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## RESEARCH REPORT

CHEYENNE MOUNTAIN SYSTEM ACQUISITIONS:

PROBLEMS AND PRINCIPLES



LIEUTENANT COLONEL ELLIS K. CONOLEY

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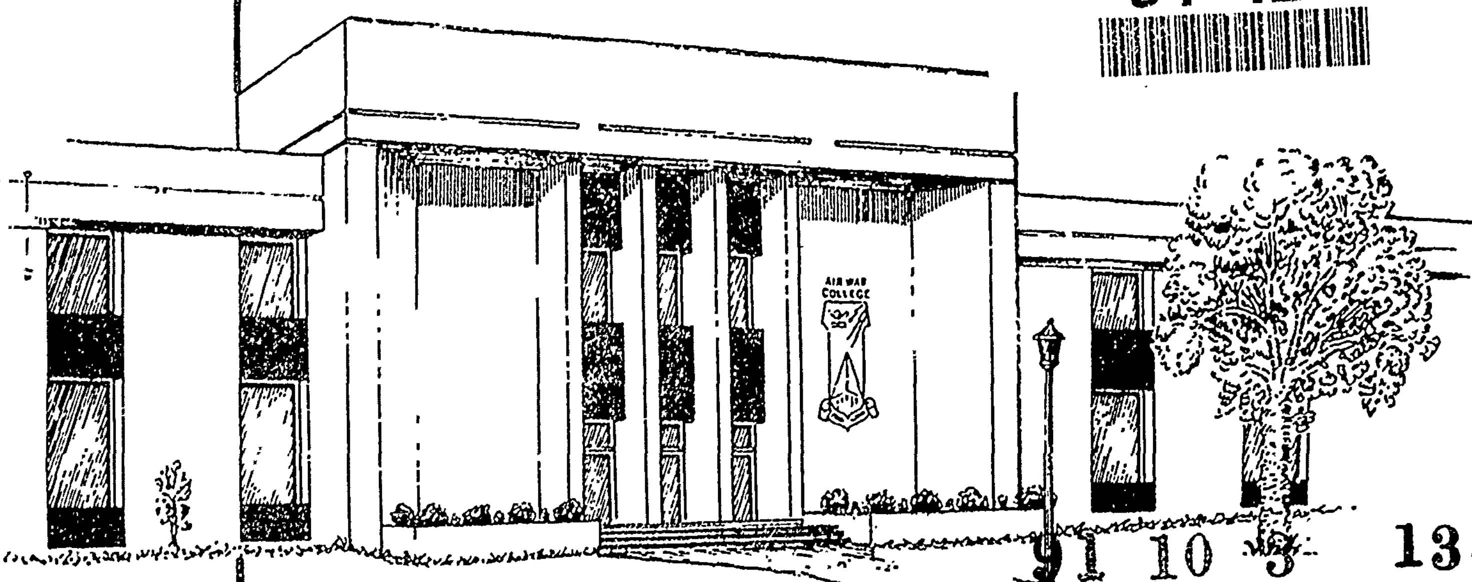



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# CHEYENNE MOUNTAIN SYSTEM ACQUISITIONS: PROBLEMS AND PRINCIPLES

by

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A DEFENSE ANALYTICAL STUDY SUBMITTED TO THE FACULTY

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# EXECUTIVE SUMMARY

TITLE: Cheyenne Mountain System Acquisitions: Problems and Principles

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Acquisition of computer systems for the NORAD Command Post at Cheyenne Mountain has been problematic throughout its entire history. The acquisitions have been characterized by unrealistic specifications, budget overruns, slipping schedules and ill-defined responsibility in each of the three historical programs--NOCOPS, 427M and the Cheyenne Mountain Upgrades. When problems were encountered in each of these phases, intervention by high command levels was necessary in order to achieve operational capability. An historical study of these problems and solutions leads to principles which were shown to work in the Granite Sentry Program, and which should be required in future Cheyenne Mountain acquisitions.

## BIOGRAPHICAL SKETCH

Having been involved with Cheyenne Mountain computer systems at various times from 1972 through 1989, the author brings a unique set of experiences to bear on the analysis of the Cheyenne Mountain acquisitions. From 1972-1975, as an orbital analyst in the NORAD Space Defense Center, the author gained operational experience as a user of the original NORAD Combat Operations Program Systems. From 1975-1977, he obtained through the Air Force Institute of Technology a Master's Degree in Computer Science from the University of Texas at Austin. From 1977-1985, as a computer software project manager, he monitored the implementation of the 427M system, and he was involved with upgrades to radar and optical systems which interface to NORAD. From 1986-1987, at HQ AFSPACECOM, he was the branch chief over the development of CSSR and CCPDSR. Finally, from 1987-1989, the author was the project leader for the AFSPACECOM Granite Sentry Development Office. Thus, the author has had the opportunity for over 17 years to observe various phases of the development and implementation of the increasingly complicated Cheyenne Mountain computer support systems.

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## DEDICATION

This paper is dedicated to every one of the members of the Granite Sentry team. Without them there would have been no success. It is dedicated to my father, Air Force Colonel (Ret) Rufus K. Conoley, and mother, Maxine, who have always provided just the right amount of support. Finally, it is dedicated to my wife and children who continually interrupted me (with encouragement) while I was writing. Without them it would not have been worth the effort.

## PREFACE

Over the last 17 years, my service career has provided me with direct, personal experience with all three of the major phases of the NORAD computer systems. As a user in the original NORAD Combat Operations and Space Defense (425L/496L) system, I witnessed the difficult implementation of its replacement, the 427M system. After the notorious false events of 1979 and 1980, I was a low level participant in the investigation team which recommended improvement of test control procedures.

For six years of working on programs which interfaced with the 427M system, I observed the Cheyenne Mountain Upgrades. For 6 months in 1986, I supervised the harassed AFSPACECOM managers who simultaneously were attempting to get the CSSR Block I on line, were answering GAO complaints, and were assisting their Electronic Systems Division counterparts in getting the CSSR Block II on contract. During that time, we discovered that no one possessed a complete copy of the CSSR specifications--not even the contractor who was bidding an old specification. Requirements for the replacement system could not be articulated because the user who specified them could not be identified. By August 1986, Cheyenne Mountain programs were a source of frustration to all interested parties.

Soon after it was established, the Air Force Space Command was directed to accomplish Granite Sentry on time, within budget, and by ourselves if necessary. I was placed in authority over that program and was tasked along with Lieutenant Colonel Pete Maravelias and Captain Steve Shively to work out a plan that would be successful. Fortunately, we had the devoted help of Major Generals Spraker, Brandt, Cassity, and Clark as well as then Colonel Gray. Their interaction, insight, and foresight forged the agreement which allowed Granite Sentry Phase I to reach operational capability.

These personal experiences have led me to investigate the historical environment of Cheyenne Mountain in an effort to understand the factors which have made the development of computer systems for the mission so difficult. Valuable insights into these problems have been made at each stage of the acquisitions. It is my hope that these principles may be used to formulate a model for successful future acquisitions.

Acknowledgment: A special gratitude is due my brother Patrick who was a tireless editor.

# CHAPTER I

## INTRODUCTION

The North American Aerospace Defense Command (NORAD), a bi-national United States and Canadian command, is responsible for detecting an air or missile attack on North America, assessing the nature of the attack, and notifying United States and Canadian leaders of the attack. This mission is accomplished through a system of space and air surveillance sensors, communication devices, and computers which pass data to information processing centers at Cheyenne Mountain Air Force Base near Colorado Springs, Colorado. These centers pass the processed surveillance information to the NORAD Command Post (NCP), also located within Cheyenne Mountain. The duty of the Command Post is to assess the information it has received and to complete the proper notification in a timely manner. The successful functioning of this warning system is a pillar of deterrence.

The command centers in Cheyenne Mountain are operated by the United States Space Command (USSPACECOM), a unified command made up of the Air Force Space Command (AFSPACECOM), the Army Space Command, and the Naval Space Command. Located at Peterson Air Force Base near Colorado Springs, USSPACECOM is responsible for ensuring that NORAD is supported with the computer systems it needs to perform its critical warning and assessment mission.

AFSPACECOM implements the support, and the Electronic Systems Division (ESD) of the Air Force Systems Command (AFSC) serves as acquisition agent.

Historically, NORAD computer acquisitions have been characterized by changing requirements, schedule delays, and budget overruns. These have led to repeated investigations by Congress, by the United States General Accounting Office, and by Department of Defense agencies. This paper discusses the history of these acquisitions in order to understand the factors which have contributed to these problems and to determine principles which, if implemented, may improve the acquisition process.

## Problem Statement

What factors historically have contributed to problems with Cheyenne Mountain system acquisitions?

What principles historically have been successful and may contribute to future successful acquisitions?

## Assumptions

Recently, investigators have attempted to measure the success of programs by cost effectiveness, i.e., fielding a system as capable as possible, as close to schedule as possible, and for the appropriate cost. (1:28) These criteria are used in this paper to measure the success of a program from the management point of view. The operational measure of a successful program is, however, subjective. If the system does not meet the user's basic needs, then meeting the job specification on time and within budget does not matter. The user must be satisfied.

## Limitations

The author's years of involvement with the Cheyenne Mountain computer systems provide a unique, personal point of view for this study. Many statements are based upon personal observation and are difficult to verify independently. Also, the author's involvement with a relatively successful phase of the upgrade program introduces some bias. Similarly, hindsight bias can perturb analysis in a field of rapidly changing technology such as computer science. (2:22) It is hoped that careful analysis will minimize these potential problems.

Organizations and relationships in these acquisitions are extremely complex. To some extent, they have been simplified to make the subject comprehensible by the general reader.

There are limits to what can be done in a short time by a single researcher. There is a wealth of writings on program management, software development, and leadership. Even after the effort spent by this researcher, some excellent advice pertinent to environments like Cheyenne Mountain may have been missed.

## Background Information

Command and control systems have several features which distinguish them from other systems. These systems are software dominated and are generally implemented on commercial off-the-shelf hardware. (3:20) They are one-of-a-kind systems with the development model being the final operational product. (3:19) They are information systems which must perform acceptably with imperfect information and which must degrade gracefully under stress. (4:5) They greatly reflect the personality of the commander using them and therefore require flexibility. (4:5) Success of command and control systems is difficult to define because performance measures for these systems are ultimately subjective. (3:19) Finally, these systems are typically embedded within a larger framework of interconnected systems. (3:19)

Complex systems historically have been implemented by either a conventional or an evolutionary acquisition strategy. The conventional strategy is designed for systems with well-understood requirements needing little refinement during development. "A conventional acquisition strategy requires a detailed definition of the capabilities and characteristics of the *entire* system before starting full-scale development." (4:6) This strategy produces turnkey systems, which are intended to be finished products. Conventional strategies have traditionally been overseen contractually by the military, but have been managed by civilian agencies who are contracted to deliver the specified product. With civilian contractor management, changes in the program require renegotiation of the contract.

The <u>evolutionary</u> strategy is designed for systems which will change, or evolve, during development but which remain within a defined architectural framework. (4:3) An evolutionary strategy addresses

> ... the need to field a well-defined core capability quickly in response to a validated requirement, while planning through an incremental upgrade program to eventually enhance the system to provide the overall system capability. (4:3)

With evolutionary acquisitions, management by the military is possible with contractors responsible for specific tasks within the greater acquisition.

For NORAD systems, when Air Force Systems Command (AFSC) is the acquirer, a System Program Office (SPO) is assembled with the SPO director as the single agent responsible for acquisition. (5:8) When Air Force Space Command (AFSPACECOM) is involved with an acquisition, a Command Manager (CM) represents AFSPACECOM on all matters relating to the acquisition. (5:9-10)

## Contents

This examination begins in Chapter II with a history of the original NORAD Combat Operations System (NOCOPS, or 425L) and the original space defense computational system (496L). Chapter III treats the Cheyenne Mountain Improvement Program (427M) which replaced the original programs. Chapter IV begins with the Cheyenne Mountain Upgrades which are designed to replace 427M and concludes with the formulation of the Granite Sentry agreement. Chapter V presents the principles incorporated into the plan for the Granite Sentry acquisition. Chapter VI covers the implementation through 1989 of Phases I and II of Granite Sentry. Each of the foregoing chapters attempts to elucidate the factors which have complicated and the principles which have facilitated the acquisition process at each stage. Chapter VII summarizes the principles learned from this historical analysis and which, if implemented, may help to structure a better Cheyenne Mountain acquisition model.

# CHAPTER II

## THE ORIGINAL SYSTEMS

There are three historical stages of the Cheyenne Mountain information system. The first stage was the 425L NORAD Combat Operations System (NOCOPS) and the associated 496L space defense computational system. These, and other related systems, were hosted on multiple processing units. The second was the Cheyenne Mountain Improvement Program (427M), a relatively monolithic system which replaced the first system in 1979. The Cheyenne Mountain Upgrades, which includes Granite Sentry, is the third stage which is currently replacing 427M by a distributed architecture system. This chapter discusses the development of the original 425L and 496L systems.

In 1959, the Air Force began to construct a survivable Combat Operations Center (COC) to house the operational NORAD centers. (6:2) (7:1) These included the NORAD Command Post, the Battle Staff Support Center, the Weather Support Unit, and the Air Defense Operations Center (ADOC). An information processing system, designated 425L, would be developed to support the COC. All of the centers would have appropriate communications links as well as closed-circuit television displays. (7:28)

Through 1959, the Air Force mission of the COC was to counter a manned bomber threat. However, with the increasing missile threat at the turn of the decade, Headquarters USAF re-directed planning to stress missile attack warning and space computation. (6:2) The Air Force planners were thrust from a comfortable, well-understood bomber defense to one involving concepts and software which had not yet been developed.

Recognizing the problems inherent in developing complex systems, the Department of Defense commissioned the 1960 Winter Study Panel to overview the issue. The panel expressed concern over the difficulties of integrating systems in the absence of a consistent set of operational objectives and standards for system design. (8:2) It recommended an evolutionary acquisition approach for one-of-a-kind systems. (8:1) Following the Winter Study recommendations, requirements dated 19 June 1961 directed that 425L be acquired in a five-phase evolutionary manner, that an experimental test facility be constructed, and that the program be managed by the military. (6:3) The program would utilize commercial off-the-shelf equipment from industry or from government sources. (6:3) (7:27) Two not-for-profit corporations, the MITRE Corporation and System Development Corporation, were designated as system designer and software developer, respectively. The Electronic Systems Division (ESD) of Air Force Systems Command (AFSC) would serve as acquisition agent for the project.

For the next four years 425L was evolved through four pre-operational phases. Several other programs under simultaneous development by other governmental agencies were required to be included in the COC and to be integrated with the

425L system. (6:3) These programs were the Defense Communications Agency communications processors, the Intelligence Data Handling System (IDHS), the Ballistic Missile Early Warning System (BMEWS) Display Information Processor (DIP), a display distribution system, and the closed circuit television system. (40:6) As a result of the diverse programs, independent organizations, and interfaces, the equipment configuration changed many times. (7:36) Other changes concerned how the space tracking system, 496L, would interface with the 425L system. The agencies involved with NORAD could not agree on the integration requirements or a baseline, resulting in halting progress, program slips, and increased cost. (7:36)

Progress on Cheyenne Mountain integration languished. On 29 October 1963, the US Department of Defense Office of Development, Research and Engineering brought its concern over the changing requirements, increasing costs, slipping schedules, and integration problems to the attention of the Secretary of Defense. (7:27) In December, the Secretary directed CINC NORAD to appoint the Cheyenne Mountain Complex Task Force to study in depth the "requirements, technical design, operational plan, and acquisition management for the NORAD COC complex of systems in Cheyenne Mountain." (42:44) The term "Cheyenne Mountain Complex" (CMC) was formalized to mean all of the computer systems within the mountain. (7:27) The task force recommended that a single agency be appointed responsible for Cheyenne Mountain integration. (41:74)

As a result, the Secretary of Defense directed the formation of the Cheyenne Mountain Complex Management Office (CMCMO), a single manager responsible for bringing the COC to initial operational capability (IOC). The CMCMO was headed by an ESD officer with a NORAD deputy. (41:74) The ESD Program Director reported to the ESD Vice Commander. (9:44) The NORAD Deputy personally represented CINC NORAD. (7:39) With the exception of the contracting officer, the entire team was located in Colorado Springs. Other implemented recommendations were a finalized, baseline equipment configuration, the separation of missile warning from space defense, and the continuation of the experimental test facility. (7:40)

With the formation of the CMCMO in July 1964, the individual programs began to see real progress. Within 18 months, the 425L system reached IOC. (6:4) In all, eleven other systems were integrated with 425L over the next four years, including an early version of the Command Center Processing and Display System (CCPDS) which was necessary to provide a catastrophic failure backup for 425L and the DIP. It also gave CINC NORAD the same display of the same information seen in the Strategic Air Command (SAC) command post. Interface to 496L, however, remained manual.

In its Cheyenne Mountain Complex Final Technical Review (CMCFTR) of May 1966, the CMCMO summarized the key points which finally led 425L and 496L to successful completion, and it recommended that they be used in similar programs in the future. System flexibility was essential because of constant change in the world environment and because of changes in the interfaces dictated by changing system users. (6:26) The evolutionary growth concept was a major contributor to success. There must be sufficient [illegible] between stages to allow lessons learned in one stage to [illegible] porated in the next. (6:28) Operational test-beds and a mock-up of the command post should be located close to the user but remain under the developer's control to prevent the user from using the test-bed operationally and interfering with testing. (6:26) The design, hardware, and contractor management should be be controlled by the military rather than by contractors. This approach was perceived to give maximum effect for minimum dollars expended. (6:28) Finally, a sizeable detachment of the program office should be collocated with the user. Collocation reduced response time and facilitated turning the system over on schedule. (6:28)

In summary the system was a one-of-a-kind product which pushed the state of the art of computer science. Performance requirements were changing during implementation, and interfaces were challenging due to the use of multiple hardware types. Management was fragmented with unclear channels of responsibility and authority to see that the program was executed. The Secretary of Defense directed formation of a single management organization which brought the SPO to the user and the original systems to operational status.

## CHAPTER III

## THE CHEYENNE MOUNTAIN IMPROVEMENT PROGRAM

As the 425L and 496L systems reached IOC in 1966, there were projections of growing Soviet ballistic missile capabilities and a steady increase in the number of earth orbiting objects. Within a decade, the existing systems would be inadequate for NORAD's mission requirements. (10:7) Further, the equipment was first generation, transistor vintage. As it aged, there would be growing problems with reliability and parts availability. Finally, Cheyenne Mountain had no uninterrupted power supply; power fluctuations within the CMC had damaged system hardware, sometimes with loss or alteration of data. (10:7) Consequently, in June 1969, NORAD began formal planning of the Cheyenne Mountain Improvement Program 427M, a replacement for 425L, 496L, the Display Information Processor, and their communications systems. This replacement was thought to entail a simple rehosting of existing software to more capable computers. (11:25) After the rehosting reached IOC, the program would evolve whatever additional capabilities were needed. Unfortunately, the contracting structure did not support the evolutionary phase of the effort. (12:85)

In order to address the previous problem of multiple interfaces, 427M was designed to be more monolithic than the distributed systems it replaced. The number of mainframe computers would drop from 11 to two. These two machines would perform all of the space, air, missile warning, and command and control functions. (11:25) This approach appeared valid since the computer systems of the era far exceeded the memory and processing capabilities of the original systems. Using only two mission machines would also minimize cost. The Department of Defense specified that the computers be Honeywell mainframes, a business-oriented system used in the World Wide Military Command and Control System (WWMCCS). (11:38)

Once again, as with the 425L acquisition, the 427M System Program Office (SPO) office was established at ESD in Massachusetts rather than in Colorado Springs. (11:45) In October 1969, citing the success of the CMCMO, NORAD requested a permanent ESD presence in Colorado Springs. (11:45) Consequently, AFSC and ESD renamed the 425L/496L Field Office as the 427M Field Office, but did not give it any decision-making capability or local engineering support. (11:45) The SPO remained in Massachusetts.

In 1971, MITRE, ESD, and NORAD jointly published the technical requirements which defined the specifications for contractors bidding on 427M contracts. The program was partitioned into three major segments, all of which would be developed simultaneously. The NORAD Computer System (NCS) would replace the 425L system, the DIP, and the CCPDS, consolidating missile warning functions into one system. (10:9) The Space Computational Center (SCC) would replace the 496L system. The communications processors and technical control would be replaced by the Communications System Segment (CSS). Each of these systems would be connected to display consoles via a modular display system, and the existing closed-circuit television and large group displays would be interfaced to the 427M system.

Software contracting for 427M was cumbersome. (11:34) In October 1972, the Philco-Ford Corporation was awarded an overall 427M integration and communications contract. System Development Corporation won the SCC contract in early 1973. System Development was also responsible for the hardware for the display system which Ford would have to integrate. (13:1328) NORAD would provide the software for the NCS.

Within a few months, Ford had subcontracted to System Development for software work, and System Development had subcontracted to Ford for software work! (10:33) Contract administrators were fearful that efforts would be confused, and the Defense Contract Audit Agency saw the reciprocal arrangements as an opportunity for overcharging, fraud, and finger-pointing when the schedule slipped. (10:36) However, the arrangements had to continue lest the program lose time during recompetition.

In 1974, ESD predicted a program slip and cost growth. AFSC determined that a third mission-processing node would be required to meet the processing and availability requirements. It also recommended improvements in the contractor-to-SPO communications and that NORAD assume more of the software development tasks. Funding was increased, the schedule was slipped, and the third node was added. However, the recommendations for software development and improved communications were not followed. (11:25)

In 1975, the program office announced a further slip. NORAD again insisted that the SPO be located at Colorado Springs and that it be given decision-authority. NORAD also insisted on close coordination with ESD and close, consistent direction of the contractors. (11:55) AFSC agreed to move 427M program management to Colorado Springs, but kept its business management in Massachusetts. AFSC would retain overall project authority, and NORAD would perform more programming in-house. (11:55)

The requirements of the program were prioritized so that the software teams could concentrate on the essential. NORAD assumed responsibility for the NCS software integration, for SCC software, and for CSS expansion software. It increased its role in testing 427M, it deleted a major requirements package in a common display set which was to reside on the SCC, and it agreed to an earlier implementation. (11:55) Finally, the SCC contract was restructured according to NORAD direction. (11:56) In short, 427M was modified to be a design-to-budget effort. (11:55) The baseline, however, was not yet frozen. (11:56)

Work progressed on the individual pieces of 427M. Even though the WWMCCS equipment was ill-suited for the job, it was beginning to function, although not to performance specification. In 1976, NORAD raised 427M to first priority status, (11:61) and all NORAD program management was concentrated under a single manager as Assistant to Vice CINC

ADCOM (the USAF component of NORAD) for 427M. (14:65) In April 1976 NORAD assumed responsibility for system engineering, integration, and test for the entire 427M system. (11:62) MITRE performed as system engineer for NORAD and provided engineering support to ESD. ESD maintained responsibility for the CSS program. (10:33)

In 1977, the program failed a major milestone when the CSS was not ready for testing as a complete system. As a result, NORAD requested an Independent Review Group (IRG) to assess the program. The IRG noted that management had been fragmented-- there was no single point of contact for the program. Guidance to software developers came from several NORAD organizations, and differing direction arrived from ESD. (11:64) (13:1328) The IRG concluded that

> joint management of 427M [had] hampered the program's progress. ESD's integration role was very narrow and inadequate from a systems viewpoint. [NORAD] was without a systems engineering resource ... The divergent interests and the difficulties encountered [indicated] that total management responsibility should be vested in a single authority. (10:32)

Finally, recognizing the difficulty of meeting the overstated specification and matching the performance of the original systems, the IRG concluded that 427M should be declared operational when it reached an equivalent functionality with the old system. This state was referred to as "equivalent operational capability" (EOC). (11:38) Following the IRG's recommendations, CINC NORAD agreed to take operational control of 427M and bring it to EOC with continued MITRE engineering and

ESD contract support. (11:65)

CCPDS was originally intended to be replaced as part of 427M. However, 427M did not meet the availability of the old systems, and the need for a more available missile warning function was apparent. Two programs were produced to ensure near continuous missile warning availability. The first was the Mission Essential Backup (MEBU) software which was hosted on the CCPDS computers. (11:57) The second was the Missile Warning Bypass (MWBP), a communications system which bypassed CSS. While there were reasons for building these systems, no criteria were given for an availability of 427M which would allow their elimination.

The 427M system requirements were an excellent example of the "second system effect". (15:55) The first system built to perform a task is usually constructed carefully and with restraint. The second, or replacement, system, however is usually overdesigned. All the frills and ideas which were set aside on the first system tend to be included in the second system. (15:55) These additions, plus the natural tendency to produce a perfect system, can lead to impossible requirements. The original 427M specifications simply were not attainable with the technology of the times. (13:1327) Compounding the problem, continued software baseline changes had improved 425L and 496L so much that by 1977, when 427M arrived at 1974-level performance, the new system was three years of changes behind. (11:23) The defining of "Equivalent Operational Capability" by the IRG was an acknowledgment that 427M was far short of the requirements.

In summary, limitations of a business computer system, a limited commercial operating system which had to be enhanced in mid-stream, and the addition of non-WWMCCS interface computers were significant obstacles. The NORAD programming agency continued to release versions until 1977. Contractors proceeded with the bidding, hoping that engineering change proposals (ECP) would correct financial as well as schedule problems. (13:1327) But the entire original CMC system could not simply be rehosted to a modern computer system, and the requirement to automate the original space manual operator functions and display functions was beyond the scope of 1970's technology. (10:215) The assumption was erroneous that a modern, time-sharing system could exceed the capabilities of the 11 distributed systems of the vintage mountain. Specifications were not adjusted to the reality of the hardware and software system until near the end of the program. However, in three extra years, with twice the originally budgeted funds, and under the criticism given by numerous monitoring agencies, 427M eventually reached the first stage of its evolution, EOC, in September 1979.

Thus, the 427M acquisition suffered from many of the same problems as the original system. There was no single authority to ensure execution of the over-ambitious, one-of-a-kind project with rapidly changing requirements whose management was located remote from the user. NORAD involvement escalated until it was responsible for integration and all of the software except communications. Bringing 427M to EOC req  red user involvement in a single integration organization, mov  g a portion of the SPO to Colorado Springs, and military management of the contractor resource by both ESD and NORAD. No real progress was made until the user component was moved under the Vice Commander.

# CHAPTER IV

## THE CHEYENNE MOUNTAIN UPGRADE PROGRAMS

On 9 November 1979 and again on 3 and 6 June 1980, the 427M system transmitted missile attack indication messages to SAC and to the National Military Command Center in Washington. Consequently, 427M became the subject of a series of investigations which concluded that the fragmented management of its acquisition was a prime reason for its problems. (16:13) In the paper, NORAD Computer Systems are Dangerously Obsolete, the House of Representatives confirmed that 427M needed to be replaced. (17:17) The replacement programs for the 427M system were designated the Cheyenne Mountain Upgrades (CMU). (18:1)

The upgrades were to implement a distributed architecture tied together by a robust Communications System Segment Replacement (CSSR). The CSSR would handle all CMC internal and external data communications with the exception of certain intelligence information. (19:13) Missile warning functions on the NORAD Computer System (NCS), the Mission Essential Backup (MEBU), and the Command Center Processing and Display System (CCPDS) would be replaced by the Command Center Processing and Display System Replacement (CCPDSR). Space surveillance functions would be replaced by the Space Defense Operations Center (SPADOC). The formal program start was early 1981, with a scheduled completion of March 1987. (17:18) The remainder of the NCS functions of Battle Staff Support, Weather, Air Defense, the NORAD Command Post, and the production of integrated displays were to be consolidated into the NCS Replacement (NCSR). (18:4) A conventional strategy was selected for the CSSR, SPADOC, and CCPDSR acquisitions. Each of the System Program Offices was located in Massachusetts. The acquisitions were to be turnkey, but were to be acquired in increments. Specifications were written, competitions run, and contracts awarded.

Immediately, CSSR began to experience growth in requirements and cost. By 1989, the cost of the program had risen from $202 million to $350 million. The IOC for Block I slipped to 1990. Block II was awarded in February, 1987, with IOC scheduled for 1991. (19:27) Thus, conceived in 1981, CSSR will take as long to develop as the entire 427M system. SPADOC was conceived as a rehosting followed by a four-phase evolution. By 1989, SPADOC had increased in price from $290 million to $487 million, and the IOC had slipped from 1988 until 1994. SPADOC will take almost a decade to complete. (20:48) In 1987, the CCPDSR operational date was slipped until 1992 in order to accommodate the rising program costs of SPADOC and CSSR and to avoid the turmoil of having too many programs in simultaneous test within the CMC.

As a result of the development problems, the US General Accounting Office (GAO) investigated CMU in depth. The GAO concluded that the use of commercial off-the-shelf operating systems for CSSR caused an unacceptably slow restart from a power outage. Further, CSSR could not meet the required message throughput, and wiring and message standards were lacking for communication among programs. (19:4-6) GAO further observed that technical control was at its growth limit, and that the users and acquirers did not agree on the specifications of the system. (19:21) The GAO noted computer security problems in SPADOC Block 4. (20:48) After seven years of development, the system did not meet 14 of 23 performance requirements. (20:13) The entire CMU was criticized as having no single organization truly in charge. (17:23) The report ackowledged that the problem resolution structure documented, formally tracked, and discussed problems, but emphasized that it did not often resolve them. (17:23)

The lists of problems constituted a repeat of the 427M difficulties couched in the computer specifications of the 80s. The "second system" problems of automating the man-machine interface and integrating man missions on a single system unsuited for the job were reborn. Color graphic displays were asked to switch as fast as a monochrome system to display a database one thousand times as large. Sophisticated custom computer security enhancements slowed the basic system down to the point that almost no work could be performed. The modern operating system of perhaps a billion instructions was expected to load as quickly as its 1960s counterpart of 3000 instructions. Pressing the state-of-the-art caused the contractors repeatedly to redesign and augment the commercial software.

Software maintainers numbering several hundred Air Force and contractor personnel were experts on the current systems which they had maintained for 10 years. The maintenance organization could make gigantic changes in a single release. Improvements in 427M made it perform almost as well as, if not better than, the replacement, exaggerating the user's expectations for the replacement and setting the stage for disappointment. (19:27-29) The specified capabilities for the CMU did surpass those of 427M. For example, the CSSR is specified to exceed the existing CSS in 10 critical areas. (21:7) Unfortunately, the CSSR has not yet been proven, and it will have a hard test against the mature 11 year-old system.

The interface among systems was designated a potential problem area in 1982 by a review committee called for the purpose of exploring the risks and benefits of a distributed processing system. (22:2) Standardization in message protocols and formats was cited as critical for implementing the architecture. Unfortunately, the CSSR, SPADOC, and CCPDSR programs went on contract with different message sets and protocols. (17:24-25)

The most condemning criticism was that there was no single entity in charge of either the 427M development or of the current modernizations. (17:3) Numerous agencies were in charge, but none truly responsible for success. The current, traditional program organizations did not readily share risk and success as did the final CMCMO and 427M organizations. A 1983 attempt to reestablish a single manager for the CMU resulted in the management being assigned to the Systems Integration Office. (23:1) That agency was responsible for CMU interface and certification standards, but it could only enforce standards indirectly by refusing to certify a system. (45:3) Thus, the CMU was experiencing problems similar to the previous systems.

In May 1983, plans for the NORAD Computer System Replacement (NCSR) began to be coordinated through the NORAD staff. The goals for the NCSR were minimal operational risk, an achievable schedule, and interfaces to other programs. (24:1) The NCSR was planned to begin in 1986 with IOC in 1988. As with the 427M acquisition, the schedule was short because the task was seen by NORAD to be a software rehosting effort. (25:1) By February 1984, HQ Air Force Operations Plans questioned the optimistic schedule. (26:1) By April 1985, ESD provided the first cost estimate of $489 million. General Herres, CINC NORAD, questioned both the architecture and the cost, insisting on "clearly defined program objectives broken down into sequential implementation packages." (27:1)

The SPO then proposed an incremental development which would begin with the Air Defense Operations Center (ADOC) in 1986, but which included no schedule for the NORAD Command Post, the Battle Staff Support Center, or for the Weather Support Unit. Each of these programs was to be a separate, future acquisition. Questioning the three-year ADOC schedule and the number of acquisitions, CINC NORAD directed his staff to examine alternative ways of executing the NCSR. Consequently, the remaining functions--Battle Staff Support, ADOC, and Weather Support--were consolidated into the Granite Sentry Program in a statement of need written 19 July 1985. (28:1)

Meetings at all levels during the fall of 1986 resulted in an agreement between CINC NORAD and the commander of ESD. Granite Sentry would be executed in an evolutionary fashion, with each phase building on the previous phase. Represented by ESD and AFSPACECOM, the Air Force would be the military manager for the project. Both commands would function as overall risk-takers. (29:49) ESD would provide program support and management, and AFSPACECOM would develop the software. (29:49) (30:7) Both commands would contribute other support as needed to ensure priority execution. (30:10) Although these tasks might be accomplished with contract support, responsibility would clearly fall on the appropriate military organizations. (29:49) Most important, ESD was identified as the single agency ultimately responsible for execution. ESD would assist in program advocacy and would be the final arbiter of schedule and cost discussions. In a sense, AFSPACECOM would act as a software and systems contractor to ESD. This arrangement ensured that one agency was in charge of the program, but it incorporated shared risks and responsibilities. The initial cadre of AFSPACECOM developers was tasked to work out the mechanics of the program with the ESD SPO.

CHAPTER V

# GRANITE SENTRY PRINCIPLES

From November 1986 until March 1987, the AFSPACECOM and ESD components of the newly formed Granite Sentry Cadre met to finalize the ground rules for implementation. ESD would provide a program office in Colorado Springs with its deputy and other personnel collocated with the AFSPACECOM development office. AFSPACECOM would enhance the initial staff of eight programmers with a programming team of 40 beginning in January 1987. (31:1) The key personnel from both commands were to be frozen for four years, thus ensuring continuity of management and a consistent viewpoint. (30:7) The program would be executed within the 1987 budget of $141 million through 1991, and ESD would not make funding adjustments without AFSPACECOM concurrence. (30:15) The problems of changing baseline and interface requirements were addressed by limiting 427M version releases to one per year. Emergencies, of course, would be excepted. (30:7)

The program would be implemented in five evolutionary phases with two-year delivery cycles overlapping by one year. (29:45) The shortened development cycle was intended to control requirements growth. The logic was that, if the user knew he would have to wait no more than 24 months and that the phase planning provided for new requirements, there would be less pressure to change the baseline in mid-phase.

The user would be intimately involved with the development from phase definition through testing, and would help define, agree upon, and prioritize capabilities to be implemented in each phase. If the schedule ran out before a part of the software was finished, the user would choose whether to slip the schedule or to postpone some requirements to a future phase. The phasing provided slack for accommodating high priority requirements slips from prior phases.

A distributed computer architecture was adopted to allow maximum flexibility of mission and display processing. The system would rely to the maximum extent possible on unmodified commercial off-the-shelf software and hardware from a single vendor. Using a single vendor was intended to be a risk-reducer as well as a force-multiplier. Since all interfaces except the external world would be through one vendor's standard products and protocols, a single entity would be responsible for correcting system-level integration problems. The military software resources would be concentrated on mission software. (30:6) Equipment for any phase would be the best production models available for mass purchase. Staying close to but not at the state of the art would bring the most current technology to the Cheyenne Mountain user.

As discussed in the previous chapter, extremes of computer system security had hurt other programs. Unless NORAD was willing to pay for it in both cost and schedule, no elaborate security measures would be implemented. Should security implementation be required, only commercially available security packages from the vendor would be used, and these only when their use would not degrade overall system performance. Such a choice would allow the vendor to maintain its security packages under normal vendor configuration control. (30:6)

The operational system would be tested on a full-up system configuration test-bed located away from the operational environment but able to be connected to the current system test-bed. (29:19) This allowed as realistic testing as possible short of the operational environment. Each phase would be prototyped starting with displays, since a good display would mean more accurate specification, more on target coding, and a happier user.

Implementation of ADOC within 24 months was selected as the Phase I challenge. (29:5) The baseline system needed to be expandable to accommodate subsequent phases; it was partitioned into communications processing, mission processing, and display processing. The existing Communications System Segment (CSS) was to be used for connection to the external air surveillance and control systems. Phase I (ADOC) would be connected in parallel with the 427M system, allowing the operators a choice of which system to use for air defense. Vendor communications buses would interconnect the Phase I computers and provide for the required flexibility and growth.

In order to move into a renovated NORAD Command Post by 1990, the remaining command post functions of missile warning and space display needed to be accomplished on Granite Sentry equipment. (29:5) Missile warning was chosen as the Phase II implementation since it was the most time-critical function. The 1990, Phase III delivery would consist of the renovated command post and the space display software. In 1991, the CSSR and SPADOC systems would be delivered in Phase IV. Effort that year would be reserved for interfacing these systems and for any required clean-up work from the previous phases. In 1992 and 1993, the Phase V task would be display and interface processing related to WWMCCS Information System and the Advanced Weather Display System. Additionally, the space processing functions would be transferred to SPADOC as the final phase of SPADOC was delivered. The overall scope of Granite Sentry was ambitious. Each year would see at least one software release, and each program would require interface to a data source outside the Granite Sentry system.

The planning team attempted to counter potential problems in two ways. First, the effort was kept as modular as possible after 1990 in order to facilitate the movement of major programs should one of the interfaces announce a slip. Second, the workload in these years was light enough to allow time for true deficiencies to be completely reworked. The plan was approved by both AFSPACECOM and ESD senior staff on 10 November 1986, and the program moved into the execution phase the next spring.

In summary, the Cheyenne Mountain Upgrades experienced the same problems as their predecessors. Born out of frustration on all sides, Granite Sentry in effect became an experiment to validate the concept of an ESD and AFSPACECOM team as a military management organization employing the principles of collocation of major SPO functions with the software developer and user, of intense user involvement, and of the evolutionary acquisition strategy within the CMC.

# CHAPTER VI

# GRANITE SENTRY IMPLEMENTATION

## PHASES I AND II

Although the senior staff had agreed to the shared development program, there was much discussion about responsibility among the staff during the first six months after the reorganization of Granite Sentry. Some organizations felt that the SPO should perform all work necessary to execute Granite Sentry, leaving AFSPACECOM merely to monitor and assume the role of critic. Others recommended that AFSPACECOM perform the work itself reducing ESD to a monitoring role. The program office believed that such unbalanced division would be counterproductive and would tend to relieve either AFSPACECOM or ESD of responsibility. It brought the issue to the attention of the AFSPACECOM Deputy Chief of Staff for Systems Integration, Maintenance, and Support in July 1987. The following division of labor between ESD and AFSPACECOM was then defined. (32:27 September 87)

The ESD Program Office would be responsible for all Granite Sentry new development. ESD would purchase equipment, write software through the AFSPACECOM software house, and be responsible for the Granite Sentry side of any interface to existing systems. AFSPACECOM would be responsible for coding, testing, and implementing interfaces from Granite Sentry to the existing systems. Finally, equipment associated with the operational system, such as communications gear, which would be used in various stages of the program, would be managed by AFSPACECOM. The Deputy SPO Director in Colorado Springs represented the Program Director in all but schedule decisions. This division assigned responsibility to the agency best able to handle the task. (29:49) The AFSPACECOM software effort was to be matrixed via a specialized software development division dedicated to Granite Sentry. That division would also perform the configuration management required for the software effort.

Unfortunately, the 40 programmers were not available in January 1987. (29:50) Although it needed at least 10-to-15 programmers, only three had been assigned on a part time basis by March. (33:5) Consequently, Government Services Administration (GSA) programmers were hired to carry out the required Phase I design. This was suboptimal from the point of view of program management since it was likely that the GSA contract would terminate in October 1988, leaving the program without the experienced personnel who started the design. Further, the GSA contract did not require Ada language programming experience, and the programmers had to be trained. To stabilize the workforce, AFSPACECOM engaged in a separate contracting effort to obtain Ada software developers.

By the time the GSA programmers were arriving in strength, AFSPACECOM freed 16 programmers to begin working Phase I. The entire team arrived in May 1987 and began writing specifications for a system design review June. Since few were trained on the systems software or on Ada, the June design was inadequate. (34:1) The month of July was spent in training, and internal milestones were adjusted.

By autumn 1987, the lack of Phase II software manpower was critical. The problem was briefed to the ESD and AFSPACECOM Vice Commanders at the November Senior Review Group. Major General Brandt, the ESD Vice Commander, formally complained of the resource problem to Major General Spraker, the AFSPACECOM Vice Commander. As a result of their discussion, the Granite Sentry Development Office (GSDO) was formed and assigned to the AFSPACECOM Vice Commander. The software personnel were still matrixed, but their reporting chain was changed to assign them functionally to the GSDO. The total number of Air Force personnel committed to Granite Sentry was reduced to 25 because of AFSPACECOM's other commitments including 427M software maintenance. (35:1)

Contracting problems slipped the Ada software contract award to March 1988, placing Phase I and Phase II further behind. Resources who should have been coding in January were still in training in June. Phase I had lost a total of 246 man-months, and Phase II was behind by 129 man-months. (36:7) As a result of the slow progress, Phase II limited its prototyping efforts to displays, and Phase I concentrated on coding rather than integration. The whole phasing sequence suffered because, in an attempt to make up the lost effort, the Phase I designers were kept on Phase I instead of transitioning to Phase II design as the original concept dictated. However, keeping Phase I on schedule was important to both ESD and AFSPACECOM, and the resource was applied there rather than on Phase II.

While CINC NORAD had agreed upon the Granite Sentry concept, the users were skeptical. Their uncertainty manifested in 427M software changes which NORAD and the AFSPACECOM software maintenance house believed were needed in order to keep the operational system current and to hedge against possible Granite Sentry Phase I failure. These changes necessitated rewriting approximately 15,000 lines of Granite Sentry code, which absorbed much of the effort that months of overtime had been able to recover and which contributed to the eventual Phase I slip. (37) To persuade NORAD that Granite Sentry was committed to deliver a useful system, two things needed to happen. First, as with bringing 427M on line, the changes to the existing systems needed to be minimized. (38:40) Second, the user needed to become very involved with its development. In a large step of faith, the SPO and the GSDO resolved to keep the development open, allowing the user access to the programmers and system whenever possible.

NORAD did become extremely involved in the display system and in software demonstration . Generals Bourgeois, Andrus, and Reed spent a great deal of time refining the display requirements. CINC NORAD approved the Phase I displays in June, 1988 and the Phase II displays in March, 1989. The software demonstrations convinced NORAD personnel that Granite Sentry's goal was a satisfied user because the coders were often able to accommodate changes to the system in response to their suggestions. The demonstrations also convinced the programmers that the user needed the product and cared for it as a system rather than as a set of specifications. However, the user tended to fine tune the system before it was finished, leading to some animated discussions about schedules and deadlines. User involvement accomplished the goal of increasing user support, and it illustrated the value of the flexible evolutionary approach. (3:19)

User involvement also reduced program cost. For example, the specification required that data for all missile launches be available for display, but it did not state the timeliness criteria for the term "available for display." A strict interpretation could have led to purchasing more communications gear and much larger workstations in order to meet the tightest display times. At a feasibility briefing, NORAD representatives observed that after a certain point only summary information was necessary and asked for the implementation of summary reporting. (39) As long as the individual events were available somewhere in the system and were retrievable within a stated time frame, only summary information required immediate availability. (39)

Thus, from the beginning, Granite Sentry Phase I implemented the principles of evolutionary development, military management, a teamed SPO with both ESD and AFSPACECOM responsible for success, collocation of a deci ion-making portion of the SPO with the developer and user, and intimate user involvement. The evolutionary approach demonstrated its ability to incorporate new requirements with the user determining the delivery schedule.

The final factor which contributed to success of 425L and 427M was the assignment of the user or SPO organizations to high command levels. Such assignment did not occur initially in Granite Sentry. Manpower shortages and lack of support were chiefly responsible for the failure of Phase I to reach IOC in December, 1988. Once the manpower and support problems were addressed by forming the GSDO and assigning it to the AFSPACECOM Vice Commander, the Phase I project made excellent progress. Phase I was turned over to test at the end of February 1989, and it reached IOC on March 16th. Considering that the real development did not begin until July 1987, the 24-month Phase I project was implemented after only a 20-month programming effort.

The Phase II missile warning effort started late because the design team was not assigned to Phase II on time. Until July 1989, personnel who should have been designing Phase II were still assisting the Phase I team with the final ADOC release. By this time, however, NORAD had become a strong supporter of Granite Sentry and prioritized both ADOC and missile warning requirements. It remains to be seen whether Phase II and subsequent phases can recover from the Phase I slip which was due to the initial lack of resources.

# CHAPTER VII

## CONCLUSIONS AND RECOMMENDATIONS

The Cheyenne Mountain system acquisitions have historically been chaotic and troubled. Traditionally, the user has not been involved with new systems until it is too late to correct problems easily. As with other acquisitions for the Department of Defense, these programs have suffered from changing requirements and specifications which are beyond the state of the art. The extremely capable software maintenance organization has been able to transform the system being replaced so that it sometimes surpassed the operator's vision of the replacement system. The traditional contract structure has also hindered Cheyenne Mountain programs. It is nearly impossible to write a specification for a one-of-a-kind system planned for turnover years later. The user's real future requirements are difficult to predict, and the user's needs change due to software maintenance, impacting the contracted baseline. With no intermediate system to deliver, the program office must renegotiate contracts to meet new requirements, the schedule is slipped, and the process begins anew.

Problem resolution has been deliberate and slow to act, rarely reaching the correct decision in time to have positive effects on programs. As problems were encountered in each stage, intervention by senior military or civilian officers was necessary to get the programs to operational capability. For the original NOCOPS, senior involvement was instrumental through the Cheyenne Mountain Complex Task Force; for 427M, the Independent Review Group; and for the early Cheyenne Mountain Upgrades, the General Accounting Office. Each of these groups recognized the problems and recommended specific actions to resolve them. These principles were incorpora ed into the Granite Sentry agreement, and except for resource problems, the principles were vindicated in the Granite Sentry Phase I acquisition.

The following principles influenced Granite Sentry Phase I success: an evolutionary acquisition strategy, a teamed approach with ESD and AFSPACECOM sharing responsibility for success or failure, a decision-empowered SPO Deputy Director collocated with the user and developer, a user intimately involved with the development, and an AFSPACECOM Granite Sentry Development Office managed by the military.

The evolutionary acquisition approach focused the program on implementing limited, single phases with short development cycles rather than a large-scale, long-term development. The short development cycle minimized the affect of 427M maintenance software releases on the Phase I development and allowed Phase I to maintain parity with the operational system. The evolutionary approach controlled current requirements growth by providing opportunity for new requirements in later phases. It allowed a working system to be used in the operational environment. The two-year phase cycle was short enough to minimize both manager and developer turnover, reducing the loss of corporate knowledge. Knowledge of senior staff interest in the project inspired the programmers and managers to produce a successful project, and productivity was maintained at a high level.

From the beginning of the agreement, the ESD program office demonstrated its commitment to produce a solid product for NORAD on AFSPACECOM's schedule. Collocating the deputy program manager and staff with the developers in Colorado Springs streamlined the decision-making process as it had for the earlier CMCMO. There was little significant disagreement between the Granite Sentry Development Office and the Program Office.

User involvement was crucial. Prototyping provided the opportunity for early hands on experience, allowing the user's input to make a difference in the delivered product. The delivery cycle was short enough that the user who approved the specification for a phase saw the delivered system, enhancing NORAD's desire to participate. The impact of NORAD's involvement in the teamed workforce cannot be overstated.

The Granite Sentry Development Office became the focal point for AFSPACECOM after the office was assigned to the Vice Commander. As with the final 427M and CMCMO organizations, when the vice and the general staff demonstrated interest in the program's success and became intimately involved, the rest of the staff followed suit and progress was made. The single organization for implementation placed much responsibility on the development office, but allowed the freedom to deal with the staff and to make rapid decisions. The contractual structure allowed military management to focus the contractors rapidly without the delay of contract renegotiations.

The synergy and balance afforded by the above factors made the implementation of the Air Defense Operations Center a success. Without any one of them, ADOC could easily have joined the ranks of other troubled Cheyenne Mountain programs. Should any of the factors change significantly, AFSPACECOM and ESD should again meet at senior levels to ensure that a correct balance is again struck.

A single integration organization with decision authority for Cheyenne Mountain should be appointed. The organization should have power to immediately address and direct solution of Cheyenne Mountain integration problems. It should be composed of both ESD and AFSPACECOM personnel. To not take action is to ignore the lessons of the past 24 years and three major projects.

The negative influence of current system software maintenance changes needs to be controlled. NORAD and AFSPACECOM should take a stronger stand to control change. The maintenance organization would still be used for emergency software work, but should concentrate on influencing the new systems before it assumes maintenance responsibility of a problem at IOC. Last, the other programs and their eventual replacements should be organized in an evolutionary development structure. No specification is perfect and no user can ever be expected to truly know what he wants until he sees what he gets. Acquisitions should first deliver an achievable basic system followed by controlled software and hardware enhancement with user involvement in an evolutionary approach. This is the optimal vehicle for ensuring that the user gets what he needs to carry out the vital NORAD mission.

## GLOSSARY

| | | |
|---|---|---|
| ADCOM | - | Aerospace Defense Command |
| ADOC | - | Air Defense Operations Center |
| AFSC | - | Air Force Systems Command |
| AFSPACECOM | - | Air Force Space Command |
| BMEWS | - | Ballistic Missile Early Warning System |
| CCPDS | - | Command Center Processing and Display System |
| CCPDSR | - | CCPDS Replacement |
| CINC | - | Commander in Chief |
| CMC | - | Cheyenne Mountain Complex |
| CMCFTR | - | CMC Final Technical Review |
| CMCMO | - | Cheyenne Mountain Complex Management Office |
| CMU | - | Cheyenne Mountain Upgrades |
| COC | - | Combat Operations Center |
| CSS | - | Communications System Segment |
| CSSR | - | CSS Replacement |
| DIP | - | Display Information Processor |
| DOD | - | Department of Defense |
| ECP | - | Engineering Change Proposal |
| EOC | - | Equivalent Operational Capability |
| ESD | - | Electronic Systems Division |
| GAO | - | United States General Accounting Office |
| GSA | - | Government Services Administration |
| GSDO | - | Granite Sentry Development Office |
| IDHS | - | Intelligence Data Handling System |
| IOC | - | Initial Operational Capability |
| IRG | - | Independent Review Group |
| MEBU | - | Minimum Essential Back Up |
| MWBP | - | Missile Warning By Pass |
| NCCS | - | NORAD Command and Control System |
| NCP | - | NORAD Command Post |
| NCS | - | NORAD Computer System |
| NCSR | - | NCS Replacement |
| NOCOPS | - | NORAD Combat Operations System |
| NORAD | - | North American Aerospace Defense Command |
| SAC | - | Strategic Air Command |
| SCC | - | Space Computational Center |
| SPADOC | - | Space Defense Operations Center |
| SPO | - | System Program Office |
| SSC | - | Space Surveillance Center |
| USAF | - | United States Air Force |
| USSPACECOM | - | United States Space Command |
| WWMCCS | - | World Wide Military Command and Control System |
| 425L | - | NOCOPS |
| 427M | - | Cheyenne Mountain Improvement Program |
| 496L | - | Space Defense Computational System |

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