assuming that all calculated values would come from a "qualified" code. It is believed that this feature is not desirable in that even a qualified code may produce bad numbers. Also, some codes may produce better results if the user is allowed to correct or modify intermediate results of an iterative process; e.g., the step size of an optimization algorithm.

Both designs have an extremely desirable feature, the development of a multi-technology dictionary of terms. A standardized set of definitions for the engineering community has been needed for a long time, and IPAD could make it worth the cost of preparing the definitions.

Both the Boeing and General Dynamics designs address the need for doing optimization in design environments. Boeing directed its comments toward the three types of optimization; direct optimization, tradeoff studies, and model refinement. General Dynamics surveyed the random and nonrandom methods of direct optimization, concluding that the nonrandom methods were probably faster and more accurate for the IPAD type of problem. Both reports correctly concluded that the user must be able to extremize any constrained objective function as a function of any number of independent variables. However, it would seem that one very important aspect of optimization in the IPAD design environment has been overlooked; the man-in-the-loop capability of IPAD.

It has long been observed that a good model does not yet exist of the nonlinear capabilities of an engineer's mind. An engineer can look at a plot of a few data points and predict, often quite accurately, the behavior of the curve between the data points. The same prediction may be extremely difficult to achieve with numerical optimization techniques. It would thus seem that a very effective technique for performing design optimization is to start an optimization algorithm, let it compute by itself for a while, and let the user intervene and guide the optimization process from his interactive terminal. An intelligent user could probably save many hours of computer time by doing this. General Dynamics briefly mentions the user interface with regard to the termination criterion for the optimization algorithm, but it would seem that the user should have control over more than termination of the optimization process.

The General Dynamics and the Boeing designs recommend that only the newest large-scale computers be used with IPAD to provide a system which is responsive when serving a large number of interactive users and handling batch operations. The latest computers have operating systems and central processing units that handle more information than previous models.

Studies made by McDonnell Douglas Automation seem to support this. The studies were designed to determine the maximum number of interactive terminals that may be added before batch processing and response time at the terminals are seriously degraded. Within the past two years, the company has made extensive use of three CDC machines, first the 6400 and 6500, and now the Cyber 74. The Cyber 74 is similar to the CDC 6600 since the central processing unit is the same, but it has greater input-output capability. It has been used mostly for batch processing, but interactive capability has been added.

There are many complications in making the studies and in interpreting the results, such as the size of the central memory core, the availability of extended core storage, and the type of operating system and job mix. The tests are not complete at this point, but preliminary estimates show that the Cyber 74 is able to provide better response time and handle more

terminals than the CDC 6400 or 6500. None of the tests included the Type 5 terminals defined by General Dynamics.

Both reports indicate that overall design time can be reduced by up to 50 percent in some areas with an IPAD system. The reason for this improvement lies in the use of interactive computing systems and integrated computer codes. Two systems used by McDonnell Douglas Corporation are the CADD and GRID programs, and both have increased productivity. These systems have been in use for a number of years and have provided a great deal of experience to support the contention that interactive systems not only provide a better design environment for the engineer, but also represent a cost-effective way to design.

Section 6

WORK, COST, AND TIME TO EXTEND THE IPAD SYSTEM TO MISSILE DESIGN

This section presents the tasks, cost estimates, and schedule for modifying an IPAD system configured for aircraft design to apply to missile design. The cost estimates for utilizing IPAD for aircraft design given in references 2 and 3 include data on preparation and conversion of operating modules. It is believed that these costs would not change drastically if the IPAD system were oriented toward missile development. Further, since some of the operating modules for aircraft could be used in missile design with little or no modification, the cost of adding missile design capabilities to an IPAD system for aircraft should be lower than the cost of developing and installing a separate system.

The activities involved in modifying an IPAD aircraft system so that it is applicable to missile design, the schedule, and the estimated costs for the three design phases are shown in tables 52 through 54. A summary of the schedule and cost is given in table 55. The schedule for this effort is presented in figure 24. It is assumed that all the codes applicable to the system studies phase of design will be used during preliminary and detailed design, and that the preliminary design codes will also be used in detailed design. (In actuality, there may be a few instances where the codes apply to only one design phase.)

Some of the codes are public and may be already operational on an IPAD-type system. One notable example is the NASTRAN code with its approximately 90 boxes of source cards, which is included in the codes listed for use in preliminary structural design. Other existing codes, especially in aerodynamics, might also be usable for missile design and would not require conversion. Figure 25 presents a graph of the quantity codes to be converted for all technologies for each design phase.

TABLE 52
TASKS AND COST AND TIME ESTIMATES FOR
MODIFYING IPAD FOR MISSILE DESIGN
USE - SYSTEM STUDIES

Task	Man-Months		Computer Cost(\$)	Flow Time (months)
	Engineering	Programming		
Select and collect operating modules in missile technology	6	0	0	2
Specify certification tests and requirements for operating modules	4	0	0	1
Prepare IPAD data bank for operating modules	16	14	15,000	2
Convert operating modules for IPAD operation	176	234	117,000	10
Check out operating modules	30	20	20,000	2
Prepare documentation	24	6	4,000	6
Train users	10	2	4,000	2
Supervision	10	10	0	20
Totals	276	286	\$160,000	20

TABLE 53
TASKS AND COST AND TIME ESTIMATES FOR
MODIFYING IPAD FOR MISSILE DESIGN
USE - PRELIMINARY DESIGN

Task	Man-Months		Computer Cost (\$)	Flow Time (months)
	Engineering	Programming		
Select and collect operating modules in missile technology	6	0	0	2
Specify certification tests and requirements for operating modules	4	0	0	1
Prepare IPAD data bank for operating modules	16	14	15,000	3
Convert operating modules for IPAD operation	193	258	129,000	12
Check out operating modules	35	25	40,000	5
Prepare documentation	30	10	5,000	6
Train users	15	2	6,000	4
Supervision	12	12	0	24
Totals	311	321	\$195,000	24

TABLE 54
TASKS AND COST AND TIME ESTIMATES FOR
MODIFYING IPAD FOR MISSILE DESIGN
USE - DETAILED DESIGN

Task	Man-Months		Computer Cost (\$)	Flow Time (months)
	Engineering	Programming		
Select and collect operating modules in missile technology	4	0	0	2
Specify certification tests and requirements for operating modules	4	0	0	2
Prepare IPAD data bank for operating modules	20	15	10,000	2
Convert operating modules for IPAD operation	70	94	47,000	6
Check out operating modules	12	8	10,000	3
Prepare documentation	12	3	3,000	6
Train users	6	2	2,000	2
Supervision	8	7	0	15
Totals	136	129	\$72,000	15

TABLE 55
SUMMARY OF EFFORT REQUIRED TO EXTEND
IPAD TO SUPPORT MISSILE DESIGN

Missile Phase	Effort	Increment	Cumulative
System studies	Engineering (man-months)	276	276
	Programming (man-months)	286	286
	Computer cost (\$)	\$160,000	\$160,000
	Flow time (months)	20	20
Preliminary design	Engineering (man-months)	311	587
	Programming (man-months)	321	607
	Computer cost (\$)	\$195,000	\$355,000
	Flow time (months)	24	44
Detailed design	Engineering (man-months)	136	723
	Programming (man-months)	129	736
	Computer cost (\$)	\$ 72,000	\$427,000
	Flow time (months)	15	59

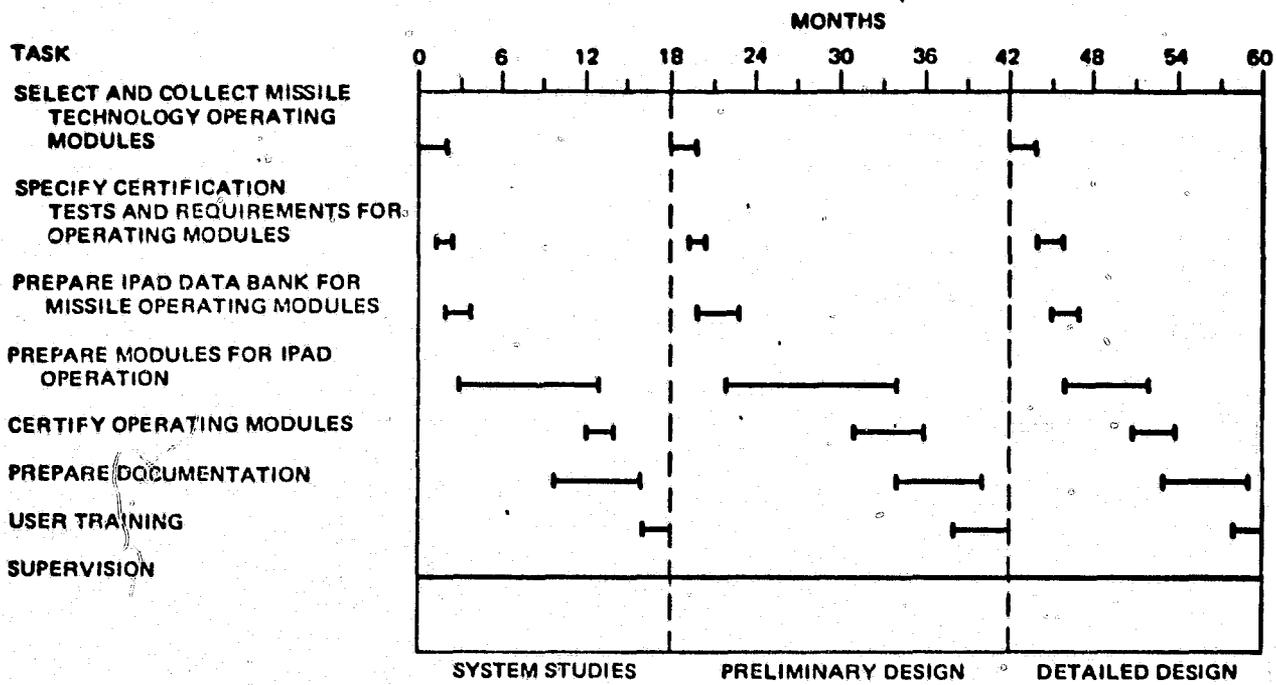


Figure 24.—Schedule for Adding Missile Design Capability to an IPAD System for Aircraft

Data on the number of source cards used by McDonnell Douglas Astronautics Company-West in performing missile design are given in figure 25. These data are based on the use of the known computer codes listed in Section 5. Tables 52 through 55 were prepared following the example presented in reference 2 (Volume VI, pages A16 and A17). The operating modules selected for system studies would contain some 400,000 source statements which would need conversion. It was assumed that 800 source statements could be developed in a programmer man-month and that 8,000 source statements could be converted in a programmer man-month. In preparing operating modules, it was assumed that engineering time required would be three-fourths of the programmer time. A computer cost of \$500 per month for each programmer was assumed.

The selection and collection of candidate operating modules for missile design will be strongly influenced by whoever does the work. If the installation is a Government agency, most of the operating modules selected will probably be publically owned codes. If a private company is doing the job, many of the operating modules selected will probably be already developed and owned by the company. In any case, a survey will be required for each technology to determine which operating modules should be selected and incorporated in the IPAD system. It is expected that each technology would be represented by a specialist who could select the desired operating modules for IPAD and specify check cases for them.

To prepare the IPAD data bank for the selected missile operating modules, the definitions of the variables used by the various technologies will be entered into the data bank. Thus, when the selected operating modules are brought into the IPAD system, the needed variables will be available and known by the system.

The operating modules selected will be converted from the language in which they are written (most likely FORTRAN) to the IPAD language (e. g., IPADL or some other proposed derivative of FORTRAN). Commands in the data manipulation language must be inserted into the code to allow the operating modules selected to get values from and place new values in the data base.

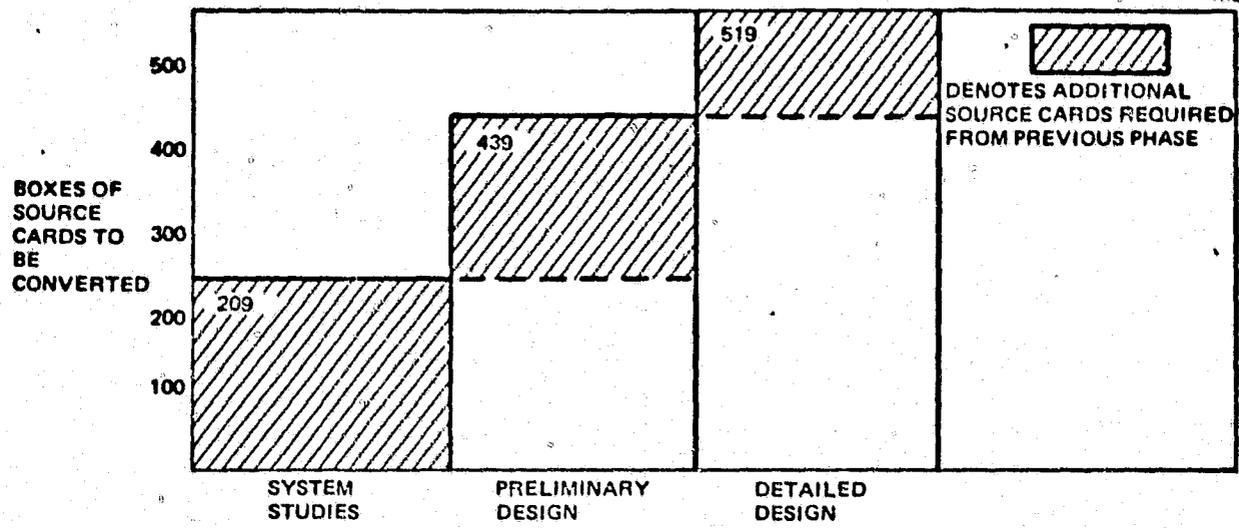


Figure 25.—Estimate of Boxes of Source Cards

It may be desirable to introduce new codes to accommodate the interactive user of the operating modules.

The converted operating modules will be certified simply by setting up the specified check cases and doing an in-depth check of the output. If errors occur, then corrections must be made and the test cases rerun.

In preparation of documentation, it is assumed that the documentation of an incoming operating module is complete and that only the IPAD-peculiar documentation must be added. This might include, for example, interactive capabilities added to the code because of the IPAD environment, new error messages, sample runs of the operating modules selected under the IPAD system, or IPAD EXEC commands to execute the operating modules selected.

Good documentation is also essential for success in using IPAD in missile design. The IPAD environment will be quite a change from the customary environment of the missile designers. Definitions and tutorial aids will be stored in the IPAD system during preparation of the operating modules instead of being found only in manuals, but the user should have reference material which he may study while not actually at an interactive terminal using IPAD.

User training is also considered essential for IPAD to be accepted by the missile design community. Training for each operating module will probably be offered in the form of a class taught by the engineer directing the conversion of the particular module. It is expected that the students will be setting up a sample case of their own to run, as this is the best way to learn how to use a given computer code. The data in tables 52 through 55 include estimates of the teacher preparation time and presentation costs, but not the time and computer costs for the persons being trained.

REFERENCES

1. Anon.: Skylab Design Coordination Lack Cited. Aviation Week and Space Technology, vol. 99, no. 5, July 30, 1973, pp. 47-49.
2. Gillette, W. B.; Southall, J. S.; et al.: Final Report: Feasibility Study of an Integrated Program for Aerospace-Vehicle Design (IPAD). Seven volumes. Report No. D6-60181-3, The Boeing Company, 1973.
3. Garroq, C. A.; Hurley, M. J.; Dublin, M.; et al.: Final Report: Feasibility Study of an Integrated Program for Aerospace-Vehicle Design (IPAD). Six volumes. General Dynamics Corporation, Convair Division, 1973.
4. Hall, A. D.: Three-Dimensional Morphology of System Engineering. System Science and Cybernetics, vol. SSC-5, no. 2, Apr. 1969.
5. Hawkins, J. A.: Generalized Figures of Merit for Infrared Imaging Systems. Report No. DRL-TR-68-12, University of Texas at Austin, Nov. 1968. (Available from DDC as AD-832 158.)
6. Isaacson, D. N.; and Blakemore, J. W.: A Mathematical Model for Predicting the Probability of Detecting Targets Against Various Backgrounds Utilizing a Forward-Looking Infrared System. IRIS, vol. 2, no. 11, Oct. 1966, p. 201.
7. Sendall, R. L.: Figures of Merit for IR Imaging Systems. IRIS, vol. 15, no. 3, Jan. 1971, p. 59.
8. Lloyd, J. M.: The Optical Transfer Function of Real-Time Infrared Imaging Systems. IRIS, vol. 15, no. 3, Jan. 1971, p. 159.
9. Lloyd, J. M.; and Sendall, R. L.: Improved Specifications for Infrared Imaging Systems. IRIS, vol. 14, no. 2, Aug. 1970, p. 109.
10. Friden, G. B.; and Singer, G. D.: Computer Simulation of Electro-Optical Imaging Devices. IRIS, vol. 17, May 1972, p. 111.
11. Kennedy, H. V.: Comparison of Formulas for Determining the Sensitivity of Infrared Systems. IRIS, vol. 17, May 1972, p. 321.
12. Wolfe, W. L.: Handbook of Military Infrared Technology. U. S. Government Printing Office, 1965.

13. Anon.: Computer Model for Real-Time Night Reconnaissance Strike Process. General Research Corporation, May 1968. (Available from DDC as AD-392049L.)
14. Payne, J. R.; et al.: Combined Reconnaissance, Surveillance, and Signal Model (CRESS). SRI, Nov. 1968. (Available from DDC as AD-848 482.)
15. Schaefer, A.; et al.: Multiple Airborne Reconnaissance Sensor Assessment Model (MAR SAM II). Honeywell Inc., 1968. (Available from DDC as AD-834915L.)
16. Mortenson, J. E.: Computer and Engineering Design System. Paper No. WD 1818, McDonnell Douglas Astronautics Company, Jan. 1972.
17. Fischer, D. J.: Multispectral Acquisition/Recognition Study. Vol. 2. Report No. MDC G5025, McDonnell Douglas Astronautics Company, Dec. 1973.
18. Meriwether, H. D.; Nowek, R. S.; and Mausser, D. C.: Structures Department Short Term Computer Utilization Plan - Second Report. Report No. DAC-58359, Douglas Aircraft Company, July 1966.
19. Meriwether, H. D.; Myzel, S. J.; Nowek, R. S.; and Ward, C. C.: Structural Mechanics Branch Short Term Computer Utilization Plan. First Quarterly Report. Report No. SM-52270, Douglas Aircraft Company, Dec. 1965.
20. Petrovits, S.: Modern Design Techniques by Computer Graphics. Report No. MDC A0767, McDonnell Aircraft Company, Dec. 1970.
21. Winton, W. R.: A Discussion of the Logic and Capabilities of a Fully Automated General Missile Sizing Program. Paper No. 3532, Douglas Aircraft Company, June 7, 1965.
22. Ward, R. D.; and Koeller, E. G.: Computer Coded Design - Drafting (CADD) An Advanced Design Tool. Report No. MCAIR 73-019, McDonnell Aircraft Company, Oct. 18, 1973.

APPENDIX A

AERODYNAMIC
COMPUTER PROGRAM
SPECIFICATIONS

COMPUTER PROGRAM SPECIFICATION

TITLE AUTOMATED DATCOMFORM PREPARED BY H. Tiffner DATE 1-18-74LANGUAGE FORTRAN IV HOST MACHINE CDC 6600PROGRAM SIZE 20 (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner _____

ABSTRACT

The Automated DATCOM Program contains methods for predicting the subsonic longitudinal aerodynamic characteristics of body alone, wing alone, wing-body, wing-body-vertical tail, wing-body-vertical tail-horizontal tail, and low-aspect-ratio wing-body combinations. Body configurations may be either axisymmetric or asymmetric, while wing or tail planforms may be straight, tapered, cranked, or double delta. The analyses performed by the program include power (propeller and jet) and ground effects; however, control effects are not calculated. Multiple case input capability is provided with a maximum of twenty Mach numbers and twenty angles of attack per Mach number. Output for each configuration consists of coefficients C_D , C_L , C_m , C_N , C_A , X_{CP} , C_{PB} , and C_{DB} versus angle of attack. Ground effects may be calculated at ten elevations.

TECHNICAL PROGRAM ELEMENT

TITLE Arbitrary Body LibraryFORM PREPARED BY H. Tinner DATE 2-18-74LANGUAGE FORTRAN IV HOST MACHINE CDC 6500PROGRAM SIZE 12 (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational XX, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private XX, Owner MDAC

ABSTRACT

The Arbitrary Body Library preprocessor is capable of assembling five different programs from the subroutine library:

1. Arbitrary body aerodynamics program - calculates inviscid/viscid aerodynamic characteristics of vehicles in the supersonic/hypersonic Mach number regime.
2. Ablation effects program - considers the effects of surface ablation on the aerodynamics of bodies of revolution.
3. Simplified Newtonian aerodynamics program - a small, efficient code which calculates inviscid Newtonian aerodynamics for completely general geometries. This version has a sophisticated graphics module which includes the effects of secondary shadowing.
4. Specialized aerodynamic sizing program - employs parametric spline interpolation to perform specific aerodynamic sizing calculations on a specific class of vehicle. A change in vehicle baseline usually requires a major recoding.
5. Multidimensional interpolation program - generates direct variables spline interpolation of functions of up to three independent variables. Extension to higher dimensionality is straightforward, but as yet, incomplete.

COMPUTER PROGRAM SPECIFICATION

TITLE Computerized Aircraft Sizing and Optimization (CASO)FORM PREPARED BY H. TimmerDATE 1-18-74LANGUAGE FORTRAN IVHOST MACHINE IBM 370/165

PROGRAM SIZE

2

(Boxes of Source Cards)

TIMING

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 (Words)

OUTPUT VOLUME 10 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT

STATUS: Operational X, Programming In Development , Not Programmed

REFERENCE

OWNERSHIP: Public , Private X, Owner MDAC

ABSTRACT

Using a reasonable base design whose aerodynamic characteristics, engine performance and weight breakdown have been determined by conventional methods, the engineer can study the size and performance effects of wing geometry and other selected perturbations. The program scales the base airplane until takeoff, approach and energy maneuverability thrust requirements and design mission radius are met. The program is also capable of systematically perturbing wing geometry to search for a combination resulting in the lowest possible takeoff gross weight for a given set of performance requirements.

COMPUTER PROGRAM SPECIFICATION

TITLE Body of Revolution Aerodynamics
Information Network (BRAIN)

FORM PREPARED BY H. Timmer DATE 1-18-74

LANGUAGE FORTRAN HOST MACHINE CDC 6500

PROGRAM SIZE 5 (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

This Computer Program, the Body of Revolution Aerodynamics Information Network (BRAIN), is a system of computer sub-programs which define theoretical and empirical aerodynamic characteristics for axisymmetric bodies. It presently includes the Van Dyke second-order hybrid potential flow theory, second-order shock-expansion theory, modified Newtonian flow theory, empirical drag calculations, skin friction calculations, and viscous cross-flow theory. BRAIN may be used to calculate distributed and total drag and stability characteristics, local pressure coefficients, local and mean skin friction coefficients, boundary layer parameters, and high angle of attack characteristics. Aerodynamic analysis can be made for bodies of revolution at angles of attack from 0 to 90 degrees for Mach numbers in the supersonic or hypersonic regimes.

COMPUTER PROGRAM SPECIFICATION

TITLE Neumann Potential FlowFORM PREPARED BY H. TimmerDATE 1-18-74LANGUAGE FortranHOST MACHINE CDC 6500PROGRAM SIZE 5 (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

An exact method of solving the Neumann, or secondary boundary value problem, has been applied to the calculation of subsonic flows about or within arbitrary, three-dimensional axisymmetric bodies. Solid body, inlet, and internal flow problems can be solved. The method is also capable of dealing with several bodies at once in the presence of one another. Consequently, interference problems can be treated with ease. Boundaries need not be solid, i.e., flows involving area suction can be calculated. Compressibility effects are included by applying the subsonic similarity rule (Goethert transformation) to the configuration prior to calculating the potential flow solution. The Neumann method utilizes a source density distribution on the surface of the body and solves for the distribution necessary to make the normal velocity zero on the boundary.

This computer program calculates all force and moment coefficient distributions and total values up to angles-of-attack where viscous separation occurs on the body lee side.

COMPUTER PROGRAM SPECIFICATION

NO. H292
H293
H294TITLE Inviscid Flow Fields Program ComplexFORM PREPARED BY H. Timmer DATE 1-18-74LANGUAGE FORTRAN HOST MACHINE CDC 6000 seriesPROGRAM SIZE 2 (Boxes of Source Cards)

TIMING (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 (Words)

OUTPUT VOLUME 10 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This computer program complex links together three axisymmetric/two-dimensional inviscid flow field programs: H292 (blunt body inverse method solution), H293 (cone field solution), and H294 (supersonic region method of characteristics). These programs are based on the NASA/Ames trio described in NASA TN D-2970 (August 1965) by M. Inouye, J. V. Rakich, and H. Lomax. Principal features of the programs as originally received include operations with equilibrium air and other selected gas mixtures, application of quadratic entropy gradients normal to supersonic streamlines, and propagation of embedded coalesced or flare-attached shock waves through the supersonic field. Some major capabilities added by MDAC include streamtube tracing, refined aerodynamic coefficients (pressure, drag, flap normal force and moment arm), bow-shock/flare-shock intersection solution and subsequent field generation above and below the slip line emanating therefrom, and propagation of boundary layer effects by including boundary layer profiles in the method of characteristics starting lines and maintaining the resulting total enthalpy variations between streamlines downstream. Currently under development are solutions of the shock intersections, complete flow fields, and shock-body impingements generated by two-nosed or separating vehicles in hypersonic flight using modular rotational method of characteristics.

249

ORIGINAL PAGE IS
OF POOR QUALITY

COMPUTER PROGRAM SPECIFICATION

TITLE Multi-Jet Base FlowFORM PREPARED BY H. Timmer DATE 1-18-74LANGUAGE FORTRAN IV HOST MACHINE CDC 6500PROGRAM SIZE 2 (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 (Words)OUTPUT VOLUME 10 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private , Owner NDAC

ABSTRACT

This computer program calculates the base flow characteristics for a rectilinear multi-rocket configuration as a function of altitude. The recirculation regions between nozzles are related to interactions with the nozzle plume impingements and the external ambient environment.

COMPUTER PROGRAM SPECIFICATION

TITLE Boundary - Layer Separation and Re-attachment ProgramFORM PREPARED BY H. TimmerDATE 1-18-74LANGUAGE FORTRAUHOST MACHINE CDC 6500PROGRAM SIZE 2

(Boxes of Source Cards)

TIMING _____

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

This computer program predicts from laminar and turbulent analyses the separation and re-attachment point location, complete layer profiles, shock geometry and distribution of pressure and shear stress.

COMPUTER PROGRAM SPECIFICATION

TITLE Time Dependent Blunt Body ProgramFORM PREPARED BY H. TimmerDATE 1-18-74LANGUAGE Fortran IVHOST MACHINE CDC 6500PROGRAM SIZE 2 (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public , Private _____, Owner _____

ABSTRACT

This computer program predicts the subsonic portion of the shock layer surrounding an axisymmetric body in supersonic flight by using time dependent finite difference equations.

COMPUTER PROGRAM SPECIFICATION

TITLE Equivalent Body Analogy Jet Interaction ProgramFORM PREPARED BY H. Timmer DATE 1-18-74LANGUAGE FORTAN IV HOST MACHINE CDC 6500PROGRAM SIZE 5 (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

This computer program predicts the downstream influence of the jet on the basic body flowfield by representing the jets by equivalent solid bodies. The resulting pressure distribution is integrated over the surface to obtain resultant aerodynamic forces and moments as well as jet amplification factors.

COMPUTER PROGRAM SPECIFICATION

TITLE Conical Flow ProgramFORM PREPARED BY H. Timmer DATE 1-19-74LANGUAGE Fortran IV HOST MACHINE CDC 6500PROGRAM SIZE 2 (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

This computer program predicts the flowfield about a conical body of arbitrary cross-section at angle-of-attack.

COMPUTER PROGRAM SPECIFICATION

TITLE Base Pressure Program

FORM PREPARED BY H. Tirmer DATE 1-18-71

LANGUAGE FORTRAN IV HOST MACHINE CDC 6500

PROGRAM SIZE 2 (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

This computer program calculates the base pressure distribution for blunted cones in the supersonic/hypersonic Mach number range.

COMPUTER PROGRAM SPECIFICATION

TITLE Three Dimensional Boundary LayerFORM PREPARED BY H. Timmer DATE 1-18-74LANGUAGE FORTRAN IV HOST MACHINE CDC 6500PROGRAM SIZE 2 (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 (Words)OUTPUT VOLUME 10 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

This computer program computes three dimensional boundary layer flows over general geometries for both laminar and turbulent flows. Streamline coordinate system and effective approximating scheme minimizes common restrictions on cross flow magnitude and geometry.

COMPUTER PROGRAM SPECIFICATION

TITLE Kutler Three Dimensional Inviscid Flow FieldFORM PREPARED BY H. TimmerDATE 1-18-74LANGUAGE FORTRANHOST MACHINE CDC 6500PROGRAM SIZE 2 (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 (Words)OUTPUT VOLUME 10 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private X, Owner MDAC

ABSTRACT

This computer program has the following features:

- 1) Inviscid supersonic flow with options for ideal or real gas properties
- 2) Conservation equations solved by a finite difference scheme
- 3) Bow shock treated as a sharp discontinuity
- 4) Nonaxisymmetric configurations and bodies at angle of attack can be analyzed.

COMPUTER PROGRAM SPECIFICATION

TITLE Vortex Sheet ProgramFORM PREPARED BY H. TirmerDATE 1-18-74LANGUAGE FORTRAN IVHOST MACHINE CDC 6500PROGRAM SIZE 2

(Boxes of Source Cards)

TIMING _____

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

This computer program predicts the transonic aerodynamic characteristics of bodies of revolution by supplementing slender body theory with vortex sheets.

COMPUTER PROGRAM SPECIFICATION

TITLE Linearized Velocity Distribution Due to ThicknessFORM PREPARED BY H. TimmerDATE 1-18-74LANGUAGE Fortran IVHOST MACHINE IBM 370/165PROGRAM SIZE 2 (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

This computer program computes swept wing velocity and pressure distributions for varying wing-body combinations in subsonic flow.

APPENDIX B

THERMODYNAMICS
COMPUTER PROGRAM
SPECIFICATIONS

COMPUTER PROGRAM SPECIFICATION

TITLE Real/Ideal Gas Aerodynamic Heating and Ablation Program (Aero-Heat) (JA70)FORM PREPARED BY D. Hender DATE 11-20-73LANGUAGE Fortran IV HOST MACHINE CDC 6500PROGRAM SIZE 5 (Boxes of Source Cards)TIMING Variable (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 (Words) VariableOUTPUT VOLUME 10 (Words) VariableBASIS FOR TIMING, INPUT, AND OUTPUT Material types, lamina thickness, problem time.STATUS: Operational , Programming In Development , Not Programmed REFERENCE Douglas Report No. DAC-58629OWNERSHIP: Public , Private , Owner McAuto

ABSTRACT

Program JA70 performs aerodynamic heating analysis on missiles and space vehicles. The program will determine the flow field based on body geometry and altitude, calculate heat transfer to the vehicle wall at some point of interest, and compute the temperature distribution through the wall of the vehicle. The flow field and heat transfer computations may use either real gas or ideal gas analysis. The heat source may include solar radiation, hot gas radiation, free molecular flow, and any independent heat source the engineer may want to enter. The vehicle wall may be a thin or thick skin, and may consist of up to four different materials which may be divided into a maximum of eighty lamina. The program can simulate either a 1959 ARDC or a 1962 ICAO standard atmosphere, or any non-standard atmosphere entered by the engineer.

Optional capabilities include:

1. Ablation
2. Internal gas
3. Material thickness optimization
4. Automatic plotting
5. Trajectory tape input from programs F650 and AB60
6. Output tape for F678 charring ablator program
7. Short form output
8. Mass transfer effects

COMPUTER PROGRAM SPECIFICATION

TITLE Three-Dimensional Heat Transfer (JA03)FORM PREPARED BY D. Hender DATE 11-20-73LANGUAGE Fortran IV HOST MACHINE CDC 6500PROGRAM SIZE 5 (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words) Variable

OUTPUT VOLUME 10 _____ (Words) Variable

BASIS FOR TIMING, INPUT, AND OUTPUT Node size, problem length in seconds,
material typesSTATUS: Operational , Programming In Development _____, Not Programmed _____REFERENCE A3-773-LCCO-JA03-1, A3-773-LCOO-JA03-2OWNERSHIP: Public _____, Private , Owner McAuto

ABSTRACT

Computer Program JA03 calculates three-dimensional heat transfer in a system which can be defined in rectilinear, cylindrical and spherical coordinates. The system is divided into an arbitrary number of small sections called "nodes."

These are classified as right rectilinear, cylindrical and spherical in shape. JA03 uses standard equations for the calculation of conduction, convection and radiation, and incremental temperature change of a node is defined as the net heat exchange at the node divided by the heat capacitance. An approximation to the time temperature history of the system and/or the steady-state temperature solution may be obtained.

The input to the program specifies for each node its shape and dimensions, heat transfer connections, material properties, heat transfer coefficients, incident heat flux, optical properties, and initial node temperature. Temperatures, heat sources, heat transfer coefficients, and incident heat flux may be input as functions of time. Temperature dependent heat transfer coefficients may also be input as functions of two variables. Incident heat flux tables may be input from loadsheets, an F872 master tape, or an MVO6 master tape. Material properties may be input from loadsheets or from the JA16 Master file which is stored on the disk. Additional inputs are required for various optional capabilities such as ablation, dummy nodes, fluid flow, fuel flow, printing of rates of heat flow and integrated heat flow, resistance-capacitance printout, periodic cycling of time dependent tables, and microfilm plotting.

APPENDIX C

FLIGHT MECHANICS
COMPUTER PROGRAM
SPECIFICATIONS

COMPUTER PROGRAM SPECIFICATION

TITLE GENERAL VEHICLE PERFORMANCE ANALYSIS TOOLFORM PREPARED BY O. D. Jordahl DATE 11-29-73LANGUAGE FORTRAN IV HOST MACHINE CDC 6000PROGRAM SIZE 30 (Boxes of Source Cards)TIMING 20 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 4 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT Typical simulation of the Hercules missileSTATUS: Operational , Programming In Development , Not Programmed REFERENCE GVPAT Documentation ManualsOWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

The McDonnell Douglas General Vehicle Performance Analysis Tool (GVPAT) is a FORTRAN computer program library which is structured to simulate trajectories for many different aerospace vehicles. Modular construction has been employed to facilitate future growth and modification of the Library. GVPAT draws together into one package many of the capabilities of trajectory programs currently in use at MDAC-W.

The desired capabilities of the GVPAT Library are extracted and executed as one computer program via an auxiliary program, the GVPAT Preprocessor, and computer dependent utility programs.

GVPAT documentation is contained in three different manuals. The GV1 Manual, GVPAT Subroutine Specifications, contains the detailed information concerning program logic and equation development at a subroutine level. The GV2 Manual, GVPAT General User Instructions, presents the minimum necessary information to form a GVPAT data deck and to use the program. The GV3 Manual, GVPAT Sample Cases, offers a variety of sample cases as an aide to program usage.

COMPUTER PROGRAM SPECIFICATION

TITLE PERFORMANCE ANALYSIS AND DESIGN SYNTHESIS COMPUTER PROGRAMFORM PREPARED BY M. H. RossDATE 12-20-73LANGUAGE FORTRAN IV HOST MACHINE CDC 6000, UNIVAC 1108, UNIVAC 1110PROGRAM SIZE 14 (Boxes of Source Cards)TIMING 200 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 4 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT Shuttle Vehicle trajectory optimizationSTATUS: Operational X, Programming In Development , Not Programmed REFERENCE PADS Vol. 1, 2, and 3 MDC G4287 11/72OWNERSHIP: Public X, Private , Owner

ABSTRACT

The Performance Analysis and Design Synthesis (PADS) computer program has a two-fold purpose. It can size launch vehicles in conjunction with calculus-of-variations optimal trajectories and can also be used as a general-purpose branched trajectory optimization program. In the former use, it has the Space Shuttle Synthesis Program as well as a simplified stage weight module for optimally sizing manned recoverable launch vehicles. For trajectory optimization alone or with sizing, PADS has two trajectory modules. The first trajectory module uses the method of steepest descent; the second employs the method of quasi-linearization, which requires a starting solution from the first trajectory module.

NO. _____

COMPUTER PROGRAM SPECIFICATION

TITLE MODULAR SIMULATION SYSTEM

FORM PREPARED BY M. H. Ross DATE 2-19-74

LANGUAGE FORTRAN IV HOST MACHINE UNIVAC 1108 or CDC 6000

PROGRAM SIZE Very large (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE This program was written by Logicon Inc. under contrac to Aerospace Corp.

OWNERSHIP: Public X, Private _____, Owner _____

ABSTRACT

Two, three or six-degree of freedom trajectory program. Has multi-vehicle simulation capability. Modules and models are caused to load through key cards in input stream. The data for each module follows the key card.

COMPUTER PROGRAM SPECIFICATION

TITLE THREE-DEGREE-OF-FREEDOM TRAJECTORY SIMULATIONFORM PREPARED BY R. J. RothDATE 2-19-74LANGUAGE FORTRAN IVHOST MACHINE CDC CYBER 74PROGRAM SIZE Approx 7 boxes (Boxes of Source Cards)TIMING .1 sec/integration step (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 (Words) totally variable - user dependentBASIS FOR TIMING, INPUT, AND OUTPUT STATUS: Operational X, Programming In Development , Not Programmed REFERENCE MDAC Manuals XA1, XA2, XA3OWNERSHIP: Public , Private X, Owner MDAC

ABSTRACT

Program AB60 performs the three-dimensional simulations of the powered and unpowered flight of a multistage vehicle under trim conditions over a rotating or non-rotating, spherical or ellipsoidal body with an atmosphere. The simulation is accomplished by a numerical integration of the two-body equations of motion (assuming point mass vehicle) which are a function of central and external forces. This program assumes the 1962 ICAO (International Civil Aviation Organization) standard atmosphere unless a non-standard model is input. Vehicle control is accomplished by a pre-programmed attitude rate control. Wind profiles, or boost and/or re-entry phases, as well as the vehicle aerodynamics may be represented by variable length data tables. Vehicle thrust-weight as a function of time is also input in tabular form. Numerical integration is performed by a modified Runge-Kutta scheme which employs a variable step size technique to generate a near-optimum computing interval. Some of the optional program features available to the user are the following: an iterative hunting procedure which varies specified parameters in an attempt to satisfy desired flight conditions; an optimization procedure to extremize a specified payoff function; a scheme using Hermite interpolation to determine trajectory times at which specified values of selected variables occur.

APPENDIX D

STRUCTURES
COMPUTER PROGRAM
SPECIFICATIONS

COMPUTER PROGRAM SPECIFICATION

TITLE TEXGAP - Texas Grain Analysis ProgramFORM PREPARED BY E. GillisDATE 11-27-73LANGUAGE Fortran IVHOST MACHINE CDC 6600PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 900 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed REFERENCE Dunham, R. S. and E. H. Becker, University of Texas, TIMCAM 73-1,
August 1973.OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

TEXGAP is an elastic propellant grain analysis program which combines all the features of, and supersedes, programs SA58, SA60, SA62 and SA64. Results of this program can be input to G394 AVGSAP Viscoelastic Program.

COMPUTER PROGRAM SPECIFICATION

TITLE AVGSAP - Automated Viscoelastic Grain Structural AnalysisFORM PREPARED BY E. Gillis DATE 11-27-73LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 5 (Boxes of Source Cards)TIMING 600 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private _____, Owner MDAC

ABSTRACT

AVGSAP is a program for viscoelastic grain structure analysis. It has design curves from DAC Report-61727 stored in memory for parametric study. Program accounts for ablating grain. Uses input from Program TEXGAP.

COMPUTER PROGRAM SPECIFICATION

TITLE TRANSVERSE ACCELERATION STRESS ANALYSISFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 600 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____REFERENCE Rohm & Haas AMGO38 ProgramRohm & Haas Technical Report S-116OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

Code obtains an elastic solution for an compressible solid of revolution subjected to lateral body force. Code is the Rohm and Haas AMGO38 program (Reference R&H Technical Report S-116). Code is based on the finite element displacement formulation. Equations are solved by the extended Ritz method. Input to the program consists of description of geometry, material properties, and lateral acceleration load. Output consists of tabulated nodal displacements and element stresses and strains.

COMPUTER PROGRAM SPECIFICATION

TITLE VISCOELASTIC GRAIN STRUCTURE ANALYSISFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Fortran IV HOST MACHINE CDC 6500PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 900 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 6 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

Program performs a linear viscoelastic analyses by means of the Schapery direct incremental method. Program is an abbreviated version of program G394 and lacks the built-in elastic solutions and the capability to do an ablating analysis. Input to the program consists of time dependent loads, motor case and propellant material properties, and elastic influence coefficients. Output consists of time dependent bond stresses, bore strains, and resulting cumulative damages.

COMPUTER PROGRAM SPECIFICATION

TITLE Heat Conduction of Solid Propellant Rocket Motor NozzlesFORM PREPARED BY E. Gillis DATE 27 Nov. 1973LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 1 Box (Boxes of Source Cards)TIMING 300 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 4 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner "MDAC"

ABSTRACT

This is an axisymmetric finite element heat conduction program used to generate time dependent temperature distributions in nozzles.

COMPUTER PROGRAM SPECIFICATION

TITLE SAAS III, FINITE ELEMENT STRESS ANALYSIS OF AXISYMMETRIC AND PLANE SOLIDS WITH DIFFERENT ORTHOTROPIC, TEMPERATURE-DEPENDENT MATERIAL PROPERTIES IN TENSION AND COMPRESSION

FORM PREPARED BY E. Gillis DATE Nov. 21 1973

LANGUAGE Fortran IV HOST MACHINE CDC 6600

PROGRAM SIZE 3 (Boxes of Source Cards)

TIMING 600 (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 8 (Words)

OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE Aerospace Report No. TR-0059 (S6816-53)-1

By J. G. Crose and R. M. Jones, 6-22-71

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

The finite element method is used to determine the displacements, stresses, and strains in axisymmetric and plane solids with different orthotropic, temperature-dependent material properties in tension and compression, including the effects of internal pore fluid pressures and thermal stresses. The mechanical loads can be surface pressures, surface shears, and nodal point forces as well as acceleration or angular velocity. The continuous solid is replaced by a system of elements with triangular or quadrilateral cross sections. Accordingly, the method is valid for solids which are composed of many different materials and which have complex geometry. Two-dimensional mesh generation and temperature interpolation features allow the computer program to be readily used.

COMPUTER PROGRAM SPECIFICATION

TITLE FATIGUE ANALYSIS AND DESIGNFORM PREPARED BY F. D. FloodDATE 7-28-72LANGUAGE Fortran IVHOST MACHINE CDC 6600PROGRAM SIZE 3

(Boxes of Source Cards)

TIMING 2/detail

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 2 (Words)

(Words)/Detail

OUTPUT VOLUME 10 0 (Words)(Pages/detail = 10^3 words/detail)BASIS FOR TIMING, INPUT, AND OUTPUT Estimates per Michael Dilio, BCS Programmer.STATUS: Operational ___, Programming In Development XX, Not Programmed ___REFERENCE Boeing D6-24956, "Structural Design for Durability", Structural Durability Group, Jan. 1972; Boeing D6-24957, "Fatigue Design Methods and Allowables", Structural Durability Group, February 1972.OWNERSHIP: Public ___, Private XX, Owner The Boeing Company

ABSTRACT (From D6-24957)

This fatigue analysis and design method includes the following significant features:

- o A fatigue check and margin similar to the static strength check.
- o Equivalent fatigue load conditions that replace exceedance type spectra.
- o An estimating technique to size structure for fatigue in the earliest design stages.
- o An inventory of fatigue-rated detail design based on test and service experience and methods of determining fatigue ratings for new designs.
- o Final fatigue check calculations reduced to a single major stress excursion expected each flight with a factor for the additional damage of smaller stress excursions.
- o A visibility fatigue check format that relates detail design quality to the operating load environment.

COMPUTER PROGRAM SPECIFICATION

TITLE A Computer Program to Design Conical Shell StructureFORM PREPARED BY E. Gillis DATE _____LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 2 (Boxes of Source Cards)TIMING 100 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private X, Owner MDAC

ABSTRACT

The program will determine the thickness of a conical shell structure subjected to axial, bending, torsional shear, transverse shear, and external pressure loads. The temperature of the shell may vary with thickness and, in turn, compressive yield strength and modulus of elasticity will vary with temperature. The program starts with an initial shell thickness and increments the thickness by .010 until the instability and interaction requirements are satisfied, and a positive margin of safety exists. The temperature at each .010 increment is input and the program will determine modulus of elasticity and compressive yield strength from input data. The program calculates actual and allowable stresses for a particular thickness and either terminates if a positive margin of safety exists or increments the thickness and recomputes stresses. Since critical buckling stresses are limited at the compressive yield strength, buckling in the plastic range is not considered.

COMPUTER PROGRAM SPECIFICATION

TITLE Stress Analysis - Santa Program SystemFORM PREPARED BY E. Gillis

DATE _____

LANGUAGE Fortran IVHOST MACHINE CDC 6600PROGRAM SIZE 1-1/4

(Boxes of Source Cards)

TIMING 30 to 600

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____REFERENCE MDAC/W Memorandum A-830-DBGD-189, dated 5-23-69, Thermal Stress Analysis
Computer Program (Elastic-Plastic)OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

The finite element method is applied to the determination of displacements and stresses in axisymmetric solids with orthotropic, temperature-dependent properties. The continuous body is replaced by a system of ring elements with triangular or quadrilateral cross sections. Since elements are of arbitrary shape and can have different material properties, the procedure can be applied to bodies composed of many different materials of complex geometry. The analysis is used as a basis for the development of a general computer program which is capable of thermal stress analysis of axisymmetric solids. Mesh generating and temperature interpolating options allow the program to be readily used.

COMPUTER PROGRAM SPECIFICATION

TITLE SNASOR II - A Finite Element Program for the Static Non-Linear Analyses of Shells of Revolution

FORM PREPARED BY E. Gillis DATE 11-21-73

LANGUAGE Fortran IV HOST MACHINE CDC 6600

PROGRAM SIZE 2 (Boxes of Source Cards)

TIMING 300 (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 2 (Words)

OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development ___, Not Programmed ___

REFERENCE _____

OWNERSHIP: Public ___, Private X, Owner MDAC

ABSTRACT

Program analyses elastic, geometrically nonlinear, thin shells of revolution subjected to symmetric or asymmetric mechanical and thermal loading. The finite element method of structural analysis is utilized with either a modified Newton-Raphson method or incremental stiffness procedure being employed to solve the nonlinear equations of equilibrium. Using the SNASOR code, the static nonlinear response of shells of revolution can be obtained in relatively short periods of time for a large number of important shell problems.

COMPUTER PROGRAM SPECIFICATION

TITLE Axisymmetric Loading of Compressible Solids of RevolutionFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 1200 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____REFERENCE Rohm & Haas Technical Report S-76.OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

Code obtains an elastic solution for thermal gradients, axial body force, and varying pressure. Code is the Rohm & Haas AMGO32 program (Reference R&H Technical Report S-76). Code is based on the finite element displacement formulation. Equations are solved by the extended Ritz method. Input to the program consists of description of geometry, material properties, and load conditions. Output consists of tabulated nodal displacements and element stresses and strains.

COMPUTER PROGRAM SPECIFICATION

TITLE Static Aeroelastic Load Analysis for Missile BodiesFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 120 - 1800 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 4 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____REFERENCE Douglas Report No. SM-42655, December 30, 1962OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

Program SA54, Static Aeroelastic Load Analysis for Missile Bodies, calculates the shears, bending moments, axial loads, and bending deflections for an elastic missile body. In addition, the local angle of attack along the body is obtained for surface pressure calculations. Although this is primarily intended as a load determination method, the aerodynamic force and moment coefficients for the elastic body and the distribution along the body can be obtained as an option.

Although methods are presently available for solution of the aeroelastic problems through use of standard matrix abstraction programs, these methods are best suited for determining the elastic missile aerodynamic parameters, rather than the missile loads required for structural sizing and design. These methods can be used for procedure, since it requires several computer programs and runs, and the intermediate human element associated with transcribing data from one program to another. These are not efficient methods of load determination, and due to the engineering and computer time involved, are not ideally suited to preliminary design and proposal parametric studies.

COMPUTER PROGRAM SPECIFICATION

TITLE General Missile Sizing ProgramFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Fortran IV HOST MACHINE CDC 6000PROGRAM SIZE 15 (Boxes of Source Cards)TIMING 60 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 4 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT One Preliminary Design ConfigurationSTATUS: Operational , Programming In Development , Not Programmed REFERENCE Douglas Paper No. 3632., W. R. Winton, 7 June 1965.OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

The General Missile Sizing Program performs both the sizing and preliminary design of missile configurations for a specified level of performance. The program contains all the design and analysis functions required to design a missile and determine its performance. These functions include solid propellant grain, motor case, nozzle, airframe, heat shield, and control system design. The computation of in-flight air loads and configuration aerodynamics, and trajectory simulation and optimization.

COMPUTER PROGRAM SPECIFICATION

TITLE Vehicle Mass Characteristics DeterminationFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Fortran HOST MACHINE CDC 6600PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 60 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This computer program is designed to give a quick and easy method by which to calculate:

1. Detail weight, horizontal center of gravity, and moment of inertia about the three coordinate axes through the detail part center of gravity.
2. Total configuration weight, center of gravity coordinates about all three axes, and moment of inertia (roll, yaw, and pitch) about the vehicle center of gravity.
3. Also available, at request, are total mass distribution along any or all three coordinate axes, principal axes data, and "EI" distribution.

Data related to principal axes include principal moments of inertia, direction angles of the principal axes, and products of inertia about two coordinate axes.

A geometric data load sheet is available for this program which also eliminates engineering time to calculate mass properties input data.

COMPUTER PROGRAM SPECIFICATION

TITLE Computer Aided Design and Drafting SystemFORM PREPARED BY E. GillisDATE 11-21-73LANGUAGE N/AHOST MACHINE IBM 370PROGRAM SIZE N/A

(Boxes of Source Cards)

TIMING N/A

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 N/A (Words)OUTPUT VOLUME 10 N/A (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner _____

ABSTRACT

The CADD system is a combination of computer hardware devices and programmed logical procedures. Attached to the IBM computer by coaxial cables are a number of IBM Graphics Terminals. The terminals have an electronic display surface similar to a television screen, control buttons, typewriter keyboard, and a device called a lightpen. Through the Graphics Terminal the designer "converses" with the computer. In manipulating the various terminal controls the designer rapidly constructs a true mathematical model of his layout geometry. This is displayed at any desired scale or position on the terminal display surface. The designer may continue to "interact" with his computer-stored model, analyzing and changing it until he has achieved an optimum solution.

COMPUTER PROGRAM SPECIFICATION

TITLE NASTRANFORM PREPARED BY E. GillisDATE 11-21-73LANGUAGE Fortran IVHOST MACHINE CDC 6600PROGRAM SIZE 5 (Boxes of Source Cards)TIMING 1800 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

3600 Degree of Freedom ProblemSTATUS: Operational , Programming In Development , Not Programmed REFERENCE Nastran User's ManualOWNERSHIP: Public , Private , Owner NASA

ABSTRACT

NASTRAN is a program used for static and dynamic analysis of structures. A finite element structural model is used, wherein the distributed physical properties of a structure are represented by a finite number of structural elements. These elements are interconnected at a finite number of grid points. Loads and/or deformations are applied to these grid points and general displacements for the structure are calculated. NASTRAN contains twelve separate problem solution sequences called rigid formats. Each of these rigid formats is associated with the solution of problems for a particular type of static or dynamic analysis. NASTRAN plotting capability consists of both undeformed and deformed plots of the structural model. Response curves are also available for transient response and frequency response analyses. In addition to the rigid format procedures, the user may choose to write his own Direct Matrix Abstraction Program (DMAP). The procedure permits the user to execute a series of matrix operations of his choice along with any utility modules or executive operations that he may need.

Restrictions included in NASTRAN are:

1. Nonplastic analysis only.
2. No prebuckling nonlinearity in buckling module.
3. Temperatures are constant through plate element thickness.
4. Cannot input base excitations for transient response analysis.
5. Cannot handle colinear or coplanar degrees of freedom.

COMPUTER PROGRAM SPECIFICATION

TITLE DATRAMFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 2 (Boxes of Source Cards)TIMING 100 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed REFERENCE A3-250-ABC3-1044, Dated 12-16-71TM-60, December 1971, ABC3OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

DATRAM is a CDC 6000 series program that is designed to read FORMAT (SA49) table data and matrix input data, convert it to NASTRAN (PO730) input data, and punch that data in a ready-to-use form.

Table data read by DATRAM may be on cards and/or tape (no editing). If both tape and cards are input for table data, the tape will be processed first and cards later. Card data and tape data must not duplicate or conflict with each other. Colinear or coplanar degrees of freedom within the structural idealization will remain unconstrained in NASTRAN data input.

Matrix data read by DATRAM may be on cards or tape, but not both. The various tables in the table data may be incremented if desired. The increments need not be the same for all tables. The punched output (input for NASTRAN) will contain the cross-referenced and incremented data.

NO. P2260

COMPUTER PROGRAM SPECIFICATION

TITLE BIGPIX

FORM PREPARED BY E. Gillis

DATE 11-21-73

LANGUAGE Fortran IV

HOST MACHINE CDC 6600

PROGRAM SIZE 1-1/2 (Boxes of Source Cards)

TIMING 100 (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 3 (Words)

OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

BIGPIX is a program that is designed to read discrete element input data for FORMAT, NASTRAN or CASD* and plot a structural idealization. The idealization plot differs from similar plots of the past in that P2260 labels all elements, joints and vectors. Symbols are also used to describe the previously mentioned items. The plot is created by the use of large table plotters using paper or mylar. This plot is intended to replace the traditional hand drawn structural idealizations from which input data is derived.

This program is part of a system of programs that generate data for discrete element analyses. A graphics program exists at Douglas Aircraft that produces data without the hand drawn idealization. This program also produces punched data. BIGPIX is intended to supplement the above mentioned program thus further automating the computer solutions for discrete element structural analyses.

*CASD input is considered to be punched from FORMAT input forms.

C-4

COMPUTER PROGRAM SPECIFICATION

TITLE Missile Rail Dynamic ResponseFORM PREPARED BY E. Gillis DATE 11-27-73LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 120 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT

STATUS: Operational , Programming In Development , Not Programmed REFERENCE Douglas Report No. MDC G0197, dated February 3, 1970OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

Computer Program SA 92 is designed to compute the dynamic response of a missile in motion along a supporting rail, under the influence of various time-dependent loads. The most important distinguishing feature of this program from other dynamic response programs is its automatic handling of the two sources of non-linearity:

1. The varying of the interaction between missile and rail as the missile moves along the rail.
2. The varying of the interaction between missile and rail as the "shoes" which connect them come into intermittent contact with the rail surfaces.

Other features of the program which are important from the user's standpoint are as follows:

1. All matrix and vector input is via magnetic tape from existing structures programs, e.g., DAO2, SA40, SA48, SA49, and SA76. This input includes: stiffness and inverse mass matrices, equilibrium displacement vectors due to constant or initial loads, and extractor matrices for calculation of element forces or other linear functions of response.
2. Loads are entered in tabular form as functions of time or missile position (along the rail) and are obtained at each time point by linear interpolation. (Quadratic interpolation is optional).

COMPUTER PROGRAM SPECIFICATION

TITLE Rib-Stiffened Shell BucklingFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 1/2 (Boxes of Source Cards)TIMING 30 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 2 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT Typical Stiffened Shell Buckling ProblemSTATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This program determines the buckling load for a rib-stiffened cylindrical shell structure which is subjected to a combination of axial and lateral pressure loads. The input consists of the shell dimensions, the stiffener dimensions or section properties, spacings, orientation angle, and stiffener eccentricities relative to the shell thickness, material moduli, and hoop load. The output includes the load for buckling of the shell between stiffeners as well as that for overall buckling and buckling between frames. Also, stiffening rigidities and data for construction of fastoon curves can be included in output.

COMPUTER PROGRAM SPECIFICATION

TITLE FormatFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 5 (Boxes of Source Cards)TIMING 1800 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

FORMAT (FORTRAN Matrix Abstraction Technique) is a digital computer program system consisting of three distinct programs written entirely in FORTRAN IV. The system provides for generation, manipulating, printing, and plotting of large order (i.e., 2000) matrices commonly used in state-of-the-art structural analyses. Phase I of the system automatically generates matrices required in the thermomechanical analysis of structures by the Force or Displacement Methods including those necessary in joining, symmetric/antisymmetric reaction disconnect, vibration, and stability analyses. Modules for converting continuous-to-discrete loads, and analytic-to-discrete geometry and for maintenance of a master case data file are also provided to minimize input data requirements. Phase II provides an abstraction capability to effect basic matrix algebra via the standard matrix operations (e.g., add, multiply, etc.), several pseudo-matrix operations (e.g., adjoin, diagonalize, etc.), and several control operations (e.g., save and print matrices, etc.). The sequence of operations is user designated. Phase III provides for self-explanatory report form printing of matrix data resulting from Force of Displacement Method analyses, and a nominal graphical display capability for matrix and geometry data.

COMPUTER PROGRAM SPECIFICATION

TITLE PLANE STRAIN SOLUTION FOR COMPRESSIBLE MATERIALSFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 1200 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____REFERENCE Rohm & Haas Technical Report S-76OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

Code obtains an elastic solution for arbitrary thermal gradients, body force, and varying pressure. Code is the Rohm & Haas AMGO33 program, (Reference R&H Technical S-76). Code is based on the finite element displacement formulation. Equations are solved by the extended Ritz method. Input to the program consists of description of geometry, material properties, and load conditions. Output consists of tabulated nodal displacement and element stresses and strains.

COMPUTER PROGRAM SPECIFICATION

TITLE Axisymmetric Loading of an Incompressible Materials Solid of RevolutionFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 1800 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____REFERENCE Rohm & Haas Technical Report S-76OWNERSHIP: Public _____, Private , Owner _____

ABSTRACT

Code obtains an elastic solution for thermal gradient, axial body force, and varying pressure. Code is the Rohm & Haas AMG32A program (Reference R&H Technical Report S-76). Code is based on the finite element displacement formulations. Equations are solved by the extended Ritz method. Input to the program consists of description of geometry, material properties, and load conditions. Output consists of tabulated nodal displacement and element stresses and strains.

COMPUTER PROGRAM SPECIFICATION

TITLE Plain Strain Solution for Incompressible MaterialsFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 1800 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____REFERENCE Rohm & Haas Technical Report S-76OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

Code obtains an elastic solution for arbitrary thermal gradients, body force, and varying pressure. Code is the Rohm & Haas AMGO33A program (Reference R&H Technical Report S-76). Code is based on the finite element displacement formulation. Equations are solved by the extended Ritz method. Input to the program consists of description of geometry, material properties, and load conditions. Output consists of tabulated nodal displacements and element stresses and strains.

COMPUTER PROGRAM SPECIFICATION

TITLE Weight Optimization Program for Stiffened CylindersFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 3 (Boxes of Source Cards)TIMING 150 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This program optimizes, with respect to weight, a stiffened cylinder under externally applied loads. The stiffening grid configuration may be (a) 0-90 degree integral ribs, (b) isogrid, or (c) skin-stringer. The stiffening ribs may be capped and may be either internal or external. The manner of loading may be any combination of differential pressure, axial load, bending, and lateral shear. The program permits up to ten successive load conditions.

NO. PO461

COMPUTER PROGRAM SPECIFICATION

TITLE Thermal Stress Analysis Under Asymmetric Loads

FORM PREPARED BY E. Gillis DATE 2-19-74

LANGUAGE Fortran IV HOST MACHINE CDC 6600

PROGRAM SIZE 1-1/2 to 2 (Boxes of Source Cards)

TIMING 60 to 600 (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 2 (Words)

OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT Typical average problem size

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE Aerospace Report No. TR-0172 (52816-15)-1

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This program describes elastic-plastic solution for a body of revolution under asymmetric load. The body can be composed of several orthotropic materials having temperature-dependent properties. The effect due to plastic flow and also the variation of material properties in the circumferential direction is considered. The analysis is made by an energy method incorporated with a finite element technique. Fourier series are used to describe the load functions and the displacements. The solution is obtained iteratively by successive approximations.

COMPUTER PROGRAM SPECIFICATION

TITLE Discrete Element Buckling Analysis for Cylinders Under General Loading

(DEBACUL)

FORM PREPARED BY E. Gillis DATE Nov. 21, 1973LANGUAGE Fortran IV HOST MACHINE CDC 6600PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 600 (Central Processor Decimal Seconds of CDC 6600)INPUT VOLUME 10 3 (Words) 100 KOUTPUT VOLUME 10 4 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This program computes bifurcation buckling loads for general cylinders and curved panels under arbitrary loads. The prebuckling stress analysis accounts for coupling between membrane and bending displacements, and the user has the option of including the effects of prebuckling rotations on the incremental stiffness matrix. The discrete element model is based on the Bogner-Fox-Schmit (BFS) plate and cylindrical panel elements. Arbitrary displacement boundary conditions, including symmetry and antisymmetry, are possible.

COMPUTER PROGRAM SPECIFICATION

TITLE Thermal Stress AnalysisFORM PREPARED BY E. GillisDATE 11-21-73LANGUAGE Fortran IVHOST MACHINE 6600PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 30 Seconds to 10 Minutes (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT Typical average problem sizeSTATUS: Operational , Programming In Development , Not Programmed REFERENCE MDAC/W Memorandum A-830-BBGO-189, dated 5-23-69, Thermal StressAnalysis Computer Program (Elastic-Plastic)OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This program computes the elastic-plastic stress distribution in a body of revolution subjected to an axisymmetrical environment consisting of external radial pressure and thermal gradient. The body can be composed of several orthotropic materials having temperature-dependent properties. The analysis is made by an energy method incorporated with a finite element technique. The plastic action for each orthotropic material is based on the yield stress surface determined from a quadratic function of the uniaxial yield stresses. Identical non-dimensional uniaxial stress-strain relations along the principal axes of material are assumed in consideration of plastic flow.

COMPUTER PROGRAM SPECIFICATION

TITLE Weight Record ProgramFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Samson HOST MACHINE IBM 7094PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 60 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

The WT03 CA provides a method of maintaining on magnetic tape, an up-to-date record of vendor and DAC supplied parts. The record consists of the following information for each part recorded: part number, part description, material, code, class, change letter, unit weight, and notes. Any new part can be added to the record or any existing part can be either changed or deleted by entering the correct information on a WT03 load sheet and submitting it to computing operations. The WT05 WEIGHT WRITE-UP program has the capability of automatically retrieving this part information, if given the part number. This capability requires that information for any part be determined and recorded only once, thus reducing the time and effort spent by the weight analyst for any further reference to that part.

COMPUTER PROGRAM SPECIFICATION

TITLE Weight Write-UpFORM PREPARED BY E. GillisDATE 11-21-73LANGUAGE SamsonHOST MACHINE IBM 7094PROGRAM SIZE 1

(Boxes of Source Cards)

TIMING 60

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

The program provides a method of maintaining on magnetic tape an up-to-date record of engineering drawing and the parts that make up these drawings. Not only does the program provide for maintaining this record, but also supplier totals and averages of weights, classes, moments and centers of gravity for each drawing. The program can also update part information on the WT05 WEIGHT RECORD tape as well as retrieve information from it to complete the program input. The master tape generated by this program, the WT05 Weight WRITE-UP master tape, will serve as the main source of data for all control books and reports output by following programs in the WT WEIGHT SERIES.

COMPUTER PROGRAM SPECIFICATION

TITLE WEIGHT WRITE-UP FILE TRANSLATORFORM PREPARED BY E. GillisDATE 11-21-73LANGUAGE SamsonHOST MACHINE IBM 7094PROGRAM SIZE .1 (Boxes of Source Cards)TIMING 60 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This program modifies a WT05 tape replacing specific fields with loadsheet information and generates a new WT05 tape with the desired substitutions. The WT05 master tape can be used as an input Weight Write-up tape for the WT program report generators. The six fields which may be changed are the Job Number, Section Number, Material Code, Design Group, Vehicle Section-Functional Code and the Sequence Code Fields. The WT06 program was written to efficiently change a large volume of detail and write-up lines on a WT05 tape with only a small amount of input cards.

COMPUTER PROGRAM SPECIFICATION

TITLE Call Number, Effectivity and Next AssemblyFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Samson HOST MACHINE IBM 7094PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 60 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This program provides a method of maintaining on magnetic tape an up-to-date record of vehicle effectivity and next assembly for each and every individual write-up without affecting the write-up itself. The program also provides for listing desired portions of the data in any of four possible sorts; (1) call number, effectivity; (2) call number, next assembly; (3) next assembly, call number; and (4) effectivity, call number.

COMPUTER PROGRAM SPECIFICATION

TITLE Spin-Radius-LoadFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Samson HOST MACHINE IBM 7094PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 60 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

The WT09 program maintains, on magnetic tape, an up-to-record of supplementary weight data. This data, in conjunction with WT05 data, is used to compute detail weight distributions and detail moments of inertia. The WT09 master file contains entries for all single parts or assemblies considered to be such shape, weight, or position as to require a separate entry. There also exists one entry for each write-up which reports values for all items not listed separately. Each WT09 item contains a model code, a call number, an item number, a horizontal span, radii of gyration, and load points for concentrated or cantilevered loads. The WT09 tape file may be updated by inserting new items, deleting old items, or changing existing items. It is recommended that the engineer entering the data for this program be familiar with the program that will use this data, so that the required data is provided, and yet, full advantage is taken of the automatic features of this program and those using the data.

COMPUTER PROGRAM SPECIFICATION

TITLE Weight Basic DecksFORM PREPARED BY E. GillisDATE 11-21-73LANGUAGE SamsonHOST MACHINE IBM 7094PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 60 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private X, Owner MDAC

ABSTRACT

This program maintains an up-to-date magnetic tape record of basic deck titles and information used with the programs in the WT series. Deletion of current items and addition of new items provide the updating capabilities in each deck. Printouts of each basic deck may be requested.

Our basic deck forms one logical file on the WT10 tape. Currently, five basic decks are on the tape. The decks are listed below.

1. Functional Code Basic Deck - File one contains a list of vehicle section-functional codes with the corresponding title.
2. Sequence Code Basic Deck - File two contains a list of specially-packed codes and their corresponding sequence code titles.
3. H-Arm Code Basic Deck - File three contains limits of standard bays.
4. Translation Code Basic Deck (DAC to NASA) - File four consists of three parts; first is the material code translation. Second is the position time code translation, and third is the functional code translation. The Douglas vehicle section functional code, or parts thereof, may be translated to NASA position time codes or to NASA functional codes.
5. Conversion Code Basic Deck - File five is in two parts, A and B. Part A contains a list of Douglas vehicle section-functional codes with their corresponding report title codes. Part B is a list of title codes and their corresponding report titles, which is in sort by conversion code and title code.

COMPUTER PROGRAM SPECIFICATION

* TITLE ALPHANUMERIC PARTS LISTING* FORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Samson HOST MACHINE IBM 7094PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 60 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

The WT11 program provides a method of obtaining a list of all parts for a given vehicle in order by part number as recorded on the W105 WEIGHT WRITE-UP MASTER tape. This provides another method of checking the accuracy and completeness of the weight data for any vehicle. It provides the only method of obtaining a vehicle part list from the weight records.

COMPUTER PROGRAM SPECIFICATION

TITLE FUNCTIONAL AND SEQUENTIAL CODE CONTROL BOOKFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Samson HOST MACHINE IBM 7094PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 60 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

The WT16 program supplies a weight control book listing detail items sorted and summarized by functional and sequential codes. It reports weights and average horizontal, vertical, and lateral centers of gravity for functional code generations and sequence codes.

The basic types of output may be classified as follows:

1. The functional code detail
2. The functional code summary
3. The buildup summary
4. The inflight summary, and
5. The call number list

The user has the option of using functional and material codes as they are written in the WT05 file or translating them to other desired codes by use of the WT10 translation codes.

COMPUTER PROGRAM SPECIFICATION

TITLE WEIGHT SECTION LIST

FORM PREPARED BY E. Gillis DATE 11-21-73

LANGUAGE Samson HOST MACHINE IBM 1108

PROGRAM SIZE 1 (Boxes of Source Cards)

TIMING 60 (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 3 (Words)

OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

This program prepares a weight assembly report for a particular vehicle configuration. Listed in write-up assembly sequence, this report presents the drawing number, title, total weight and average horizontal, vertical, and lateral centers of gravity for each effective sub-assembly. This list is then repeated with the individual weights and average centers of gravity being replaced by the accumulative totals of the sub-assemblies, summarized by generation.

COMPUTER PROGRAM SPECIFICATION

TITLE H-ARM CONTROL BOOKFORM PREPARED BY E. GillisDATE 11-21-73LANGUAGE SamsonHOST MACHINE IBM 1108PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 60. (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This program provides an automated method of obtaining a weight control book, grouping and summarizing items in horizontal bays. Each item is assigned to the bay in which its horizontal center of gravity is contained. Two types of printouts are possible: a detail control book, or a summary control book with partial detail capabilities. The detail control book lists all detail lines of all write-ups effective on a given vehicle. These detail lines are grouped by bays and each bay is either in sort by call number and item number or by functional code, call number, and item number as desired by the engineer. Total weight, average class, and average H, V, and I arms are printed for each different call number, or functional code, within the bay. Totals and averages are printed for each bay, and a grand total for all bays. The summary control book lists only the totals and averages for each bay and the grand total and averages, but prints no detail lines or sub-totals. In addition, detail printouts of NON-STANDARD BAYS (not more than four) can be obtained with the summary control book if the engineer specifies the H-ARM limits of the non-standard bays on the loadsheet.

COMPUTER PROGRAM SPECIFICATION

TITLE WEIGHT TRANSLATION PROGRAMFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Samson HOST MACHINE IBM 7094PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 60 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

The WT20 Program translates weight and mass characteristics data from the Douglas weight record system to a format specified by NASA. Douglas material, function, and sequence codes are translated to NASA material, function, and position time codes. Due to limitations in NASA's format, weight lost and/or gained because of rounding DAC values are accumulated and reported as adjustment items.

The output from the program consists of the following items:

1. A deck of punched cards which serves as the report to NASA.
2. A list containing for each writeup, translated, the Douglas call number, title, change letter, section number, model, and date plus the corresponding NASA serial code assigned the write-up.
3. A list of all errors encountered by the program.

COMPUTER PROGRAM SPECIFICATION

TITLE DETAIL WEIGHT AND INERTIA DISTRIBUTIONFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Samson HOST MACHINE IBM 7094PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 60. (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

The WT21 program provides a detail weight and moment of inertia distribution by standard bays. Various degrees of accuracy may be achieved in this program by specifying the extent of WT09 SPAN RADIUS LOAD data to be used. Limited editing of the WT05 WEIGHT WRITE-UP data is permitted so that the engineer may tailor the distribution to his needs. WT05 write-up items may be excluded for particular call numbers, vehicle sections, functional codes, or sequence codes. Each part, if it is to be included, is distributed over the specific span. The engineer can request that concentrated or cantilevered loads be included in the weight and moment of inertia distribution, or that they be excluded entirely from the distribution. A weight and moment of inertia distribution is generated for one vehicle configuration per computer run. A printout of all concentrated or cantilevered loaded items is generated for every run.

The WT21 program has an optional capability to provide data for machine plotting by a WT44 program. A moment of inertia distribution and weight distribution including concentrated and cantilevered loads is plotted by the WT44 program.

COMPUTER PROGRAM SPECIFICATION

TITLE DESIGN WEIGHT STATEMENTFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Samson HOST MACHINE IBM 7094PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 120 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This program is a general weight reporting program, providing a detail weight control book accompanied by a summary control book as requested. The write-ups are sorted by a major sort field, secondary sort field, call and sequence number, and item number. The major and secondary sort fields are determined by the user.

The basic types of output may be classified as follows: the detail control, listing all detail lines and appropriate averages and totals effective on a particular vehicle; the summary control book, listing the total weights and corresponding titles; and the comparison-summary control book providing the capability of comparing the weight records of two different vehicles.

COMPUTER PROGRAM SPECIFICATION

TITLE WEIGHT RECORD PRINTOUTFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Samson HOST MACHINE IBM 7094PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 60. (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private X, Owner MDAC

ABSTRACT

The WT30 Program generates a partial or complete printout of the WFO3 WEIGHT RECORD tape. A maximum of twenty models may be requested. The printout is ordered by part number and then model. Items printed for each part are part number, description, material code, change letter, class, unit weight, date of entry, and reference number.

COMPUTER PROGRAM SPECIFICATION

TITLE WEIGHT WRITE-UP AND SUMMARY LINE TOTALS PER VEHICLEFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE Samson HOST MACHINE IBM 7094PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 60. (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

The purpose of Program WT35 is to generate via the S-C 4020 plotter the following reports: (1) a list of WT05 weight write-ups in sort by section number (or manufacturing index (M.I. number)) and call number; (2) a list of WT05 summary lines in sort by title code, functional code and call number; (3) a list of WT-5 summary lines in order by functional code and call number. (NOTE: The WT05 weight write-ups and summary lines are retrieved from the WT05 WEIGHT WRITE-UP master tape which is generated by the WT05 WEIGHT WRITE-UP Program).

Each of the above reports will: (1) show vehicle effectivity for up to 18 optionally defined vehicles; (2) be accompanied by a companion report containing intermediate totals only; (3) conclude with a sub-total and a grand total (the sub-total is the total weight of the vehicle and the grand total is the sub-total plus the base weight); (4) contain write-ups selected by the effectivity codes input to define each vehicle.

COMPUTER PROGRAM SPECIFICATION

TITLE SELECTED EQUIPMENT REPORT

FORM PREPARED BY E. Gillis DATE 11-21-73

LANGUAGE Samson HOST MACHINE IBM 7094

PROGRAM SIZE 1 (Boxes of Source Cards)

TIMING 60 (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 1 (Words)

OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

Program WT40 selects requested equipment from the WT05 Weight Write-up master tape. Input to WT40 consists of two control cards containing model code, effectivities, and function code for one of our generations. The WT07 Model X master tape (where X is the desired model) is searched for write-up information having an effectivity range which includes one of the input effectivities. The detail lines of the write-up selected are then located on the WT05 Weight Write-up master tape. Those detail lines having the desired function code character by characters in a specified generation which do not have zero weight are written on tape and sorted by vehicle section, function code, call number, and item number. Output consists of a list of the detail lines in a sort followed by a grand total of the weight of the equipment.

COMPUTER PROGRAM SPECIFICATION

TITLE DETAIL MOMENTS OF INERTIA

FORM PREPARED BY E. Gillis DATE 11-21-73

LANGUAGE Samson HOST MACHINE IBM 7094

PROGRAM SIZE 1 (Boxes of Source Cards)

TIMING 60 (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 2 (Words)

OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This CA provides a method of calculating moments of inertia, products of inertia and direction angles of principal axes in accordance with various functional code, buildup and inflight conditions.

The information generated by this program is output in the form of one or more of the following three reports.

1. The functional code report showing the centers of gravity, moments of inertia, and products of inertia about the vehicle axis.
2. The Buildup Summary showing the weight centers of gravity, moments of inertia, products of inertia (about both the common center of gravity and the principal axes) and the direction angles of the principal axes for each member of some set of pre-defined "units."
3. The Inflight Summary showing the weight centers of gravity, moments of inertia, products of inertia (about both the common center of gravity and the principal axes) and the direction angles of the principal axes for the remaining weight of the vehicle after some portion of the vehicle has been jettisoned (or consumed) during the flight of the vehicle.

COMPUTER PROGRAM SPECIFICATION

TITLE SPAN-RADIUS-LOAD PRINTOUTFORM PREPARED BY E. GillisDATE 11-21-73LANGUAGE SamsonHOST MACHINE IBM 7094PROGRAM SIZE 1 (Boxes of Source Cards)TIMING .60. (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public o, Private X, Owner MDAC

ABSTRACT

The WT33 program prepares a status of the WT05 WEIGHT WRITE-UP and the WT09 SPAN-RADIUS-LOAD master tapes. This program indicates the completeness of the WT09 data for use in the WT21 and WT23 programs. This status is indicated for a desired vehicle by a printed output showing each WT05 detail item which has a corresponding WT09 detail item. The detail WT09 item is printed immediately following its corresponding WT05 detail item. Following these details for each write-up are the WT05 summary items, but adjusted to exclude the detail items already listed, thus representing the portion of the total write-up using the general WT09 item (item number _____) for the write-up. The general WT09 item is printed following summary items and is followed by the write-up totals. A grand total for all write-ups comprising the vehicle is supplied at the end of the output.

COMPUTER PROGRAM SPECIFICATION

TITLE SABOR 5/DRASTICVFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE FORTRAN IV HOST MACHINE CDC 6000, IBM 360/65PROGRAM SIZE 5 (Boxes of Source Cards)TIMING 600 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT

STATUS: Operational , Programming In Development , Not Programmed REFERENCE MDC G0515 SABOR 5/DRASTIC V User's Manual by A. J. Cwiertney, Jr., Feb. 1970OWNERSHIP: Public , Private , Owner USAF

ABSTRACT

SABOR 5/DRASTICV is a discrete element program for the linear-elastic, dynamic response analysis of meridionally curved, variable thickness, branched, thin shells of revolution subjected to arbitrary time varying external mechanical loading. The discrete elements may be of soft-bonded double-layer type or of the single-layer type wherein the material of a shell layer may be isotropic or orthotropic with principal axis oriented at an arbitrary skew inplane angle with respect to the meridional and circumferential directions. The complete code can handle 200 meridionally curved shell elements corresponding to a maximum of 1206 degrees of freedom.

COMPUTER PROGRAM SPECIFICATION

TITLE STACUSS IFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE FORTRAN IV HOST MACHINE IBM 360/65PROGRAM SIZE 8 (Boxes of Source Cards)TIMING 600 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development , Not Programmed REFERENCE SAMSO-TR-71-137 Spades-Stress-Wave Propagation and Dynamic Effects in Shells, August 1971, by A. J. Cwiertney, Jr., and M. H. Schneider, Jr.OWNERSHIP: Public , Private X, Owner MDAC-WD

ABSTRACT

STACUSS I determines the response of linear-elastic, orthotropic, single-layer shells of revolution with cutouts, stiffeners, and material properties varying along the shell's principal coordinates. The structure can be subjected to concentrated and/or distributed static mechanical loading. This code uses the finite element solution technique. The code contains two-dimensional quadrilateral and triangular hybrid shell elements, and a curved tapered beam stiffener element. The structure can be subjected to concentrated and/or distributed static mechanical loading.

COMPUTER PROGRAM SPECIFICATION

TITLE SABOR CS-2, FINITE ELEMENT SHELL AND CORE ANALYSISFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE FORTRAN IV HOST MACHINE CDC 6600PROGRAM SIZE 3 (Boxes of Source Cards)TIMING 700. (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____REFERENCE MDC G0519, SABOR CS-2 User's ManualOWNERSHIP: Public _____, Private , Owner MDAC/WD

ABSTRACT

SABOR CS-2 is a MDAC-W version of an MIT Program (CS-1) that uses the finite element displacement method to analyze general asymmetric static loading and deformation behavior of isotropic thin elastic shells of revolution with an elastic orthotropic solid of revolution core. CS-2 has a mesh generator that plots mesh using SC-4060 plot routines.

COMPUTER PROGRAM SPECIFICATION

TITLE AXIS, AXISYMMETRIC LARGE DEFORMATION ELASTIC PLASTIC DYNAMIC RESPONSE PLATE
AND SHELL ANALYSIS

FORM PREPARED BY E. Gillis DATE 11-21-73
LANGUAGE FORTRAN IV HOST MACHINE CDC 6600
PROGRAM SIZE 2 (Boxes of Source Cards)
TIMING 360 (Central Processor Decimal Seconds of CDC6600)
INPUT VOLUME 10 2 (Words)
OUTPUT VOLUME 10 5 (Words)
BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE MDC G3749, Elastic Plastic Axisymmetric Transient Response of Plates
and Shells Subjected to Mechanical and Thermal Loads, H. L. Chane, Jan. 1973

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

Computer Program AXIS employs finite difference techniques to compute the dynamic response of hard bonded double layered plates, spheres, cylinders and cylinders with hemispherical ends, due to blast, impulsive and thermal loads. The program accounts for prestresses, multiple pulses, variable boundary conditions, material fracture, viscous damping, and elastic strain hardening strain rate sensitive material behavior. The Von Mises yield condition and flow rule are applied. SC 4060 plot routines are incorporated for plotting strain, stress, displacement, pressure and energy histories; and plotting deflection profiles at maximum response and at the end of the computer run.

COMPUTER PROGRAM SPECIFICATION

TITLE DARTS, LARGE DEFORMATION ELASTIC PLASTIC DYNAMIC RESPONSE RING ANALYSISFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE FORTRAN IV HOST MACHINE CDC 6600PROGRAM SIZE 2 (Boxes of Source Cards)TIMING 360 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____REFERENCE MDC G0899 Dynamic Elastic Plastic Response of Rings and InfinitelyLong Cylinders with Variable Properties, H. L. Chane, December 1971OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

DARTS is a finite difference code which computes the dynamic response of hard bonded multi-layered rings and arcs due to blast, impulsive and thermal loads. The program accounts for pre-stresses, multiple pulses variable boundary conditions, material fracture, viscous damping, variable width and elastic strain hardening; strain rate sensitive material behavior. SC-4060 plot routines are incorporated for plotting strain, stress, displacement, pressure and energy histories; and plotting deflection profiles at maximum response and at the end of the computer run.

COMPUTER PROGRAM SPECIFICATION

TITLE TDELT*

FORM PREPARED BY _____ DATE _____

LANGUAGE _____ HOST MACHINE _____

PROGRAM SIZE 5/8 (Boxes of Source Cards)TIMING 50 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT _____
Average Problem SizeSTATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC/WD

ABSTRACT

The TDELT program is used to integrate curvatures along a conical shell to find the deflected shape. The products of curvature (d) and station (Z) are input. This value is used as a constant over a fairly large integration interval.

*Program is always used in conjunction with Program TCURVE.
Data given combines both programs.

COMPUTER PROGRAM SPECIFICATION

TITLE TCURVEFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE FORTRAN IV HOST MACHINE CDC 6600PROGRAM SIZE 1/2 (Boxes of Source Cards)TIMING 50 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

Average Problem SizeSTATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC/WD

ABSTRACT

The TCURVE program is used to calculate thermal stresses and body centerline curvature resulting from a radial and circumferential temperature gradient. Only longitudinal stresses are found and Poisson effects are neglected. An elastic-perfectly plastic material can be used. In the present version the heat shield must be phenolic carbon and the substructure can be beryllium or aluminum.

A total of 11 radial nodes and 12 circumferential nodes can be used. Temperatures can be input at these nodes or an interpolation routine can be used. This required input at 0, 30, 45, 90, 120, 180°.

COMPUTER PROGRAM SPECIFICATION

TITLE BOND, LARGE DEFORMATION VARIABLE PROPERTY ELASTIC PLASTIC DYNAMICRESPONSE OF SOFT BONDED RINGS AND INFINITELY LONG CYLINDERSFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE FORTRAN IV HOST MACHINE CDC 6600PROGRAM SIZE 2 (Boxes of Source Cards)TIMING 360 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____REFERENCE MDC G0899 Dynamic Elastic Plastic Response of Rings and Infinitely
Long Cylinders with Variable Properties, H. L. Chane, December 1971OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

The computer program BOND uses finite difference techniques to compute the dynamic response of soft bonded rings and infinitely long cylinders with variable properties subjected to partitioned impulsive loads. The program accounts for viscous damping, material fracture orthotropic and isotropic material properties, and elastic strain hardening strain rate sensitive material behavior. SC-4060 plot routines are incorporated for plotting strain, stress, displacement and energy histories; and plotting deflection profiles at maximum response and at the end of the computer run.

COMPUTER PROGRAM SPECIFICATION

TITLE DYNAMOS 5

FORM PREPARED BY E. Gillis DATE 11-21-73

LANGUAGE FORTRAN IV HOST MACHINE CDC 6000

PROGRAM SIZE 1 (Boxes of Source Cards)

TIMING 120 (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 2 (Words)

OUTPUT VOLUME 10 4 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE DAC 63325, Dynamic Analysis of Soft-Bonded Double-Layer Orthotropic Cylindrical Shells, April 1970, A. S. Cwiertny, jr., and C. D. Babcock, Jr.

OWNERSHIP: Public , Private , Owner _____

ABSTRACT

DYNAMOS 5 is a computer code for determining stresses and strain in multilayer, hard-bonded or soft-bonded (finite shear stiffness) orthotropic cylindrical shells subjected to time-dependent loading. The differential equations of motion are solved for simple support boundary conditions using the normal mode expansion technique for solution of the forced vibrations problem.

COMPUTER PROGRAM SPECIFICATION

TITLE CYLINDER, ASYMMETRIC FINITE DEFLECTION ELASTIC PLASTIC DYNAMIC RESPONSE
ORTHOTROPIC CLINDER ANALYSIS

FORM PREPARED BY E. Gillis DATE _____
LANGUAGE FORTRAN IV HOST MACHINE CDC 6600
PROGRAM SIZE 2 (Boxes of Source Cards)
TIMING 1500 (Central Processor Decimal Seconds of CDC6600)
INPUT VOLUME 10 2 (Words)
OUTPUT VOLUME 10 5 (Words)
BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE Franks, R. H. Cylinder: A Computer Program for the Inelastic Dynamic
Response of Orthotropic Cylindrical Shells. Kam Nuclear, KN-67-533(R), Sept. '67

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This program uses finite difference techniques to calculate the dynamic response of an orthotropic cylindrical shell due to blast, impulsive and thermal loads. The program accounts for multiple pulses, variable boundary conditions, and viscous damping. The Hill modified Von Mises yield condition and Sander's non-linear finite deflection shell equations are applied.

COMPUTER PROGRAM SPECIFICATION

TITLE CYLINDER, ASYMMETRIC FINITE DEFLECTION ELASTIC PLASTIC DYNAMICRESPONSE ORTHOTROPIC CYLINDER ANALYSIS

FORM PREPARED BY _____ DATE _____

LANGUAGE _____ HOST MACHINE _____

PROGRAM SIZE 2 (Boxes of Source Cards)TIMING 1500 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____REFERENCE Franke, R. H., Cylinder: A Computer Program for the InelasticDynamic Response of Orthotropic Cylindrical Shells. Kaman Nuclear, KN-67-533 (R),
Sept. '67OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

This program uses finite difference techniques to calculate the dynamic response of an orthotropic cylindrical shell due to blast, impulsive and thermal loads. The program accounts for multiple pulses, variable boundary conditions, and viscous damping. The Hill modified Von Mises yield condition and Sander's non-linear finite deflection shell equations are applied.

COMPUTER PROGRAM SPECIFICATION

TITLE THERMOVISCOELASTIC WAVE PROPAGATIONFORM PREPARED BY E. Gillis DATE 11-21-73LANGUAGE FORTRAN IV HOST MACHINE CDC 6600PROGRAM SIZE 3 (Boxes of Source Cards)TIMING 600 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____REFERENCE Rohm and Haas AMG063 Program, Rohm and Haas Technical Report S-175

OWNERSHIP: Public _____, Private _____, Owner _____

ABSTRACT

Code performs a one-dimensional stress wave propagation analyses, and was written primarily for the nuclear loading but can be used to obtain a solution for arbitrary time dependent boundary force or displacements. Program solves the coupled equations of motion and transient heat transfer by the extended Ritz method. Code is the Rohm and Haas AMG063 program (Reference R&H Technical Report S-175). Program modified by MDAC to include the cumulative damage failure criterion. Input consists of nodal locations, material properties, and load conditions. Output consists of nodal displacements and velocity and element temperatures and stresses.

COMPUTER PROGRAM SPECIFICATION

TITLE DYNAMOS 3A

FORM PREPARED BY E. Gillis DATE 11-21-73

LANGUAGE FORTRAN IV HOST MACHINE CDC 6000

PROGRAM SIZE 1 (Boxes of Source Cards)

TIMING 120 (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 2 (Words)

OUTPUT VOLUME 10 4 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE DAC 61298, Fortran Program for Determining Dynamic Response of Multi-Layered Orthotropic Cylindrical Shells, by J. J. Dietrich

OWNERSHIP: Public , Private , Owner # MDAC/WD

ABSTRACT

DYNAMOS 3A is a computer code for the dynamic response analysis of layered (hard-bonded) cylindrical shells. Linear response is obtained using the normal vibration modes as generalized coordinates. The critical impulse for incipient yield is computed for the inner and outer wall, as well as the average for each layer at various shell locations. The Hencky-Von Mises yield criteria is used for isotropic materials, and a special case of Mohr's theory is used for orthotropic materials, which accounts for different yield stress in the axial and circumferential direction. The program has been modified to handle impulsive spot loads which are uniform in the radial direction and cover a rectangular area on the surface of the cylinder.

COMPUTER PROGRAM SPECIFICATION

TITLE PETROS 3, LARGE DEFORMATION ELASTIC PLASTIC DYNAMIC RESPONSE OF MULTILAYER
VARIABLE THICKNESS SHELLS

FORM PREPARED BY _____ DATE _____
 LANGUAGE FORTRAN IX HOST MACHINE CDC 6600
 PROGRAM SIZE 3 (Boxes of Source Cards)
 TIMING 360 - 3600 (Central Processor Decimal Seconds of CDC6600)
 INPUT VOLUME 10 3 (Words)
 OUTPUT VOLUME 10 5 (Words)
 BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE PRL Contract No. 60, ASRL TR 152-2 PETROS 3: A Finite Difference
Method and Program for the Calculation of Large Elastic-Plastic Dynamically
Induced Deformations of Multilayered Variable Thickness Shell, Nov. 1971

OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

This program uses finite difference techniques to compute the dynamic response of variable thickness ^(*) hard bonded, multilayer, multimaterial, thin Kirchhoff plates and shells of any initial shape due to blast, impulsive and thermal loads. The program accounts for variable boundary conditions, arbitrarily large deformations and elastic strain hardening strain rate sensitive material behavior.

APPENDIX E

PROPULSION
COMPUTER PROGRAM
SPECIFICATIONS

COMPUTER PROGRAM SPECIFICATION

TITLE Solid Rocket Motor Analysis TOOL (SRMAT)FORM PREPARED BY J. W. Robinson DATE 1-17-74LANGUAGE Fortran HOST MACHINE CDCPROGRAM SIZE 35 (Boxes of Source Cards)TIMING 30 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

SRMAT performs rapid and accurate preliminary design and analysis of solid propulsion systems for use in sizing and optimization studies of missile configurations and propulsion systems. Design synthesis is accomplished for each of the major elements of the complete propulsion system (propellant configuration, motor case, blast tube, nozzle and thrust vector control). The functions performed by SRMAT include optional grain design selection, computation of insulation requirements, burning surface area and propellant loading analysis, motor case design, motor performance analyses, nozzle and blast tube sizing and design and computation of inert weights.

The program can design several types of grain configurations including slotted-tube, conocyl, star, dendrite, disc, and end burning grains for both continuous and dual thrust histories. Motor cases may be either cylindrical or conical and of isotropic or orthotropic construction. The nozzle design capability includes two types of fixed nozzles and five types of movable nozzles with six potential thrust vector control systems consisting of liquid injection thrust vector control, hot gas thrust vector control, gimbal ring, ball and socket, flexible seal and jet tabs. The program also incorporates design capability for pintle nozzle single chamber thrust magnitude control.

COMPUTER PROGRAM SPECIFICATION

TITLE One-Dimensional Equilibrium Nozzle Analysis ProgramFORM PREPARED BY J. W. Robinson DATE 1-17-74LANGUAGE Fortran HOST MACHINE CDCPROGRAM SIZE 1 (Boxes of Source Cards) 60KTIMING 5 - 30 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 1 (Words)OUTPUT VOLUME 10 2 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC version of NASA-Lewis Research Center Program, Standard ICRPG Program

ABSTRACT

This computer program performs computations involving chemical equilibrium in complex systems. It is based on iteration equations for chemical equilibrium computations that are independent of choice of components. The program permits calculations such as: (1) chemical equilibrium for assigned temperatures and pressures, (2) theoretical rocket performance for both frozen and equilibrium compositions during expansion, and (3) Chapman-Jouguet detonation properties.

COMPUTER PROGRAM SPECIFICATION

TITLE Grain Design and Internal Ballistics Evaluation ProgramFORM PREPARED BY J. W. RobinsonDATE 1-17-74LANGUAGE Fortran IVHOST MACHINE CDCPROGRAM SIZE Est. 6(Boxes of Source Cards) 115KTIMING 100 to 1000

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 20 (Words)OUTPUT VOLUME 10 50 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC version of Hercules Grain Design and Internal Ballistics Evaluation Program

ABSTRACT

The Grain Design Program is used in developing the surface area versus burn distance curve of a solid propellant motor.

The Ballistic Program uses the data computed for each burn in the Grain Design Program to generate internal ballistics data for the motor. A one dimensional steady state model of the internal gas flow is used. Burn rates at intervals along the motor axis are computed as functions of pressure and gas velocity at that location. This allows non-uniform burning to be taken into account in subsequent burns computed by the Grain Design Program.

The program includes options to compute the pressure transient at motor ignition and the tailoff at burnout.

COMPUTER PROGRAM SPECIFICATION

TITLE Nozzle and Control System Preliminary Design Computer ProgramFORM PREPARED BY J. W. Robinson DATE 1-17-74LANGUAGE Fortran HOST MACHINE CDCPROGRAM SIZE 3 (Boxes of Source Cards)TIMING 50 - 150 (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 (Words)

OUTPUT VOLUME 10 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

Program was developed to design and size nozzles and control systems for solid rocket motors. It performs the preliminary design of conventional and submerged fixed nozzles, flexible seal and gimbal ring (subsonic split line) movable nozzles, liquid and gaseous secondary injection thrust vector control systems, and jet interaction control systems. In addition, empirical performance predictions can be obtained for the secondary injection systems.

COMPUTER PROGRAM SPECIFICATION

TITLE Three Dimensional Heat Transfer Computer ProgramFORM PREPARED BY J. W. Robinson

DATE _____

LANGUAGE FortranHOST MACHINE CDC 6500PROGRAM SIZE 5 (Boxes of Source Cards)TIMING Variable (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 (Words)OUTPUT VOLUME 10 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner McAuto

ABSTRACT

Computer Program JA03 calculates three-dimensional heat transfer in a system which can be defined in rectilinear, cylindrical and spherical coordinates. The system is divided into an arbitrary number of small sections called "nodes."

These are classified as right rectilinear, cylindrical and spherical in shape. JA03 uses standard equations for the calculation of conduction, convection and radiation, and incremental temperature change of a node is defined as the net heat exchange at the node divided by the heat capacitance. An approximation to the time temperature history of the system and/or the steady-state temperature solution may be obtained.

The input to the program specifies for each node its shape and dimensions, heat transfer connections, material properties, heat transfer coefficients, incident heat flux, optical properties, and initial node temperature. Temperatures, heat sources, heat transfer coefficients, and incident heat flux may be input as functions of time. Temperature dependent heat transfer coefficients may also be input as functions of two variables. Incident heat flux tables may be input from loadsheets, an F872 master tape, or an MV06 master tape. Material properties may be input from loadsheets or from the JA16 Master file which is stored on the disk. Additional inputs are required for various optional capabilities such as ablation, dummy nodes, fluid flow, fuel flow, printing of rates of heat flow and integrated heat flow, resistance-capacitance printout, periodic cycling of time dependent tables, and microfilm plotting.

COMPUTER PROGRAM SPECIFICATION

TITLE Charring Material Thermal Response and Ablation ProgramFORM PREPARED BY J. W. Robinson DATE 1-17-74LANGUAGE Fortran HOST MACHINE CDCPROGRAM SIZE 2 (Boxes of Source Cards)TIMING 120 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 (Words)OUTPUT VOLUME 10 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC Version of VIDYA Program

ABSTRACT

The Charring Material Thermal Response and Ablation Program (G508) serves in predicting the thermal response and erosion of a nozzle wall material through internal thermal response calculations (considering decomposition in depth) together with the boundary layer conditions calculated with the Equilibrium Surface Thermochemical Program (G590).

COMPUTER PROGRAM SPECIFICATION

TITLE Equilibrium Surface Thermochemistry Performance ProgramFORM PREPARED BY J. W. Robinson DATE 1-17-74LANGUAGE Fortran HOST MACHINE CDCPROGRAM SIZE 1 (Boxes of Source Cards)TIMING 30 - 120 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 (Words)OUTPUT VOLUME 10 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC version of VIDYA Program

ABSTRACT

The Equilibrium Surface Thermochemistry Program (G590) calculates surface equilibrium of the ablative with the combustion gas environment. Mass flow from the ablating surface combines with the combustion gases and effects the boundary layer and heat exchange between the combustion gas and wall. This program contains thermochemical equilibrium equations similar to ODE (H659) and produces the same combustion species and gas properties when the mass flow of pyrolysis gases is zero. Two important uses are provided by this program. First, it is used to evaluate, comparatively, specific materials for use with different exhaust gas compositions for overall chemical erosion performance. The second use is the generation of the surface thermochemistry input for the thermal response and ablation program (G508).

COMPUTER PROGRAM SPECIFICATION

TITLE Advanced Thrust Vector Control Preliminary DesignFORM PREPARED BY J. W. RobinsonDATE 1-16-74LANGUAGE FortranHOST MACHINE CDCPROGRAM SIZE 30(Boxes of Source Cards) 140K wordsTIMING 50 - 250

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 (Words)OUTPUT VOLUME 10 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner AFRPLContract F04611-71-C-0013

ABSTRACT

A computer program developed to (1) evaluate preliminary duty cycles for missile systems, (2) develop specifications for the control system being employed, (3) perform preliminary design analysis on any of the control options, and (4) predict the performance capability of a vehicle utilizing the control system characteristics obtained from the program. The seven potential control inputs are liquid injection thrust vector control, hot gas thrust vector control, gimbal ring, ball and socket, flexible seal, jet tabs, and aerodynamic surfaces. The program has the capability to determine the thrust magnitude required to fly trajectories where thrust vector and thrust magnitude control is required. The nozzle design capability includes two types of fixed nozzles and five types of movable nozzles. The program also incorporates design capability for pintle nozzle single chamber thrust magnitude control with or without thrust vector control. Two material options are available for case design, metal and filament wound glass. A three dimensional six degrees of freedom trajectory routine is available in the program.

COMPUTER PROGRAM SPECIFICATION

TITLE Solid Propellant Motor PerformanceFORM PREPARED BY J. W. RobinsonDATE 1-17-74LANGUAGE FortranHOST MACHINE CDCPROGRAM SIZE _____ (Boxes of Source Cards) 100K

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner _____

ABSTRACT

Generates the description of solid propellant motor performance from propellant characteristics, grain shape, description of the motor design, igniter, altitude history, and gas properties.

COMPUTER PROGRAM SPECIFICATION

TITLE Solid Motor Ballistic Reconstruction ProgramFORM PREPARED BY J. W. RobinsonDATE 1-16-74LANGUAGE FortranHOST MACHINE CDC

PROGRAM SIZE _____ (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____REFERENCE Report No. PDM 71-2OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

Program to provide capability to reconstruct the ballistic performance of a solid vector. The program is motor independent in that all relationships used in the model are standard, and it is only through data input that specific motor characteristics are loaded into the program.

COMPUTER PROGRAM SPECIFICATION

TITLE Solid Motor Ballistic Performance Prediction ProgramFORM PREPARED BY J. W. Robinson DATE 1-16-74LANGUAGE Fortran HOST MACHINE CDCPROGRAM SIZE _____ (Boxes of Source Cards) 23K core

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 (Words)OUTPUT VOLUME 10 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____REFERENCE Report No. FDM 71-1OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

Program to provide capability to predict perturbations to the ballistic performance of a solid motor whose design is already known. Program can also be used to generate trade-off factors and may have some utility in preliminary design situations.

APPENDIX F

SENSOR
COMPUTER PROGRAM
SPECIFICATIONS

NO. _____

COMPUTER PROGRAM SPECIFICATION

TITLE FIR2

FORM PREPARED BY D. J. Fischer

DATE _____

LANGUAGE FORTRAN

HOST MACHINE CDC 6500

PROGRAM SIZE 1/2 box

(Boxes of Source Cards)

TIMING 60 sec

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 (Words)

OUTPUT VOLUME 10 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE MDC G5025

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

Calculates the probability of an observer recognizing a target when viewing a display where the sensor is a framing infrared emerging system (FLIR, DLIR, IR line scanner).

NO. _____

COMPUTER PROGRAM SPECIFICATION

TITLE TVACT

FORM PREPARED BY D. J. Fischer DATE _____

LANGUAGE FORTRAN HOST MACHINE CDC 6500

PROGRAM SIZE 1/2 box (Boxes of Source Cards)

TIMING 60 sec (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 (Words)

OUTPUT VOLUME 10 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed 0

REFERENCE MDC G5025

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

Calculates the probability of an observer recognizing a target when viewing a display where the sensor is a ranged gated LLLTV plus a pulsed GaAs laser illuminator.

NO. _____

COMPUTER PROGRAM SPECIFICATION

TITLE RADTV

FORM PREPARED BY D. J. Fischer DATE _____

LANGUAGE FORTRAN HOST MACHINE CDC 6500

PROGRAM SIZE 1/2 box (Boxes of Source Cards)

TIMING 60 sec (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE MDC G5025

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

Calculates the probability of an observer recognizing a target when viewing a display where the sensor is a passive LLLTV.

COMPUTER PROGRAM SPECIFICATION

TITLE ATMOSPHERIC TRANSMISSION

FORM PREPARED BY D. J. Fischer DATE _____

LANGUAGE FORTRAN HOST MACHINE CDC 6500

PROGRAM SIZE 1 box (Boxes of Source Cards)

TIMING 1 minute (60 seconds) (Central Processor Decimal Seconds of CDC660)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT Core requirement 40K

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public , Private _____, Owner _____

ABSTRACT

This program calculates the atmospheric transmission and background radiance between 1 micren and 30 micrens.

NO. _____

COMPUTER PROGRAM SPECIFICATION

TITLE UHF DATA LINK

FORM PREPARED BY D. J. Fischer DATE _____

LANGUAGE FORTRAN HOST MACHINE GE 225

PROGRAM SIZE 50K (Boxes of Source Cards)

TIMING 60 seconds (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT NAFI

STATUS: * Operational , Programming In Development , Not Programmed

REFERENCE NAFI TR-1600

OWNERSHIP: Public , Private , Owner _____

ABSTRACT

UHF data link performance program and plotting program.

* This program has been coded but not made operational on the CDC 6500.

APPENDIX G

GUIDANCE AND CONTROL
COMPUTER PROGRAM
SPECIFICATIONS

COMPUTER PROGRAM SPECIFICATION

TITLE 3-D TERMINAL GUIDANCE SIMULATIONFORM PREPARED BY HV DATE 2-21-74LANGUAGE FORTRAN IV HOST MACHINE CDC 6500PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 100 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 4 (Words)OUTPUT VOLUME 10 4 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private X, Owner MDAC

ABSTRACT

EG02 is a 3-D guidance simulation incorporating all elements necessary to evaluate performance of a seeker-guided interceptor. This includes target, interceptor, and terminal seeker dynamics, seeker noise sources, interceptor performance errors, state estimators and guidance mechanization. Exo and endoatmospheric versions are available. The program is used primarily in a Monte Carlo mode to generate miss distance statistics and circular error probability.

COMPUTER PROGRAM SPECIFICATION

TITLE GENERAL VEHICLE PERFORMANCE ANALYSIS TOOLFORM PREPARED BY O. D. Jordahl DATE 11-29-73.LANGUAGE FORTRAN IV HOST MACHINE CDC 6000PROGRAM SIZE 30 (Boxes of Source Cards)TIMING 20 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 4 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT Typical simulation of the Hercules missileSTATUS: Operational , Programming In Development , Not Programmed REFERENCE GVPAT Documentation ManualsOWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

The McDonnell Douglas General Vehicle Performance Analysis Tool (GVPAT) is a FORTRAN computer program library which is structured to simulate trajectories for many different aerospace vehicles. Modular construction has been employed to facilitate future growth and modification of the Library. GVPAT draws together into one package many of the capabilities of trajectory programs currently in use at MDAC-W.

The desired capabilities of the GVPAT Library are extracted and executed as one computer program via an auxiliary program, the GVPAT Preprocessor, and computer dependent utility programs.

GVPAT documentation is contained in three different manuals. The GV1 Manual, GVPAT Subroutine Specifications, contains the detailed information concerning program logic and equation development at a subroutine level. The GV2 Manual, GVPAT General User Instructions, presents the minimum necessary information to form a GVPAT data deck and to use the program. The GV3 Manual, GVPAT Sample Cases, offers a variety of sample cases as an aide to program usage.

NO. H211

COMPUTER PROGRAM SPECIFICATION

TITLE 6-D CONTROLS TRAJECTORY SIMULATION

FORM PREPARED BY HV DATE 2-25-74

LANGUAGE _____ HOST MACHINE _____

PROGRAM SIZE _____ (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

This program performs a 6-D rigid body controls analysis using vehicle and control system parameters and a simplified trajectory simulation.

COMPUTER PROGRAM SPECIFICATION

TITLE END GAME SIMULATION

FORM PREPARED BY _____ DATE _____

LANGUAGE FORTRAN IV HOST MACHINE CDC 6500PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 100 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 4 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

The program is a 1-D simulation since only the motion in the miss distance direction is considered. A fixed engagement time is used to determine miss distance due to target maneuvers, target tracking noise, target filter response, interceptor response to commands, and also to guidance philosophy.

COMPUTER PROGRAM SPECIFICATION

TITLE VEHICLE MODES AND FREQUENCIESFORM PREPARED BY HV DATE 2-21-74LANGUAGE FORTRAN IV HOST MACHINE CDC 6500PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 100 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 4 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private X, Owner MDAC

ABSTRACT

Determines beam finding, compression, and torsional modes and frequencies. The program uses mass stiffness and distribution to determine vehicle mode shapes and frequencies.

COMPUTER PROGRAM SPECIFICATION

TITLE CEP ANALYSIS PROGRAM

FORM PREPARED BY HV DATE 2-25-74

LANGUAGE FORTRAN IV HOST MACHINE _____

PROGRAM SIZE 2 (Boxes of Source Cards)

TIMING 50 (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 3 (Words)

OUTPUT VOLUME 10 4 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDC

ABSTRACT

This program performs circular error probability analysis for single and multi gimbal axis systems and strapdown systems for boost and reentry problems.

COMPUTER PROGRAM SPECIFICATION

TITLE SHAPING NETWORK SYNTHESISFORM PREPARED BY HV DATE 2-25-74LANGUAGE FORTRAN IV HOST MACHINE CDC 6500PROGRAM SIZE 1/2 (Boxes of Source Cards)TIMING 80 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 1 (Words)OUTPUT VOLUME 10 4 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT 8TH ORDER POLYNOMIAL SHAPING NETWORKSTATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This program accepts Z-plane transfer function data and stability parameters with weighting coefficients. It computes digital shaping network coefficients which achieve the desired stability characteristics.

COMPUTER PROGRAM SPECIFICATION

TITLE NUHYAP MULTIRATE NUMERICAL, CONTINUOUS, AND HYBRID SYSTEM ANALYSISFORM PREPARED BY HV DATE 2-27-74LANGUAGE FORTRAN IV HOST MACHINE CDC 6500PROGRAM SIZE 1-1/2 (Boxes of Source Cards)TIMING 60 sec (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 600 (Words)OUTPUT VOLUME 20K (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner NDAC~~ABSTRACT~~

This program provides capability for multirate numerical, continuous, and hybrid system analysis. It performs the following functions in either the S- or Z-plane:

Bode plots of transfer functions

Algebraic manipulation of transfer functions

Direct conversion of Laplace to Z-transforms in polynomial form

Direct conversion of high rate Z-transforms to a low rate Z-transforms

COMPUTER PROGRAM SPECIFICATION

TITLE HYDRAULIC ACTUATION SYSTEM PRELIMINARY DESIGNFORM PREPARED BY HV DATE 2-21-74LANGUAGE FORTRAN IV HOST MACHINE CDC 6500PROGRAM SIZE 3 (Boxes of Source Cards)TIMING 50 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 4 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

Hydraulic Actuation System Preliminary Design predicts weight and geometry parameters and evaluates performance for control actuation system elements.

COMPUTER PROGRAM SPECIFICATION

TITLE VALVE ACTUATOR FREQUENCY AND TRANSIENT RESPONSEFORM PREPARED BY HV DATE 2-25-74LANGUAGE FORTRAN IV HOST MACHINE _____PROGRAM SIZE 1-1/2 (Boxes of Source Cards)TIMING 70 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 4 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

This program computes frequency and transient response characteristics for hydraulic and pneumatic actuators.

COMPUTER PROGRAM SPECIFICATION

TITLE ACTUATOR FRICTION ANALYSISFORM PREPARED BY HV DATE 2-25-74LANGUAGE EXTENDED FORTRAN HOST MACHINE TYMSHAREPROGRAM SIZE 1/2 (Boxes of Source Cards)TIMING 20 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 1 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This program determines actuator friction levels for use in controls analysis.

NO. CA48

COMPUTER PROGRAM SPECIFICATION

TITLE MULTILOOP LINEAR ANALYSIS

FORM PREPARED BY HV DATE 2-21-74

LANGUAGE _____ HOST MACHINE _____

PROGRAM SIZE _____ (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

This program accepts differential equations and system transfer functions and will compute Nyquist and Bode plots as well as transient response for desired parameters.

APPENDIX H

COST
COMPUTER PROGRAM
SPECIFICATIONS

NO. _____

COMPUTER PROGRAM SPECIFICATION

TITLE LIGHT AREA DEFENSE STUDY (LADS)

FORM PREPARED BY A. Goodwin

DATE 2-13-74

LANGUAGE _____

HOST MACHINE TYMSHARE

PROGRAM SIZE 1

(Boxes of Source Cards)

TIMING _____

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 2 (Words)

OUTPUT VOLUME 10 2 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

LADS is a small program for a tactical missile. It accepts approximately 50 inputs and outputs approximately 50 items. It calculates investment and first unit cost. It has options which permit selecting a 2, 3, or 4 stage vehicle, liquid or solid propulsion, three different types of guidance, throughput or calculated values for sensors and data processor.

COMPUTER PROGRAM SPECIFICATION

TITLE PRELIMINARY SURFACE-TO-AIR MISSILE COST MODEL (SAMCOM)FORM PREPARED BY A. J. Goodwin DATE 2-13-74LANGUAGE FORTRAN HOST MACHINE CDCPROGRAM SIZE 1 (Boxes of Source Cards)TIMING 40 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

SAMCOM is a cost model for a surface-to-air missile. It accepts approximately 1,000 input items. It has options permitting selecting different types of structural material, two different types of controls, two different thrust configurations, and two types of ordnance. It outputs total life cycle costs by budget category for R&D, T&E, investment and operational phases of a program. It also outputs first unit hardware cost. Except for the options listed above, the configuration cannot be varied except by revising the program.

COMPUTER PROGRAM SPECIFICATION

TITLE ADVANCED TERMINAL INTERCEPTOR TECHNOLOGY PROGRAM (ATITP)

FORM PREPARED BY A. J. Goodwin DATE 2-13-74

LANGUAGE FORTRAN HOST MACHINE CDC

PROGRAM SIZE See SCALE (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 3 (Words)

OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private X, Owner MDAC

ABSTRACT

ATITP is a special use of SCALE. It utilizes only one submodel. It has the capability of all types of output and output manipulation procedures described for any one submodel of SCALE.

COMPUTER PROGRAM SPECIFICATION

TITLE SYSTEMS COST ANALYSIS LIFE CYCLE ESTIMATE (SCALE)FORM PREPARED BY A. J. Goodwin DATE 2-13-74LANGUAGE FORTRAN HOST MACHINE CDCPROGRAM SIZE 1-10 (Boxes of Source Cards)TIMING 40-800 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 5 (Words)OUTPUT VOLUME 10 4 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private , Owner MDAC

ABSTRACT

SCALE is a complex computerized model combining up to 32 submodels. Its major current use is for determining life cycle costs for the Site Defense System. It accepts input data from up to 32 matrices of 2,500 values each. It compiles CER's* from an extensive library and can accept new CER's in its preprocessor input. It outputs total life cycle costs including detail R&D, T&E, investment and operational costs for each submodel specified. It has numerous routines for rearranging outputs to different WBS structures, budget categories, and funding schedules. Its operation requires a high degree of familiarity with the program and several pre-arranged storage files.

* Cost estimating relationships.

APPENDIX I

ARMAMENT
COMPUTER PROGRAM
SPECIFICATIONS

COMPUTER PROGRAM SPECIFICATION

TITLE MISSILE QUANTITIES REQUIREMENTSFORM PREPARED BY H. C. ThompsonDATE 2-27-74LANGUAGE FORTRAN

HOST MACHINE _____

PROGRAM SIZE 2

(Boxes of Source Cards)

TIMING 600

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 4 (Words)OUTPUT VOLUME 10 3 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT Estimate of requirements and knowledge of type of computation involved.STATUS: Operational , Programming In Development , Not Programmed REFERENCE UnknownOWNERSHIP: Public , Private , Owner Government.

ABSTRACT

This program is a war game program. It will compute missile quantities required to fight particular types of engagements. Inputs will be a target array and firing positions and firing doctrine. Output will be quantities of missiles fired and estimated outcome of battle: Equipment destroyed, casualties, missiles fired, duds encountered, battle length, battle outcome.

COMPUTER PROGRAM SPECIFICATION

TITLE SALVO GUNFIRE PROGRAMFORM PREPARED BY H. C. ThompsonDATE 2-27-74LANGUAGE FORTRANHOST MACHINE CDC 6600PROGRAM SIZE 1/10

(Boxes of Source Cards)

TIMING 60

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT Previous use on CDC.STATUS: Operational X, Programming In Development , Not Programmed REFERENCE NoneOWNERSHIP: Public , Private X, Owner MDAC

ABSTRACT

This program uses Monte Carlo techniques to compute probability of killing an area target with surface termination weapon. Inputs consist of target area damage matrix, aiming and round-to-round errors (sigmax and sigmay), number of rounds per salvo, and number of salvos. Output is table of fraction of target destroyed as function of number of salvos.

COMPUTER PROGRAM SPECIFICATION

TITLE ANTI-AIRCRAFT EFFECTIVENESS PROGRAMFORM PREPARED BY H. ThompsonDATE 2-27-74LANGUAGE FORTRANHOST MACHINE CDC 6600PROGRAM SIZE 1/10 (Boxes of Source Cards)TIMING 60 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 1 (Words)OUTPUT VOLUME 10 3 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT Previous use on CDC.STATUS: Operational , Programming In Development , Not Programmed REFERENCE NoneOWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

This program can be used to estimate kill probabilities using an algorithm suggested by BRC. Inputs are vulnerable area, distance from aim point to vulnerable area, aiming SIGMA, bias SIGMA, number of shots fired. Output is a table or kill probability as a function of number of shots from 1 to N shots. The method used is probability and is similar to binomial probability method

COMPUTER PROGRAM SPECIFICATION

TITLE Magic Computer SimulationFORM PREPARED BY H. C. ThompsonDATE 2-27-74LANGUAGE FortranHOST MACHINE CDCPROGRAM SIZE 5 (Estimated)

(Boxes of Source Cards)

TIMING 1800 (Estimated)

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 5 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational X, Programming In Development _____, Not Programmed _____REFERENCE 51 JTCC/MF Air to Surface Technical Reports (JMEM), Air Force SystemsCommand, Andrews Air Force BaseOWNERSHIP: Public _____, Private _____, Owner Government

ABSTRACT

This program computes vulnerability data for targets. The vulnerability data will be used as basic input to lethality programs. This program is used currently by BRL and was designed for use on the special BAL computer. Since it is available in JMEM list, it will be usable on CDC or IBM machines.

COMPUTER PROGRAM SPECIFICATION

TITLE Air-To-Air Terminal Encounter Simulation Program

FORM PREPARED BY H. C. Thompson DATE 2-26-74

LANGUAGE Fortran HOST MACHINE CDC 6600

PROGRAM SIZE 2 (Boxes of Source Cards)

TIMING 60 (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 3 (Words)

OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT Previous use on MDAC CDC 6600

STATUS: Operational X, Programming In Development , Not Programmed

REFERENCE Air to Air Terminal Encounter Simulation Computer Program, TN 4565-1-70,

Naval Weapons Center

OWNERSHIP: Public , Private , Owner NWC, China Lake, California

ABSTRACT

This program calculates kill probability for air terminated weapons using Monte Carlo techniques. Target is MIG-21. Kill mechanisms included are blast, fragmentation, rod type, and directed energy. A number of fuzing options are available.

COMPUTER PROGRAM SPECIFICATION

TITLE JMEM Anti-Personnel Lethal Area ProgramFORM PREPARED BY H. Thompson DATE 2-26-74LANGUAGE Fortran HOST MACHINE CDC 6600/IBM Sys. 360PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 60 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT Previous use on IBM Sys. 360.STATUS: Operational , Programming In Development , Not Programmed REFERENCE 61 JTGG/ME Air to Surface (JMEM) Technical Reports. Air Force Systems Command, Attn: SDOO, Andrews AFB, Washington, D. C. 20331OWNERSHIP: Public , Private , Owner Government

ABSTRACT

This program calculates the lethal area of surface terminated weapons used against personnel targets. Input consists of name of weapon, control cards specifying assault condition and personnel posture, weapon position card, and weapon description cards. Program calculates kill probability(pk) for numerous points on the target plane, then computes lethal area as the sum of pk times area. Printout contains map of pk and lethal area answers.

COMPUTER PROGRAM SPECIFICATION

TITLE Air to Air Terminal Encounter Simulation ProgramFORM PREPARED BY H. ThompsonDATE 2-28-74LANGUAGE Fortran

HOST MACHINE _____

PROGRAM SIZE 2 (Boxes of Source Cards)TIMING 60 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT Prior operations with this programSTATUS: Operational X, Programming In Development _____, Not Programmed _____

REFERENCE _____

OWNERSHIP: Public _____, Private _____, Owner Air Force Armament Laboratory
Eglin Air Force Base, Florida

ABSTRACT

This program computes curves of kill probability as a function of miss distance, fuze error and warhead type, for a variety of targets. The problem solved is similar to program P5041. This program is primarily a design program whereas program P5041 is primarily an analyst's program. Inputs are similar to P5041. Output is much larger. Computations are based on a series of burst points created at equally probable points around the target. Output consists of tables of burst points, blast kill requirements, and kill probably tables and plots for each warhead investigated.

APPENDIX J

UNDEVELOPED
COMPUTER PROGRAM
SPECIFICATIONS

COMPUTER PROGRAM SPECIFICATION

TITLE PARAMETRIC SYSTEMS ANALYSIS (Air Terminated)FORM PREPARED BY H. C. ThompsonDATE 2-27-74LANGUAGE FortranHOST MACHINE CDC 6600PROGRAM SIZE Estimate 2 (Boxes of Source Cards)TIMING Estimate 300 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT Estimate of desired program.STATUS: Operational ___, Programming In Development ___, Not Programmed XREFERENCE _____OWNERSHIP: Public ___, Private ___, Owner _____

ABSTRACT

This program will compute estimated warhead lethality in parametric form. Results will be plotted and printed on microfilm or microfiche. Inputs will be target vulnerable area, missile size, target and missile velocities and directions, and estimated miss distance. Calculation will be made based on one target altitude and estimated weapons size to fit on missile. Output will be curves or single shot lethality as a function of miss distance, warhead weight, and warhead kill mechanism.

COMPUTER PROGRAM SPECIFICATION

TITLE ORDNANCE COSTSFORM PREPARED BY H. ThompsonDATE 2-28-74LANGUAGE FORTRANHOST MACHINE CDC 6600PROGRAM SIZE 1/10

(Boxes of Source Cards)

TIMING 30

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 1 (Words)OUTPUT VOLUME 10 2 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT Previous usage of similar programs.STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner _____

ABSTRACT

Program will compute ordnance costs based on cost-quantity (learning curve) methods. The basic algorithm used will be

$$\text{Cost} = \text{Weight} \times \text{constant} \times (\text{Quantity})^{-.15}$$

Inputs are weight and ordnance type Outputs are costs.

COMPUTER PROGRAM SPECIFICATION

TITLE Design SpecificationFORM PREPARED BY H. C. Thompson DATE 2-28-74

LANGUAGE _____ HOST MACHINE _____

PROGRAM SIZE 1 (Boxes of Source Cards)TIMING 1200 (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 2 (Words)OUTPUT VOLUME 10 3 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT Estimated.STATUS: Operational __, Programming In Development __, Not Programmed X

REFERENCE _____

OWNERSHIP: Public __, Private __, Owner _____

ABSTRACT

This program is conceptual. It will be a modified PERT program to provide schedules and estimated costs. Boiler plate type specifications will be contained as data and will be assembled by the computer. Updates to the boiler plate to make it warhead specific will be obtained from the project data bank.

COMPUTER PROGRAM SPECIFICATION

TITLE Test Data RecorderFORM PREPARED BY H. ThompsonDATE 2-28-74LANGUAGE FortranHOST MACHINE CDCPROGRAM SIZE 1

(Boxes of Source Cards)

TIMING 60

(Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 3 (Words)OUTPUT VOLUME 10 3 (Words)BASIS FOR TIMING, INPUT, AND OUTPUT EstimateSTATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner _____

ABSTRACT

This program processes recorded test data and stores processed data in data bank.

COMPUTER PROGRAM SPECIFICATION

TITLE Data ReductionFORM PREPARED BY H. Thompson DATE 3-1-74LANGUAGE N/A HOST MACHINE _____PROGRAM SIZE N/A (Boxes of Source Cards)TIMING N/A (Central Processor Decimal Seconds of CDC6600)INPUT VOLUME 10 N/A (Words)OUTPUT VOLUME 10 N/A (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational __, Programming In Development __, Not Programmed X

REFERENCE _____

OWNERSHIP: Public __, Private __, Owner _____

ABSTRACT

This program will process test data recorded on magnetic tape during a test and convert the data to desired test values. Examples of data output are velocities, drag coefficients, particle direction, spray angles, and density of fragmentation wave.

NO. _____

COMPUTER PROGRAM SPECIFICATION

TITLE • COMBINED RECONNAISSANCE, SURVEILLANCE, AND SIGINT MODEL (CRESS)

FORM PREPARED BY D. J. Fischer DATE _____

LANGUAGE FORTAN HOST MACHINE _____

PROGRAM SIZE _____ (Boxes of Source Cards)

TIMING 60 seconds (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 (Words)

OUTPUT VOLUME 10 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT 65K core required

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE S. R. I.

OWNERSHIP: Public , Private , Owner

ABSTRACT

Simulation of the operational use of photo, IR line scanner, radar, visual, laser, LLETV, SIGINT sensors.

C-9

NO. _____

COMPUTER PROGRAM SPECIFICATION

TITLE ATMOSPHERIC TRANSMISSION FROM 0.25 TO 28.5 μ m

FORM PREPARED BY D. J. Fischer DATE _____

LANGUAGE FORTRAN HOST MACHINE CDC

PROGRAM SIZE 1/2 box (Boxes of Source Cards)

TIMING 60 (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 (Words)

OUTPUT VOLUME 10 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT 60K core requirement

STATUS: Operational , Programming In Development , Not Programmed X

REFERENCE AFCRL, Hanscom Field, Bedford, Mass.

OWNERSHIP: Public X, Private , Owner

ABSTRACT

This program calculates the atmospheric transmission between 0.25 microns and 28.5 microns.

COMPUTER PROGRAM SPECIFICATION

TITLE RISK

FORM PREPARED BY A. J. Goodwin DATE 2-20-74

LANGUAGE FORTRAN HOST MACHINE E9

PROGRAM SIZE Estimate 1 (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 4 (Words)

OUTPUT VOLUME 10 3 (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational , Programming In Development , Not Programmed

REFERENCE _____

OWNERSHIP: Public , Private , Owner MDAC

ABSTRACT

The RISK model accepts data which specifies the lowest, most likely and the highest anticipated cost for up to 50 major cost elements in program. Using this input data, the model randomly varies each cost element and calculates up to 500 different total program costs. From this spread of costs, it determines the most likely cost and the probability of over running or under running the cost by several different amounts.

COMPUTER PROGRAM SPECIFICATION

TITLE _____
(Program to be used during detail design phase)

FORM PREPARED BY A. J. Goodwin DATE 2-20-74

LANGUAGE _____ HOST MACHINE _____

PROGRAM SIZE _____ (Boxes of Source Cards)

TIMING _____ (Central Processor Decimal Seconds of CDC6600)

INPUT VOLUME 10 _____ (Words)

OUTPUT VOLUME 10 _____ (Words)

BASIS FOR TIMING, INPUT, AND OUTPUT _____

STATUS: Operational ____, Programming In Development ____, Not Programmed X

REFERENCE _____

OWNERSHIP: Public ____, Private X, Owner _____

ABSTRACT

This program would have the capability of receiving actual costs incurred to date and data on anticipated material cost, labor hours, labor rates and overhead ratios. In addition, it will accept schedule information. From this data it will calculate and project the total current estimate of the cost of the program at completion. It will compare this estimate with the program budget or the previous estimate.