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All Source Analysis System (ASAS) Migration from VAX to Alpha AXP Computer Systems

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Editor

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Michael Sierchio

MIGRATION FROM VAX TO ALPHA AXP COMPUTER SYSTEMS

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1.0 SCOPE

The Jet Propulsion Laboratory's (JPL's) experience migrating existing VAX applications to Digital Equipment Corporation's (Digital) new Alpha AXP processor is covered in this document. The rapid development approach used during the 10-month period required to migrate the All Source Analysis System (ASAS), the 1.5 million lines of FORTRAN, C, and Ada code, are also covered. ASAS, an automated tactical intelligence system, was developed by the Jet Propulsion Laboratory for the U.S. Army. Other benefits achieved as a result of the significant performance improvements provided by the Alpha AXP platform are also described.

2.0 INTRODUCTION

2.1 Alpha AXP Processor Overview

The Alpha AXP is the newest family of high-speed computers developed by Digital Equipment Corporation. The family includes several sizes of computers, from desktops to larger processors, all using the new Alpha AXP chip running at speeds of up to 200 MHz. The Alpha AXP utilizes a Reduced Instruction Set Computer (RISC) load-store architecture. All data is moved between registers and memory without computation, and all computation is done between values in registers. The Alpha AXP was designed to encourage multiple instruction issue implementations sustaining up to 10 new instructions per clock cycle. Current production Alpha AXP processors can execute two instructions per clock cycle, and Digital plans to release an Alpha AXP which processes four instructions per clock cycle by the end of 1994.

The Alpha AXP architecture uses a linear 64-bit virtual address space. Registers, addresses, integers, floating-point numbers, and character strings, are all processed as full 64-bit quantities. The Alpha AXP can currently address 256 MB of physical RAM and up to 1 GB in future system releases. To run OpenVMS AXP, OSF/1 (UNIX), and Windows NT operating systems, the Privileged Architecture Library code (PAL code) provides memory management, exception handling, and other unique features to each operating system. By having different sets of PAL code for different operating systems, the architecture itself is not biased toward a particular computing style. The Alpha AXP architecture was designed with the following goals:

- High performance.
- Longevity.
- To run OpenVMS and OSF/1 (DEC's UNIX).
- Easy migration from the VAX customer base.

Currently, the Alpha AXP 3000 Model 500X, one of the mid-range Alpha AXP processors, outperforms all other processors in its class. The performance of Alpha AXP 3000 MODEL 500X against the SGI Challenge L, SPARCserver1000, and IBM RS/6000 is described in Table 2-1.

Table 2-1. Comparison of SPEC92 results, single chip processors

Model/Chip/Operating System	SPECfp92	SPECint92
Digital AXP500X 200 MHz DEChip 20164 OSF/1	159.6	106.9
SGI Challenge L 150 MHz MIPS 4400 IRIX 5.0	96.5	94.5
SPARCserver 1000 50 MHz SuperSPARC+ Solaris 2.2	78.3	66.5
IBM RS/6000 42 MHz RIOS-1 AIX	65.4	32.9

The longevity of the Alpha AXP processor remains to be seen, but the Alpha chip architecture was designed to support the product for the next 15 years. This is evident in the 64-bit address scheme and pipelining capabilities.

The Alpha AXP processor currently supports three operating systems: (1) OpenVMS, a new version of VMS containing POSIX compliant constructs; (2) OSF/1, Digital's version of UNIX, and (3) WindowsNT.

The PAL code is a set of routines that is necessary, but impractical, to implement as a single RISC instruction. Many of the Alpha AXP PAL code routines perform functions similar to complex VAX instructions, which on a VAX CPU are implemented in microcode.

There are significant differences between the VAX and Alpha AXP architectures. The major differences are listed in Table 2-2. Clearly, Digital has been successful in achieving its goals.

2.2 Rapid Development Methodology

One of the integral components of any well-defined task is a set of guidelines that defines how a task will be accomplished. One of the key components of the ASAS Project's approach to its Alpha Migration activity was to use Rapid Development Methodology (RDM). This methodology facilitated our success through the following conditions:

- Shortened development cycle.
- Well-defined, short-term deliveries.
- Team development concept.
- Limited documentation.
- Functional prototype for user evaluation.

Table 2-2. Comparison of Alpha AXP and VAX architectures

Alpha AXP	VAX
64-bit addresses	32-bit addresses
64-bit processing	32-bit processing
Multiple Operating systems: OpenVMS, OSF/1, WindowsNT	One operating system: OpenVMS
Instructions - Simple - All same length (32 bits)	Instructions - Some Complex - Variable length
Load/store memory access	Permits combining operations and memory access in single instruction
Severe penalty for unaligned data	Moderate penalty for unaligned data
Many registers	Relatively few registers
Out-of-order instruction completion	Instructions completed in order issued
Deep pipelines and branch prediction	Limited use of pipelines
Large page size (which varies from 8 KB to 64 KB, depending upon hardware)	Smaller page size (512 bytes)

This approach consisted of building a technical team with expertise in all the necessary disciplines to develop, build, and test software systems. The team was given a well-defined goal and the authority to accomplish that goal in the most efficient manner. If an existing process or procedure was not effective, the team could modify that procedure to accomplish its task.

Typical software development activities following DOD-2167A involve a detailed review process and require a number of documents pertaining to software requirements, design, and implementation. With RDM, only a subset of the required DOD-2167A documentation is identified and written during prototype development. The specific subset of documentation selected for development is limited to those documents or portions of documents, that are necessary to guide the RDM activity. Upon completion of an RDM delivery, additional documentation could be developed, depending upon user requirements.

This methodology typically saves money when compared to a full DOD-2167A implementation and quickly provides the customer (end user) with a working product for evaluation and demonstration. The end user can work with the product, evaluate it, and determine if it fulfills their needs. As a result of their early evaluation, the customer can request a series of system modifications and improvements to enhance system acceptance. These modifications can be incorporated into the next release.

2.3 Hardware Implementation

For ASAS, incorporation of an Alpha AXP processor into an existing VAX system was necessary because of the ASAS Project's dependency on the existing VAX configuration and the peripheral devices attached to it. One of the key objectives of the hardware migration was to provide state of the art performance and functionality, while maximizing reuse of existing hardware assets where applicable, and reducing the overall size and cost of the upgrade. Several ASAS systems were already fielded, being used by U.S. Army military intelligence units worldwide. The U.S. Army wanted to improve system performance at minimal cost. The Alpha AXP platform offered the first opportunity for such an upgrade.

To begin the hardware migration, an evaluation of the existing configuration was performed. With formalized systems such as ASAS, the functional configuration information was available in the form of system description documentation. Key items considered in this evaluation were:

- CPU.
- Memory.
- Bus I/O speed and formats.
- Disk I/O format and disk capacity.
- Communication device/network options.
- Graphics controllers.
- Monitors.
- Printers.
- I/O devices (keyboard and mouse).

Aside from the functional issues, certain physical requirements must also be addressed. They include issues such as packaging, human factors, environmental, power consumption, and data connectivity.

Once these issues were evaluated, a preliminary system was configured to begin software migration and further refine the workstation's final physical configuration. For ASAS, the replacement Alpha AXP was directly integrated into the existing TEMPEST workstation housing, replacing the original VAX computer. The workstation was used to benchmark performance, test new and replacement functions, host existing hardware and software, and evaluate physical requirements issues.

2.4 Software Migration

Migration of software from VAX to the Alpha AXP was accomplished via one of two methods, native or vesting, depending on the status and availability of the new compilers for the Alpha AXP. The desired method is to compile and link the software using the new native compilers developed for the Alpha AXP processor. Performance increases from Alpha are not just the result of the faster processor. The compilers have been significantly rewritten to incorporate the pipelining and dual instruction capabilities of the Alpha AXP chip's RISC implementation.

Therefore, to obtain maximum performance benefits, native compiling is desirable. However, there are situations where native compilation is not possible, such as when a compiler is not available or when commercial products have not been upgraded to run on the Alpha AXP environment. Digital expected that this situation would occur during the early stages of release of the Alpha AXP, and they provided a capability to run existing VAX binary images directly on the Alpha AXP. Digital developed the DECmigrate utility to convert VAX instructions to Alpha AXP-understood instructions, bypassing the compile and link steps altogether. The process is termed vesting. There is a processing penalty incurred when running vested code. Performance of vested executables on Alpha AXP processors will be an improvement over performance on a VAX, but will fall short of the performance gains possible when built native. However, it may be the only viable alternative to quickly migrate software to the Alpha AXP.

The number of VAX code modifications necessary before a successful compile and link can be achieved varies for each Alpha programming language. For example, on ASAS, two major subsystems were written in ADA. The Alpha AXP ADA compiler is virtually identical to the VAX ADA compiler, and the migration of these two subsystems (about 80,000 lines) was accomplished in less than two weeks. On the other hand, the PASCAL compilers were significantly different. Software written in Pascal required substantial code changes (10%–15%) to conform to new standards and to compile successfully. The bulk of ASAS code was written in FORTRAN and C, and typically required only minimal changes to compile.

To take full advantage of the Alpha AXP's speed and architecture, all data segments (variables) must be *word-aligned*—that is, each variable should be mapped to start at the beginning of a 128-bit quadword. Since the VAX architecture entailed the use of 32-bit words, and there was no real performance impact for mapping data to sub-word boundaries, a complete remapping of data to the Alpha AXP's quadword boundaries would be necessary to obtain optimum system performance. However, for ASAS, such an activity would entail complete remapping of all data structures system wide. The cost of that activity was prohibitive, so we chose to compile our modules with the NOALIGN option, not reformatting our global areas. (A speed reduction penalty is paid for using this option, but overall performance is still much faster when compared to the VAX versions of ASAS software. See section 4.3.2. for additional details.)

The software migration schedule was further reduced, thanks to the performance of the Alpha AXP, in compiling, linking, and debugging activities. The Alpha AXP's speed in building software significantly increased the productivity of the software development team. For example, to compile and link a large subsystem consisting of more than 210,000 lines of FORTRAN code expended twelve (12) hours of clock time on a VAX 3800. With the Alpha AXP, the same compile and link takes only 5 1/2 hours. The same was true for all 23 subsystems in ASAS. The build and test cycle was shortened significantly, thereby increasing the productivity of software developers.

As subsystems were migrated, tested, and benchmarked on the Alpha AXP, the benefits of migration were proven quickly and dramatically. Processing times were dramatically reduced when compared to times required to perform the same operations on the VAX. In some cases graphics operations that would require over 90 seconds to complete on the VAX, would complete

in less than 5 seconds with the Alpha AXP. We typically observed a 20 to 30 times improvement in performance.

3.0 MIGRATION GOALS

3.1 System Engineering Goals

Effective system engineering during development of the Alpha AXP version of ASAS added value to the migration effort. While ASAS met most functional specifications, system performance of earlier VAX 3800-based systems has always been considered to be poor. Software modifications could only offer a partial solution, as significant improvements could only be obtained with new hardware. Several potential improvements were identified and prioritized at the start of the migration effort to determine whether hardware and/or software solutions could be used to solve the performance bottleneck. In addition, many system level issues were identified. The following goals were identified:

- Develop an integrated product (hardware and software) providing functionality identical to the current system.
- Minimize changes to the user interface.
- Define potential new system configurations.
- Prioritize system anomalies.
- Identify third party software alternatives to existing products that provide additional capabilities (upgrades).
- Identify hardware alternatives to existing products that provide new or additional capability.
- Identify key operational bottlenecks.

For the ASAS Alpha migration the system engineering process required a knowledge of how ASAS is operationally used. ASAS is one of many tactical systems used by the Army. Interoperability of ASAS with other tactical military systems was a critical issue and had to be assured. In fact, the migration activity provided an opportunity to upgrade or add interoperability capabilities which did not exist.

3.2 Hardware Goals

The goals of the Alpha migration effort were quite straightforward from a hardware perspective. The Alpha system had to meet all system specifications developed for the original VAX processor. The specific set of hardware goals is listed below:

- Minimize effort for retrofit of existing systems in the field.

- Maximize reuse of existing workstation hardware components (excluding the Alpha AXP CPU itself).
- Meet or exceed the current system's interoperability performance requirements with other systems.
- Reduce overall system footprint.
- Meet or exceed all existing system specifications for functional performance, including these factors:
 - Environmental conditions
 - Operating temperatures
 - Reliability
 - Maintainability
 - TEMPEST

3.3 Software Goals

The goals of the software migration effort were to retain complete system functionality while improving overall system performance. More specifically the goals were to:

- Maximize use of native code versus vested code.
- Maintain an identical *look and feel* for the user.
- Retain the existing software architecture, unless a system engineering assessment or operating system constraint dictated that a modification was necessary.
- Utilize the identical commercial software baseline used in the VAX processor.
- Maximize use of production software versus beta-test versions.

3.4 Cost and Schedule Goals

Cost and Schedule considerations were also quite simple; provide a completely working product within a very short time period and within a relatively small budget. Specific goals were:

- Minimize system development costs for both hardware and software to establish proof-of-concept through RDM.
- Shorten delivery schedules to demonstrate capabilities and benefits of migration by rapid prototyping.
- Define high risk items early, preferably during the planning stage, and develop contingency plans.
- Produce the first prototype within three months.
- Produce a completely operational system within nine months.

4.0 MIGRATION STRATEGY

4.1 Rapid Prototype Approach

JPL's Rapid Development Methodology is an approach to system development (software and hardware) that provides working systems early and continues to provide a working product throughout the life of system development. RDM provides working products faster than can be achieved through application of the typical system development cycle. The use of RDM for the migration of ASAS was critical to the success of this venture. It allowed for quick turnaround of information. System users were provided with prototypes during the early stages of development. Their comments were easily accommodated and were reflected in the final system released to the field.

The ASAS migration consisted of a four-phase effort. The first phase of that effort, prototyping, covered a 90-day evaluation period when the proof-of-concept was demonstrated. Vital planning information for a complete migration was obtained. The second phase, complete system migration, required the most effort. Both the hardware and software systems were completely upgraded for operation with the Alpha AXP platform. The third phase of the migration activity consisted of detailed system testing. Both the hardware and software systems were thoroughly tested. The fourth and final phase of the activity consisted of a complete retrofit of several existing systems. Both hardware and software were upgraded for two ASAS systems, currently in use by the U.S. Army in the field.

The first 90 days of the effort were earmarked to be an evaluation period for identifying issues and allowing for a detailed analysis of existing applications. The key activity during this phase of the migration involved determining the feasibility and relative ease of a complete software migration to the new Alpha AXP processor. To meet that end, critical components of ASAS software were evaluated. The DECmigrate utility provided the team with flexibility to quickly vest those portions of the system required for the applications to run. Through a combination of vesting and native development, critical components of the system were migrated for the purposes of demonstration and evaluation. Additionally, the specifications for a workstation outfitted with an Alpha AXP was completed. By the completion of this phase, it was believed that a complete migration to the Alpha AXP was possible, and detailed plans for system migration were formulated.

During this phase of the activity, the evaluation team was quite small, typically consisting of only four engineers. Their goal was to demonstrate the proof-of-concept and to identify potential technical hurdles to a complete system migration. The team selected specific time-critical processes to be migrated in order to benchmark Alpha AXP performance. The initial 90-day period provided sufficient data to develop a comprehensive task plan for the complete migration effort for both hardware and software. The comprehensive task plan for the complete migration was used in subsequent phases of the effort to allocate personnel and hardware to the task. The allocation of system's versus application's programmers was approximately a 30/70 split. The addition of test and configuration management to the team provided the full compliment of resources to build, test, and support the migration.

Hardware and software staff worked together to identify, resolve, and isolate interface issues between the hardware and software. In the ASAS migration effort, developers on the team had a knowledge base from completing the design and development on the VAX. Although this experience was valuable, ultimately the most valuable knowledge was that of the architectural differences between the two platforms and the technical information gained from the 90-day evaluation.

The migration schedule also benefited from the Alpha AXP's increase in performance through a dramatically reduced build cycle. Prior to introduction of the Alpha AXP, a complete compile and link of ASAS software required about 2 weeks (10- to 8-hour days). The Alpha AXP reduced a complete build cycle to just 2 1/2 days. The increased turnaround enabled the migration team to identify and correct reported problems at a much higher rate than on the VAX 3800s.

4.1.1 Phase I--90-day Evaluation Period

An early evaluation of both hardware and software was necessary to identify the corresponding components for the new Alpha AXP based system. A 90-day evaluation period was established to identify component level details of all hardware and software items necessary to build a prototype system. The goal of the prototype activity itself was twofold: (1) to prove that migration of the ASAS code was possible, and (2) to develop a strategy for migration of the entire VAX3800-based product to the Alpha AXP platform.

The prototype effort began with evaluation of available documentation describing the VAX 3800-based system. In most cases, documentation was available to describe the hardware and software components to a sufficient level of detail to allow work to proceed. In those cases where documentation was not available, the migration proceeded through detailed physical analysis of the existing system. For hardware, the approach was to dismantle an existing fielded system to identify components, revision levels, and connectors. For software, when documentation of commercial products that reside in the system were not available from vendors, the vendors provided direct support through phone and other forms of communication.

After identification of the hardware and software items was completed, an Alpha configuration plan was devised and a task plan was developed to address specific technical issues related to that configuration. With a migration effort, some items (either hardware or software) transferred very easily to the Digital Alpha AXP environment. Some items required a unique technical plan to accomplish the migration of that specific item. For example, the ASAS VAX system used a communication interface board (e.g., DSV11) to provide a number of protocols to external communication devices. On the Alpha AXP, a new interface board had to be configured and the software supporting that device had to be developed to provide equivalent functionality. The integration of a new communications interface board warranted a detailed task plan within the migration activity.

With the target Alpha configuration and a task plan defined, a schedule for the development of a prototype was developed, based upon the task relationships and dependencies. An integral part of this schedule was the procurement of hardware items and software packages for the Alpha AXP.

The establishment of a complete software configuration and development environment was also accomplished at this time. The necessary compilers, COTS packages, and support tools were obtained and installed on an Alpha AXP. Additionally, Digital's software configuration management tools for the Alpha AXP Code Management System (CMS) and Module Management System (MMS) were installed.

The availability of test tools and data that could be used for the integration and test activity was evaluated, as well. It was found that test procedures and data existing from the original 3800-based software development activity could be used for the integration and test activities of the Alpha AXP migration. Extra time was added to the task plan to cover areas where the existing test procedures were found to be inadequate. Once completed, the task plan included time for the development and modification of test scenarios and data to validate the accuracy and completeness of the migration.

At the conclusion of the prototype phase of this activity, the Alpha Migration staff had a good handle on the following key items:

- Prototype Alpha AXP hardware configuration.
- Prototype software configuration.
- Integrated task plan and schedule.
- Software development environment.
- Procurement plan for all required hardware and software items.

4.1.2 Phase II – Implementation

The implementation of the task plan required assignment of key personnel to all tasks according to the task plan description in the previous phase. In addition to having personnel experienced with code migration to the Alpha AXP (from the prototype effort), the ASAS Project also brought experienced personnel from previous ASAS code development activities to this phase of the effort. The hardware and software implementation activities were performed in parallel to support a common integration milestone. The details of the hardware integration were rather complex but were not directly coupled to the ASAS software. Consequently, the hardware implementation was performed independent of the software development activities. This action permitted testing of specific hardware (e.g., TEMPEST testing) requirements without impacting software development activities.

Software migration was performed in a bottom-up fashion. The lowest level of the software baseline (i.e., OpenVMS Operating System) was installed first and then commercial third-party products were installed on top of OpenVMS. Those products included such items as a database management system and a forms manager. The ASAS Project's experience has shown that matching third-party software packages to the current version of OpenVMS was critical to a successful migration. System failures often occurred when these third-party products and the operating system were out of synchronization.

Having established the operating system and support software packages necessary for running the application, the migration of the applications began. The software migration schedule was derived, usually, from the software design and the software hierarchy. The lowest level routines and subsystems were migrated first. The complexity of the migration was a function of:

- Standards used during software development (how well the original programmers conformed to system specifications).
- Languages used for implementation.
- Whether the software was built native or vested.

The complexity of the migration was a function of the standards used for initial development of the software. VAX software written in FORTRAN or C that compiles without errors, may not compile on the Alpha AXP. The compilers have been rewritten for the Alpha AXP to take advantage of the capabilities of the Alpha chip. The code optimization features of the Alpha AXP compilers are much more sophisticated than those on the VAX. Depending upon the language, the code modifications required varied. Based upon the ASAS Project's experience with approximately 1.5 million lines, JPL developed ASAS code. The following estimates about the magnitude of software changes necessary to recompile are listed below:

<u>Language</u>	<u>Approximate Impact</u>
ADA	< 1 %
FORTRAN	< 5 %
C	< 10%
PASCAL	< 15%

The complexity of the software migration was also a function of whether the application could be built completely native, or whether some of its components had to be vested. The ASAS Project's guidelines for migration required that Smartstar, a forms management package, be retained. Since Smartstar is a BASIC (language) program, and BASIC compilers were not available for the Alpha AXP, the only alternative was to vest the Smartstar software package. The interactive application code, however, was typically written in FORTRAN and was compiled native using the new Alpha AXP compilers. The final executable, however, being a concatenation of JPL-developed source code and Smartstar, contained both native code and vested Smartstar routines. Although there was a performance "hit" for linking both native and vested software together in the same executable, the performance was still dramatically better than the VAX.

4.1.3 Phase III – Prototype Testing

As subsystems of the application were migrated to the Alpha AXP, testing of the prototype began at the subsystem level. As part of the original software development activity, test procedures and data were developed to validate system requirements. Existing test procedures and data were used for testing and integration of the prototype. Code changes were necessary to address migration-specific issues, such as floating point format differences. In addition, problems existing in the software surfaced due to differences between the VAX and Alpha AXP architectures. A

number of instances occurred in the ASAS Project's migration where a particular coding practice on the VAX would work, but that same approach on the Alpha AXP produced the wrong result.

Differences between VAX and Alpha AXP required tuning of OpenVMS system parameters to optimize performance. Typically, executable images on Alpha AXP are much larger due to the RISC instruction set. Because the size of executables is larger, memory becomes a critical resource in reducing page fault rates. The evaluation of system performance and tuning of the configuration provided valuable information into finalizing the Alpha AXP configuration.

Operational testing of the prototype was a critical step in validation of the migration and demonstration of the performance improvements. In addition to the completion of another level of testing, evaluation of new system capabilities was performed. Upon completion of performance tuning and operational testing, new performance levels were demonstrated. The ASAS Project's migration to the Alpha AXP allowed a new system configuration with 6 Alpha AXP 500s rather than 10 VAX 3800s. Performance increases of 10 to 30 times were realized even with a reduced set of processors. The performance data collected from integration testing will support the definition of new (reduced) system configurations.

4.1.4 Phase IV – Retrofit Existing Systems

After the hardware and software prototypes were completed and validated, a detailed task plan for retrofitting existing 3800 configured systems was developed. Two 3800 systems previously fielded to the U.S. Army were identified as candidates for the initial upgrade. Components were ordered, and the Central Processing Unit (CPU) portions of the workstations were returned to JPL for retrofit. Once completed, the complete systems were tested at JPL and later at Fort Hood, Texas. After successful completion of this phase, the systems were returned to the Army for evaluation and operational use.

4.2 Hardware Configuration Definition

Using the hardware goals identified in Section 3.2, each functional area of the VAX workstation was evaluated and the trade-offs analyzed. Even though these goals dealt with the procurement of hardware items, software and system engineering issues had to be considered as well. Through a well thought out combination of hardware and software upgrades, the proper hardware was selected. The ASAS Project's experience with the migration of ASAS to the Alpha demonstrated that:

- 1) Performance enhancement was not solely the function of the CPU speed, but rather a combination of CPU, RAM capacity, bus throughput, and disk I/O. By providing increases in some or all of these areas, significant performance gains were realized.
- 2) Specific performance increases could be measured after portions of the target software were migrated to the Alpha. Consequently, system performance for a completely migrated system could be modeled after completion of the first prototype.

- 3) The rapid prototype approach provided shortened schedules and frequent deliveries that allowed us to address changing customer priorities and goals.

4.2.1 Alpha AXP Hardware Functional Requirements

All hardware components of the ASAS workstation were evaluated during the initial prototyping activity. Based on analysis of prototypes results, recommendations were made in the following areas:

- CPU.
- Memory.
- Disk I/O Format and Disk Storage Capacity.
- Communication.
- Network Connectivity.
- Bus I/O Speed and Format.

As each component of an existing configuration was evaluated, its Alpha AXP equivalent typically provided better performance in a smaller physical package with improved reliability. A comparison of VAX and Alpha AXP components is provided in Table 4-1. The comparison between a VAX 3800 and an Alpha AXP 500 provides insight into the significant differences in performance and throughput that can be realized.

4.2.2 VAX versus Alpha AXP Trade-off

As previously mentioned, the Alpha AXP offers significant performance boosts for ASAS applications formerly running on VAX 3800 processors. The power of the new Alpha AXP CPU and its memory are the key to this improvement. The capabilities of VAX 3800 and Alpha AXP are compared at a functional component level in the following paragraphs. In every case, the performance improvements were substantial.

4.2.2.1 Central Processing Unit Comparison

The VAX 3800 CPU processor is a 32-bit processor which runs at 33 MHz and can address a maximum of 64 MB physical RAM. Architecturally, the VAX 3800 architecture is based on a Complex Instruction Set Computer (CISC) design. All aspects of the VAX 3800 have been improved upon with the introduction of the Alpha AXP. For example, the Digital 3000 model 500X AXP, one of the line of Alpha AXP processors, offers significant improvements in processing capability. Its CPU speed, clocked at 200 MHz, operates under a 64-bit architecture (the source of many migration issues). The Alpha AXP is a RISC-based system that currently has the ability to address 256 MB of physical RAM. Future operating system releases are expected to support up to 1 GB of RAM. As an industry reference, Digital provides a SPECMARK89 measurement of 118+ and a MIPS measurement of 151.

Table 4-1. VAX versus Alpha AXP Component Comparison

Functional Area	Current System Configuration	Proposed System Configuration	Advantages and Tradeoffs
CPU	VAX 3800 CISC 3.8 specmark 33 MHz Bus design 64 MB RAM max. 32-bit architecture	Alpha AXP RISC, 118+ specmark 150 MHz Workstation 1 GB RAM max. 64-bit architecture	RISC performance enhancement. Alpha AXP clock rate significantly higher. Faster CPU, Memory, and I/O. Increased memory capacity. Performance improvements. S/W migration. Chassis modification.
MEMORY	DR-300-32 Q-Bus I/O 64-MB max.	64 MB SIMMS Alpha AXP resident 256/1 GB max.	Faster memory handling. Larger addressable memory. Memory trade-in Physical Layout.
DISK I/O	QD21 ESDI issues Q-Bus I/O MSCP only Two device limit 15 Mbit/s	SCSI-II + SCEA Adapter SCSI-II Alpha AXP res. (SCSI-II) MSCP/TSCP (SCSI-II) Seven Devices (SCSI-II) 5 MB/s (SCSI-II)	Standard device I/O saves space. SCSI-II handles various device types. Multiple devices. Faster Data I/O adapter allows most SCSI. virtually limitless device interface. Can support RM option with same HA Adapter. Allows seven deep. Forty-nine available SCSI addresses. Unable to use Q-Bus PCB in Alpha AXP. Cannot use ESDI Disks.
Storage	Maxtor 760 760 MB 5.25" form factor 18 Ms AVG Seek Time 15 Mbits/s	Seagate/Hitachi 1.2 - 1.4GB 3.5" form factor 9 ms AVG. Seek Time 5 MB/s	Larger storage Smaller Faster Access High I/O rates
COMM Serial I/O	CM-DHV11 8 channel/Async 38.4K max. I/O Q-Bus	Magma 8+2 8 channel Async I/O 2 parallel ports 38.4K max. I/O Turbo channel	Duplicated functionality. Two parallel ports for flexibility. Unable to use Q-Bus PCB in Alpha AXP.
Network	EXOS 203 Q-Bus Ethernet 802.3 Dual rail	None Required Alpha AXP resident Ethernet 802.3 Thinwire	Use existing channel. TCP/IP supported. Unable to use Q-Bus PCB in Alpha AXP. Extra net board required.
SCSI	CQD-220 SCSI for Q-Bus MSCP/TSCP 4.8 MB/s Transfer	SCSI-II + Adapter See above	Saves Turbo channel. Unable to use Q-Bus PCB Alpha AXP.
BUS I/O	Q22 32-bit design 72 (some lines red) 3.3 MB/s avg. 5.0 MB/s burst All functions need 2 available slots	Turbo Channel 64-bit design 96 lines 50 MB/s avg. 100/MB/s burst 4 functions on board	Requires new controller. Unable to use Q-Bus PCB in faster bus. More functions resident on system

4.2.2.2 Memory Comparison

Advances in RAM capacity offered many options to consider in this area. Current VAX 3800 configurations consist of a single 32 MB PCB and can be configured to support a maximum of 64 MB.

Memory configuration of the Alpha AXP is most similar to the memory design of common personal computers or workstations, using Single In-line Memory Module (SIMM) insert boards. Because SIMM sets are smaller (5.65" X 1.0"), higher in density, and snap directly into the mother board, the memory design has smaller space requirements and faster cycle and access times. Other notable points include expansion and performance. Currently, the OpenVMS and OSF/1 operating

systems can address 256 MB of RAM. Future versions will expand RAM capacity to 1 GB. Although the 16 Mbit chips are not ready for release, the concept of a workstation with 1 GB RAM will open a wide range of possibilities. Creation of memory resident tables and processes that need not be accessed over a bus or through disk I/O are closer to reality.

4.2.2.3 Disk I/O Format and Disk Storage Capacity Comparison

Disk I/O and storage capacity were two areas in which performance increases were realized during the upgrade to the Alpha AXP. A typical ASAS VAX 3800 configuration uses Maxtor XT-8760E ESDI hard disk drives. Disk I/O is controlled by the Emulex QD21 in the current design. This ESDI controller provides emulation of Digital's Mass Storage Control Protocol (MSCP) small device interface to the hard disk. The QD21 has limited connection capacity and can only handle two MSCP peripherals.

The disk configuration for an Alpha AXP-based system used the Small Computer Systems Interface, version II, (SCSI-II). Special external controller boards are not required since the controller is resident on the Alpha AXP mother board itself. The SCSI-II control interface is capable of handling two independent SCSI bus configurations. Each bus can support seven MSCP and TSCP devices. Consequently, the Alpha AXP mother board is capable of supporting access to fourteen SCSI-II compatible peripherals.

There were many commercially available options for the fixed disk capability at the time the retrofit was being designed. The minimum requirements for the media were (1) SCSI-II interface, (2) minimum storage capacity of 1.2 GB, (3) 3.5-inch form factor, (4) average access time no more than 9 to 10 milliseconds, and (5) a minimum data transfer rate of 10 MB/second. The first workstations were equipped with 1.2 GB disks. Subsequent systems were equipped with 1.4GB disks which became readily available during the hardware system development phase. With the growth of higher density disk drives, future workstations may be equipped with 2.5 GB drives. With the combination of the aforementioned SCSI-II throughput speed and the increased performance of the new SCSI-II high density disks, the Alpha AXP-based work station measurably increased disk I/O.

4.2.2.4 Communication

The VAX computer has no built-in communications capability. Add-on communication boards are required in all cases. The Alpha AXP computer comes with communications port capability built into the mother board. Its features are identified below:

Asynchronous Communication—The Alpha AXP system comes equipped with one asynchronous communication port, RS-423A. The Turbo channel option available from MAGMA, Inc. is the MAGMA 8+2. It will support eight asynchronous channels and two parallel ports which allow for the use of various output devices provided as printer subsystems.

Network Communication— The Alpha AXP has an Ethernet port resident on the motherboard. This port supports IEEE 802.3 standard Ethernet.

4.2.2.5 Bus I/O Speed and Format

The VAX bus design routed all communications through the back plane Q-Bus. The Alpha AXP bus concept is significantly different. Because of the motherboard approach and the move away from the "one function equals one board" thinking, the proposed Alpha AXP has only a limited need for bus options. Memory, SCSI-II, Ethernet, graphics acceleration, and communication options have all been placed "on board," making system I/O between these processors faster.

Alpha AXP-based machines currently have a design for I/O interfaces called *Turbo Channels*. The data rate of the Turbo Channel is 100 MB/s (burst) with a standard throughput of 50+ MB/s which is a significant improvement over the Q-Bus which operates at a maximum burst of 3.3 MB/s.

4.2.3 Physical Configuration

The activity involved in introducing a Digital Alpha AXP processor into the current fielded hardware platform as a replacement for the existing 3800 VAX processor is described in this section. As part of the RDM philosophy, JPL's approach was to use as few engineering designs and production steps as possible. Prototypes were developed, quickly tested and evaluated, and modified, as needed. Ultimately, a final design configuration was completed. Available technology, such as prepackaged rugged workstation processors and rack/chassis mountable devices, permitted rapid delivery by using a simple assembly process and minimum functional testing to produce a large quantity of reliable systems for retrofit in the field in a very short period of time.

4.2.3.1 Use of Commercial Hardware

While the use of commercial off the shelf systems (COTS) is adequate for most business and scientific applications, the use of COTS products is of concern when implementing systems for military use. While ASAS must conform to strict requirements for TEMPEST and EMI shielding for all fielded systems, the customer allowed the use of COTS products during the prototype development. There are cost advantages to using commercial hardware in a fielded system. However, there are several issues that require immediate resolution. Security, environmental, and logistical concerns are the most critical.

For example, when using COTS hardware in a DIA accredited system, all previous TEMPEST and EMI testing and approvals are considered invalid. In order to maintain system approval, special waivers to use COTS hardware for classified processing had to be secured for the interim. Also, using COTS equipment upon completion of the prototype negates certain

environmental tests performed on the current system. Special consideration and waivers may also be necessary during this phase as well.

Using COTS hardware during the interim stage may have a certain impact on training and maintenance. However, in this instance, the ASAS Project recommended no changes to training and maintenance material during this phase.

The use of COTS hardware provided immediate performance gains in all areas. Even with the aforementioned concerns, the use of COTS in the field to realize these immediate performance gains and elicit feedback from the users may be an option.

4.2.3.2 Use of Existing Assets

For this hardware upgrade, the sponsor's specifications required the use of existing assets for the prototype system, when possible. Through evaluation of the existing system, all interface formats for peripheral devices (drives, monitors, etc.) were determined. As stated previously, one design goal was to use as many of the main components of the existing system as possible. By using existing components, cost savings could be realized in the areas of acquisition, training, and maintenance.

There were several candidate devices in the ASAS system configuration that were considered for reuse including monitors, optical disk drives, keyboards, and mice. The costs and time associated with developing new, rugged components is motivation to use existing assets. There were several technical issues associated with this strategy, but the challenges were met by the engineering staff. For example; the rugged monitor in the ASAS workstation is a dual scan monitor with a maximum vertical scan rate of 54/kHz. The Digital HX Graphics Accelerator board provided with the standard Alpha AXP workstation will only drive monitors with a minimum scan rate of 66 kHz. This problem of incompatible scan rates was solved through direct communication with Digital. After proving the concept, JPL contracted with Digital to modify their graphics board to drive the existing monitors.

4.2.3.3 Packaging Issues

Packaging the Alpha AXP CPU into the existing workstation design was not easy. The standard size and form of the workstation had to be retained. Standard connectivity to all peripheral devices had to be considered as well. The major issues are listed below:

- 1) Data Interface: Each physical connection on the VAX had to be duplicated for the Alpha AXP. This meant that interface cables for each connection had to be fabricated for each external interface. Sketch engineering based on existing interface designs reduced costs. JPL had experience in building interface cabling and with limited production of cable at reduced costs (as compared to full production cost).
- 2) Power : Alpha AXP systems are specifically designed for the commercial office environment, reducing the requirements for power significantly when compared to

their VAX equivalents. Packaging these systems for fielded systems allowed alternate power supplies to be considered. The Alpha AXP design has incorporated the SCSI controller, Ethernet controller, and RAM onto the "mother board." This has significantly reduced the power consumption for each workstation.

- 3) Environmental: Environment all requirements fall into four basic categories; thermal, shock, vibration, and TEMPEST. The commercial Alpha met certain tolerances, however, it did not meet the existing military requirements. Design of the prototype had to account for the following issues to meet or exceed the current capabilities in the field including:

- Airflow thermal exchange, operability under high temperatures.
- Shock tolerance.
- Vibration (operational and non-operational).
- Radiated emissions.
- Dust.
- Noise.

Accommodating these environmental requirements played a large role in the cost of replacing a fielded system.

4. Logistics: Documentation, training, and maintenance were integral parts of the transition to the proposed system. During the migration phases, all existing equipment, drawings, manuals, and tools were evaluated to reflect the system upgrade. Reuse of existing manuals minimized the impact and the cost to the development of new training and maintenance materials, as well as the drawing packages.

4.2.4 Alternate Configurations

As a result of performance improvements from migrating to the Alpha AXP, the physical configuration of the ASAS enclave was reduced. With the VAX 3800-based configuration (Figure 4-1) four support processors were required in addition to the six workstation processors to perform compute-intensive activities. Still, processing backlogs of several hours were not uncommon during periods of high message traffic.

The ASAS Alpha AXP enclave configuration (Figure 4-2) has enough processing power to eliminate the need for the four support processors. The background automatic processes, which were previously loaded on the four support processors, are now loaded directly on the workstation processors in tandem with all analyst operations. Still, no performance degradation has been identified, either to automatic or analyst operations. The Alpha AXP configuration did not experience any backlogs in processing data, even for periods of high message volume. Finally, the system could provide the commander with an integrated picture of the battlefield in real time. The performance improvements allowed the analyst to perform routine system operations faster and allowed them more time to perform their analysis functions.

4.3 Software Migration Approach

4.3.1 Commercial Packages, Compilers, and Build Environments

To begin the software migration, the development environment and build tools were installed on the Alpha AXP. For configuration management, the ASAS Project uses two OpenVMS utilities that were previously supported under VMS: Configuration Management System (CMS) and Module Management System (MMS). CMS provides a repository for source code files and object libraries. It maintains a history of changes to source code files as they are edited by the programmer. MMS provides the description of dependencies between objects and executables. It provides developers with the capability to modify specific routines and relink only those executables that reference those routines. Since the Alpha AXP and VAX use the same Files-11 file system, transferring source code files was simple.

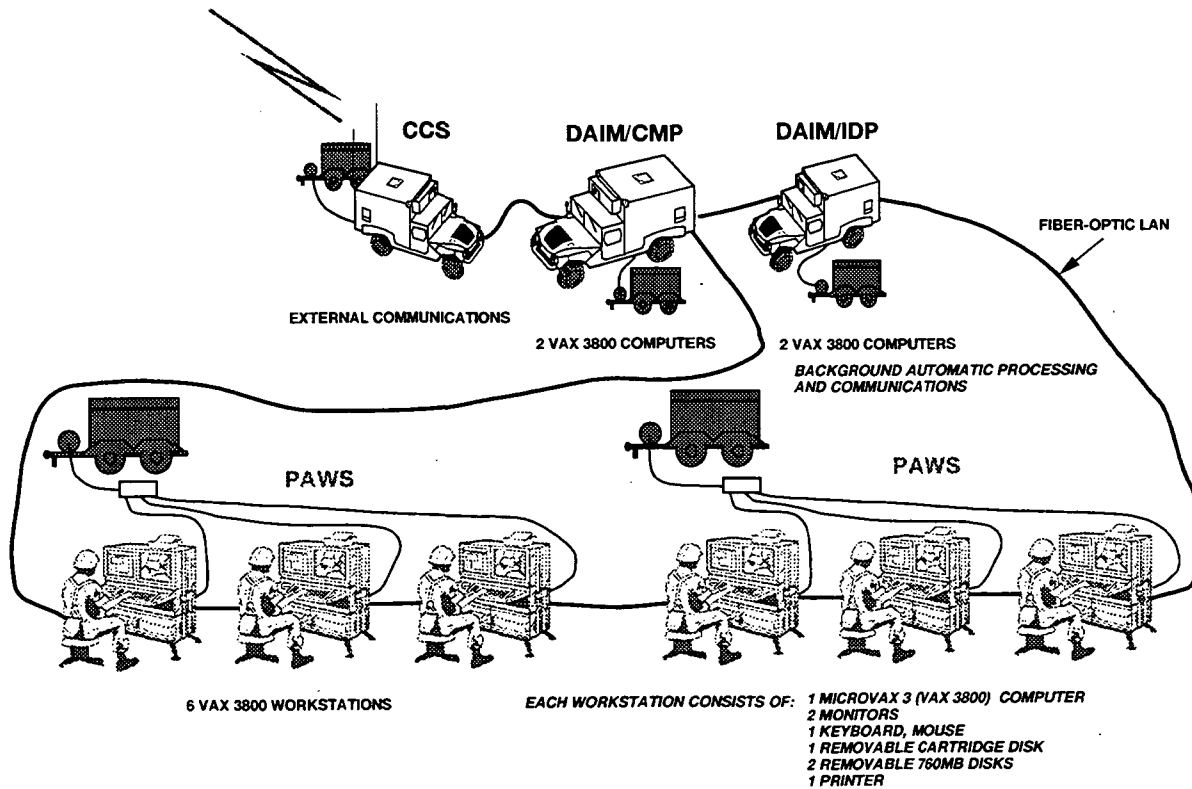


Figure 4-1. The ASAS 3800 Enclave. The enclave consists of six workstations and four support (background) processors.

Migration from VAX to Alpha AXP

Depending upon the languages and products used to build an application, some compilers were not available at the time of migration. While FORTRAN and C were available at the onset of the migration effort, Pascal and ADA were not available until later. Our experience with Digital has shown that they have been reliable in meeting their compiler release dates (Table 4-2).

In addition to dealing with the late arrival of Digital S/W products, evaluation of the Third Party Commercial Software was completed. The products fell into the following categories: (1) database management system, (2) forms management, (3) graphics packages, (4) spreadsheets, and (5) network software. The evaluation of each product was focused on determining its current availability for use on the Alpha AXP with OpenVMS. At the time of this migration effort, the Alpha AXP had been commercially available for only about one year, and many third-party vendors were completing their own migration to the Alpha AXP. In some cases, third-party packages were vested when native versions were not complete. A critical feature of DECmigrate is the capability to link both vested and native code in a single executable. This action facilitated the migration of the ASAS Software since the Smartstar forms management package had not been migrated by the vendor.

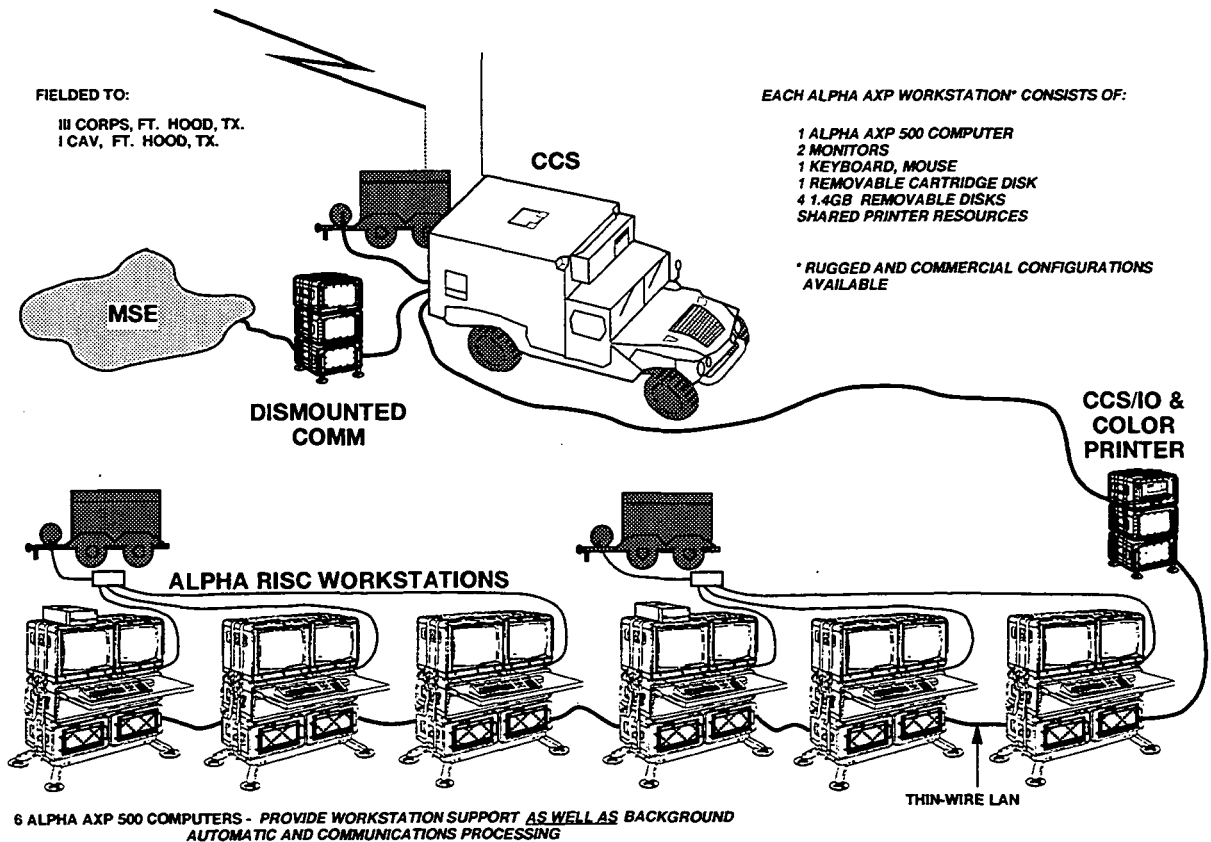


Figure 4-2. The ASAS Alpha AXP Enclave. The enclave consists of six workstations. The four support (background) processors associated with the 3800 enclave are no longer needed.

Table 4-2. OpenVMS Operating System AXP™ Software Rollout Schedule

	November '92	January - June '93	July - December '93	January - June '94
Operating System	Open VMS AXP O/S V1.0 (Open VMS VAX 5.4-2)	OpenVMS OVS, AXP, version 1.5 SMP New Batch/Print Network Booting	POSIX (1003.1..2)	Open VMS O/S AXP, Version "EPSILON" Volume Shadowing Host-Based RMS Journaling (Open VMS VAX 5.5)
Cluster		VMS cluster, (Initial configurations, limited multi-architecture, dual-host DSSI)	VAXcluster Console	VMS clusters (expanded configurations)
Networks	DECnet (end node)	TCP/IP Services X.25 SNA 3270	DECnet/OSI Mail Transport x.500 Server	CDE MAILbus 400
Language and Application Development	DEC FORTRAN DEC C MACRO-64 assembler DXML (math library) DECset (full)	Pascal Ada OPS5 VUIT DEC COBOL	DECps Datatrieve C++ RALLY	PL/I
Middleware	DECwindows Motif (Including CDA, Bookreader) NAS 250 & 300 Advanced Developer Kit	SQL Services ACAS DQS GKS PHIGS DEC AVS DECmessageQ Message Router POLYCENTER Agent Open 3D NAS 200, 250, 300 Integrated Runtime	DEC/EDI DECcmds (driver)	 NAS 400 Integrated Runtime
Transaction Processing and Information Management	FMS	Rdb DBMS DSM ACMS Desktop Client SQL Multimedia, V1.1 CDD/Repository DECforms	Data Distributor DECobject database ACCESSWORKS Instant SQL ACMS runtime	Rdb/Expert ACMS Development RTR
End User Tools		DECwrite Notes DECpresent DECchart		
Other	DECram DECmigrate	PATHWORKS DECscheduler POLYCENTER SW DIS	ALL-IN-1 Integrated Office System	SERdb

OpenVMS™ AXP™ Systems Software Public Schedule
Source: Digital Equipment Corporation

01 Feb 1993

Our evaluation also addressed upgrades of COTS packages in addition to their availability on Open VMS. For example, Oracle Corporation released its new version (Oracle 7.0.13) on Alpha, but not the version (Oracle 6.0.33) ASAS was currently built against. This required the ASAS Project to upgrade to Oracle 7.0 and address the COTS upgrade issues, as well. The ASAS Project expended a considerable amount of time integrating and testing new versions of COTS products on the Alpha AXP. Several times during the migration of ASAS, receipt of a patch to a COTS package was critical to making continued progress.

4.3.2 Migration Strategy for Software Items

Once third-party packages were obtained and made operational, the previously developed VAX 3800 application code had to be evaluated. The migration of ASAS involved code written in many languages: C, FORTRAN, ADA, PASCAL, and MACRO-32. MACRO-32 code had to be completely rewritten, as this is a VAX processor-specific language. ASAS had less than 1000 lines of MACRO-32, and this was rewritten in C.

Compiler availability for the Alpha AXP determined which software items could be compiled native on the Alpha AXP. Some items were vested since a compiler was not yet

available. It is possible, however, to combine both native and vested code in an Alpha AXP executable. We used native compiled code where possible, but linking vested and native software together worked well, also.

In addition to identifying those software items that could be compiled, an evaluation of the source code was conducted to identify coding practices that would affect recompilation on the Alpha AXP. These practices did not keep applications from running on OpenVMS, but they did have a significant impact on performance. Two major differences between the VAX and Alpha AXP architecture are: (1) data alignment and (2) choice of data type. Data is naturally aligned when its address is an integral multiple of the size of data in bytes. For example, a long word is naturally aligned at any address that is a multiple of 4. A structure is naturally aligned when all its members are naturally aligned. On Alpha AXP systems, the default is to align each data item naturally, so the Alpha AXP does not provide hardware support to minimize the performance degradation from using unaligned data. Our experience has shown that references to naturally aligned data on OpenVMS Alpha AXP systems are 10 to 100 times faster than references to unaligned data.

The Alpha AXP's RISC architecture does not perform VAX D-floating arithmetic (56 bits of precision) and does not support the H-floating point data type. Because Alpha AXP compilers do not support H-floating data, modifications to use G-floating were made where possible. There were a number of other issues that were reviewed when compiling on the Alpha AXP. The VEST utility served as a tool to identify them, such as:

- Static unaligned data.
- Floating point references (H-floating and D-floating).
- Privileged code.
- Nonstandard coding practices.
- Code referenced to openVMS data or code other than by using system services.
- Uninitialized variables.

With the results of the evaluation complete, a module-by-module plan was defined to identify the specific migration method for that module. Clearly, a simple recompile and link was the goal, but our migration schedule dictated that vesting was necessary, as well. The two migration paths are compared in Table 4-3.

4.3.3 Maintain Existing Look and Feel

The migration of the user interface was critical to the success of our effort. The goal was to provide an identical "look and feel" to the user. Essential to maintaining the look and feel was the migration of the menus and forms that are currently in use. The ASAS system has 1,143 forms for controlling various aspects of the user interface. If modification to the forms or to the code supporting the forms had been required, the magnitude of the migration effort would have increased

Table 4-3. Migration Path Comparison

Factor	Recompile/Relink (NATIVE)	Translate (VESTED)
Performance	Full Alpha AXP capability	Typically 25 to 40% of native Alpha AXP potential
Effort required	Varies; easy to difficult	Easy
Schedule constraints	Based on availability of native compilers	None: Available now
Programs Supported		
Age	PreVAX VMS Version 4.0 source accepted	Only OpenVMS VAX Version 4.0 or later supported
Limitations	Privileged Code supported	Only user mode code supported
VAX Compatibility	High: most code will recompile and link without difficulty	Complete via emulation
Ongoing support maintenance	Normal source code and maintenance	No source maintenance

significantly. It would also have meant that the forms and form handling would change for the user. The effort spent in providing an identical “look and feel” was well spent, as impacts to documentation and training would have significantly increased the overall cost and schedule for upgrading to the Alpha AXP.

4.3.4 Test, Evaluation, and Tuning

As the software was being migrated, other engineers were developing the test and validation environment. Test software was evaluated and migrated in the same fashion as the applications code was handled. Test data files were easily transferred to the Alpha AXP system through conversion utilities supplied by Digital. A complete set of regression and stress test procedures was developed to validate the accuracy of the migration.

It was important to measure the improvements in performance gained by the Alpha AXP migration. Consequently, a complete set of performance measures were developed. The evaluation of performance was conducted in a number of different areas to assess overall system performance improvements. Those areas include:

- System initialization and startup
- Process activation from menus
- Database access times for read and writes
- Graphics operations
- Computation-intensive functions or modeling
- I/O-intensive operations

There were several findings about system performance. The more significant findings are covered here. The most striking performance statistic was that the system could operate at extremely high rates even with the reduction of four background processors previously required with the 3800 VAX systems. It was found that the six Alpha AXP processors included with the new Alpha AXP configuration provided more than enough computing power. In fact, system level performance improvements were found to be between 20 to 30 times for computing-intensive activities and up to 50 times for graphic functions. Supplementing the Alpha AXP with additional main memory provided a performance improvement in itself, because executables in this RISC architecture are much larger. Memory pages themselves are defined as 8192 versus 512 bytes. Testing was conducted in 64 MB increments to determine the optimal memory configuration. A minimal system configuration of 192 MB of RAM was found to provide optimal configuration for each Alpha AXP computer. The number of disk drives in the system also affected performance as well. Database-intensive operations benefited from multiple drive configurations. The optimum configuration for each ASAS workstation was three and 1.4 GB disk drives. In the case of the ASAS system, the number of processors was reduced, due to the significant increases in system performance.

5.0 Conclusions

Based on the experience of migrating ASAS, migration of existing applications from VAX to the Alpha AXP can provide many benefits;

- Eliminate performance bottlenecks.
- Reduce the system footprint.
- Provide a hardware platform that runs three operating systems, OpenVMS, OSF/1, WindowsNT.
- Increase programmer productivity.
- Provide a platform for future enhancements.

As described in the previous sections, a number of factors can add to the complexity of a migration. Typically, an application that has been well designed and followed standards for software development has a high probability of success. For example, the ASAS software using OpenVMS 1.5, Oracle 7.0.13, Smartstar, Multinet, DECnet, and XGKS was completed in 10 months. The software and hardware prototype was completed and operational testing started in December 1993. This was accomplished using a team of 14 software engineers and 2 hardware engineers. The operational testing of the Alpha AXP lasted approximately 2 months and concluded with a successful test of the Alpha AXP in the Warfighter exercise at Ft. Hood, Texas.

At the beginning of the ASAS migration effort, the focus of the activity was on completing the migration. The reduced configuration (6 Alpha AXP processors versus 10 VAX 3800s) worked very well. Further evaluation of system performance led to additional downsized configurations. It was found that the system could perform very well with a minimal configuration of just two Alpha

AXP-powered workstations. Consequently, a new, two-node configuration (two Alpha AXP 500s) was introduced and is now in use in the field. These new configurations provided the program with capabilities that were unforeseen until the advent of the Alpha AXP. In addition to simply providing these new configurations, the system performance can now truly be called "real-time." The processing and correlation of intelligence data are now processed by ASAS at the speed at which the communications system can deliver messages. The operational testing at Ft. Hood demonstrated that the analyst workload was sufficiently reduced for the first time. The speed of the system allowed analysts to perform their primary function, analysis of the battlefield situation. At the completion of the exercise at Ft. Hood, the consensus from the customer and the user was unanimous. The Alpha AXP was dramatically faster and the benefits from migration are well worth the cost.

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