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AD B008952

AUTHORITY: AFWL ltr 29 Apr 85

AFWL-TR-75-67

(2)

AFWL-TR-75-67

AD B008952

AIR FORCE WEAPONS LABORATORY COMPUTATIONAL REQUIREMENTS FOR 1976 THROUGH 1980

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January 1976

Final Report

Distribution limited to US Government agencies only because of test and evaluation of military systems (Jan 76). Other requests for this document must be referred to AFWL (DYS), Kirtland Air Force Base, New Mexico 87117.

AIR FORCE WEAPONS LABORATORY

Air Force Systems Command

Kirtland Air Force Base, NM 87117

AFWL-TR-75-67

This final report was prepared by the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico under Job Order 06CB. Dr. Clifford E. Rhoades, Jr., (DYS) was the Laboratory Project Officer-in-Charge.

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This technical report has been reviewed and is approved for publication.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

14

1. REPORT NUMBER: AFWL-TR-75-67

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

9

4. TITLE (and Subtitle)

6

AIR FORCE WEAPONS LABORATORY COMPUTATIONAL REQUIREMENTS FOR 1976 THROUGH 1980

5. TYPE OF REPORT & PERIOD COVERED: Final Rep[redacted]rt.

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

10

Edmund A. Nawrocki, Clifford E. Rhoades, Jr.
Denzil R. Rogers

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Air Force Weapons Laboratory
Kirtland Air Force Base, New Mexico 87117

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

62601F, 06CB

12 77p.

11. CONTROLLING OFFICE NAME AND ADDRESS

Air Force Weapons Laboratory
Kirtland Air Force Base, New Mexico 87117

11

12. REPORT DATE: Jan[redacted]976

13. NUMBER OF PAGES: 76

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)

UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to US Government agencies only because of test and evaluation of military systems (Jan 76). Other requests for this document must be referred to AFWL (DYS), Kirtland Air Force Base, New Mexico 87117.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Computational Requirements
Theoretical Requirements
Data Automation Requirements

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

The large scale scientific computational requirements of the Air Force Weapons Laboratory for 1976 through 1980 are described in this report. Present computer resources fall far short of meeting requirements. The acquisition of a scientific computer of advanced design is the best and most cost effective approach to meeting mission requirements. The ultimate benefit resulting from such acquisition by the Laboratory is the increased security of the United States by ensuring orderly progress in nuclear and laser research. (OVER)

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SECURITY CLASSIFICATION OF THIS PAGE(*When Data Entered*)

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ABSTRACT (Cont'd)

The availability of an advanced, large-scale, scientific computational system is vital to the performance of the Laboratory mission. Without such a resource, it is impossible for mission requirements to be met.

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SUMMARY

In 1972, the Air Force Weapons Laboratory began to face a crisis in its computation capabilities. Computer resources were becoming less responsive to the needs of the Laboratory and thus were adversely influencing the Laboratory's scientific effectiveness and mission responsiveness. A complete analysis by scientists, engineers, and managers on the Computational Advisory Council identified two major areas of difficulty.

First, the two CDC 6600s, which were the mainstay of computing equipment in 1973, had a very high system utilization. This high utilization together with the enormous number of jobs processed resulted in poor turnaround and a condition of saturation. The consequences of system saturation and poor turnaround were unreasonable delays, increased costs, reduced scientific and engineering effectiveness, and inefficient use of valuable technical manpower.

More important, however, were the intrinsic limitations of the CDC 6600s. Central memory size and central processing speed were limiting the complexity of weapons technology problems that could be solved and the validity of the results. These constraints were impeding necessary and important progress in nuclear and laser research. Limitations fundamental to the 6600 hardware were found to constitute an unacceptable restraint on the Laboratory in performing its mission.

A study of various alternatives showed that acquisition of a general purpose scientific computer of advanced design would be the most effective for mission accomplishment and also would be the most economical solution. The benefits from such an acquisition include ensuring orderly progress in nuclear and laser research, providing the design of modern weapon systems and the study of their effects, and obtaining more economical prototype engineering development programs.

PREFACE

This volume, which was originally completed in March 1974 as a data automation document (DAR AFSC-B-74-124), is the first report since 1968 to discuss the computational requirements of the Air Force Weapons Laboratory. This discussion concentrates primarily on the Laboratory's large-scale scientific computational requirements for 1976 through 198[illegible]. While this report is essentially nontechnical, it is intended to be of use to both technical and management personnel. Sufficient background information of an historical as well as a technical nature is included to allow the Laboratory's computational requirements to be placed in appropriate perspective. Additional volumes of a more technical nature are planned as further details become useful.

The content of the present report is intended to be identical to the original data automation document of March 1974. Sections VI and VII on project costs and benefits, respectively, were revised in May 1974. The appendix was completed in June 1974. A small number of editorial changes have been made to this report.

The authors of this report acknowledge with gratitude the efforts of those who helped collect, analyze, and understand the available data and prepare this manuscript. The authors wish especially to thank the following individuals whose behind-the-scenes labor proved indispensable.

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SECTION I

ACQUISITION OF A LARGE SCALE SCIENTIFIC COMPUTER

1. INTRODUCTION

a. Mission and Responsibilities

(1) The following AF and AFSC regulations define the mission and responsibilities of the Air Force Weapons Laboratory (AFWL):

(a) AFR 80-38, dated 6 September 1973, established policy for the conduct of the Air Force Survivability Program. It defines the program's objectives and the responsibilities of the major commands in support of these objectives. It charges AFSC to develop a survivability technology which includes analytical techniques for survivability/vulnerability assessment and simulation apparatus and other test facilities to verify system hardness. This regulation also provides for a Nuclear Criteria Group whose purpose is to establish hardness criteria for AF systems and names the Commander, AFWL, as a member of this group.

(b) AFSCR 23-49, dated 19 June 1973, prescribes the mission of the AFWL.

(c) AFSCR 80-19, dated 7 February 1966, outlines the responsibilities and functions of the AFWL in the AFSC survivability program.

(2) The AFWL is the principal AFSC organization charged with planning and executing the USAF exploratory, advanced, and engineering development programs in nuclear weapon effects, nuclear weapon components, laser systems, advanced weapon technology, radiation hazards, nuclear survivability/vulnerability and nuclear safety. It also plans, manages and conducts the USAF Civil Engineering Research, Development, Test, and Engineering (RDT&E) Program. The AFWL provides technical or managerial assistance in support of studies, analyses, development planning activities, acquisition, test, evaluation, modification, and operation of aerospace systems and related equipment.

(3) The AFWL is the lead AF Laboratory for the Integrated Nuclear Weapon Effects Program and the High Energy Laser Program. In this capacity, the AFWL "establishes and maintains a competent and comprehensive in-house RDT&E

capability in the research, exploratory development, and advanced development areas assigned," as directed by AFSCR 23-49.

(4) The major in-house capability developed by the AFWL in fulfillment of its responsibilities is that of performing advanced scientific and engineering calculations. The AFWL's computational requirements are based on:

(a) The nuclear weapon and laser systems research programs described in the following documents:

AFWL Technical Objective Number 1, Nuclear Weapon Technology, TOD 73-WL FY 73-1, AFWL-TR-73-90, April 1973 (SECRET).

AFWL Technical Objective Number 2, Advanced Radiation Technology, TOD 73-WL FY 73-2, AFWL-TR-73-91 (SECRET).

AFWL Plan, WL TP-Jun 72, 30 June 1972 (SECRET)

Air Force Requirements for Nuclear Weapon Effects Research, FY 75-79, January 1973 (SECRET-Restricted Data).

(b) The survivability/vulnerability programs described in the following documents:

Research and Technology Division Survivability and Vulnerability Technology Summary, RTTW66-77, 15 August 1966 (SECRET-Restricted Data).

Nuclear Survivability/Vulnerability Technology Plan, WL WLPP 67-015, 6 October 1967 (SECRET-Restricted Data).

Space Mission Space Study Executive Summary, January 1974, SAMSO TR 74-11.

(c) The simulation and analysis program required by the JCS guidelines for systems in the following documents:

Hardening of Military Satellite Systems Agains the Effects of Nuclear Weapons, JCS Memorandum, 27 June 1968 (TOP SECRET).

Hardening Guidelines for Military Satellite Vehicles, JCS Memorandum (Appendix), 27 June 1968 (SECRET-Restricted Data).

b. Background

(1) The United States ceased atmospheric nuclear testing in 1962 and ratified the Nuclear Test Ban Treaty in 1963, with full recognition that serious gaps remained in our knowledge and understanding of nuclear weapon

phenomena. With this action, the emphasis of effects research shifted from the experimental to the theoretical; and the AFWL, founded in May 1963, received the charter to develop a theoretical capability to address nuclear weapon effects problems. Similarly, the computing requirements of the weapons community as a whole, including the AFWL, shifted from data analysis and reduction to scientific computing.

(2) Scientists at the AFWL proceeded to formulate the physics describing weapon output and weapon effects, to develop computer codes corresponding to this physical description, and to maintain computing facility capable of solving the necessary problems. (See section II.) They established the validity of the theoretical solutions and increased national confidence in this theoretical approach to weapon research by duplicating, via computer calculations, existing experimental data. Knowledgeable individuals in the Department of Defense and the Atomic Energy Commission--aware of the deficiencies existing in the field test data in many areas of current national concern--recognize that this theoretical capability provides the most definitive description of a nuclear environment and regard it as the primary source of weapon phenomenology information available to systems designers and operational planners.

(3) Modern weapon technology is increasing the need for continuing weapon effects research. Current engagement philosophies, antimissile defense, modern kill-mechanisms, fratricide, multiple delivery missile systems, and increased yield, flexibility and accuracy pose serious questions about the behavior and survivability of materials and components under conditions of temperature, pressure, and radiation far beyond the ranges previously studied. Therefore, such supposedly well-known phenomena as blast and thermal effects require further theoretical investigation--especially since insufficient experimental field data exist. Other phenomena which were insufficiently instrumented during the days of nuclear testing include prompt and delayed nuclear radiation, cratering, ground shock, electromagnetic pulse, and radar blackout. Many additional phenomena, such as reentry vehicle ablation and radar backscattering effects of dust and water clouds, were not considered systems problems at the time experimentation was possible; as a result, no direct experimental data whatsoever exist in these areas. Other systems questions remaining unanswered relate to ablation of reentry vehicles in a dust environment, radar tracking through a fireball, exposure of an operational

aircraft or missile to high altitude electromagnetic pulse, missile launching after exposure of a silo to a near miss, and infrared interference with missile detection and tracking systems. This is only a partial inventory of areas in which knowledge of phenomenology and systems design information is deficient. Under the terms of the Test Ban Treaty, the theoretical capability developed by the AFWL provides the only means of attacking such problems successfully.

(4) For developing technologies represented by laser systems it is difficult to be definitive, but one may rely on experience gained from the older nuclear technology. The Atomic Energy Commission found in thirty years of designing nuclear devices that theory or experiment alone will not lead to achieving design objectives in a timely, economic manner. A laboratory simply does not have the financial resources to field an experiment to test every new idea and design concept nor to build a data base which would incorporate various situations involving different materials, sizes and configurations. The AEC found that theoretical calculation and experiment supplement each other in achieving design objectives at the lowest cost and in the shortest time span (Computer Applications and Requirements in AEC Laboratories, February 1969). It found that calculations permit more effective testing by insuring that fully optimized designs are tested and test results are fully analyzed. The tests serve as check points against the calculations, each enhancing the other. Theoretical calculations also lead to a more thorough understanding of the physical processes involved. This knowledge provides the basis upon which questions concerning survivability and vulnerability can be addressed. Existing physical evidence shows that development of laser systems and associated technology requires massive modeling techniques analogous to those used in the development of nuclear weapons. In addition, many of the physical processes occurring in the laser cavity, beam propagation, and laser matter interaction are common to nuclear phenomena; the mathematical techniques and codes, already developed, are applicable to laser design and effects problems. For example, some problems which require computer solution include radiation cavity and nozzle design, laser matter interactions and beam propagation through atmospheres in various states of ionization and consisting of various chemical species, including water vapor, pollutants, and blow-off from laser matter interactions. Work in these areas requires a computational effort similar in magnitude to that of nuclear research. Modern scientific computers and mathematical techniques will be used with the same effectiveness in laser system design and effects studies as they were in the nuclear field.

c. The availability of an advanced, large-scale scientific, high capacity computational system is vital to the performance of the AFWL mission. Without such a resource, it will be impossible for mission requirements to be met.

2. CURRENT ENVIRONMENT

a. Present Hardware and Software Configuration

(1) The AFWL's computational resources include two CDC 6600s, each with 131 K 60-bit words of central memory and 500 K 60-bit words of extended core storage (ECS) shared by the two computers. An additional 500 K words of ECS will be added in CY 74. (Refer to DAR 73-3-214.)

(2) The hardware configuration has two CDC 6638 and three CDC 854 disk drives. This is the total rotating mass storage available on both systems. The 854 drives serve as users' library devices housing local routines like plotter, mathematical, graphic, and sort subroutines. The 854 disk drives provide minimal storage capacity and a slow access rate. The 6638 drives are mainly used as operating system storage devices with limited amounts of space available for user permanent file capability. During CY 74, the systems will be upgraded with eight CDC 844 disk files which will provide an additional 944 million characters of on-line storage.

(3) Refer to section III for a complete hardware description at this Data Processing Installation (DPI).

(4) The AFWL's computer installation uses the CDC SCOPE 3.2 operating system, heavily modified by AFWL software personnel. Plans are to convert to the SCOPE 3.4 operating system in CY 74.

(5) The CDC intercom subsystem is connected to the CDC 6600 Serial Number 43. Intercom provides computer capability to remote users. The intercom software operates in conjunction with the SCOPE operating system to provide a remote site batch or interactive access to the central computer. This eliminates the need for geographically remote users to spend time physically traveling to the computer center, provides faster throughput of jobs, and allows both card input and printer output at remote sites.

(6) CDC 6600 Serial Number 6 processes over-the-counter work. The computational requirements of many jobs run on this system use all the major resources available on the system (i.e., central memory and extended core storage). This mode of operation greatly restricts running in a multiprogrammable mode, basically reducing the system to a serial processor. Classified

jobs constitute another processing restriction which limits maximum utilization.

b. Present Operating Philosophy

The Computation Branch is committed to optimize use of available computational resources. Emphasis centers on full use of the central processing unit (CPU), since it is the basis of the 6600 computing power. To this end, both computers are in operation 24 hours a day, 7 days a week. The computer operators' schedule runs in such fashion that the CPU is performing some operation at all times, if possible. Please refer to DAR 73-B-214, which was approved 15 Feburary 1974, for a detailed discussion of the current operation at the AFWL.

c. System Utilization

(1) The CDC 6600 computer system has two basic units--a central processor unit (CPU) and ten peripheral processor units (PPUs)--to perform all the tasks each job may require. The CPU provides memory and the arithmetic and control mechanisms. The PPUs provide input/output, buffers, and other auxiliary equipment such as disks, tapes, etc.

(2) The jobs run at the AFWL's computer center vary widely in the demands they make on the computer resources. Some jobs use a few seconds of computer time; others use hours. Some use a few thousand words of memory; others use all available memory. Some jobs need no ECS; others use the full 500 K words. Some jobs make greater demands on PPUs than on CPU; i.e., they use very little computational power of the computer, mainly needing input/output and buffering operations. These jobs are called PP-bound. Other jobs use the CPU exclusively, making very few demands on the PPUs. These jobs, called CP-bound, make maximum use of the computational power of the computer. A judicious mixture of CP- and PP-bound jobs is necessary to achieve effective utlization of computer resources.

(3) The above paragraph describes some of the extremes between which the computer jobs at the AFWL fall. Short jobs include true debug runs where the user is developing a new code, testing new mathematical techniques or adapting an outside-developed code to our machines; and short production runs where the user needs to get results for his project quickly. The user needs quick turnaround because what he does next depends on the results of the most recently submitted job. Typically, he requires three or four turnarounds a day. The current average of jobs per month is about 20,000. Just about all are of the

small-job variety and are run, essentially, Monday through Friday. This workload saturates both machines, such that a typical user's turnaround is several hours. The production jobs require large memory and run from one hour to hundreds of hours. The jobs in this category are considerably fewer in number than the debug (10 percent of the total jobs submitted) but they use over 50 percent of the available computer time. The large radiation/hydrodynamics codes are prime examples of production codes.

3. PROBLEM AND OPPORTUNITY

a. The present computer resources fall far short of satisfying the AFWL's computational requirements. Deficiencies in computer support are in two major categories: system's saturation and computer system capacity limitation. A discussion of these deficiencies and their ramifications appears below:

b. System's Saturation

(1) Figure 1 displays the average number of jobs run by the AFWL computer center per day. The top curve on figure 2 gives the percent utilization of the available time at the AFWL computer center. Here available time is defined as the number of hours per month minus the number of hours of scheduled and unscheduled maintenance. Utilization is consistently above 95 percent. The number of jobs per month exceeds 20 000.

(2) In the context of queuing theory, such high utilization together with the enormous number of jobs processed necessarily imply poor turnaround for any given problem. Statistical analysis of the system job record and hardware performance analysis (Performance Analysis of the Air Force Weapons Laboratory CDC 6600 Computer System, December 1973, Directorate of Information Systems Technology, Hq Electronic Systems Division) quantitatively demonstrate this.

(3) The sheer volume of work submitted for processing saturates the system input, work, and output file spaces. To regain system equilibrium, the central site operator must lock out the input queues during prime work hours several times per day. This action denies the user access to the machine and seriously impedes turnaround. For example, of the 20,000 jobs per month, 90 percent run in five minutes or less and account for about 30 percent of central processor (CP) time. Approximately 80 percent use two minutes or less CP time per job. Turnaround on a three-minute job is a minimum of four hours. A five-minute job experiences one day turnaround. In short, the prime-shift volume of work exceeds computer processing capability.

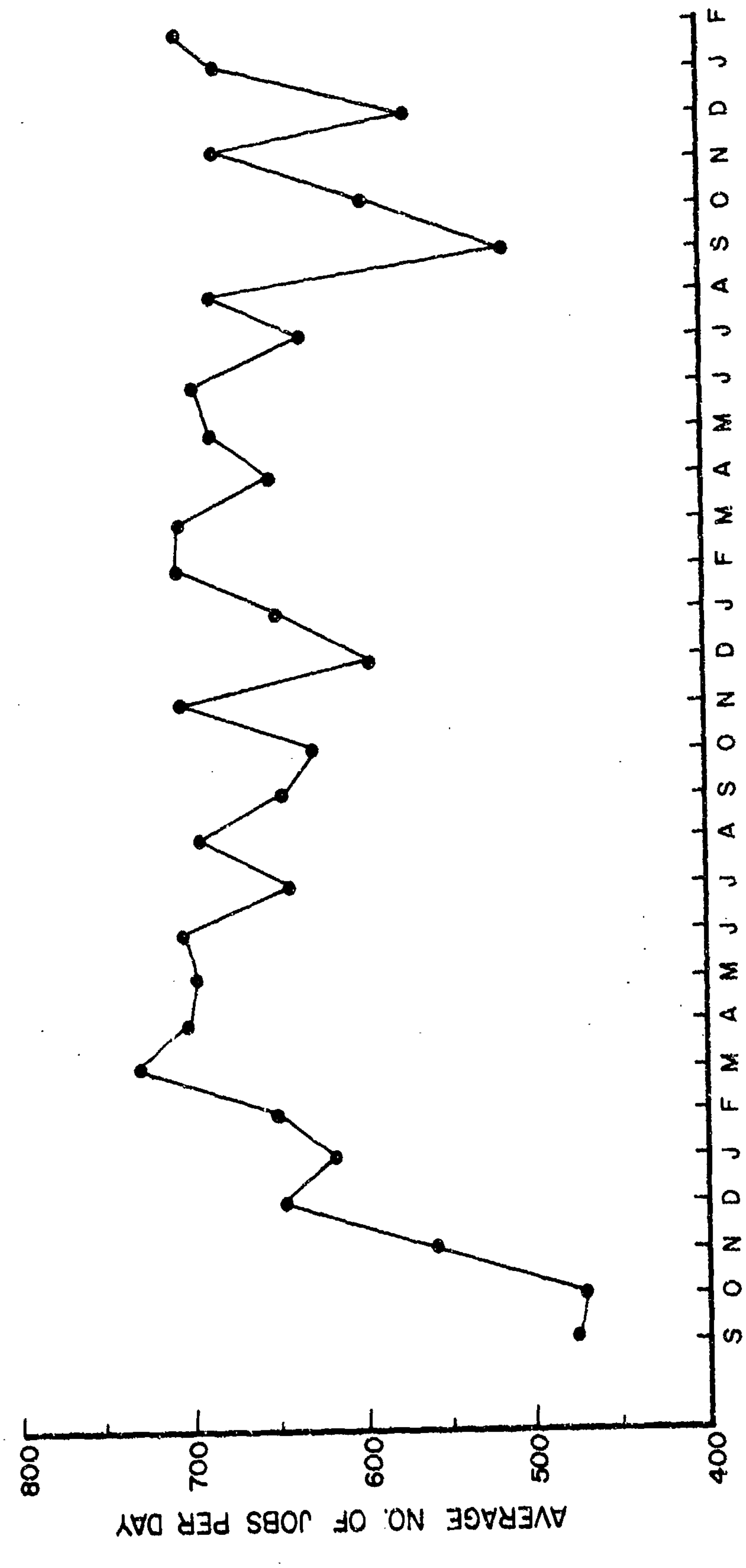

Figure 1. Average Number of Jobs Run by the AFWL Computer Center Per Day

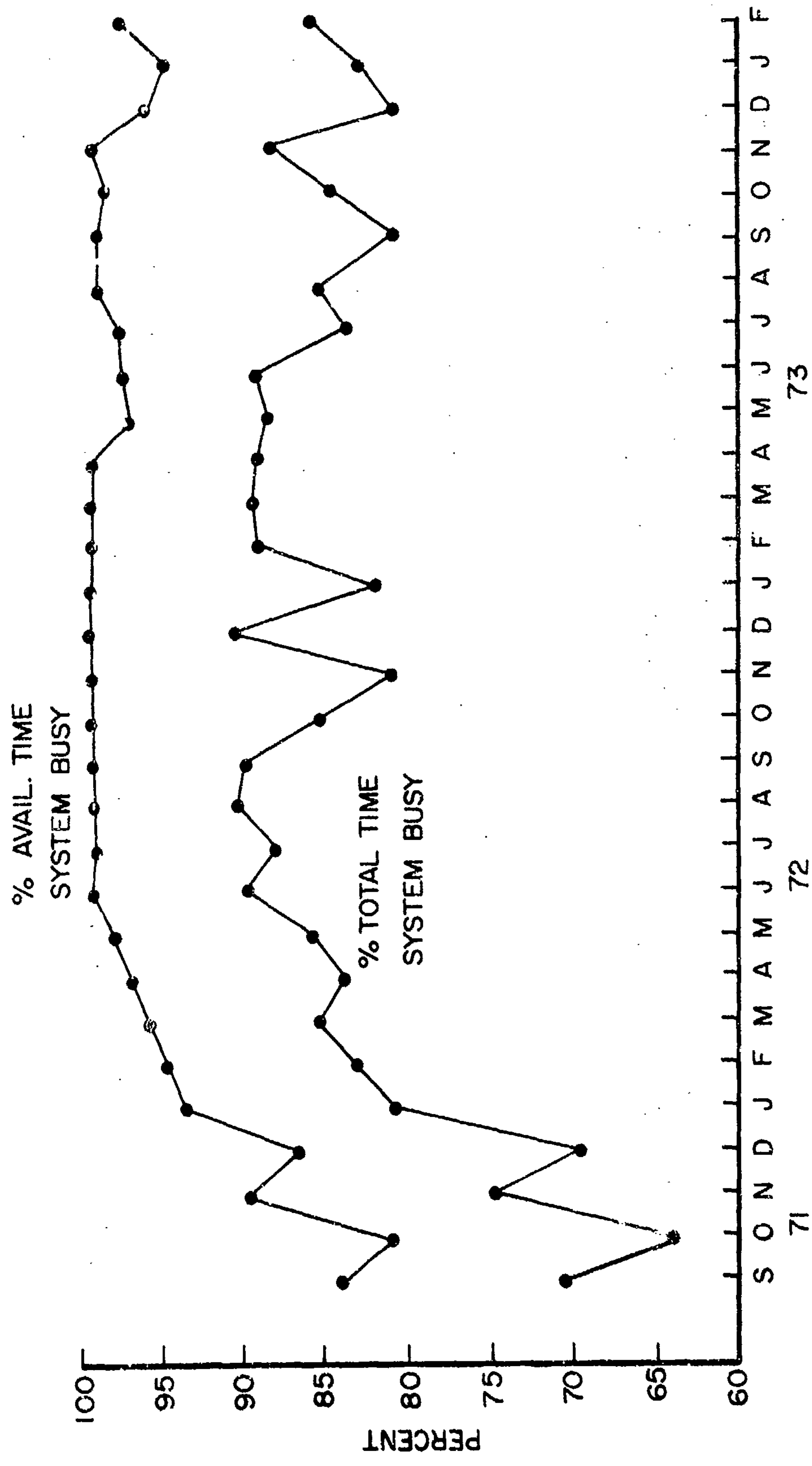

Figure 2. Percent Utilization of the Available Time at the AFWL Computer Center.

(4) The consequences of system's saturation and associated poor turnaround are delays, increased costs, reduced scientific effectiveness and inefficient use of scientific and engineering manpower. Today, technical manpower represents the most expensive and critical resource in the Department of Defense. Their efficient use is mandatory (Senator John L. McClellan, Report of the Senate Appropriations Committee, January 1974).

c. Computer System Capacity Limitation

(1) Limitations inherent in the system itself impede the orderly progress in nuclear and laser research. Central memory size and central processing speed are the factors which limit the complexity of the problems which can be solved on a computer and the validity of the results. For example, the CDC 6600 has the computational power to give a detailed solution to two-dimensional hydrodynamic problems and one-dimensional hydrodynamic problems coupled with additional processes like radiation transport or elastic/plastic deformation phenomena. It also permits significant development of advanced scientific and engineering codes. However, three-dimensional effects and other phenomena described by several physical processes are beyond the capacity of the 6600. The 6600 also does not have the computational power to permit full-scale simulation of an entire strategic interchange to evaluate tactical deployment of a weapon system in an interactive battle environment. Therefore, the limitations imposed by the present system constitute the most serious problem facing the AFWL.

(2) Turnaround is also a problem for large-scale production jobs. Currently, such a job requiring one hour of central processing time, 25 percent of central memory and 30 percent of extended core storage experiences three or four days turnaround. While a response of 18 to 24 hours is reasonable for this job, 96 hours response is not, because results of previous runs must be analyzed before intelligent decisions can be made about code modification and/or parameter variation before submission of the next run. Solution of a given problem may require as many as 20-50 runs. Therefore, calculations to optimize weapon systems deployment and engagement strategy, to model a simulation experiment, to design an airworthy, vibration-minimized laser system, or to understand the role of anomalous absorption in laser matter interactions require a year or more of real time. Larger codes which treat the problems more completely experience event longer response times.

d. Table 1 displays problems, the solutions to which are vital to the national defense but beyond the capability of present computational resources. Additional detailed technical information appears in section IV.

e. Workload Projections

(1) Table 2 shows workload projections for FY 74 through FY 80. The FY 77 projected hours are dependent upon an advanced computer system installed at AFWL early in that fiscal year running three-dimensional hydrodynamic codes and three-dimensional finite structural analysis codes. This computer time will be used for production runs on three-dimensional codes already in existence.

(2) The projected computer hours in excess of approximately 12,000 hours prior to FY 77 (advanced computer installation) will be handled by AFSC Net or by contract.

(3) Refer to section V for Program Element Code.

4. COST ESTIMATES

a. The operating expense of the new computer facility will be borne by AFWL project funds and other facility users. The estimated initial cost of the new system will be in the vicinity of two thousand dollars per hour. Since the new computer will be approximately 40 times the speed at 20 times the cost of the 6600 computer, the net cost per hour will be reduced by 50 percent. This represents an initial estimate which is anticipated to decrease further as utilization goes up. If it is later determined to be cost effective to purchase the system, the price per hour will be reduced further.

b. A summary of the ADP costs, FY 74 through FY 80, are contained in table 3. A brief discussion of the items in the table which represent the February 1974 submission of the DD-COMP(AR) 996 report follows:

(1) Capital Costs

(a) Site Preparation (O&M)

FY 74, $70 K. Power upgrade for the CDC 6600 upgrade in FY 75 of 500 K words of Extended Core Storage (ECS) and eight 844 Disk Drives.

FY 75, $100 K. Major air conditioning cooling tower modifications/repair anticipated.

FY 77, $30 K. Minor building modifications, power changes, air conditioning, etc.

Table 1

PROBLEMS BEYOND THE CAPABILITY OF THE CDC 6600

PROBLEM	TYPE PROBLEM	RELEVANT PHYSICAL PROCESSES	USAF SYSTEMS IMPACTED
Multiburst Environment	3-D	Hydrodynamics coupled with radiation transport, elastic/plastic deformation, non equilibrium chemistry	ABRES, DSP, HSD, MM, B-1
Nuclear Detonation Over 100 km	3-D	Magnetohydrodynamics, non equilibrium chemistry	DSP, C^3 Systems, Radar
Structure Loading	3-D	Hydrodynamics coupled with elastic/plastic and structural response	MM, MX
EMP	3-D	Electromagnetic wave propagation, transient response, integral systems response	MM, B-52, B-1, F-111, E-4A, SCAD, SRAM, AWACS, EC-135
Laser Systems Design and Development	3-D	Fluid dynamics, magnetohydrodynamics, beam propagation structural response, system modeling	Laser Systems, Prototypes, ALL, Gas Dynamic, Chemical, Electric Discharge Lasers

ABRES	Advanced Ballistic Reentry System	C^3	Command, Control and Communication
DSP	Defense Support Program	SRAM	Short Range Attack Missile
HSD	Hard Site Defense	SCAD	Subsonic Cruise Armed Decoy
MM	Minute Man	AWACS	Advanced Warning and Control System
MX	Minute Man Follow-on	ALL	Airborne Laser Laboratory

Table 2

WORKLOAD PROJECTIONS FOR FY 74 THROUGH FY 80

FY 74	-	15,793
FY 75	-	31,244
FY 76	-	32,844
*FY 77	-	80,433 (New Computer Installed)
FY 78	-	125,209
FY 79	-	143,540
FY 80	-	148,926

* CDC 6600 equivalent hours

Table 3

DPI 6379 ADP COST SUMMARY

	FY 74	FY 75	FY 76	FY 77	FY 78	FY 79	FY 80
Capital Costs							
EDPE Purchases	43	50					
Site Prep (O&M)	70	100		30			
(MCP)			880				
In-House Op Costs							
Leased EDPE (L&M)	321	692	1924	5021	5021	5021	5021
Leased PCAM	2	3	3	3	3	3	3
Supplies & Mag Dvs	223	237	241	240	250	270	285
Tele Comm	214	167	176	247	243	241	252
Other (Tax, Parts, etc.)	24	33	89	209	213	213	213
Contract Services							
ADPS Support	70	70	100	150	150	100	100
Owned ADPE Maint	509	534	519	519	519	519	519
	1476	1886	4001	6458	6399	6367	6393

(b) Site Preparation (MCP)

FY 76, $880 K. Add-on to present computer facility to make room for new computer in FY 76/FY 77.

(2) In-house Operating Costs

(a) Leased EDPE (L&M)

FY 75, Increase of $371 K over FY 74. Primarily due to full year L&M for the new CDC 844 disk drives, six months for the new ECS, half-year for projected new microfilm equipment, and a full year on two data 100 terminal systems.

FY 76, Increase of $1,232 K over FY 75. Primarily due to fourth quarter L&M for new computer which is estimated at $4 M per year, or $1 M per quarter. This will be adjusted on the next budget update to remove the new computer cost from FY 76, since the new system is presently not projected until FY 77. Other cost increases are due to full-year L&M for the ECS, microfilm system, and other miscellaneous system augmentations.

FY 77, Increase of $3,097 K over FY 76. Primarily due to full year L&M of new computer which is estimated to cost approximately $4 M per year L&M. The $97 K is primarily associated with projected increases in remote terminal requirements.

(b) Supplies and Magnetic Devices

FY 74 - FY 80. Estimated cost increases associated with use of more supplies and increasing prices.

(c) Tele-Comm

FY 74 - FY 80. Estimated costs are associated with the communications equipment for access to the ARPANET, the new terminal communication cost for upgrading our present system, and projected increased communication costs for the new computer system.

(d) Other

FY 74 - FY 80. Other costs include cost for New Mexico state taxes, parts costs, and other miscellaneous costs. The projected costs are based on our present systems as compared to the estimated value of the new computer system.

(3) Contract Services

FY 74 - FY 80. The new computer system will require at least one additional full-time systems analyst during the first two or three years of operation. This requirement can be substantially higher, depending on what support is provided under the equipment acquisition contract.

5. OBJECTIVES

a. The objectives of this DAR are

(1) To apprise the Secretary of the Air Force of the computational requirements of the Air Force Weapons Laboratory.

(2) To identify the scientific research and engineering development problems which require vastly increased computational support for solution.

(3) To gain approval for installation of a large-scale scientific computer of the following general characteristics:

(a) Central processor speeds of 20-100 times the CDC 6600.

(b) Large-scale fast random access central memory of 1 million, 60-64-bit words.

(c) Bulk core storage of 4 million words.

(d) System disk storage of 320 million words.

b. This equipment will be used to augment the currently installed CDC 6600s. This will be accomplished according to current plans by installing the new computer in close proximity to the AFWL CDC 6600s and by interfacing the new computer with the CDC 6600s. This will allow the CDC 6600 computers to function as scheduler and resource allocator for the new computer so that optimal program mixes can be processed on the new computer. Continued use of the CDC 6600s will eliminate mass rewrites of many codes being run on the CDC 6600. The housekeeping functions performed by the CDC 6600 computers will include allocating to each computer those functions or programs which can best be performed by each. In addition, as the CDC 6600 will be interfaced by a TIP to the AFSC Net, users of the AFSC Net will have access to the new computer.

6. ASSUMPTIONS AND CONSTRAINTS

a. This DAR contains the following assumptions

(1) The mission of the AFWL will remain as stated in paragraph 1a.

Emphasis will continue on in-house research, especially large-scale theoretical calculations of nuclear weapon effects and laser modeling, design, and effects.

(2) The computer industry will have developed by FY 76, a commercial, large-scale, scientific computer with central processing speeds 20 to 100 times the speed of the CDC 6600 and with 1 million words of high-speed, random access memory.

(3) Funding levels from various DOD sources will continue to meet the costs of operations.

b. Associated with the above assumptions are the following constraints:

(1) The AFWL computer codes must be run in-house.

(a) These codes are so complex and the output so voluminous that constant monitoring by the scientist is essential. This condition precludes the use of off-site computational facilities, which include those of contractors, other DOD laboratories and facilities accessible by a terminal network. The various computers also have different word lengths; the numerical schemes in AFWL computer codes could become unstable on machines with smaller word lengths than the CDC 6600.

(b) The codes are so large and complex that they are not easily adapted to other systems and, particularly, other computers. Going from computer to computer, facility to facility as time becomes available would require a large expenditure of the scientist's time adapting codes to fit the computer of the moment. This time would be at the expense of actual computation and analysis of R&D problems.

(c) AFWL computational requirements demand a major fraction of the proposed large-scale, scientific computation center. Therefore, it is reasonable that the center be located at the AFWL. Other AFSC users whose requirements for computer support are more modest have access to the AFWL facility through the AFSC Net, as arranged through Host/Tenant Agreements.

(d) Unlike a "data processing shop" where the identical code is run repeatedly, nearly all codes at the AFWL are of a non-recurring nature; that is, the codes are frequency modified between runs to improve the modeling of the problem. This procedure is a fundamental characteristic of the research performed at the AFWL.

(2) Due to the nature of the calculations performed at the AFWL, it is essential that the computers have basic machine cycles equivalent to the state of the art and that rapid turnarounds be possible in order to obtain maximum utilization of limited manpower resources and to gain solution to problems in a reasonable time.

(3) Ease of operation is a major consideration for any computer system if it is to be a useful tool for scientific research and engineering development. The new computer must be a general-purpose scientific machine of flexible architecture; that is, the computer hardware and software must not require undue or excessive constraints on the solutions of problems in weapon technology.

7. ALTERNATIVES

a. The AFWL may maintain present levels of sophistication in its computational studies. However, this alternative would not be responsive to AF and national security needs identified in paragraph 1a. Though nuclear weapons have been in the inventory for nearly thrity years and research into their design and effects has continued for a similar length of time, the requirement for further research and information remains valid. Paragraph 1b(3) discusses areas in which weapon effects knowledge is deficient. There are old problems which have been around many years awaiting development of more powerful computational tools; e.g., fireball phenomenology above 100 km where a three-dimensional capability is required to properly treat the geomagnetic effects of the earth, multiburst phenomenology, etc. New weapon designs, sophisticated kill mechanisms, changing engagement philsophies, and new technologies such as laser systems spawn an ever-increasing number of problems requiring computational analysis. As systems increase in sophistication so do the corresponding physical processes. Past experience shows that designs based on information obtained from physical descriptions, compromised to accommodate a lack of computational power, lead to test failures, costly redesigns, and retrofits. Therefore, three-dimensional effects and more complex physics preclude preservation of the status quo and force the AFWL to increase its computational resources.

b. The AFWL may obtain another CDC 6600 or CDC 7600. While these machines could relieve turnaround and saturation problems, they would not give the AFWL the capability to address the problems outlined in paragraph 3.

c. The AFWL may use ARPA Net. However, there is no computer on the network with the capability to solve the problems outlined in paragraph 3. This includes the Illiac IV.

(1) The Illiac IV has a central memory of 2 K 64-bit words for each of its 64 processing elements. This gives a total memory of 131 K 64-bit words compared to the 131 K 60-bit words of the CDC 6600. Therefore, the Illiac cannot handle larger meshes or more complicated physics than the CDC 6600.

(2) The architecture of the Illiac IV provides high computational speeds for those problems, solutions to which involve a single algorithm performed repetitively on many sets of data. The two primary considerations in programming for speed are the exploitation of the simultaneous arithmetic capability and the distribution of operands in the memories so that the required argument sets can be assessed without time-consuming rearrangements of storage. Computer codes, in general, contain a broad mixture of operations, some of which can only be done serially and others which can be done simultaneously. Hence, each computer code varies in its ability to exploit Illiac architecture. The major production, radiation/hydrodynamics codes at the AFWL--the logical users of the Illiac IV--contain many features which are essentially serial and, consequently, inefficient in PE utilization. Some of these features are: real equations of state in tabular form, inversion of tridiagonal matrices, particle-movement routines, and solution of nonlinear equations. The small memory of the Illiac also contributes to low PE utilization by increasing the time required to rearrange storage.

(3) Access times and transfer rates in I/O operations also limit the usefulness of the Illiac IV. The I/O capability of the system is not commensurate with its capability to compute. Preliminary estimates show that for each 6 seconds of computation 20 minutes are required to obtain the output. AFTAC-TN-70-1 contains a discussion of this problem as related to the big code user.

(4) In an independent study, the Atomic Energy Commission concluded that the Illiac IV is not a viable computational tool for large-scale, two-dimensional problems. The analysis by Dr. T. Kishi of Lawrence Livermore Laboratory is available as UCRL 51467.

d. The AFWL may contract the work to private companies, other DOD laboratories, the AEC. However, these organizations do not have the computational resources, either, to assume the added work. Experience shows that the AFWL can do in-house calculations considerably cheapter than contractors.

The AFWL achieved the lowest cost of computer charges in the scientific defense community through efficient utilization of resources. Consequently, DOD contractors prefer to use the AFWL computational resources. Another important consideration is that by doing in-house research, the AF can ensure not only responsiveness to AF needs but, also, timely, cost-effective results. It is also the only way the AF can be truly knowledgeable on modern weapons and their effects.

8. BENEFITS

a. Acquisition of advanced computer systems will ensure orderly progress in nuclear and laser research at the AFWL. It will allow solutions of large mesh problems and other problems requiring a more detailed treatment of the physics than is currently possible with CDC 6600 computational capability.

b. The ultimate benefit resulting from the acquisition of advanced scientific computing systems by the AFWL will be increased security for the United States. This computing capability makes possible the design of modern weapon systems and the study of their effects in what past experience has shown to be a timely, cost-effective manner.

(1) It will permit full-scale simulation of an entire strategic interchange to evaluate tactical deployment of weapons systems in an interactive battle environment.

(2) It will permit evaluation of probable systems response of planned systems to a realistic nuclear environment--before hardware commitments are made.

c. Computer analyses of the laser prototype engineering development program provide the following benefits:

(1) Reduced Research and Development Time and Cost. Most alternatives can be evaluated and the degree of uncertainty reduced prior to management approval of a design and build program. Analyses can be done from concept drawings and the degree of modeling detail adjusted for the information desired for "go" or "no go" decisions.

(2) Reduced Design and Testing Costs During Component Design. Since testing will always be the ultimate validation tool, computer analysis has the potential to reduce cost in getting from initial design to final sign-off validation.

(3) Computer analysis shows promise of quadrupling the design alternatives considered without increasing overall design costs. The ultimate goal is to reduce prototypes tested to one or two for validation prior to actual testing.

(4) Faster Resolution of Prototype Problems. If problems do occur during prototype testing, it becomes critical that they be resolved rapidly. The old shotgun approach usually gets the problem resolved but the price is high. One advantage of computer analyses is speed.

(5) Better Product. Last but not least, a better product can be designed. Complete generality of computer modeling for analyzing different materials and new structural concepts provide the designer with a tool to approach innovative designs with a much higher level of confidence.

d. In the case of nuclear weapons, this computational capability is the only tool available to this nation under the terms of the Test Ban Treaty. The information generated by the AFWL-developed theoretical capability to address such problems provides the basis for enhancing the negotiating position of the United States in the Strategic Arms Limitation Talks as well as improving the survivability, cost-effectiveness, and operational flexibility of modern weapon systems.

SECTION II

APPLICATION OF DIGITAL COMPUTERS TO SCIENCE AND ENGINEERING

The fundamental laws of physics describe, in principle, all physical processes observed by man. These laws, such as Newton's laws of motion (as modified by Einstein's theory of relativity); the laws of conservation of mass, momentum, and energy; the laws of quantum mechanics; and Maxwell's equations for electromagnetic fields are normally stated mathematically in the form of partial differential equations. Each equation expresses a relationship between derivatives, or between derivatives and given functions, of the variables which describe an instantaneous state of a physical system. The equations establish a relation between the increments of certain quantities and these quantities, themselves.

The variables which define the state of a system may be combinations of scalars, vectors, and tensors. A quantity which can be completely determined by one number is a scalar. For example, time, temperature, energy, and density are all scalars. Any quantity which requires three numbers for complete definition is a vector. Some examples of a vector are position, velocity, electric field, and magnetic field. A tensor is any quantity which requires nine numbers for complete definition. Some examples are stress and strain. This illustrates the growth in the number of variables which must be considered as one describes more complex physical phenomena.

A partial differential equation provides local information about a physical process. It describes on a micro-scale how a certain state will develop in the immediate future, or it describes the influence of a state on other states in the immediate vicinity. Integration or "solution" of the partial differential equation is the mathematical process by which the transition from the micro- to macro-scale is made; that is, the solution of the partial differential equation provides the global description of the physical process.

The solution to a partial differential equation contains both arbitrary functions and arbitrary constants. This is to be expected, since a partial differential equation expresses a general physical law and not a specific case. Boundary conditions, both spatial and temporal, define the specific physical problem. A boundary condition is a postulated event in space and time expressed by the statement that the pertinent physical variables have a value or set of values throughout a specified region of space within a specified interval of time. One must have as many physical boundary conditions as there are arbitrary functions or constants in the integrated equation.

In brief, a partial differential equation is a mathematical formulation of some physical law which describes a given physical process. Its application to a problem of interest requires the specification of appropriate boundary conditions.

The partial differential equations describing physical processes are generally very complicated. For example, a series of coupled equations may describe the event, or the equations may be nonlinear. Analytical solutions are possible in very few cases and, even then, only after various assumptions simplify the problem. Unfortunately, after the simplifying assumptions are made, the remaining equations no longer accurately describe the actual physical process. However, the modern scientific computer and appropriate numerical techniques allow solutions to these complex equations with increased accuracy through fewer compromises of pertinent physical phenomena.

Numerical solution of partial differential equations assumes a discrete representation of the continuous physical system, both in space and time. One divides the region of interest into a mesh of zones and describes the state of the system at some instant of time by defining a value for each pertinent variable for each zone. This description provides the initial and boundary conditions for the problem. The finite difference analogs corresponding to the partial differential equations govern the development of the physical processes in the discretized system. This discrete representation is an approximation to the actual continuous physical system, and rigid mathematical rules must be obeyed to guarantee meaningful and sufficiently accurate results. Reducing the size of the time steps and zone dimensions (thereby increasing the total number of zones) improves the approximation and the accuracy of the results, but at the expense of increased memory requirements and running time. For one-dimensional calculations, the running time increases approximately as the square of the number of zones. For two-dimensional calculations, the running time increases approximately with the 3/2 power of the number of zones if the increased storage requirement can be accommodated by the central memory of the computer. If auxiliary memory such as disks, tapes, or drums must be used, the actual running time increases by a factor of 2 or 3.

The state of the art of computer development has historically provided the main constraint on computer use for the solution of physical problems. Computer memory and speed are the limiting factors which determine the complexity of the problem and the accuracy to which it can be solved numerically. The computers of the 1950s had the capacity to solve, for example, simple, well-posed, one-dimensional, hydrodynamic problems. A typical problem involved 100 zones and ran about 100 to 1000 time steps. Such a problem consumed approximately 100 hours of computer time. Expanding to two spatial dimensions required a mesh containing 100 x 100 zones and an increase in computational power by a factor of, roughly, 1000. By the early 1960s a factor of 100 more computing power was available, which enabled one to address a limited class of two-dimensional problems. However, this frequently necessitated some compromises in the physics and in the accuracy of results, as well as increased expenditure of computer time. It was also possible to add more physics to essentially one-dimensional hydrodynamics problems. For example, one could now couple a multi-frequency (20 frequency groups) radiation transport formulation to the basic hydrodynamics. This resulted in successful calculations of early-time fireball phenomenology. In the mid-1960s, the CDC 6600 provided the factor of 1000 necessary to perform meaningful two-dimensional calculations on a broader scale. The 6600 gave more accurate results than previously possible, since now one had the computational power to include a more accurate description of the physical process. However, the 6600 is not capable of providing solutions to weapon and systems problems which require more sophisticated physics, such as elastic-plastic deformation, electron and ion conduction, magnetic fields, non local particle transport, and viscosity.

In brief, the demand for increased capacity and sophistication is the result of three major factors: (1) the need for expanded zoning in current codes, (2) improved and expanded physics in current codes, and (3) the capability to investigate new ideas.

SECTION III

PRESENT CONFIGURATION

This section presents a complete hardware description of this DPI.

QUANTITY/MODEL	DESCRIPTION
6640 ECS Storage Controller	Four central computer connections with direct memory access, controls up to two million words of extended core storage to or from up to four 6000 series central computers.
2/6622 Magnetic Tape Controllers	In the process of being salvaged.
4/626 Magnetic Tape Transports	In the process of being salvaged.
2/405 Card Readers	Reads 1200 cards/minute for 80 column cards, reads 1600 cards/minute for 51 column cards, 4000 card hopper capacity, 240 card secondary stacker capacity for limited sorting or rejecting.
3/3555 Printer Controllers	Single channel connection, controls one printer, full line buffer, train image storing, checking.
3/512 Line Printers	Train printer, prints 1200 lines/minute using 48 character train, skips 70 inches/second at six lines/inch or 60 inches/second at eight lines/inch, 136 columns.
10/6681 Data Channel Converters	Permits 3000 series peripheral equipment to be attached to 6000 series channels.
3898 Microfilm Recorder/Controller	Contains control logic, symbol generator, vector generator, and interface to 3000 series standard 12-bit channel (on-line) for maximum of two output devices, either 282 or 283, includes separate 284 microfilm recorder cabinet containing camera, film magazine, five-inch CRT and associated controls, contains 2048 buffer storage for display regeneration, symbol repertoire contains 126 symbols including 501 printer compatible set.

QUANTITY/MODEL	DESCRIPTION
2/6613 Central computers	Sixty-bit word size, 131,072 words of magnetic core storage, ten peripheral and control processors each with 4096 twelve-bit words of independent magnetic storage, twelve 12-bit data channels, floating point hardware, eight operand, eight addressing, and eight increment registers, central processor interrupt through exchange jump option, includes instruction stack, logic coupler for addition of extended core storage and required power and cooling equipment.
2/6638 Disk Systems	Capacity dependent upon record size, e.g., 131 million six-bit characters with 640 character records, 167 million six-bit characters with 4084 character records, 25 to 110MS positioning time, 1.68 million characters/second transfer rate, two independent access mechanisms, one read/write control, two channel connections, sector addressable.
3234 Disk Storage Controller	Two channel connection controls up to eight access mechanisms of disk storage drives and disk files, off-line maintenance capability.
3/854 Disk Drives	Capacity of 8.2 million six-bit characters, 30 to 165 MS positioning time, 208K characters/second transfer rate, single access mechanism, addressable in sectors of 256 characters.
6635 Extended Core Storage	Magnetic core storage, 500 K 60-bit words, three microsecond first-word approximate access time, up to ten million words/second transfer rate, includes control enabling communications via 6640 ECS controller.
282 Display Console	19-inch round CRT with 11.5 x 11.5 inch display area.
284 Microfilm Recorder Cabinet	Housing for camera.
3446 Card Punch Controller	Single channel connection, controls one card punch, full card buffer.

QUANTITY/MODEL	DESCRIPTION
2/3447 Card Reader Controller	Single channel connection, controls one card reader, full card buffer.
415 Card Punch	Punches 250 cards/minute, 80 column card, programmable offset stacking, 1200 card hopper capacity, 1500 card stacker capacity, read check after punch.
6671-2 Data Set Controller	Controls one to 16 AT & T 103 (110 bits per second) or AT & T 201 (2000 or 2400 bits per second) data sets or equivalent, or any combination of these. Attaches to one standard 6000 channel.
3423 Magnetic Tape Controller	Two independent channel connections, controls up to eight tape units of a single model.
3422 Magnetic Tape Controller	Same as above.
10/607 Magnetic Tape Transports	Seven-track, 150 inches per second, 200, 556, and 800 BPI, 83.3 and 120 KC. Read forward and reverse.
3528 Magnetic Tape Controller	Two independent channel connections, controls up to eight Model 657 or 659 (intermixed) tape units, provides code conversion, 200, 556, and 800 BPI, NRZI recording.
8/659 Magnetic Tape Transports	Nine-track, 120K and 240K characters/ sec.
8/659 Magnetic Tape Transports	Nine-track, 120K and 240K characters/ second, 800 BPI, NRZI recording, reads and writes 150 inches/second, forward and reverse read.
3/6612 Console Display	Desk console with dual CRT, 10 x 10 inch display area. Includes type-writer keyboard and associated con-troller.
10122-3 ECS Memory Increment	Adds an additional 500K of ECS to an existing 500K system. Includes CEJ/ MEJ (10103, 10104) and CMAP (10169).

QUANTITY/MODEL	DESCRIPTION
2/7054-1 Mass Storage Controller	Controls up to 8 disk storage drives, connects to one standard 6000 I/O channel. Capacity of 844-2 is 118 M 6-bit characters. There are 644 characters per sector and 24 sectors per track. Two mass storage controllers are required for dual access operation.
8/844-2 Disk Storage Unit	Maximum capacity of 869 million bits when used in an unsectored format on 404 tracks. Usable capacity depends on sectoring scheme used. 10 to 55 MS positioning time - 30 MS average. 6.8 million bits/sec transfer rate at 3600 rpm.

SECTION IV

PROBLEMS BEYOND THE CAPACITY OF THE CDC 6600

1. NUCLEAR PHENOMENOLOGY ABOVE 100 km

a. Systems studies investigating degradation of radar, communications, and infrared detection and satellite systems' performance require information describing the nuclear environment resulting from detonations above 100 km. At these altitudes, the effect of the geomagnetic field is important to fireball expansion and rise. A magnetohydrodynamic model of rise and expansion will probably hold well to 200 km altitude and still have some use at higher altitudes. Taking chemical nonequilibrium into account can extend the usefulness to higher altitudes.

b. The 6600 does not have sufficient storage nor speed to produce detailed calculations of large-scale disturbances in the upper atmosphere with the spatial resolution required to make a meaningful description of the environment. These magnetodynamic problems, except for explosions over the earth's magnetic poles, are inherently three-dimensional. In addition, the upper atmospheric disturbances occur with typical spatial scales of a few thousand kilometers. However, scale heights in the D and E regions are less than 10 km. Therefore, the problem would require several hundred zones in the vertical direction to provide a minimally adequate description. The central processor time and storage requirements on a CDC 6600 for a minimum sensible mesh of 100 x 100 x 200 zones would be 3500 hours and 14 million words. Taking nonequilibrium chemistry into account doubles these requirements.

2. MULTIBURST ENVIRONMENT

a. Advanced Ballistic Reentry System penetration studies and Hard Site Defense effectiveness studies postulate battle environments characterized by multiple nuclear bursts. Descriptions of such environments are three-dimensional and, therefore, beyond the capacity of the present computer system.

b. The multiburst environment at low altitudes includes dust and condensed water vapor clouds. Predictions of this environment are necessary to define survivability/vulnerability criteria for aircraft, boost phase vehicles, and reentry vehicles traversing the nuclear cloud. This information is also needed to evaluate the effectiveness of sensor systems and future laser devices in a nuclear environment. Beside the usual hydrodynamic variables, the data required include total mass, particle distribution, effect of different kinds of surface, and effect of meteorological conditions.

c. Cratering is closely related to the dust problem. This phenomenon, involving the interaction of two materials--earth and air--includes many physical processes: hydrodynamics, radiation transport, eleastic/plastic deformation phenomena and heat transfer. The information required includes the amount of earth lofted into the air, crater size, ground shock/earth motion data, and shock enhancement effects due to ground heating of the air.

d. Fireball interactions are also part of the multiburst environment. Solutions to these problems require a three-dimensional hydrodynamic code coupled with radiation transport. The information required includes the magnitude of thermal gradients, temperature-time histories, species concentrations, and mixing rates within the nuclear fireball. This information defines the fly-through environment of aerospace vehicles, and the effects of the hot fireball region on radar, optical/infrared sensors, laser and communications systems.

e. Solutions to problems involving the multiburst environment require an advanced scientific computer. Each calculation will use nominally 2 million zones. For a pure hydrodynamic problem, each zone has six variables defined; including a radiation treatment requires an additional two variables per zone; including elastic/plastic deformation requires an additional nine variables per zone; including nonequilibrium chemistry requires an additional ten to fifteen variables per zone. Running time per problem approaches two thousand hours for a pure hydrodynamic problem; including additional physical processes more than doubles running time.

3. ELECTROMAGNETIC PULSE (EMP) PHENOMENA

a. The Aircraft and Missile, EMP, Survivability Assessment Program requires information concerning EMP phenomena resulting from a nuclear environemnt. This information provides the basis for making nuclear survivability, vulnerability, and hardness assessments of DOD weapon systems. At the present time the AFWL is supporting the B-52, B-1, F-111, and E-4A programs; by FY 75, AFWL anticipates additional programs from AWACS, SCAD, SRAM, EC-135 and a large missile. Discussion of major research areas requiring advanced computational support appears below.

b. Studies of TREE effects require circuit analysis and systems analysis codes to predict small signal ac, dc, and transient response simulations of circuits exposed to nuclear environments. Present computer resources provide the capability for these codes to simulate circuits with approximately 300 elements or characteristic equations of approximately order 100. However, nuclear survivability, vulnerability and hardness assessments of modern weapon systems require computer-aided circuit analysis be extended to allow as many as 500 elements or characteristic equations of order 2000. Solutions of the characteristic equations involve operations on sparse matrices as large as 2000 x 2000. This requirement translates to a computer speed approaching 20 times that of the 6600 and memory of about a million 64-bit words.

c. EMP vulnerability testing and analysis occur in four phases: pretest analytical models, data reduction, data analysis and threat level response extrapolations, and posttest hardware (or design) upgrade.

(1) A pretest analytical model includes projected transfer functions for all weapon system components; e.g., cables, skin, circuits, etc. Major processes in the model are Fourier transforms (FT), inverse Fourier transforms (IFT), data storage and retrieval and a matrix-solver capable of handling a 2 x 1000 x 1000 matrix.

(2) Data reduction codes check data format, edit data and do FT. Both pulse and continuous wave data require these processes.

(3) Data analysis and threat level response extrapolation codes include FT, IFT, data storage and retrieval, and standard statistical routines. Both pulse and continuous wave data require these processes.

(4) The posttest hardware (or design) upgrade phase updates the analytical model with test data. The codes use the same processes as in the pretest phase.

(5) The computer support in each of the four phases considered above involves operations on three-dimensional matrices. Up to FY 77, these operations will be on 2 x 1000 x 1000 matrices. FY 77 models will require the ability to solve 5 x 4000 x 4000 matrices. This requirement translates to a computer speed about 20 times faster than the 6600 and 2 million words of memory.

d. EMP phenomenology calculations are the basic studies investigating the complex physics of EMP generation and propagation over the full frequency range of interest. These studies support the AFWL EMP system vulnerability testing programs as well as various SAMSO testing problems. Two major phenomena which must be addressed in FY 77 - 80 are close-in system coupling analysis and late time EMP field calculations. However, both phenomena are dominated by three-dimensional effects which put them beyond the capability of the present computational system. In the former, there are both field coupling and direct/system interaction effects; and in the latter, late time, low frequency EMP environments are inherently three-dimensional. These problems require a central processor speed about 50 times that of the 6600 and a central memory about 10 times larger.

e. Systems-generated EMP are a serious threat to satellite survivability. Calculations of these phenomena include Monte Carlo predictions of the angular and energy distributions of electrons resulting from photon interactions with satellite materials. The present computer does not have the capacity to track secondary and tertiary electrons, including their histories. Other calculations requiring greater computer power include modeling charge transport and field interactions. The speed and storage requirements are about 20 times faster than the 6600 and 1 million words.

f. Under the general heading of EMP electromagnetics are various problems which require advanced computational capacity to enable accurate EM modeling of aircraft and missiles, interactions with cables and transmission lines, and coupling through apertures in aircraft and missiles. These are extremely complex processes which can only be attached through greater computational power.

4. STRUCTURAL MEDIA INTERACTION

a. SAMSO requires detailed information concerning ground shock, ground and crater motion, airblast loading on structures, structural response, and soil-silo-missile interactions for Minuteman survivability and upgrade studies and for evaluation of follow-on (MX) design concepts. This information is also of interest to the Navy's Sanguine and the Army's Safeguard programs.

b. The physics describing the relevant environment includes hydrodynamic motion and elastic/plastic deformation. The problem is three-dimensional because the axis of symmetry of the incident blast wave is different from the axis of symmetry of the structure. A three-dimensional treatment is beyond the capacity of the present system.

c. Additional phenomena which increase problem running time and storage requirements are as follows:

(1) Transient boundary layer effects may dominate the predicted structural response to the dynamic loading. Proper definition of a boundary layer requires extremely fine zoning which increases running time about ten times. Whereas a two-dimensional run without boundary layers takes a minimum of 5 hours on the 6600, a comprehensive three-dimensional treatment with boundary layers requires over 700 hours of 6600 time.

(2) The Minuteman Project Office at SAMSO is increasing its emphasis on the late time oscillatory behavior of the gound motion. Providing this information requires better wave definition, which can be attained only through finer zoning. Crude zoning will not provide systems designers with detailed shock spectra response because all but the lowest frequencies are dissipated by large zones. Finer zoning and running the problem to late times (few seconds after initial blast impact) increase the computer time by a factor of 100. A calculation, which in the past was completed overnight on a 6600, could now keep a 6600 busy for a month.

(3) Accurate soil models which take into account the anisotrophy of the soil double computer running time compared to those calculations using an isotropic model.

(4) The airblast and ground motion data are of no use if they cannot be applied to the structure of interest (e.g., a proposed MX shelter). A structure subjected to airblast and ground motions is another three-dimensional problem. A few codes such as NASTRAN (a three-dimensional, finite-element, structural response code) are available to apply to this problem when the medium can be separated from the structure. NASTRAN, however, cannot compute both the soil and structure motion simultaneously. It can only compute elastic structural response given a set of loads on the structure. However, the number of finite elements and degrees of freedom per nodal point required in these studies exceed the fast memory of the 6600. Therefore, NASTRAN must be overlaid and the elements must be stored on disk. This procedure increases running time more than ten times.

(5) In many structural problems, the medium cannot be separated from the structure. As an example, motion of a missile silo can be seriously affected by friction from the surrounding soil. In these cases, it is necessary to include both the medium and the structure in the same calculation. Solving

this problem requires a code which includes the three-dimensional, finite-differenced hydrodynamic equations with strength and the three-dimensional finite element structural response capability. Running such a problem would require hundreds of hours of 6600 time and approximately ten times more fast memory.

5. ADVANCED RADIATION TECHNOLOGY

a. Research and engineering developments of laser systems are the greatest growth areas at the AFWL. The computational requirements in support of these programs are similarly expanding rapidly.

b. At present, AFWL scientists are formulating the physics describing the physical processes associated with laser operation, cavity and nozzle design, beam propagation, and beam matter interaction. From a historical point of view, the theoretical formulation of the laser program is at the same stage as the nuclear program was in the late 1950s. By the later 1970s, a theoretical approach to laser design and effects problems will be a powerful tool available to systems designers. This is the area of greatest growth in computation requirements into the 1980s.

c. Preliminary work on a High Energy Laser System is in progress now. Since the technology for current and planned laser systems is very expensive (tens of millions of dollars), there is a considerable payoff through use of quantitative, accurate computer models that can be used to optimize a system configuration in the design stages.

d. The following are examples of laser engineering development problems requiring computer support beyond the capacity of present equipment:

(1) NASTRAN

(a) The Laser Development Division is currently performing three-dimensional, finite element structural dynamic analyses with NASTRAN on both Cycles II and III of the Airborne Laser Laboratory (ALL). The results of the analyses are the vibratory rotations and translations of a laser beam. The beam motions calculated define the requirements of an alignment system designed to reduce motions below a predetermined RMS value. Analyses also indicate modifications to the design of ALL systems that would cause a significant reduction in beam motion and, thus, reduce alignment system requirements.

(b) The same kind of structural dynamic analyses will have to be performed by the LEAPS Division if a decision is made to develop a prototype laser system. The structural idealizations for prototypes will have to contain significantly more detail than the ALL idealizations.

(c) A typical random response analysis with NASTRAN of a prototype laser system would contain 700 degrees of freedom. Clock time for the analysis is 50 hours on a CDC 6600 with 350 K octal of fast core storage. It is assumed that calculations can be contained in fast core storage and do not "spill" to disk. Eigenvalue extraction and matrix decomposition calculations with NASTRAN that "spill" will take an order of magnitude greater clock time than the same calculations performed with no "spill." Because of speed and core limitations, the CDC 6600 is inadequate for those calculations.

(d) During the period from July 1976, to January 1980, at least two of the 700 degree of freedom random response analyses would be performed per week. If the calculations could be performed on a CDC 6600, clock time per week would be 100 hours.

(2) System Optical Quality Studies

This code currently models the ALL. Optical quality includes contributions from resonator cavity, gain medium, and transfer optics to calculate the quality of the output beam. It takes about one hour of computer time to calculate 40 passes of 2^{14} mesh points in eight steps down the resonator. Gain medium kinetics are those of the CO_2GDL, with simplified hydrodynamics. 100 K_{octal} central memory and 200 K extended are used in this configuration, and agreement with experiment is mainly qualitative. This program will be expanded to include chemical lasers' kinetics and smaller mesh sizes to account for nonlinear interactions at mirror surfaces. (Another code now handles chemical laser power extraction in a very crude way; it takes three minutes per case and assumes no hydrodynamics, one temperature, and notational equilibrium. It can be made quantitative but takes days of running time and the entire computer.) The System Optical Quality Study Code will take four to five hours with only minor improvements and requires either more extended core or several hours of PP time to dump numbers on disk.

(3) Aerodynamic Turbulence Codes

Microscopic boundary layer effects have been modeled in the past by using the differential equations of macroscopic flow (Euler equations) on a small scale. Computational complexity was enormous and agreement with experiment poor for turbulent flow using this approach. A new approach due to Saffman is making the turbulent flow problem tractable and much more quantitative. ("Tractable" means two hours on a CDC 7600 for a two-dimensional problem.) When this technique is developed, it will be useful in two ways: a much better model of GDL flow and mixing for chemical lasers, and a model of the three-dimensional flow around a turret. These problems are essentially unsolvable on the CDC 6600; they begin to appear tractable with some hours on a machine 30-50 times the speed of a CDC 6600.

(4) Laser System Effectiveness Model

This is a super code which combines all subsystem analyses and generates a figure of merit for laser candidate systems in various engagement scenarios. A comprehensive systems study involving several scenarios requires 20-30 hours of computer time; each study must be repeated for several variations in parameters. The uncertainties of some effects, like wavelength scaling of turbulence, make it useless to try to upgrade this model today, but a vigorous experimental and theoretical effort is being conducted to define these uncertain effects. In one to two years, enough will be learned to make it worthwhile to include very accurate subsystem models in this code. At that point, the CDC 6600 will clearly be inadequate, as each iteration will include all of the subsystem models' growth in complexity. With the proper data and computers, this code could utlimately be used to optimize design of a total system to include mission, cost-effectiveness, maintenance required, weight, wavelength and range, vulnerability of opposing systems, and a host of other inputs. These analyses will certainly increase the value of dollars spent on hardware for testing actual systems.

SECTION V

PROGRAM ELEMENT CODE SUMMARY

The AFWL has management responsibility for five program elements (PECs 62601F, 63605F, 63723F, 64711F and 64747F). The "short titles" of associated tasks that require computer support are listed in table 4. Hq USAF does not provide a Program Management Directive (PMD) on exploratory development (PEC 62601F); therefore, a Program Management Plan (PMP) is not required. Technical guidance and direction for PE 62601F is obtained through DD Form 1634 documentation with AFSC and USAF approval of that documentation. The most recently approved DD Form 1634 documentation is dated April 1973. A summary for the remaining PECs is shown below.

PEC	PMD	DATE OF PMP
63605F	R-P2137(3)	Jun 1973
63723F	R-P2132(2)	Sep 1973
64711F	R-Q2-147(2)	Aug 1973
64747F	R-Q2-147(1)	Oct 1973

Other Air Force program supported by the AFWL computational facility are listed in table 5. Further information on these programs may be obtained from appendix C, "Research, Development, Test and Evaluation (RDT&E) Program," of Program Guidance (PG) 75-1 dated January 1973.

The Defense Nuclear Agency sponsors nuclear weapon effects research within the AFWL, and a list of tasks associated with DNA-sponsored programs is shown in table 6. Air Force efforts that are appropriate for DNA sponsorship are described in "FY 75-79 Air Force Requirements for Nuclear Weapon Effects Research," dated January 1973. Proposals requesting DNA's financial support in specific technical areas are processed through AFSC/DLCAW and USAF/RDQPN. If the proposals are approved, funds are provided to AFWL by way of USAF and AFSC.

Table 7 presents Workload Projections associated with specific PECs from FY 74 through FY 80.

Table 4

PROGRAM ELEMENT CODE SHORT TITLES (AFWL)

PEC	TASK(SHORT TITLE)
62601F	FUEL DUMPING
	IMP A/C ON AIR P O
	NUCLEAR SAFETY COMP CODE DEV
	CO_2 EDL RESEARCH
	THEO MOD CHEM LAZ SY
	THEORETICAL STUDIES
	CHEM AERODYNAMIC STY
	DIAGNOSTIC SPT, 1 KW
	SUBSON/PULSE CHEM LAS INV
	OPTICAL COMP EVAL TECH
	LASER BEAM PHASE MSMT
	BEAM DIAGNOSTICS
	PROPAGATION LAB EXPMTS
	PROPAGATION FLD EXPMTS
	THERMAL
	TREE
	SYS APS OF NUC TECH - GEN
	BLAST EFF
	ARGUS EFF
	INT RAD CAL
	OPTICAL IR
	XRAY EFF
	HARD STRUCT
	THERMAL GUST MOD B
	THERMAL GUST MOD D
	SYS ENV - RES CODES
	AERO S/V GEN AC SYS
	AERO S/V GEN MI SYS
	AERO S/V GEN BIO
	AERO S/V GEN B-1
	AERO S/V AABNCP
	KC-135 NUCLEAR HARDNESS STUDY
	NUC VUL AND HARD TECH

Table 4

PROGRAM ELEMENT CODE SHORT TITLES (AFWL) (Continued)

PEC	TASK(SHORT TITLE)
62601F (Cont'd)	ABRES S/V SUPPORT
	MM S/V
	MATERIAL CHARACTERIZATION
	PERTURBED TRAJ PROG
	NCGS ADV TECH I/H
	NCGS SYS GEN I/H
	B-1/1H BOMBER STUDY
	I/H STUDY, ADV TANKER
	NCGS, M-X
	MK-12A CRITERIA EVALUATION
	MULTI-PURPOSE MISSILE/SRBDM
	ELECTRICAL PARAM SCREENS
	ELECTROSTATIC COOLING
	NUC VUL AND HARD TECH
	OPTICAL TECHNIQUES
	PULSED POWER TECH
	THEOR SPT OF SIMU EXPT
	TURBULENT HEATING OF PLASMAS
	SHIVA
	THERMAL PHENOMENOLOGY
	ATMOSPHERIC CHEMISTRY
	WORRY CODE DEVELOPMENT
	NUMERICAL METHODS
	NUCLEAR WEAPON PHENOMENOLOGY
	RADIATION TRANSPORT
	LA SURF DAM IN WIN/THIN EDGES
63605F	DENSITY IN HOMOGEN
	ACOUSTICS/VIB OF LASER DEV
	BASIC GDL RESEARCH
	PULSE EDL
	CONCEPTUAL DESIGN
	ADV SIM CONCEPTS
	AFWL MSL FLT TEST TEMP MEAS

Table 4

PROGRAM ELEMENT CODE SHORT TITLES (AFWL) (Continued)

PEC	TASK(SHORT TITLE)
63605F (Cont'd)	FFT IN-HOUSE EFFORTS
	OPT COMP TST/EVAL
	HIGH POWER TURRET STY
	DIFRACTION GRATING
	OPTICAL MEASUREMENTS
	PHYSICS OF INTERACTION
	SOR SITE INSTR
	SOR SITE INSTRUMENTATION
	EDL FLUID SUP SYS
	EDL EL SUP SYS
	ALL IN-HOUSE DEVICE DEV
	APT IN-HOUSE PROGRAM
	ALL OPTIC INTEGR
	ALL ST DETAIL DNS
	ALL INSTRUMENTATION
	ATB AERO STUDIES
	ATB INTEGRATION
	72C0074 SYS EFF MODEL
	7310014 TRGT VULN CODE
	MATRIC SIM
	BOMBER DEFENSE
	VULNERABILITY STUDIES
	APPLICATION STUDIES
	SYSTEM MODELING
	RESONATORS FOR HP LASER
63723F	TRANS TEST HI REYNOLDS NO
	TAP VEE LOAD CAP
	AIR BASE MODEL VERIFICATION
	ENVIR SUPPORT
	BEST AREA/TIME FLYING
	ECOL IMPACT ASSESS
	ANALYSIS OF BIRD STRIKE

Table 4

PROGRAM ELEMENT CODE SHORT TITLES (AFWL) (Continued)

PEC	TASK(SHORT TITLE)
63723F (Cont'd)	TREATMENT OF PESTICIDES
	AF REFUSE VEH RTG
	CODE ANALYSIS
	AFPAV CODE COMPLETION
	DESIGN EFFECTS CRATERING
	CODE EVALUATION - BDR BACKFILL
	AFWL BDR STUDIES
	RUNWAY ROUGHNESS
	ANAL SKID DATA
64711F	FACILITY UPDATE
	EC-135 ASSESS
	PLANNING AND INTEGRATION
64747F	TRESTLE

Table 5

PROGRAM ELEMENT CODE SHORT TITLES (AF)

PEC	ORGANIZATION	SHORT TITLE
01007F	AFSC/AFSWC	MARTIN BAKER EJEC SEAT TSTS
11213F	AFSC/SAMSO	COMPUTER SUPPORT SAMSO/TRW
		SAMSO COMP SPT
		STRUCTURE MEDIA INTERACTION PROGRAM
		FREE FIELD
61101F	AFSC/DL	DENSE PLASMA FOCUS STUDIES
		PLASMA DIAGNOSTICS
62204F	AFSC/AFSWC	RING LASER
		NUTATRON
		MULTISENSOR
62702F	AFSC/RADC	COMP SPT RADC
63203F	AFSC/AFSWC	NESG
		INI
		INHI
		AIM POINT
63235F	AFSC/AFSWC	LWF NORTHROP
63305F	AFSC/SAMSO	MX SUPPORT
63601F	AFSC/AFSWC	CASM
		IMG IR
63741F	AFSC/AFSWC	PAVE STORM III
64209F	AFSC/AFSWC	TK TEST-EMER ESCAPE SYS F-15
64215F	AFSC/AFSWC	B-1 ESCAPE MOD SLED TS
		B-1 NAVIGATION TEST
64706F	AFSC/AFSWC	UPSTARS
		SKN-2400
65708F	AFSC/AFSWC	CIRIS
65805F	AFSC/AFSWC	SLED PERFORMANCE DATA BANK
		OPS SLED DGN ACQ MOD QUAL
		IMPROVED RECOVERY CAPABILITY
		ADV SLED DESIGN TECH

Table 6

PROGRAM ELEMENT CODE SHORT TITLES (DNA)

PEC	AFWL SUPPORT DIVISION	SHORT TITLE
61102H	Electronics	INTEGRATION/APPLICATION
	Civil Engineering Research	GRD MOTION
	" " "	THEORETICAL SMI STUDIES
	" " "	CYLINDRICAL IN-SITU TEST
	" " "	IN-SITU PROP TSTS
62704H	Technology	GEST
	Electronics	HIGH ALT PROD/PROP
	"	SCEPTRE DOCUMENT
	"	SYS SIM SCEPTRE
	Civil Engineering Research	EXPO I/PACE IV
	" " "	ANAL OF DATA IN FREQ DOMAIN
62707H	Technology	SUPPORT OF UNDERGROUND TEST
	"	FIREBALL PHENOMENA
	"	COMP SPT ISI
	"	METAL OXIDE STUDY
	"	BLAST VULNERABILITY
	"	STRUCTURE INFRACTION
	Electronics	ADV EMP THEO STDY
	Civil Engineering Research	MUTUAL INDUCTANCE VELOCIMETER
	" " "	SMALL SCALE CRAT
	" " "	CRATER AND EJECTOR STUDIES
	" " "	ENERGY COUPL IN EARTH MED
	" " "	TENS BEHAV OF GEOLOGIC MAT
	" " "	MATH SUPPORT
	" " "	GRABS PHASE III
	" " "	SIMUL TECH
62710H	Electronics	ARES TECH DIRECTION

Table 7

WORKLOAD PROJECTIONS BY PROGRAM ELEMENT CODE FOR FY74 THROUGH FY80

PEC	FY74	FY75	FY76	FY77	FY78	FY79	FY80
				COMPUTER REQUIREMENTS (hrs)			
11213F	1005	3000	2500	2500			
61101F	85	115	131	146	177	195	214
62204F	21	27	42	46	37	19	19
62301F	960	489	506	541	589	647	712
62303F	10	13	20	22	18	9	9
62601F	6337	18372	18462	27640	40278	47334	55800
63203F	47	64	96	106	86	45	45
63211F	11	13	13	12	12	12	12
63305F			1000	2000	6750	8100	9720
63311F	12	16	25	27	22	11	11
63601F	83	108	168	186	150	75	75
63605F	[illegible]	662	682	3340	5006	6000	8000
63723F	210	143	[illegible]	136	135	135	135
63741F	6	[illegible]	77	77	77	77	77
64706F	23	16	28	30	25	14	14
64711F	122	149	132	8660	20990	21188	1425
64747F	133	163	144	720	1080	1296	1555
65708F	43	56	88	97	78	39	39
65804D	13	17	[illegible]	25	23	11	11
920K	29	35	33	31	30	30	30
921A	372	467	704	758	626	346	346
921B	294	161	161	161	161	161	161

Table 7

WORKLOAD PROJECTIONS BY PROGRAM ELEMENT CODE FOR FY74 THROUGH FY80 (Continued)

PEC	FY74	FY75	FY76	FY77	FY78	FY79	FY80
			COMPUTER REQUIREMENTS (hrs)				
921C	105	40	[illegible]	36	39	38	38
921W	8	16	16	16	16	16	16
01007F, 62702F, 63235F, 64209F, 64215F, 921Y, 65805F	79	23	49	26	26	24	24
62704H	4589	5896	6420	28780	43170	51804	67164
62707H	240	274	260	1000	1500	1800	2160
62710H	105	130	114	114	114	114	114
61102H		700	800	3200	4000	4000	
TOTAL	15733	31244	32884	80433	125209	143540	148926

SECTION VI

SUMMARY OF PROJECT COSTS, FORMAT A

1. Submitting DOD Component: Air Force Weapons Laboratory
   Air Force System Command
   United States Air Force

2. Date of Submission: 13 March 1974

3. Project Title: A Proposal for Acquisition of a Large Scale Scientific Computer for the Air Force Weapons Laboratory

4. Description of Project Objective:

a. To identify the scientific research and engineering development problems which require vastly increased computational support for solution.

b. To gain approval for installation of a large-scale scientific computer of the following general characteristics:

(1) Central processor speeds of 20-100 times the CDC 6600.

(2) Large-scale fast random access central memory of 1 million 60-64 bit words.

(3) Bulk core storage of 4 million words.

(4) System disk storage of 320 million words.

c. This equipment will be used to augment the currently installed CDC 6600s. The new computer will be installed in close proximity to the AFWL CDC 6600s and will be interfaced to the 6600s. This will allow the CDC 6600 computers to function as scheduler and resource allocator for the new computer so that optimal program mixes can be processed on the new computer. Continued use of the CDC 6600s will eliminate mass rewrites of many codes being run on the CDC 6600. The housekeeping functions to be performed by the CDC 6600 will include allocating to each computer those functions or programs which can be performed best by each. In addition, as the CDC 6600 will be interfaced by a TIP to the AFSC Net, users of the AFSC Net will have access to the new computer.

5. Alternative: There are four alternatives to be considered, and they are Alternative A, Alternative B, Alternative C and Alternative D.

Alternative A - Maintain AFWL CDC 6600 system in essentially its present configuration and provide only that support to projects which are realizable on these existing systems.

6. Economic Life: Present CDC 6600 systems will be beyond the eight year economic life for ADPE specified in AFR 172-2 and AFM 300-12.

Items 7, 8 and 9 are contained in table 8.

10a. Total Project Cost (Discounted): $7,627,707.00.

11. Less Terminal Value (Discounted): Not used.

12a. Net Total Project Cost (Discounted): $7,627,707.00.

13. Source/Derivation of Cost Estimates:

a. Non recurring costs:

(2) Investment - This item covers the projected cost of leased equipment presently being utilized on the CDC 6600 systems by year as follows:

FY 76 - S/N 6 (6600) - $265,350
S/N 43 (6600) - 329,350
$594,700

FY 77
through
FY 84 - S/N 6 (6600) - $262,000
S/N 43 (6600) - 326,000
$588,000 per year

b. Recurring Costs: Since Alternative A is being used as the base line for costs, the following considerations are being used:

(1) Personnel Costs: No costs were identified for military or civilian personnel since no personnel will be added for this configuration. If present personnel costs are desired, they can be obtained from the 996 report.

(2) Operating Costs: Itemized costs are as follows:

(a) Materials

FY 76 Supplies $210,000
Maintenance
Owned Equip 351,733
Leased Equip 106,812
$668,545

FY 77	Supplies	$210,000	
	Maintenance		
	Owned Equip	326,500	
	Leased Eqip	108,000	
			$644,500
FY 78	Supplies	$220,000	
	Maintenance		
	Owned Equip	326,500	
	Leased Equip	108,000	
			$654,500
FY 79	Supplies	$240,000	
	Maintenance		
	Owned Equip	326,500	
	Leased Equip	108,000	
			$674,500
FY 80-84	Supplies	$255,000	
	Maintenance		
	Owned Equip	326,500	
	Leased Equip	108,000	
			$689,500

Note: Utilities are not included as an honest comparison is not available for evaluation.

c. Net Terminal Value: Terminal value will not affect the results of the analysis, as the CDC 6600s will remain at AFWL under all alternatives.

Name and Title of Principal Action Officer: Denzil R. Rogers
Technical Advisor
Computational Services Division
Air Force Weapons Laboratory

Date: 14 May 1974

Table 8

ALTERNATIVE A

8. Project Costs

7. Project Year	a. Non recurring R&D	Investment	b. Recurring Operations	c. Annual Cost	Discount Factor	Discounted Annual Cost
76		594,700	668,545	1,263,245	0.954	1,205,136
77		588,000	644,500	1,232,500	0.867	1,068,578
78		588,000	654,500	1,242,500	0.788	979,090
79		588,000	674,500	1,262,500	0.717	905,212
80		588,000	689,500	1,277,500	0.652	832,930
81		588,000	689,500	1,277,500	0.592	756,280
82		588,000	689,500	1,277,500	0.538	687,295
83		588,000	689,500	1,277,500	0.489	624,698
84		588,000	689,500	1,277,500	0.445	568,488
9. TOTALS		5,298,700	6,089,545	11,388,245		7,627,707

Alternative B - Maintain AFWL CDC 6600 system in essentially its present configuration and rely upon AFSC Net and contractor facilities to provide overflow capability

6. Economic Life: Present CDC 6600 systems will be beyond the eight-year economic life for ADPE specified in AFR 172-2 and AFM 300-12.

Items 7, 8 and 9 are contained in table 9.

10a. Total Project Cost (Discounted): $198,217,218.00.

11. Less Terminal Value (Discounted): Not used.

12a. Net Total Project Cost (Discounted): $198,217,218.00.

13. Source/Derivation of Cost Estimates:

a. Non recurring costs:

(2) Investment - This item covers the projected cost of leased equipment presently being utilized on the CDC 6600 systems and the cost of contract computer time per year as follows:

FY 76 (Lease)

S/N 6 - 6600 Lease		$265,350	
S/N 43 - 6600 Lease		329,350	
			$ 594,700

FY 76 (Contracted Computer Hours)

12,000 hrs	- Run present system		
5,000 hrs	- AFSC Net @ $400/hr	$2,000,000	
3,000 hrs	- 7600 computer @ $188/hr (hrs & cost related to 6600 equiv)	564,000	
1,300 hrs	- Contractor @ $2,600/hr	3,380,000	
3,900 hrs	- Contractor @ $1,200/hr (Above two at current contractor price)	4,680,000	
7,684 hrs	- Contractor @750/hr (Acquired at contractor facilities)	5,763,000	$16,387,000
32,884 hrs			$16,981,700

FY 77 (lease)

S/N 6 - 6600 Lease	$262,000	
S/N 43 - 6600 Lease	326,000	
		$ 588,000

FY 77 (Contracted Computer Hours)

12,000 hrs	- Run present system		
5,000 hrs	- AFSC Net @ $400/hr	$ 2,000.000	
3,000 hrs	- 7600 computer @ $188/hr (Hrs & cost related to 6600 equiv)	564,000	
1,300 hrs	- Contractor @ $2,600/hr	3,380,000	
3,900 hrs	- Contractor @ $1,200/hr (Above two and current contractor price)	4,680,000	
20,000 hrs	- Contractor @ $750/hr (Contractor facilities across U.S.)	15,000,000	
35,230 hrs	-*Contractor @ $100/hr	3,523,000	
80,433			$29,147,000
			$29,735,000

Note: * This contractor will have to be set up by the DOD with a computing facility having a computer with a basic speed of 20-40 times the CDC 6600s and high speed central memory of 1 million words and a 4 million word extended core memory. (Hours and cost have been related to DAR equivalent 6600 hours.)

FY 78 (Lease)

S/N 6 - 6600 Lease	$262,000	
S/N 43 - 6600 Lease	326,000	
		$ 588,000

FY 78 (Contracted Computer Hours)

12,000 hrs	- Run present system		
5,000 hrs	- AFSC Net @ $400/hr	$ 2,000,000	
3,000 hrs	- 7600 computer @ $188/hr (Hrs & cost related to 6600 equiv)	564,000	
1,300 hrs	- Contractor @ $2,600/hr	3,380,000	
3,900 hrs	- Contractor @ $1,200/hr (Above two at current contractor price)	4,680,000	
20,000 hrs	- Contractor @ $750/hr (Contractor facilities across U.S.)	15,000,000	
80,009 hrs	- *Contractor @ $100/hr	8,000,900	
125,209			$ 33,624,000
			$ 34,212,000

* See Note, FY 77

FY 79 (Lease)

S/N 6 - 6600 Lease	$262,000	
S/N 43 - 6600 Lease	326,000	
		$ 588,000

FY 79 (Contracted Computer Hours)

12,000 hrs	- Run on present system		
5,000 hrs	- AFSC Net @ $400/hr	$ 2,000,000	
3,000 hrs	- 7600 computer @ $188/hr (Hrs & cost related to 6600 equiv)	564,000	
1,300 hrs	- Contractor @ $2,600/hr	3,380,000	
3,900 hrs	- Contractor @ $1,200/hr (Above two at current contractor price)	4,680,000	
20,000 hrs	- Contractor @ $750/hr (Contractor facilities across U.S.)	15,000,000	
98,340 hrs	- *Contractor @ $100/hr	9,834,000	
143,540 hrs			$ ~~35,458,000~~ 36,046,000

* See Note, FY 77

FY 80 - 84 (Lease)

S/N 6 - 6600 Lease	$262,000		
S/N 43 - 6600 Lease	326,000		
		(Per Year)	$ 588,000

FY 80 - 84 (Contracted Computer Hours/Year)

12,000 hrs	- Run on present system		
5,000 hrs	- AFSC Net @ $400/hr	2,000,000	
3,000 hrs	- 7600 computer @ $188/hr (Hrs & cost related to 6600 equiv)	564,000	
1,300 hrs	- Contractor @ $2,600/hr	3,380,000	
3,900 hrs	- Contractor @ $1,200/hr (Above two at current contractor price)	4,680,000	
20,000 hrs	- Contractor @ $750/hr	15,000,000	
103,726 hrs	- *Contractor @ $100/hr	10,372,600	
148,926			$ ~~35,996,600~~ $ 36,584,600

* See Note, FY 77

b. Recurring Cost:

(1) Personnel Costs: No added personnel under this consideration so added costs are not incorporated.

(2) Operating Costs: Itemized costs are as follows:

(a) Materials

FY 76	Supplies	$210,000	
	Maintenance		
	Owned Equip	351,733	
	Leased Equip	106,812	
			$ 668,545

FY 77	Supplies	$210,000	
	Maintenance		
	Owned Equip	326,500	
	Leased Equip	108,000	
			$ 644,500
FY 78	Supplies	$220,00	
	Maintenance		
	Owned Equip	326,500	
	Leased Equip	108,000	
			$ 654,500
FY 79	Supplies	$240,000	
	Maintenance		
	Owned Equip	326,000	
	Leased Equip	108,000	
			$ 674,500
FY 80- FY 84/Yr	Supplies	$255,000	
	Maintenance		
	Owned Equip	326,500	
	Leased Equip	108,000	
			$ 689,500

Note: Utilities are not included.

c. Net Terminal Value: Terminal value will not affect analysis as CDC 6600s will remain at AFWL under all alternatives.

Name and Title of Principal Action Officer: Denzil R. Rogers
Technical Advisor
Computational Services Division
Air Force Weapons Laboratory

Date: 14 May 1974

Table 9

ALTERNATIVE B

7.	8. Project Costs					
	a. Non recurring		b. Recurring	c.		
Project Year	R&D	Investment	Operations	Annual Cost	Discount Factor	Discounted Annual Cost
76		16,981,700	668,545	17,650,245	0.954	16,838,334
77		29,735,000	644,500	30,379,500	0.867	26,339,027
78		34,212,000	654,500	34,866,500	0.788	27,474,802
79		36,046,000	674,500	36,720,500	0.717	26,328,599
80		36,584,600	689,500	37,274,100	0.652	24,302,713
81		36,584,600	689,500	37,274,100	0.592	22,066,267
82		36,584,600	689,500	37,274,100	0.538	20,053,466
83		36,584,600	689,500	37,274,100	0.489	18,227,035
84		36,584,600	689,500	37,274,100	0.445	16,586,975
9. TOTALS		299,897,700	6,089,545	305,987,245		198,217,218

Alternative C - Augment AFWL CDC 6600 systems with the purchase of an Advanced Computer System Capable of handling the AFWL Class problems

6. Economic Life: Eight years.

Items 7, 8 and 9 are contained in table 10.

10a. Total Project Cost (Discounted) $28,851,988.00

11. Less Terminal Value (Discounted) Not used.

12. Net Total Project Cost (Discounted): $28,851,988.00

13. Source/Derivation of Cost Estimates:

a. Non recurring Costs:

(2) Investment: The items covered by this alternative include cost of leased equipment presently being utilized on the existing CDC 6600 systems, the cost of and MCP item, and the purchase of an advanced computer system as follows:

FY 76 (Lease Charges)		
S/N 6 - 6600 Lease	$265,350	
S/N 43 - 6600 Lease	329,350	
		$ 594,700
MCP item for addition to computer facility		1,031,000
		$ 1,625,700
FY 77 (Lease)		
S/N 6 - 6600 Lease	$262,000	
S/N 43 - 6600 Lease	326,000	
		$ 588,000
Purchase of advanced computer system		20,000 000
		$20,588,000
FY 78 - 84 (Lease/Year)		
S/N 6 - 6600 Lease	$262,000	
S/N 43 - 6600 Lease	326,000	
		$ 588,000

b. Recurring Costs:

(1) Personnel Costs -

FY 76 0

FY 77

3 civ @ $13,032* =	$ 39,096	
5 mil @ $10,162* =	50,816	
		$ 89,912

FY 78

3 civ @ $13,055* =	$ 39,165	
5 mil @ $10,153* =	50,765	
		$ 89,930

FY 79

3 civ @ $13,061* =	$ 39,183	
5 mil @ $10,203* =	51,015	
		$ 90,198

FY 80 - 84/Year

3 civ @ $13,061* =	$ 39,183	
5 mil @ $10,203* =	51,015	
		$ 90,198

* Figures obtained from 996 report.

(2) Operating Costs: Itemized costs are as follows:

(a) Materials

FY 76	Supplies	$210,000	
	Maintenance		
	Owned Equip	351,733	
	Leased Equip	106,812	
			$ 668,545
FY 77	Supplies	$210,000	
	Maintenance		
	Owned Equip	806,500	
	Leased Equip	108,000	
			$1,124,500
FY 78	Supplies	$220,000	
	Maintenance		
	Owned Equip	806,500	
	Leased Equip	108,000	
			$1,134,500
FY 79	Supplies	$240,000	
	Maintenance		
	Owned Equip	806,500	
	Leased Equip	108,000	
			$1,154,500

FY 80 - 84/Year			
	Supplies	$255,000	
	Maintenance		
	Owned Equip	806,500	
	Leased Equip	108,000	
			$1,169,500

Note: Utilities are not included.

c. Net Terminal Value: Terminal value will not affect analysis as CDC 6600s will remain at AFWL under each alternative.

Name and Title of Principal Action Officer: Denzil R. Rogers
Technical Advisor
Computational Services Division
Air Force Weapons Laboratory

Date: 14 May 1974

Table 10

ALTERNATIVE C

7. Project Year	8. Project Costs a. Non recurring R&D	Investment	b. Recurring Operations	c. Annual Cost	Discount Factor	Discounted Annual Cost
76		1,625,700	688,545	2,294,245	0.954	2,188,710
77		20,588,000	1,214,412	21,802,412	0.867	18,902,691
78		588,000	1,224,430	1,812,430	0.788	1,428,195
79		588,000	1,244,698	1,832,698	0.717	1,314,044
80		588,000	1,259,698	1,847,698	0.652	1,204,699
81		588,000	1,259,698	1,847,698	0.592	1,093,837
82		588,000	1,259,698	1,847,698	0.538	994,062
83		588,000	1,259,698	1,847,698	0.489	903,524
84		588,000	1,259,698	1,847,698	0.445	822,226
9. TOTALS		26,329,700	10,650,575	36,980,275		28,851,988

Alternative D - Augment AFWL CDC 6600 systems with the lease of an Advanced Computer System capable of handling the AFWL Class problems

6. Economic Life: Eight years.

Items 7, 8 and 9 are contained in table 11.

10a. Total Project Cost (Discounted): $29,421,748.00.

11. Less Terminal Value (Discounted): Not used.

12. Net Total Project Cost (Discounted): $29,421,748.00.

13. Source/Derivation of Cost Estimates:

a. Non recurring Costs:

(2) Investment: The items covered by this alternative include cost of leased equipment presently being utilized on the existing CDC 6600 systems, the cost of an MCP item to make room for the advanced system, and the lease of the advanced computer system as shown below:

FY 76 (Lease Charges)

S/N 6 - 6600 Lease	$265,350	
S/N 43 - 6600 Lease	329,350	
		$ 594,700
MCP item for addition to computer facility		1,031,000
		$ 1,625,700

FY 77 (Lease Charges)

Advanced Sys Lease	$3,520,000	
S/N 6 - 6600 Lease	262,000	
S/N 43 - 6600 Lease	326,000	
		$ 4,108,000

FY 78 (Lease Charges/Year)

Advanced Sys Lease	$3,520,000	
S/N 6 - 6600 Lease	262,000	
S/N 43 - 6600 Lease	326,000	
		$ 4,108,000

b. Recurring Costs:

(1) Personnel Costs -

FY 76 0

FY 77

3 civ @ \$13,032* = \$39,096
5 mil @ \$10,162* = 50,816

\$ 89,912

FY 78

3 civ @ \$13,055* = \$39,165
5 mil @ \$10,153* = 50,765

\$ 89,930

FY 79 - 84/Year

3 civ @ \$13,061* = \$39,183
5 mil @ \$10,203* = 51,015

\$ 90,198

* Figures obtained from 996 report.

(2) Operating Costs: Itemized costs are as follows:

(a) Materials

FY 76	Supplies	\$210,000	
	Maintenance		
	Owned Equip	351,733	
	Leased Equip	106,812	
			\$ 668,545
FY 77	Supplies	\$210,000	
	Maintenance		
	Owned Equip	326,500	
	Leased Equip	588,000	
			\$ 1,124,500
FY 78	Supplies	\$220,000	
	Maintenace		
	Owned Equip	326,500	
	Leased Equip	588,000	
			\$ 1,134,500
FY 79	Supplies	\$240,000	
	Maintenance		
	Owned Equip	326,500	
	Leased Equip	588,000	
			\$ 1,154,500
FY 80 - 84/Year			
	Supplies	\$255,000	
	Maintenance		
	Owned Equip	326,500	
	Leased Equip	588,000	
			\$ 1,169,500

Note: Utilities are not included.

c. Net Terminal Value: Terminal value will not affect analysis as the CDC 6600s will remain at AFWL under each alternative.

Name and Title of Principal Action Officer: Denzil R. Rogers
Technical Advisor
Computational Services Division
Air Force Weapons Laboratory

Date: 14 May 19/4

Table 11

ALTERNATIVE D

7.				8. Project Costs		
	a. Non recurring		b. Recurring	c.		
Project Year	R&D	Investment	Operations	Annual Cost	Discount Factor	Discounted Annual Cost
76		1,625,700	688,545	2,294,245	0.954	2,188,710
77		4,108,000	1,214,412	5,322,412	0.867	4,614,531
78		4,108,000	1,224,430	5,332,430	0.788	4,201,955
79		4,108,000	1,244,698	5,352,698	0.717	3,837,884
80		4,108,000	1,259,698	5,367,698	0.652	3,499,739
81		4,108,000	1,259,698	5,367,698	0.592	3,177,677
82		4,108,000	1,259,698	5,367,698	0.538	2,887,822
83		4,108,000	1,259,698	5,367,698	0.489	2,624,804
84		4,108,000	1,259,698	5,367,698	0.445	2,388,626
9. TOTALS		34,489,700	10,650,575	45,140,275		29,421,748

SECTION VII

SUMMARY OF PROJECT BENEFITS, FORMAT B

1. Submitting DOD Component: Air Force Weapons Laboratory
   Air Force Systems Command
   United States Air Force

2. Date of Submittsion: 13 March 1974

3. Project Title: A Proposal for Acquistion of a Large Scale Scientific Computer for the Air Force Weapons Laboratory.

4. Description of Project Objective:

a. To identify the scientific research and engineering development problems which require vastly increased computational support for solution.

b. To gain approval for procurement and installation of a large-scale scientific computer having the following general characteristics:

(1) Central processor speeds of 20-100 times the CDC 6600.

(2) Large-scale fast random access central memory of 1 million 60-64 bit words.

(3) Bulk core storage of 4 million words.

(4) System disk storage of 320 million words.

c. This equipment will be used to augment the currently installed CDC 6600s. The new computer will be installed in close proximity to the AFWL CDC 6600s and interfaced to the 6600s. This will allow the CDC 6600 computers to function as scheduler and resource allocator for the new computer so that optimal program mixes can be processed on the new computer. Continued use of the CDC 6600s will eliminate mass rewrites of many codes being run on the CDC 6600. The housekeeping functions performed by the CDC 6600 will include allocating to each computer those functions or programs which can best be performed by each. In addition, as the CDC 6600 will be interfaced by a TIP to the AFSC Net, users of the AFSC Net will have access to the new computer.

5. Alternatives:

a. Alternative A - Maintain AFWL CDC 6600 system in essentially its present configuration and provide only that support to projects which are realizable on these existing systems.

b. Alternative B - Maintain AFWL CDC 6600 system in essentially its present configuration and rely upon AFSC Net and contractor facilities to provide overflow capability.

c. Alternative C - Augment AFWL CDC 6600 systems with the purchase of an Advanced Computer System capable of handling the AFWL Class problems.

d. Alternative D - Augment AFWL CDC 6600 systems with the lease of an Advanced Computer System capable of handling the AFWL Class problems.

6. Benefits/Disadvantages:

a. Alternative A - This configuration cannot be considered a solution to the problem at hand. Section IV and table 1 of the DAR identify the areas which will be impacted if DAR-AFSC-B-74-124 is not approved. If this alternative is chosen, it will not only mean that the areas of study identified in section IV and table 1 of the DAR will be curtailed but it will mean that within two to five years, the capability to perform those types of computation will have deteriorated to a point where it is no longer useful to the Air Force or DOD.

b. Alternative B - This alternative cannot be considered a reasonable solution for the following reasons:

(1) Cost is totally prohibitive.

(2) Personnel efficiency would be watered down to such a point that a high percentage of their time would be expended in modifying programs for the many, many machines they would be forced to use instead of advancing scientific problems at hand.

(3) Additional difficulties would be experienced in handling the SECRET and TOP SECRET runs required.

(4) This alternative would force DOD or Air Force to establish a contractor and supply the computer system to the contractor in order to support the class of computer problem identified in section IV and table 1 of the DAR. This approach would prove to be the most expensive by far.

c. Alternatives C and D - Either alternative would be an acceptable solution, since either would provide an advanced computer system capable of addressing problems identified in section IV and table 1 of the DAR. Since there appears to be some activity with manufacturers, at this time, in the development of advanced computer systems, the Air Force Weapons Laboratory recommends leasing the system proposed in this DAR until such time as it becomes economically feasible to purchase it. Leasing would, likewise, assure that the system possesses the capability to meet the advanced scientific problems encountered at the Air Force Weapons Laboratory.

APPENDIX

ADDITIONAL INFORMATION

Section II of this DAR contains a discussion of the formulation of physical problems for numerical solution on a computer. It goes on to describe how increasingly complex problems require a corresponding increase in computational power to obtain solutions. For example, it shows how increasing dimensionality and increasing the amount of physics increase the need for more speed and memory.

Section IV contains an unclassified discussion of current Air Force scientific problems which are absolutely beyond the computational capacity of the CDC 6600. Table 1 lists these problems and the affected Air Force systems.

The following amplifies several points in the DAR:

a. Multiburst Environment (Ref. table 1 and section IV).

(1) The description of the nuclear environment following detonation of several nuclear devices at low altitudes is one of the most pressing Air Force scientific problems at the present time. Modern weapon development, especially the increased emphasis on MIRVed reentry systems, suggests that weapon systems upon which the national defense is based will encounter such an environment. The Advanced Ballistic Reentry System, Minuteman, the Minuteman follow-on, and the advanced ballistic missile defense systems of the Hard Site Defense program are examples of missile and reentry vehicle systems which must enounter, penetrate and survive a multiburst nuclear environment and still remain functional and on-target. Increasing emphasis on the counterforce role of the U.S. strategic nuclear forces intensifies the problems relating to survivability and targeting accuracy which is always constrained by the natural and even more so by the nuclear environment. However, systems designers, operational planners, and targeteers have absolutely no experimental data describing a multiburst environment which they can use as a basis for making decisions in survivability/vulnerability studies, war gaming, targeting, battle-space management or developing and engagement philosophy. No data exist because the U.S. did not conduct multiburst experiments when atmospheric nuclear testing was possible. Therefore, the theoretical predictive capability developed at the AFWL, described in the subject DAR and made possible by modern scientific computers, constitutes the sole source of such information

under the terms of the Nuclear Test Ban Treaty.

(2) The multiburst environment is inherently three-dimensional and, therefore, beyond the calculational capacity of the largest, fastest scientific computers in use today. However, the AFWL, as the lead laboratory in the Integrated Nuclear Weapon Effects Program, was tasked to investigate several targeting scenarios for the Joint Strategic Target Planning Staff and to provide inputs toward resolving several questions relating to the multiburst environment for the American negotiators at the Strategic Arms Limitation Talks. Therefore, scientists at the AFWL, using three-dimensional radiation/hydrodynamic codes already developed and present computational capabilities, solved a very restricted class of multiburst problems. Using such mathematical "tricks" as planes of symmetry, they were able to make predictions of simultaneous multiple nuclear detonations of equal yield and occurring at the same altitude; that is to say: the computing power of present computers restricts the present predictive capability for multibursts to equal yields, at equal altitudes, at the same time. The more general and more realistic case of non-simultaneous bursts of varying yields occurring at various altitudes is absolutely beyond the capability of any computer in use at any AEC or DOD laboratory. Fourth generation equipment is required to attack these problems which must be solved.

b. EMP Effects

(1) The Air Force systems previously listed require analyses of the nuclear environment and effects associated with the hardened system. Present computational capability permits one- and two-dimensional simulation of close-in EMP effects in a free-field environment (i.e., no system structure present). The close-in EMP system interaction problem requires the incorporation of the details of the system components into such effects analyses. This makes the problem three-dimensional and beyond the capability of all scientific computers in use today. Considerable work has gone into attempting to approximate these effects in crude ways. The approximations used are of unknown validity and, thus, analysis using the 6600 computer has not been feasible. The three-dimensional problems could be solved with known techniques on fourth generation equipment.

(2) Another problem in the EMP area is the simulation of large networks to determine system hardness and to assess system survivability. Codes in use today on present computers permit simulation of networks with up to 500 elements. However, computers in use today are incapable of handling problems that contain digital-analog interfaces, nor can they support general systems

analysis codes which must simulate networks of up to 10,000 elements. The numerical techniques to handle these classes of problems have been developed. Only the arrival of a fourth generation computer will permit an attack on the full-scale simulation problem.

c. Laser Weapons

The Airborne Laser Laboratory (ALL) and prototype laser systems require three-dimensional structural dynamic analyses. The ALL has four major components which must be modeled: the aircraft, the optical bench, the airborne pointing and tracking system (APTS) and the airborne dynamic alignment system (ADAS). To date, a model of the optical bench with 630 degrees of freedom has been generated but cannot be supported by present computational capability without reducing the scope of the problem to 168 degrees of freedom by constraining some members. An ALL fuselage model with 1700 degrees of freedom, reduced to 260 degrees of freedom to fit on the computer, is also in use. Ultimately, the bench and aircraft models will have to be integrated with an APTS model and and ADAS model which are now in development. While each individual model can be handled on a reduced scale on a CDC 6600, modern scientific computers that are currently in use cannot support these integrated codes.

The Defense Nuclear Agency (DNA) is the focal point for nuclear weapon effects research (NWER) in the Department of Defense. It is responsible for supporting the requirements for NWER of all the services. Each service determines its requirements and presents them to DNA. DNA funds each service to perform research in-house or on contract. In the case of the Air Force, the Commander of AFWL chairs the AF NWER Council which includes representatives of various AF organizations involved in NWER. The Council compiles the requirements and prioritizes them. It publishes the NWER requirements document annually. The proposals then go to DNA for funding. Therefore, the NWER computing performed at AFWL is in direct support of AF systems. Of course, the results are also of interest and use to the other services. DNA is the source of funds for this research. (Ref. AFR 80-38; also pp 1 and 2 of the DAR).

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