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

As a method of reducing design and development costs for data processing systems (hardware and software) a total system design concept is proposed. The concept includes a Reconfigurable System Design Facility (RCSDF) where total system design alternatives can be emulated for the purpose of evaluating and proving designs prior to actual development.

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EVALUATION

The work performed under this contract clearly demonstrates the feasibility and outlines the usefulness of a Reconfigurable Computer System Design Facility (RCSDF) in developing and evaluating new and unique computer architectures to solve Air Force processing requirements. This effort represents the successful completion of one aspect of RADC's comprehensive investigation into the Total System Design (TSD) methodology aimed at providing more effective development tools for the system designer (TPO-5, FY-77, 78).

The results of this effort will enable RADC to proceed deeper into investigations on TSD and begin to develop various elements of the RCSDF.

Michael A Troutman

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Project Engineer

1. INTRODUCTION

The costs of developing and maintaining software for modern military systems are increasing at alarming rates. Awareness of this situation has motivated an exploration of the causes of this cost increase and ways to reduce it. One alternative that shows significant promise is total system design, which provides the necessary tools, evaluation techniques, and methods (i.e., a Total System Design Facility - TSDF) needed for extensive monitoring of the total development process. The total system design concept envisions a disciplined system design environment that allows overall system designs and alternatives to be quickly and easily evaluated minimizing actual development and life-cycle costs for new systems.

1.1 Project Scope

The objective of the initial Reconfigurable Computer System Design Facility (RCSDF) design study was the preparation of a development plan describing the necessary studies and development tasks that would achieve the required facility capabilities.

The initial RCSDF design study was organized into three major tasks:

- Task 1: Evaluation and Definition of RCSDF Capabilities, Philosophy, Procedures
- Task 2: Performance of RCSDF Technical Baseline Development Studies
- Task 3: Preparation of a RCSDF Development Plan

The three tasks of the initial RCSDF design study led to a development plan for a demonstration of the TSDF concept with available hardware and technology (the RCSDF) during the 1980s.

1.2 Recommendations

In general, the Sperry Univac study team has found RADC's concept of total system design utilizing the reconfigurable computer system design facility for system evaluation to be a viable method with significant potential for reducing future system hardware and software costs. The Sperry Univac study team recommends, via the proposed development plan, that RADC emphasize the following tasks for RCSDF development in the near future (12 to 18 months):

<u>Emulation System Architecture Study (Vol. II, para. 4.3.1)</u>
<u>Emulation Control Structure Study (Vol. II, para. 4.3.2)</u>
<u>Emulation Analysis Structure Study (Vol. II, para. 4.3.3)</u>

The Sperry Univac study team further recommends that the case study tasks identified in the proposed development plan (Vol. II, Section 4), be implemented to provide RADC a demonstration of the total system design concept.

1.3 Document Scope

The technical information developed during the initial RCSDF design study is contained in the following documents:

Volume I	RCSDF Initial Design Study-Final Report Technical Summary
Volume II	RCSDF Initial Design Study-Final Report Technical Results

2. The Total System Design Facility

The Total System Design Concept (TSDC) is a concept formulated by the Rome Air Development Center (RADC) to aid the development of more cost-effective Air Force digital system designs. The TSDC emphasizes design process automation resulting from data processing research. The future Total System Design Facility (TSDF) is general purpose in nature providing the necessary aids to support the development of realistic specifications from which cost performance effective systems can be procured. The TSDF as conceived would provide:

1) in-depth, on-line performance analysis of developing system architecture alternatives
2) shortened conception-to-specification times
3) system design with high level languages
4) the means to quickly incorporate technological advances in data processing hardware into the Air Force inventory thereby assuring longer, more useful system life
5) the means to upgrade Air Force capabilities to use advanced data processing techniques

2.1 TSDF Summary

Figure 2-1 illustrates a TSDF consisting of five subsystems. In brief, the organized ideas for a deployable application system enter into system design by means of the thought processes of man (human subsystem). These thoughts are formalized and submitted to tools (hosting subsystem) which aid and simplify the decision-making process. Decisions for functional implementation by means of hardware or software must be made here. When the implementation decision is made specifications can be submitted by the hosting subsystem to normal industrial process control procedures (system integration subsystem). The integration subsystem has been depicted with dotted lines to indicate that this procedure is rapidly moving from a process requiring human intervention to one which can be totally automated, thus further reducing hardware costs.

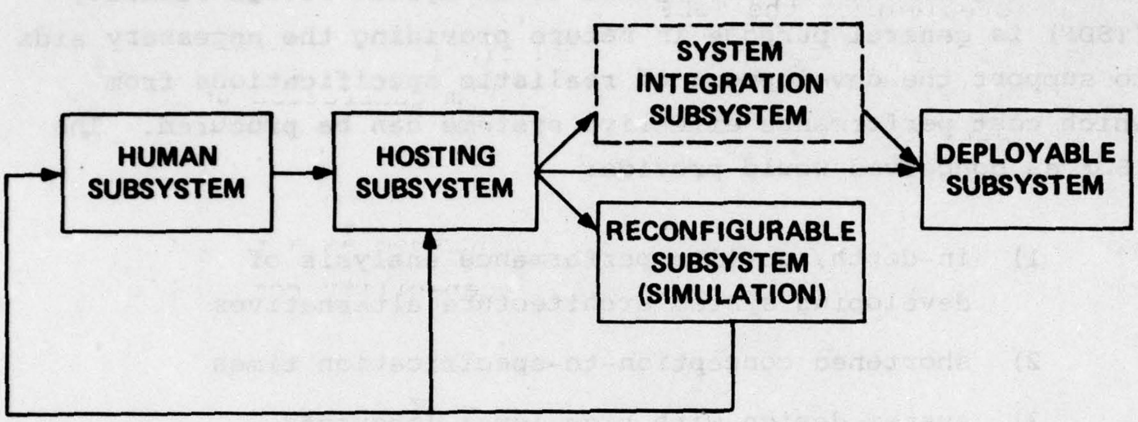

Figure 2.1. A TSDF

When the human subsystem together with the hosting subsystem has determined the means for implementation, a critical phase (evaluation) of system design is entered. Thus a Reconfigurable Subsystem (RS) usable for evaluation with controlled performance measurement (known performance deficiencies) becomes mandatory.

After evaluating the TSDC and its implementation, the TSDF, the following conclusions were reached:

- o The TSDC, as presented, has a wider applicability than just the development of hardware and software design specifications. Its scope could extend into requirements formulation phases, system tuning, and software development.
- o Automated development tools should be provided for users to guide the direction of their development.

- o Equal emphasis should be placed upon specifying and implementing the digital processing environment under which the emulated/simulated system is being tested.
- o Hosting of the evaluation process (system emulation/simulation, environment, etc.) is an essential ingredient of the TSDF. The anticipated complexity of testing and the possible multiplicity of users point to the need to centralize system generation using a data base.
- o The definition of a High Level Performance Measurement Language (HLPML) ought to be pursued as a part of the TSDF to provide users with a capability comparable to that in the HOL, HLHDL.

3. RCSDF Summary

The RCSDF operating philosophy and applicable technology identified during the initial RCSDF design study are summarized in this section.

3.1 Emulation Operating Philosophy

The RCSDF emulation operating philosophy is based on the idea that the facility provides services analogous to those provided by a computer center. However, RCSDF service is different in that it concentrates on architectural evaluation and development rather than on the normal program production.

An RCSDF user who wants to solve a class of problems must first precisely specify his problems using a requirements specification language. He then translates his requirements into HOL and EDL descriptions. He will also need to specifically define the user environment that his system will be encountering, for example: the number of users that will be on his system, the maximum (and average) data rate for the I/O channels, and the minimum response time.

Using this information, the hosting system will generate an emulated version of the hardware architecture defined by the user, the software package of his application for the computer system he defined, and the scenario and test environment.

All of this information will be passed on to the RCSDF system. The execution will be emulated, and various performance measures be monitored. The performance measurement results will be reduced data given to the user. After analysing the performance data, the HOL and EDL descriptions can be modified and the procedure repeated if necessary, until an optimum system design is reached.

The user, the host, and the facility are each responsible to each other. A simplified synopsis of these responsibilities for system design and evaluation is shown in Figures 3-1 and 3-2.

3.2 RCSDF Technical Baseline Summaries

The state-of-the-art of technologies required by the RCSDF and revealed by the baseline studies performed are summarized in this section.

3.2.1 <u>Performance Measurement</u> - Performance measurement has two distinct phases: monitoring and data presentation. Monitoring techniques include hardware, software, and hybrid methods - combinations of hardware and software. Data presentation includes results which are graphic, tabulated, or statistical.

Because of distinctive RCSDF properties, there are several special recommendations for RCSDF performance measurement:

- Software (or firmware, since microcode can be used) and hybrid monitoring techniques will be necessary to obtain most performance data.
- Hardware probes will only be useful to monitor performance data at the component levels, e.g., channel utilization and CPU utilization.
- An emulated clock system should be used to monitor the timing of the emulated system.
- The instruction time associated with each instruction may be calculated at the code generation phase and carried as a field in the instruction.
- Data logging should be provided between all emulated modules, using hardware probes to tap interface lines.
- The performance measures computation should be done in the facility.

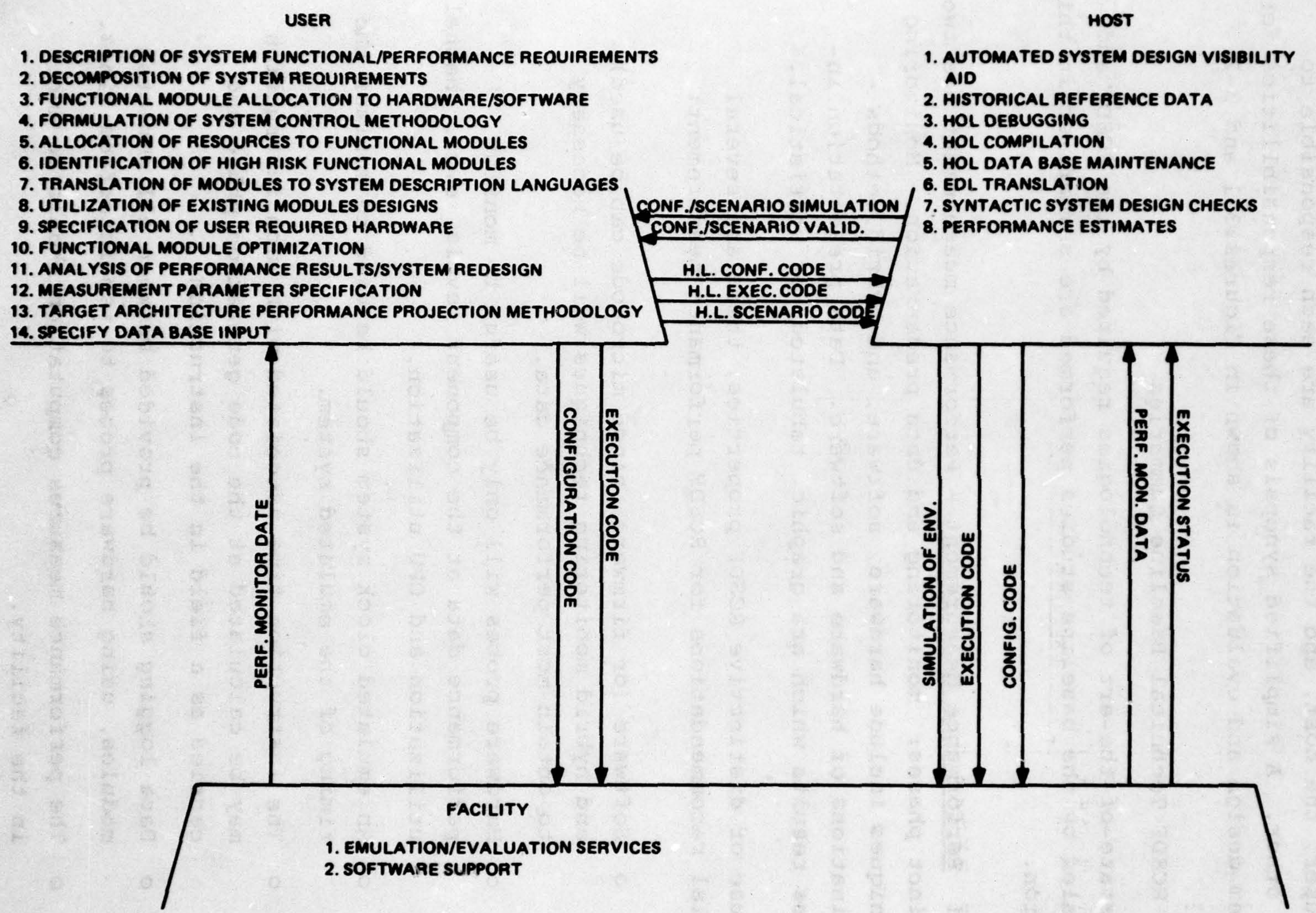

Figure 3-1. Emulation System Design Responsibilities

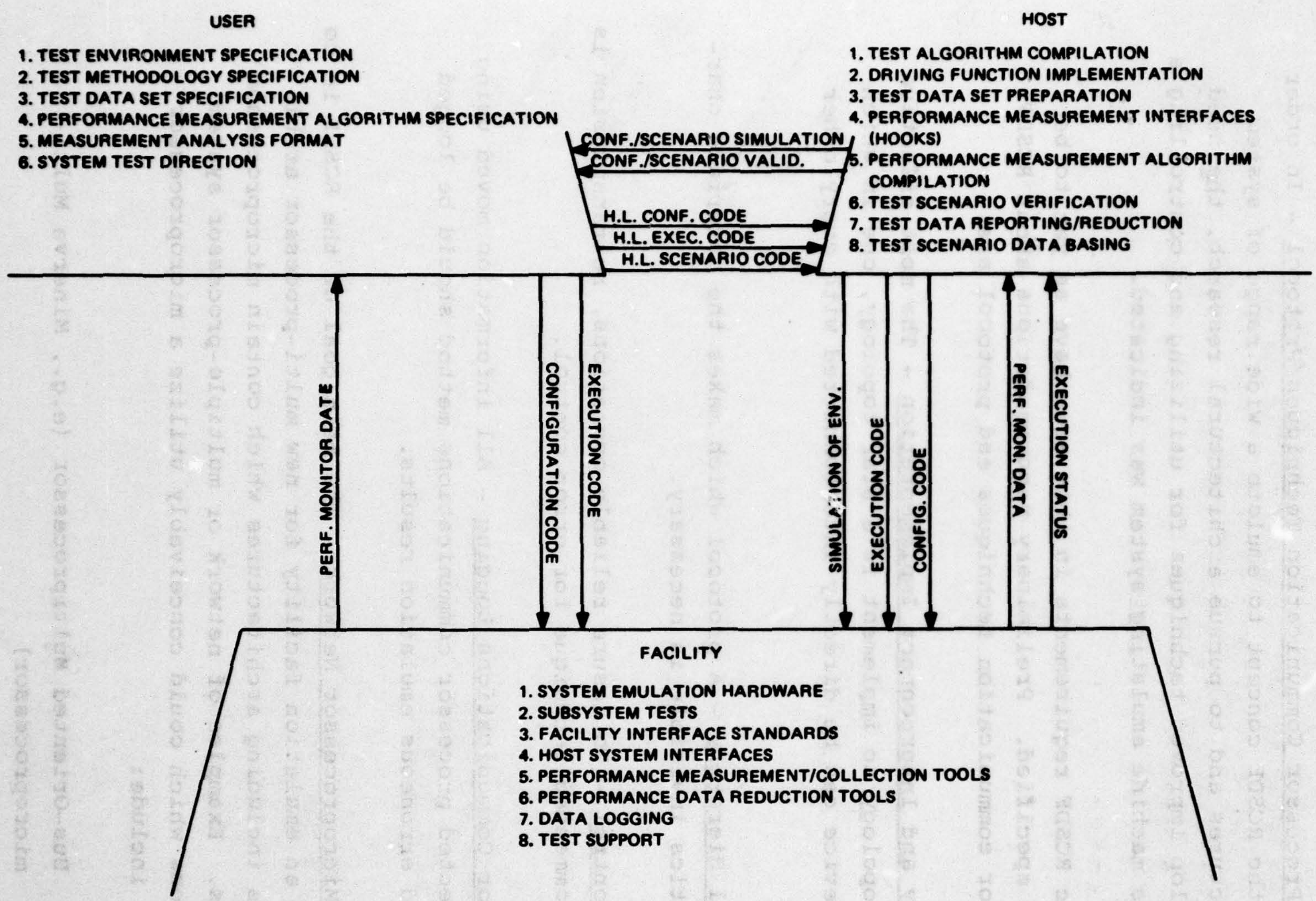

Figure 3-2. Emulation System Evaluation Responsibilities

3.2.2 Processor Communication Techniques/Protocol - In order to use the RCSDF concept to emulate a wide range of system architectures and to pursue architectural research, the need to develop improved techniques for utilizing and controlling a multiple machine emulating system was indicated.

Specific RCSDF requirements in this area have as yet to be clearly specified. Preliminary recommendations about RCSDF processor communication techniques and protocol are:

Topology and Interconnect Implementation - The most effective RCSDF topology to implement is a star topology, one in which every device can be directly interconnected with every other device.

Protocol Hierarchy - A protocol which makes the interface characteristics invisible is necessary.

Error Control - To assure reliable operations, retransmission is the recommended technique for error control.

Processor Communications Logging - All information moved using the selected processor communications method should be logged to avoid erroneous emulation results.

3.2.3 Microprocessor Network - The main goal of the RCSDF is to provide an emulation facility for new multi-processor architectures including architectures which contain microprocessor networks. Examples of network or multiple-processor system emulations which could conceivably utilize a microprocessor network include:

- Bus-Oriented Multiprocessor (e.g., Minerva Multi-microprocessor)

- o Multiport Multiprocessor (e.g., Univac 1108)
- o Hypercube Multiprocessor (e.g., Illiac IV)
- o Multistage Multiprocessor Network (e.g., STARAN's Flip Network)
- o Intercomputer Network (e.g., ARPANET)

3.2.4 Microprogramming - Microprogramming and microprogrammed devices play an important role in RCSDF development since the fundamental concepts of emulation are based on the use of microprogramming. Microprogrammed designs are fundamental for modern emulator designs.

The RCSDF emulation research facility needs to efficiently emulate a wide variety of target machine architectures. To accomplish this, there must be a "soft emulation" machine architecture available in the facility. This is in sharp contrast to the "hard emulation" machine architectures (such as the IBM 360 models) which are designed to interpret only a small set of system architectures. The QM-1 is an excellent example of the soft emulation machine since it offers the largest degree of flexibility of any known machine for emulation.

3.2.5 Operating System - The RCSDF operating system is defined as the logic provided in hardware or software necessary to maintain control of and provide user interface with the RCSDF resources. Two different operating system architectural structures were considered for the RCSDF operating system. The first, processing element control, assumes that the operating system controls the resources. The second, facility control, assumes resource control is provided by user processes or processes supplied by an RCSDF staff using interface standards enforced by a baseline operating system. It is felt that either technique could be used to develop an adequate RCSDF operating system.

The advantages of the processing element control method are the economics of being able to utilize the existing resource control capabilities in the current RCSDF processing elements. The facility control method is recognized as having a greater risk factor, but the gains which can be realized from system flexibility and adaptability to various configurations are believed to be of significance in the future.

3.2.6 Distributed Systems Organization - Unfortunately, the phrase "distributed processing" has become so popular that almost any computing complex containing more than one processing element capable of simultaneous operation is being called a distributed processing system. Nevertheless, the study has identified three areas from which research associated with "distributed system" can and should impact the RCSDF. The areas are:

- o Potential design architectures.
- o Potential architectures to be emulated.
- o Applicable techniques for controlling emulation.

RCSDF relationship to distributed system organizations requires further understanding of:

- o RCSDF Hardware Element Characteristics
- o User System Architecture Spectrum
- o User Application Spectrum
- o Emulation Control Structure

3.2.7 Design Languages - Design languages can be categorized as: 1) requirement specification languages, 2) high order languages (software design languages), and 3) emulation design languages (hardware design languages).

Requirement Specification Languages - A cost effective development of systems necessitates a carefully controlled system requirements specification phase. The heart of any machine-processable requirement/design language is a competent data base manager and tools for design retention. ISDOS (Information System Design and Optimization System) and REVS (Requirements Engineering Validation System) come closest to this ideal.

Higher Order Languages (HOL) - A HOL is a software design language that assumes the proportions similar or equivalent to that represented by a COBOL, JOVIAL, or FORTRAN programming language. Standardizing HOLS is a method proposed to reduce software engineering costs. In 1976, the DOD High Order Language Working Group (HOLWG) investigated programming language requirements and concluded that no single existing standard language satisfied all the language requirements even though all the capabilities were available in existing languages. The group recommended that work toward the production of a single HOL should start with an existing base language; PL/1, PASCAL, and ALGOL 68 were recommended. Current trends in HOL development indicate that additional capabilities are being included that provide users with high level interface to operating systems for resource and task control facilities.

Emulation Design Languages - A truly high level language whose sole purpose is emulation implementation does not exist. Nevertheless, Emulation Design Language (EDL) requirements can be satisfied by some of the Computer Hardware Description Languages (CHDLs) which allow computer hardware systems to be described in four levels of abstraction (circuit, logic, register-transfer, and processor-memory). Each level of description carries an added amount of implementation detail than the level preceding it. Typical languages in this category are: AHPL (based on APL), CDL (structured like ALGOL), ISP (Instruction Set Processor), and PMS (Processor-Memory-Switch).

4. RCSDF Development Plan

The requirements to meet the overall objectives of the Reconfigurable System Design Facility (RCSDF) are summarized herein. The study team first identified a series of additional concept formulation studies that would enable more definitive objectives to be established for the emulation facility, i.e., the RCSDF portion of the Total System Design Facility (TSDF). This was followed by the establishment of six development paths (relatively independent categories of development effort) for which smaller work and study tasks could be independently defined. Finally, the sets of tasks resulting from independent pursuit of the developmental paths were combined into a single-task set. Paragraph 4.1 lists the required concept definition studies. Paragraph 4.2 shows the required task work breakdown structure and development plan schedule, respectively.

4.1 Definitive Study Tasks

The tasks summarized below are described in paragraph 4.1 of Volume II. They are necessary to further clarify the objectives and hence tools required to complete an RCSDF by 1981-1982.

Emulation System Architecture Study - The preparation of preliminary architecture descriptions for the RCSDF assuming use of equipment already at the Rome Air Development Center, e.g., the STARAN, QM-1, and data manipulator unit. Additional equipment identified by the architecture study should include a large (10^9) mass memory and a microprocessor array.

Emulation Control Structure Study - The establishment of standard component interface procedures for the RCSDF. It includes a description of how the standards are to be implemented and enforced in order to regiment the control of resources.

Emulation Documentation Structure Study - The definition of the documents required to coordinate the use of the RCSDF with the concept of total system design.

Requirements/Design Language Procedure Study - The identification of those languages which are required for system specification, design, and development including methods of automating the retention of a systems design.

Uniform Emulation Method Study - An analysis of existing emulation techniques to determine if common emulation procedures exist or can be developed for the RCSDF.

Emulation Analysis Structure Study - A description of the tools required to enable performance measurement and analysis to be accomplished using the RCSDF.

4.2 RCSDF Work Breakdown Structure

Figure 4-7 in Volume II shows the RCSDF Work Breakdown Structure (WBS). The format agrees with MIL-STD-881A, 25 April 1975. The WBS structure follows the definitions established for electronic systems. The second level definitions applicable to the RCSDF development are:

- o Prime mission equipment
- o System/program management
- o System test and evaluation
- o Data
- o Training

5. Conclusions

In general the Sperry Univac study team has found RADC's concept of Total System Design (TSD), utilizing a Reconfigurable Computer System Design Facility (RCSDF) for system design evaluation, to be a viable method for reducing total system hardware and software costs. Two primary reasons for this conclusion can be cited. First, technology now enables the development of low cost, specialized hardware elements, thus permitting selection of hardware elements tailored to high performance military application requirement thereby ultimately reducing the dependence on high cost, complex software. The selection of specialized hardware, however, must be delayed until the system design requirements are fully known and shown to be reliable and viable. Secondly, one of the requirements of the TSD concept is the need for system component interface standards, design and documentation standards, and system performance and validation procedures to increase the availability of off-the-shelf hardware and software system elements. Development of the RCSDF emulation facility as an integral part of a total system design methodology would promote both inter- and intra-system standardization as well as more reliable procurement procedures.

The study team recognizes the technical risks involved in attempting to provide a facility capable of emulating a variety of system architectures. To reduce the risks, while promoting the benefits, Sperry Univac suggests two alternatives to the four year development plan described in Section 4 and shown in Figure 5.1a. The alternatives (Figure 5.1b and 5.1c) would proceed under a phased development approach permitting risks to be re-evaluated and benefits identified before starting the next phase.

The first alternative completes all TSD concept formulation studies before initiating implementation/specification tasks.

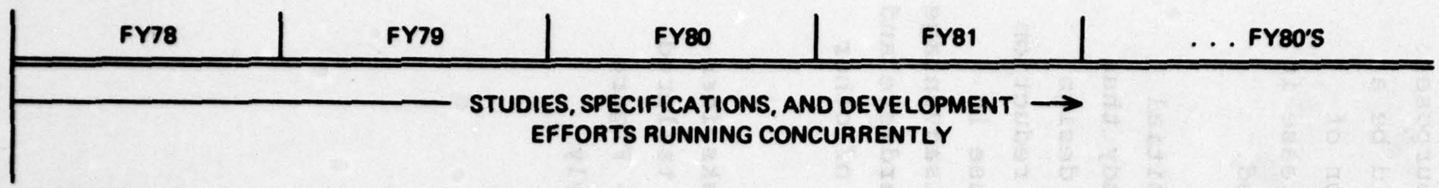

Figure 5-1a. Time Optimal

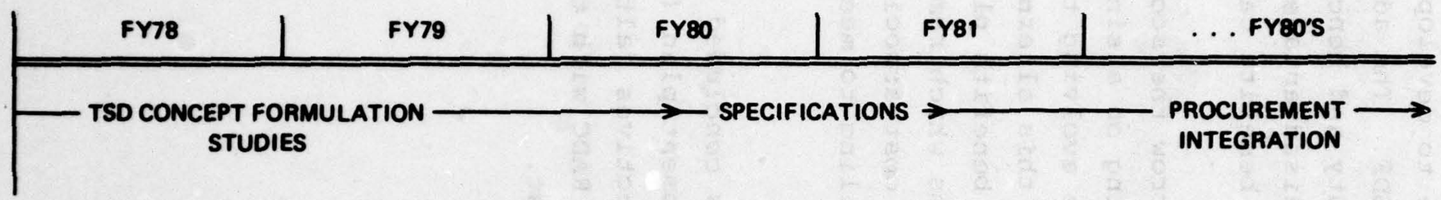

Figure 5-1b. Low Risk Alternative

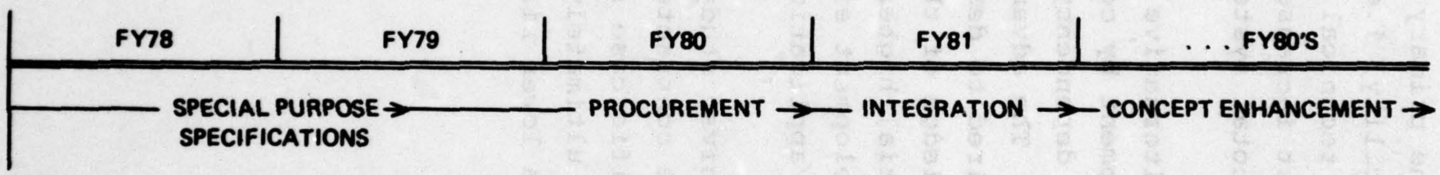

Figure 5-1c. Case Study Driven Alternative

Figure 5-1. RCSDF Development Plan Time Lines

It retains the primary objective to develop a general purpose emulation facility, i.e., an RCSDF. The advantage would be a reduction in technical uncertainty and hence elimination of potential cost increases. The disadvantage is the increase in time before total system design benefits can be achieved.

The second alternative would narrow the scope of the initial RCSDF development by concentrating on a single case study thus reducing its dependency upon the evolving total system design methodology. The advantages of this alternative are a reduction in time required to demonstrate benefits plus an increase in working knowledge of the problems which remain. The disadvantage is the potential higher program cost associated with hardware and software development efforts failing to meet the needs of other case studies/applications.

The Sperry Univac study team has concluded that the tasks identified in the contracted development plan (Section 4), tailored to meet specific case study objectives (alternative 2 - Figure 5.1c), would ultimately provide RADC with the most timely benefits at a lower risk and cost.

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