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STGT Program: Ada Coding and Architecture Lessons Learned

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STGT (Second TDRSS Ground Terminal) is currently halfway through the System Integration Test phase (Level 4 Testing). To date, many software architecture and Ada language issues have been encountered and solved. This paper, which is a transcript of the presentation at the December 3rd meeting, attempts to define these lessons plus others learned regarding software project management and risk management issues, training, performance, reuse, and reliability. Observations are included regarding the use of particular Ada coding constructs, software architecture trade-offs during the prototyping, development and testing stages of the project and dangers inherent in parallel or concurrent Systems, Software, Hardware and Operations Engineering.

Introduction

STGT is the first major Ada development program for M&DSO, which has developed other large ground stations in FORTRAN and C. In addition to the use of Ada, GE Management and Data Systems Operations faced other software development risks in the implementation of STGT. Some of these risk items are itemized below:

- A heavily distributed system (>30 processing nodes and >100 workstations in previous ground stations)
- High real-time system content (vs. 40% real-time, 60% batch processing)
- First on a DEC/VAX platform (vs. IBM mainframes and Sun/Unix workstations)
- High-availability/high-reliability architecture (99.99% availability required)
- High hardware content (>350 racks of ground communication equipment)
- Heavily automated, X-Windows, workstation-based user interface
- First artificial intelligence (AI) based hardware fault detection/fault isolation
- Short development lead time (3 years from start to delivery)

Risk items like the above don't usually translate into the impossible, they just have a way of eating into cost and schedule margins. Several steps were taken to mitigate the risks involved. An Ada Core Team was formed prior to program startup to develop language expertise. An Ada training program was developed and its completion required for all software engineers employed on the program. Despite these efforts, many lessons were learned on the job through prototyping, development and testing. This paper is intended to be a chronicle of these risk issues and (hopefully) their resolutions.

Project Composition

The Second TDRSS (Tracking and Data Relay Satellite System) Ground Terminal (STGT) is a new ground station and an upgrade to an existing ground station in White Sands, New Mexico. These ground stations will provide command and data communications from user control facilities through the TDRS, and on to the various user satellites and the Space Shuttle.

The breakdown of thousands of source lines of code developed for each Computer Software Configuration Item (CSCI) for the project is shown in Table 1.

CSCI	Size (Lines of Code)	Thousands of Hours[1]	LOC / Hour
TTC (Satellite Control)	100k	115k	0.86
DIS (Communication)	76	79	0.96
USS (Ground Equip.)	71	58	1.22
EXC (Scheduling)	26	23	1.13
WKS (Workstation Interface)	152	56	2.70
COM (Infrastructure)	23	37	0.62
MDS (Development Env.)	100	36	2.77
SIM (Simulators)	40	40	1.00
Totals	**588**	**444**	**1.32**

Note:
1 - Requirements Analysis through Software Test

Descriptions of the CSCIs are as follows:

- TTC:
  Tracking, Telemetry and Command CSCI, responsible for controlling the Tracking and Data Relay Satellites (TDRS) used by NASA to relay user satellite and space shuttle telemetry and command data. Responsible for commanding the satellite, monitoring its health, and controlling the ground antenna in order to point at the satellite.

- DIS:
  Data Interface Subsystem, responsible for interfacing with the NASA communication network, accepting scheduling orders from NASA, and switching the inputs and outputs from the ground station to data links between STGT and the other NASA locations.

- USS:
  User Services Subsystem, responsible for controlling most of the ground communications equipment (GCE) and supporting communications to the TDRS and to various user satellites.

- EXC:
  Executive, responsible for scheduling of a single Space to Ground Link Terminal (SGLT) controlling a single TDRS satellite. There will be six SGLTs overall in the two ground station installations.

- WKS:
  Workstation, responsible for operator interface, including intelligent graphically-oriented displays, operation alert messages and operator commanding capabilities.

- COM:
  Common Run-time Environment, provides common capabilities across all computers including communications within and between computers, data logging, startup/shutdown/ failover control, and device driver interfaces.

- MDS:
  Maintenance and Development Subsystem, provides COTS tools for development and maintenance environment, database displays/editors, and configuration management software.
- SIM:
  Simulations, provides simulations of the NASA scheduling interface, ground hardware, and the TDRS. Simulators are used in testing, training and problem investigation.

Software Architectural Issues

Architectural Reuse

STGT attempted a high level of reuse and incorporated reuse into its architecture. and in many ways succeeded. Attempts were made in object-oriented design, some of which succeeded in providing reliable, understandable, reusable products, and some of which only caused major headaches. Those that were problematic were usually related to lack of understanding of the scope and breadth of the situations in which the code would be reused, the computers on which the code would run, and the environments on these computers. For example, code reused on a workstation found itself in a rather different environment than on the large VAXes, due to lack of availability of large local databases.

Reuse was attempted on both large and small scales. Small-scale reuse was of course more easily planned than large-scale reuse. Large-scale reuse was more likely to result in complicated error conditions, where different subsystems (and their engineers and programmers) wanted to operate in different ways but were constrained by identical implementations due to code reuse.

Ada Reuse

In the early days we had "reuse evangelists" who proposed massive, complex, self-initializing generics for everyone. Almost every case that was ever implemented was later disabled, deleted, gutted or otherwise rewritten. Generics proved very difficult to debug using a source-level interactive debugger, relatively slow to execute in real-time, and very hard to write. Elaboration time-initialization code was also difficult to debug and prone to exception handling difficulties. Simple generics, on the other hand, were often very effective and easy to reuse. Complicated generics (including generics within generics within generics) were seldom worth the cost unless the designer and sole user were one-and-the-same, and the designer was well above-average in terms of proficiency and experienced at writing generics. That's not to say that we didn't have proficient programmers. With 100 or more programmers, just don't expect everyone to be a generics expert and design generics well.

Our best use of complex Ada generics involved data logging and retrieval software. This software utilized a high number of generics starting with primitive types (strings, integers, reals) and built up by instantiation into complex, compound record structures in various sizes and formats. This worked very well, provided a single designer/programmer was responsible for both the generic capability and it's uses.

Other good choices for Ada generics were design elements which clearly had a high degree of parallelism, such as our communications package which treated all messages the same, regardless of individual message formats. These even utilized declare blocks, which instantiated the generic on-the-fly for differing sizes or other record discriminants based on run-time values. These met with good success and surprisingly good performance on VAX Ada. Poor choices included the hardware simulators, which attempted a very high degree of generics (>50% of code was within a generic) which suffered from severe performance penalties and lack of flexibility in dealing with specific hardware behaviors.

Coding to a common source template is actually a low-tech form of reuse that should not be overlooked. It worked very easily (as long as the template was correct) and served to promulgate good examples for coding and error-handling. Templates were used for declaring, sending and receiving message objects. They worked well, until limitations in the templates were found. A more extensive effort in developing the template would have payed off handsomely in our experience.

Avoid "Monolithic" Ada packages. Trying to be all things to all people will most likely be nothing to anybody. Thinking that object-oriented design translates into "throw everything into one package" is similarly misguided. Use a layered approach instead. Define a package with just type definitions. Then define a package that provides basic operations on these types. Define higher-level packages as necessary to define more complex operations, building on lower-level packages. A careful architecture like this can help you reap big reuse benefits as new uses are found.

Following this approach allows different programs to access the object at different layers of abstraction. Some just need a type definition. Others need basic routines to manipulate the types. Some need advanced routines composed out of basic routines. Others could benefit from automatic initialization of objects at elaboration time (tends to be very trouble-prone, should be carefully controlled by a standards committee). All uses of a complex object, especially potential future ones, may suffer if the only view presented is a single complete monolithic view. A program wishing access to a type definition ends up with pages of "hidden", unused code and data, and maybe even automatic creation/initialization of objects at startup time, referencing databases defined on one computer and not others.

Variable-length strings were another good reusable package. We implemented them with a generic package, pre-instantiated sized to 256 characters. Use of a pre-instantiated package allowed easier sharing of types. However, this also encouraged waste (programmers were encouraged to use 256-byte strings where only 16 characters were necessary).

Ada Architecture issues

Error handling was our number-one architecture problem. We definitely could have benefitted from better up-front design and more prototyping. Ada tasks complicated the error handling picture drastically.

There is a lot of functional overlap between the capabilities provided by Ada exceptions and those provided by VAX/VMS Condition handlers. There were points of interference or undesirable interplay between the two as well. You need to design error handling into all system service calls. Know which exceptions are worth handling, and which you WANT to be unhandled (because they show up obvious coding or environment problems).

Taking advantage of the operating system's capabilities for calling stack tracebacks on unhandled exceptions, for example, can provide lots of power for debugging. These are especially useful if integrated into the debugging environment, as is the case with most DEC/VAX software.

Concurrency

Ada Tasks

Much fear was generated during early design phases concerning the trade-offs between concurrent operating system processes, and concurrent Ada tasks. During implementation, use was made of both single and multiprocessor machines, with varying results. Software testing and modification history have allowed us to construct better guidelines for process versus task trade-offs. In many cases, processes were used as an aid to work breakdown rather than based on strong architectural need. In some cases these choices caused problems later, and limited the range of available solutions for requirement or design changes. Ada tasking would have been more flexible.

However, increased use of Ada tasking would have required a different development support structure. This support structure would have had to allow separate development and testing of task-based functional work packages independently. The tasks could then be integrated into a single process resulting in a more reliable system.

In general, tasks were well-used and caused relatively few problems. Among the problems were prioritization, blocking, proliferation of tasks required to synchronize between other tasks, and increased rigor in defining/testing the tasking architecture. Tokens (Ada "private" objects containing pointers and flags used in the interface packages between application and service layers) were used to define message addresses. These later became a problem since they were not designed to be shared, yet were shared in some application programs among various tasks. The sheer number of tokens used in the system prevented us from embedding a task within all token types for synchronization (because of the amount of memory used for task stacks, etc.), but we later embedded "token in-use" flags to help detect instances of sharing. Earlier recognition of the problem would have allowed a range of more elegant solutions.

The following are some additional observations regarding Ada tasks:

- Task context switches are a LOT faster than process context switches. If you're thinking of adding more processes, tasks are better. However, processes are easier to split up the work among multiple independent programmers. Tasks in the same process require more programmer coordination during development.
- Tasks are like lawyers. If you have no tasks, you probably won't need any. However, once you have two tasks, you will probably need another five or ten more to handle coordination between those two tasks plus synchronize any shared inputs, outputs, resources, etc. This means that if you start out thinking that you'll write a program with a few tasks, you'll probably end up writing lots. However, this didn't appear to have been a problem. The number of tasks did not affect performance as long as they were event-driven. You may have to spend more time maintaining relative priorities of tasks as the number increases.
- We avoided PRAGMA TIME_SLICE, since we understood it to add significant overhead. We were successful in avoiding it. Several times we were tempted to use it to alleviate other tasking problems, but it was never absolutely necessary and in the end was successfully avoided.
- Multiprocessor problems were encountered, which required us to use PRAGMA SHARED and PRAGMA VOLATILE, which are implementation dependent. These relied on architecture-dependent features of VMS processors. The features worked well in our two-CPU environment.
- We would have liked to prioritize different entry points in the same task (e.g. to handle the same type of rendezvous, but from different sources), but Ada doesn't allow it. We found a kludgy way of doing it. Instead of attempting reuse, we should have duplicated the task code (i.e. via task types) and prioritized them differently. Maybe we did this because we were attempting excessive reuse, or we were afraid of proliferating tasks. Simpler would have been better.
- We worried a lot about "fairness" of tasking, however all fears appeared to be groundless. If you're worried about fairness of tasking, what you really may be worried about is that you need more CPU power. Or you may have tasks polling when instead you need to turn them around into an interrupt-driven approach.
- Beware of non-reentrant servers, services, etc. Accesses to Rdb, the relational database we used, had to be serialized by routing all task's requests through a single Rdb server task (gateway) which in turn provided

the sole control of the Rdb server. This is a fairly common problem interfacing with non-Ada facilities for which you should watch. Our COTS Graphical User Interface (GUI) non-reentrancy problem was solved with the opposite approach. We ran four copies of it, one for each operator window.

- There was still some question for us about what Delay 0.0 really did, or if it was necessary. It was documented as a way to break the execution of a long-running task and allow a context switch to another waiting task. When we attempted to verify this behavior through benchmarks however, we met with mixed results. We eventually opted not to use the feature. Instead we broke problematic long-running tasks into multiple shorter tasks.

  We also had reports of problems with the fairness of allocation of CPU time among tasks. When we investigated with benchmarks, however, all we found were problems with the benchmarks. For each case of purported probems with Delay 0.0 and tasking fairness, programmers who thought they had a problem with an Ada feature were instead using too much CPU time. The ultimate fix was to rearchitect the program to respond to events or Asynchronous System Traps (ASTs) rather than poll.

Compile-time vs. Run-Time Binding

- You can use unchecked_conversion to convert between system.address and object_access types. You'd better be very careful when using this, though. A LOT of errors were committed in this area. Need careful code review and on-the-job indoctrination, perhaps through programmer peer group inspections/walkthroughs, etc. Watch out for things like unintentionally overlayed objects and other C code type pointer errors.
- Anytime you use access types or system addresses in variables it opens the door for memory leaks around allocation/deallocation.
- The Ada compile-time binding of record types was an early problem when data logging record types were very volatile. Many low-worth recompilations were performed. Configuration management and test computer system performance were impacted by the need to accept the many new executables images that were generated. A run-time-binding architecture might have been better in these highly volatile report-writing cases. Once the formats stabilized, the structure did provide for ease of checking. Compilation tests for code impact to changing interface or record format become both routine and precise.

Message Passing Architectures

Ada Interface Definitions

Internal interface definitions, between computers and software subsystems, were captured in Ada. In most cases, representation clauses were not used. Instead the message record definition code was reused in each subsystem. Software configuration management mechanisms ensured that interfaces were modified consistently. This was reliable since all computers used the same hardware architecture and the same compiler.

Platform Dependencies

Operating System Dependencies

Many unknown, unforseen platform dependencies cropped up during the development and test phases. In many cases, these problems were the most astounding and difficult to predict of any we encountered. There is a high degree of functional overlap between the Ada compiler/language run time environment (VAX/VMS Ada 2.2–41 at this writing) and the host/target operating system (VMS 5.5–1). This overlap caused problems in error handling; Ada exception handling interfered with the generation of otherwise automatic operating system calling–tree tracebacks. It also appeared in process management (computer operators couldn't reliably cancel processes with some types of tasking structures), and debugging (generics and tasks increased difficulty of source–level debugging and thus were unpopular with programmers). While many of these are platform–dependent, they point to the overall problem of overlap between Ada's functionality and the functionality of the operating system upon which it's running. If you're running on a bare–bones processor, or a primitive operating system, then there may be little or no problem. Using a sophistcated and feature–rich operating system like VAX/VMS, on the other hand, can lead to limitations and unforeseen problems when you use Ada's advanced features and the operating system's advanced features in the same program.

We ended up having our DEC consultants write a sophisticated assembler routine embedded in each executable which detects unhandled exceptions in any task, forces a traceback, and terminates the image. This has provided us with vastly improved turn–around time for fixing fatal errors found during testing.

Some particulars we found:

- The VAX Ada Run Time Library disables certain features of VMS (like the capability of a computer operator to stop a process gracefully, unless you've coded–in your own user–defined exception handler and a means to signal termination). Also, VAX Ada's memory deallocation/stack unwind during exception propogation interfere with VMS's capability to do a call tree traceback, which would otherwise have shown a stack dump from the line raising the problem all the way back up to the top of the program. This was especially troublesome when some tasks failed due to unhandled exceptions, (coding errors), but other tasks and the process as a whole, continued to function, making it difficult to detect and isolate the problem.
- Writing debug or error messages using Put_Line caused a performance problem in real–time processes, when all tasks in the process hang behind an operating system output request

queued to the disk device. We couldn't tolerate this in many of our hard–real–time executables, so we converted these into shared memory messages between the real–time processes and a lower priority server process, who performed output on behalf of the real–time processes.

- We used tuned Record Management Services (RMS) Input/Output instead of vanilla Ada TEXT_IO or SEQUENTIAL_IO. This was because of the need for heavy–duty tuning, including buffering control and management. We implemented a Mixed I/O–like capability using discriminated records, where each record in the file contained its own embedded record format identifier. This worked quite well, except when the formats were under early development and changed often. Then backward compatibility of current software and previously archived data files became tedious.
- SHARED images (a sophisticated VMS Feature) would have been good to use in certain areas where reusable code made up almost a Megabyte of each executable image, but the integration with Ada was not smooth. By the time we developed a good working approach we had to abandon it because of the retrofit cost. This might have helped Ada's performance some, in decreasing the memory required. If it could have been done earlier with benefits amortized over more of the development phase, it would have saved money and time. We had initial misgivings about the ability to debug an installed shared image, which later appeared to have been unfounded.
- VMS has a very nice software pseudo–interrupt capability (Asynchronous System Traps or ASTs). The Ada run–time library uses these to do it's own synchronization, and instead converts each application AST into a task rendezvous. As a result, running Ada as a part of a "real" AST such as in a call from a device driver written in another language was a difficult proposition (couldn't use tasking, perform any I/O, etc.). However, the run time libary's conversion of ASTs to tasks (PRAGMA AST ENTRY) was quite accessible to programmers. Tasks seemed to be quite easy (and even natural) to use for this purpose. This enabled anyone to make use of ASTs, whereas without this we probably would have had to restrict their use to an elite group of the most experienced programmers.
- Make use of platform capabilities. Don't be an Ada zealot, thinking you have to write pure Ada code and duplicating functionality otherwise available more cheaply or efficiently in the operating system (100% code portability wasn't an issue for us – and it may not be for you either). Examples are character and numeric utilities. Just write good (portable) package specs, and implement the bodies of these in the most efficient manner, even utilizing operating system service calls or non–Ada utility packages. This is especially appropriate on complex instruction set computers (CISC) like the VAX. You can always rewrite

C-5.

the bodies for each new platform to which you port. That way you've addressed performance, reusibility and reduced risk while making good progress and leveraging the capabilities and strong points of your underlying platform.

COTS Dependencies and Integration

During the proposal phase of STGT we identified several areas where Commercial Off-The-Shelf (COTS) software could be used. We then deleted costs based on the difference between developing the application from scratch and the cost of the COTS product. However, the following concerns arose:

- We did not allocate necessary additional costs to continually evaluate and incorporate periodic updates/upgrades of these COTS products. This turned out to be a big ticket item over the life of STGT.

- Purchase good quality COTS bindings. This is a LOT of work. Availability/maturity of Ada bindings should be a significant discriminator during COTS evaluations (e.g., XWindows/Motif binding problems, Distributed File Service (DFS) bindings, device driver bindings, etc.). As usual, productivity may be gained for many at the expense of hard work by a few, or by the purchase of a proper bindings. Consider the trade-offs.

Performance

Ada Performance Characteristics

Many performance problems were encountered which required various mitigation approaches. Performance modelling was only as good as the input received (much guess work was necessary early on in the life-cycle). This lead to big surprises and varying types of late changes. Eventually larger CPUs and more memory were purchased.

There appears to be a SERIOUS dichotomy in Ada between coding for performance and coding for what most consider to be a "good" Ada style. "Good" Ada was subject to our interpretation of the current literature and to the lessons developed during prototypes by the Ada Core Team. What might be considered "good" Ada of course will change over time. Examples are:

- The generic string package was pre-instantiated for (discriminated record structures) of 256 bytes. This affords maximum reusability and similarity, but appears to waste memory and disk space due in certain cases to needlessly large structures.
- Proponents of "good" Ada often stress deeply nested procedure calls for modularity and reuse. "Fast" Ada is often relatively flat, with a shallow call depth.
- "Good" Ada makes maximum use of local variables. "Fast" Ada allocates

variables once in package bodies, then carefully reuses them within package procedure and function bodies.

- "Good" Ada makes maximum use of Generics. "Fast" Ada avoids complex generics.
- Good Ada makes minimum use of implementation-dependent PRAGMAs. Fast Ada utilizes some PRAGMAs, e.g., PRAGMA ELABORATE to force elaboration of packages before the routines are called for real-time execution.
- As a result of the apparent quandry between "good" and "fast" Ada, it seems that Ada right out of the object-oriented training book can be quite slow. You either need to allocate a bigger CPU, know very accurately the performance characteristics in advance, or plan on a tuning phase to increase the performance of your code once it's written.

Schedule pressures made us opt for the quickest solutions in most cases, that is, larger CPU's. We had some success in optimizing Ada for performance. In some cases the re-coding or reimplemetation of a component saved 50-100% of CPU or Memory resources. In one case it saved a factor of 5X CPU for a compute-intensive satellite orbit prediction function.

Configuration Management

Ada Configuration Management

- Ada dependencies are GRAPHS, most library structures/directory hierarchies are TREES. Therefore, if you lock yourself into a library structure that mimics the Ada dependency structure, you'll be disappointed eventually. We used a simple tree of SHARED code at the top, with CSCIs or subsystems below.
- Sublibraries were used versus the VAX Ada Compilation System (ACS) ENTERED units. This allowed automatic recompilation for dependent units when root units changed. The downside was that massive recompilations were forced when not all dependent libraries (and groups using those libraries) were ready to see the change. An alternative approach might have been to develop a tool for automatically re-entering changed units into dependent libraries. That also could have allowed for library dependencies more complicated than a tree.
- We used separate/duplicate libraries to reflect differing levels of software test maturity. For instance, we had one shared set of libraries in which developed code. We only updated the reused components of that library once a week. People affected by interface changes only had to support (or suffer) changes once a week.
- We could have used hierarchical libraries for test, but the computational requirements were too great. Our development CPU resources were never great enough to compile the same source code multiple times for different hierarchical libraries supporting different test maturities. Consequent-

ly all tests were forced to the same maturity – fresh from the programmer.

- We had to write a program to extract a cross-reference containing "where-used" information. ACS did not provide this information.

Ada Compilation Performance

We did a LOT of work to improve compilation speed. Some of the things we did were:

- Faster CPUs – went from VAX 8250s (1.5 MIPS) to VAX 6610s (25 MIPS).
- More memory – from 64 to 256 Mb
- Tuning of system quotas, batch queues etc.
- RAM DISK and/or semiconductor disk for shared code Ada library (most critical compilation library)
- Spread I/O over multiple disks to reduce bottlenecks
- We didn't persue but maybe should have experimented further with the effects of smaller and larger directory/library sizes on compilation speed.

Ada Compiler

- We found relatively few bugs. Most were in code generation, a few for floating point types and others which optimized away variables or code. One involved different Ada library unit interfaces depending on whether code was compiled in debug or non-debug. All were resolved in quite good order by excellent DEC support. The lesson was that compiler maturity (for VAX/VMS Ada) was not a risk factor. We also learned that run-time (vs. compile-time) bindings for certain rapidly and persistantly changing functions would have been a much better design from an operational and CM point of view.
- On the other hand, the maturity of ACS was less evident. We have had numerous problems and "features". A good Ada Program Support Environment would be greatly appreciated. We wrote 30,000 lines of "tool" and configuration management scripts. This is significantly more than we anticipated supporting. A good COTS tool available in a timely manner would have been a big productivity enhancement.
- The design of our parent libraries and sublibraries were important. We found ourselves re-creating libraries because library parent/child relationships were hard-coded rather than logical. We redid all libraries with PSEUDO-DEVICE logicals so that successive changes were less painful.

Project Management

Equally as important as the Ada lessons learned were the lessons we learned in managing and controlling a large Ada software development effort. Some of these lessons are:

Standards

- Our Software Standards and Practices Manual (SSPM) was HUGE. Far too big to be understood or enforced.

- Should have made better use of automated standards checkers or pretty-printer tools.
- Should have tailored the Language Sensitive Editor (LSE) more aggressively for our local standards and included more templates
- Standards should be issued, proven, taught, understood, reviewed, reproven, and well documented before any code is written.

Architecture and Schedule

- Allocate the Right CSCIs. We changed the allocation of CSCI's early in the development effort. Changes (reallocations) are difficult to make.
- Avoid Early Split into CSCI Production Groups. We set up a Work Breakdown Structure (WBS) and Management structure on day one. Therefore shifting of work from CSCI to CSCI became a continuous struggle. Work overall system architecture first before parochialism sets in. Set up a mechanism to provide for the overall project good at expense of an individual group.
- Avoid the pressure to accelerate schedules. Believe the "Rule of Tens" (errors found in a later phase take 10 times longer to fix). Missed goals can not be made up. Insist on operation's concepts and equipment (mission equipment) designs prior to software designs.
- View interfaces as a "contract" not as a goal. Interfaces that change are painful.
- Understand tools required and decide on their use well in advance of needs. We developed Configuration Management DCL on-the-fly, did not understand the complexities of Ada CM, and shared interface packages (which are a good idea, but caused massive recompiles). Understand and plan the role of tools throughout the whole lifecycle.
- Define and stick to a fixed methodology. We were guilty of making it up as we go. Much of the heritage we had from our Ada Core Team did not scale up into larger development efforts. Tools did not easily transition between phases.
- Do more prototyping – especially for performance. Make performance estimates based on Executed Lines Of Code (ELOCs) from actual prototypes rather than from Lines Of Code (LOCs) written or predicted to be written. Consider living (non_throwaway) prototypes for broadly used "infrastructure" code.
- Use the right language for the right function. We made some changes to use macro assembler in some critical high frequency applications. Device driver type functions were very slow in Ada as was the high use interprocess communication processes.
- Put Some Teeth into allocating and enforcing performance requirements. We allocated only very high level requirements to the CSCIs for CPU and Memory performance. These were not allocated to lower level components and were therefore untestable and unenforceable.

- Do Code Walkthrus – set aside a team to execute. We relied on peer reviews of code. This became a significant schedule pressure on the CSCI who concentrated more on their own efforts then in a thorough review of another CSCIs code.
- Understand and don't underestimate the entire domain. Understand the performance aspects of the COTS products and prototype their use. Errors in COTS are harder to fix because of 3rd party involvement. Work with COTS can begin earlier since design effort is usually not required. The effects of the operating system and hardware platform are significant, protopying and an early start is recommended.
- Know what you are buying and where to use it. For Example, Booch components were excellent at improving productivity. However know their performance characteristics before deciding where to use them and other similar COTS software.
- Hire Experts – utilize vendor consultants. On site expertise is the best way to fix problems and to get preferential access to vendor guru's and other experts. Often you fix problems before they happen, since consultants can help you with that most difficult assessment, determining what it is that you don't know.

These Lessons Learned represent only a small subset of the potential data that can be gleaned from GE's experience on STGT. The main lesson to take away from this paper is that the language, platform, COTS products, tools, etc. are just a means to an end and in themselves are responsible for neither success nor failure.

STGT Ada Lessons Learned

STGT
Second TDRSS
Ground Terminal

Dec 2-3, 1992

NASA Goddard Software Engineering Laboratory

Software Engineering Workshop

STGT Project
Ada Lessons Learned

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Chart 1

STGT Ada Lessons Learned
Agenda

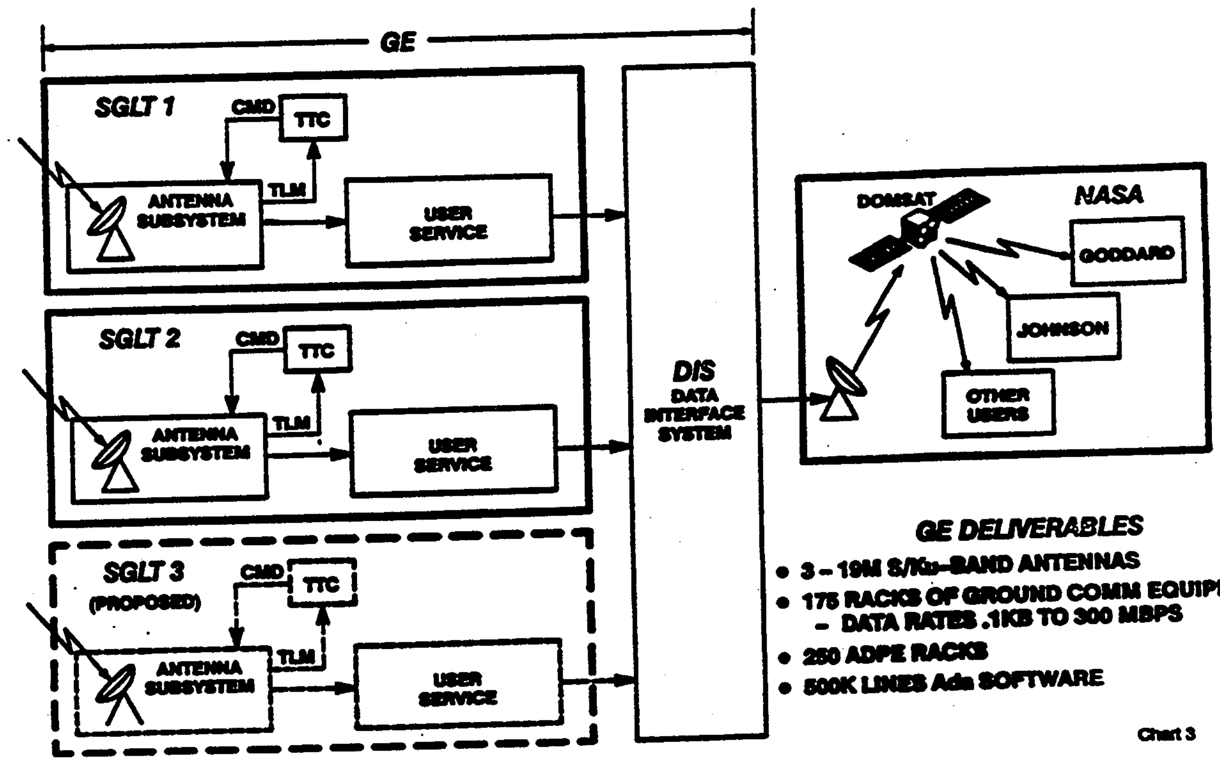
STGT
Second TDRSS
Ground Terminal

Dec 2-3, 1992

- **Project Overview**
- **Software Configuration**
- **Software Metrics**
- **Ada Project Management Lessons Learned**
  - **Project Schedule/Structure**
  - **General Issues**
  - **Performance/Sizing**
  - **Reusability**
- **Ada Lessons Learned**
  - **Generics**
  - **Tasking**
  - **COTS/Platform Dependencies**
  - **Package Structuring/Record Formats**
  - **Exceptions**

STGT Ada Lessons Learned
Project Overview

STGT
Second TDRSS Ground Terminal
Dec 2-3, 1992



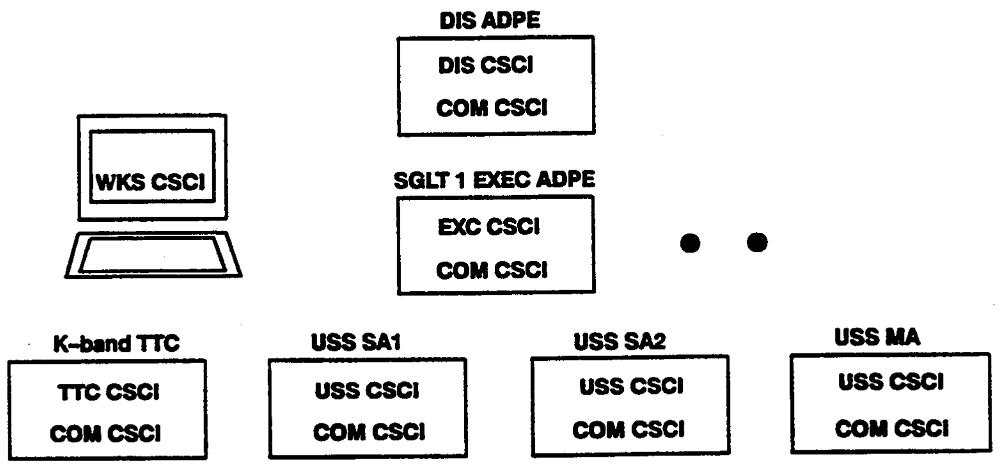
GE DELIVERABLES

- 3 - 19M S/Ku-BAND ANTENNAS
- 175 RACKS OF GROUND COMM EQUIPMENT
  - DATA RATES .1KB TO 300 MBPS
- 250 ADPE RACKS
- 500K LINES Ada SOFTWARE

Chart 3

STGT Ada Lessons Learned
Software Configuration

STGT
Second TDRSS Ground Terminal
Dec 2-3, 1992



COM CSCI	Common Services
DIS CSCI	NCC Interface
EXC CSCI	SGLT Scheduling
USS CSCI	Equipment CMD/MON
TTC CSCI	TDRS/Antenna Control
WKS CSCI	Operator Interface
SIM CSCI	SMTF Simulation
MDS CSCI	SMTF Tools

Chart 4

STGT Ada Lessons Learned
Software Metrics

STGT
Second TDRSS Ground Terminal
Dec 2-3, 1992

CSCI	Size (LOC)	Hours[1]	LOC/Hour
TTC	100000[3]	115000[2]	.86
DIS	76000[3]	79000	.96
USS	71000[3]	58000	1.22
EXC	26000	23000	1.13
WKS	152000	56000	2.7
COM	23000	37000	.62
MDS	100000	36000	2.77
SIM	40000	40000[3]	1.0
Total	588000	444000	1.32

1 – Requirement Analysis thru Software Test
2 – Includes Cost of Common Ground Control/Monitor and Fault Detection
3 – Includes Common Ground Control/Monitor and Fault Detection

Chart 5

STGT Ada Lessons Learned
Ada Project Management
Lessons Learned

STGT
Second TDRSS Ground Terminal
Dec 2-3, 1992

- Ada Project Management Lessons Learned
  - Project Schedule/Structure
  - General Issues
  - Performance/Sizing
  - Reusability

STGT Ada Lessons Learned
Ada Project Management
Lessons Learned
Project Schedule/Structure

STGT
Second TDRSS Ground Terminal
Dec 2-3, 1992

- **Allocate the Right CSCIs**
  - **Changes (Reallocation) are Difficult to Make**
- **Avoid Early Split into CSCI Production Groups**
  - **Work Overall System Architecture First**
  - **Set up a Mechanism to Provide for the Overall Good at Expense of an Individual Group**
- **Avoid the Pressure to Accelerate Schedule**
  - **Believe the "Rule of Tens"**
  - **Missed Goals Can Not Be Made Up**
  - **Insist on Operation's Concepts and Equipment Designs Prior to Software Designs**
- **View Interfaces as a "Contract" not as a Goal**
  - **Interfaces That Change Are Painful**

Chart 7

STGT Ada Lessons Learned
Ada Project Management
Lessons Learned
General Issues

STGT
Second TDRSS Ground Terminal
Dec 2-3, 1992

- **Understand Tools Required and Decide on their Use Well in Advance of Needs**
  - **CM Developed DCL on-the-fly : did not understand the Complexities of Ada : Shared Interface Packages (A Good Idea) Caused Massive Recompiles**
  - **Understand and Plan the Role of Tools Throughout the Whole Lifecycle**
- **Understand and Don't Underestimate the Entire Domain**
  - **COTS**
  - **DEC/VMS**
- **Prototype and Utilize Prototype Code Everywhere**
- **Hire the Right People Then Train/Train/Train**

Chart 8

STGT Ada Lessons Learned
Ada Project Management
Lessons Learned
General Issues

STGT
Second TDRSS
Ground Terminal
Dec 2-3, 1992

- **Define and Stick to A Fixed Methodology**
  Define in Advance and Don't Experiment
  Educate User's
- **Keep the SSPM Simple - Useful and Easy to Enforce**
- **Do Code Walkthrus - Set Aside a Team to Execute**

Chart 9

STGT Ada Lessons Learned
Ada Project Management
Lessons Learned
Performance/Sizing

STGT
Second TDRSS
Ground Terminal
Dec 2-3, 1992

- **More Prototyping - Estimates Based on Executed LOCs**
- **Complex Generics Proved to be Extremely Slow**
- **Understand Compile and Link Process (e.g. Compiler Eliminates Dead Code But Linker Does Not)**
- **Use the Right Language for the Right Function**
- **Bad Ada Is Real Baaaaad**
- **Put Some Teeth Into allocating and enforcing Performance Requirements**

Chart 10

STGT Ada Lessons Learned
Ada Project Management
Lessons Learned
Reusability

STGT
Second TDRSS Ground Terminal
Dec 2-3, 1992

- **Know What You are Buying and Where to Use It**
  Booch Components – Not Optimized for Performance
- **Don't Attempt High Level Generics Yet**
  Ground Equipment Simulation Is the Wrong Choice
- **Provide for Project Wide Reuse Czar**
  Avoid Parochialism
  Proactive Search for Opportunities

Chart 11

STGT Ada Lessons Learned
Ada Lessons Learned

STGT
Second TDRSS Ground Terminal
Dec 2-3, 1992

- **Ada Lessons Learned**
  - **Generics**
  - **Tasking**
  - **COTS/Platform Dependencies**
  - **Package Structuring/Record Formats**

Chart 12

STGT Ada Lessons Learned
Ada Lessons Learned
Generics

STGT
Second TDRSS Ground Terminal
Dec 2-3, 1992

- **Can be a Performance Problem**
- **Are to Debug with Interactive Source Level Debugger**
- **Keep Small : Don't Attempt a Reusable Ground Station**
- **Restrict Usage to Types as Formal Parameters**
- **Keep Them out of the Hands of Amateurs**
  - **Limit to Your Most Experienced People**
  - **Review/Review/and Then Again – Prototype Performance**

Chart 13

STGT Ada Lessons Learned
Ada Lessons Learned
Tasking

STGT
Second TDRSS Ground Terminal
Dec 2-3, 1992

- **Mistrusted at First – Found Many Appropriate Uses**
  - **Understand the Target Environment/Prototype**
- **Provide for Terminate Alternatives – Make Sure a Parent can Terminate Children**
- **Exceptions Must Be Propagated Upward (Free Running Tasks Need Some Control)**
- **Don't Substitute Tasks Where Procedures Would Suffice**
- **When Using Tasks – Centralize Control (one writer)**
- **If You Plan on a Few Expect Many More**

Chart 14

STGT Ada Lessons Learned
Ada Lessons Learned
COTS/Platform Dependencies

STGT Second TDRSS Ground Terminal
Dec 2-3, 1992

- **Understand Compiler/Linker and Their Interaction**
  - **Don't Count on Default Order of Elaboration**
- **Understand The Whole Domain**
  - **VMS Services Better Than Ada Features**
- **Pick COTS With Ada Bindings (Avoid Multiple Translations)**
- **SQLMODS Proved to Be Workable Interface**
  - **Imbedded SQL was Impossible to Debug**
- **Hire Experts – Utilize Vendor Consultants**
- **Product Upgrades are Large Undertakings and Come at the Most Inopportune Times**
  - **Properly Plan for and Fund Product Upgrades**
- **Avoid the Creation of Processes Without Justification**

Chart 15

STGT Ada Lessons Learned
Ada Lessons Learned
Package/Record Formats

STGT Second TDRSS Ground Terminal
Dec 2-3, 1992

- **Limit Scope of Packages – Don't Try to Encapsulate and Entire Object in One Package**
  - **Use Multiple Packages – Each With a Purpose**
  - **Know the Intended Use of the Packages (e.g. Senders vs Receivers)**
  - **Avoid Monoliths**
- **Don't Put Database Access into Interface Packages**
- **Don't Combine Loosely Related Types**
- **Create Null Instances of a Type as an Initial Value**
- **Avoid String Types – Usually Masking an Enumerated Type**
- **Renaming – Many Differences of Opinions: Be Careful**

Chart 16

STGT Ada Lessons Learned
Ada Lessons Learned
Exceptions

STGT
Second TDRSS
Ground Terminal
Dec 2-3, 1992

- **Use Only For Real Errors – Very Expensive for Use As GOTOs**
- **"When Others" obscures origin of exceptions**
- **Understand and Plan for Unhandled Exceptions**
  - **Tracebacks and Stack Dumps are Good Debugging Tools**
  - **Process/System Dumps Have Their Place**
- **Specify and Design Expected Levels of Error Handling**

Chart 17

STGT Ada Lessons Learned
Summary

STGT
Second TDRSS
Ground Terminal
Dec 2-3, 1992

- **Project Pressures Force Old Habits to Return**
- **Solidify Interfaces Under Penalty of Death**
- **Prototype Everything and Always**
- **Enforce Performance Allocations**
- **Focus Reuse and Dedicate Resources**
- **Restrict Generics**
- **Don't Be Afraid of Tasks**
- **Understand the Domain – and Hire Where Necessary**
- **Limit Scope of Packages**
- **Be Prepared to Upgrade COTS**

Panel: Is Ada Dying?

Marv Zelkowitz, University of Maryland, Facilitator

Stu Feldman, Executive Director of Computer Systems Research, Bellcore

John Foreman, Director of STARS Program, Department of Defense

Susan Murphy, AAS Software Manager, IBM

Tom Velez, President and CEO, CTA

Panel: Is Ada Dying?

- Facilitator:
  - Marvin V. Zelkowitz, NIST/CSL and Department of Computer Science, University of Maryland
- Panelists:
  - Stu Feldman, Executive Director, Computer Systems Research, Bellcore
  - John Foreman, Director of STARS Program, DARPA
  - Susan Murphy, AAS Software Manager, IBM FSC
  - Tom Velez, President and CEO, CTA

SEL interest in Ada

- Why SEL interest in Ada?
  - SEL has broadest experience with Ada within NASA
  - SEL has collected much data on the use of Ada (as well as many other technologies)
  - SEL has analyzed Ada usage from various perspectives (e.g., see last few Workshop proceedings)
- Results of SEL studies:
  - Value of Ada not unconditionally shown
  - Need to assess current status and plan future processes

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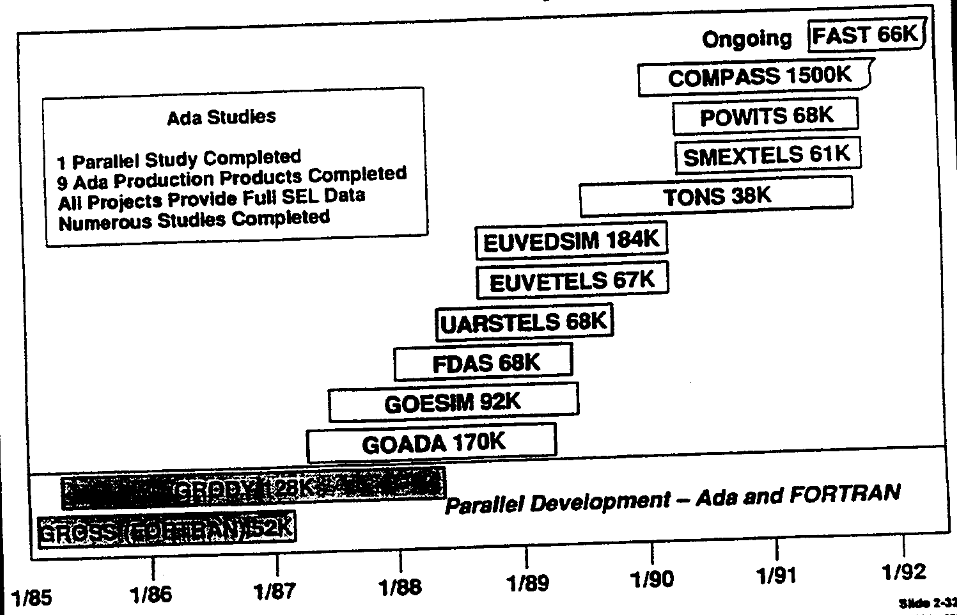
SEL Ada Projects



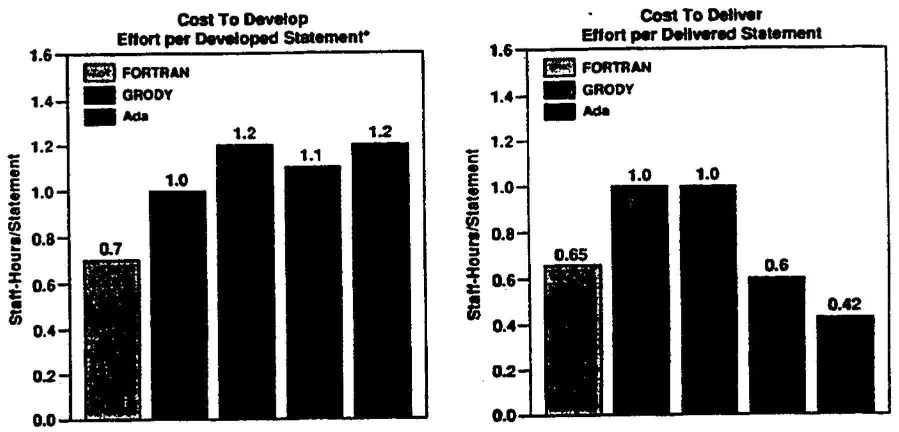
Ada Studies

1 Parallel Study Completed
9 Ada Production Products Completed
All Projects Provide Full SEL Data
Numerous Studies Completed

Slide 2-32
10000284-g050

SOFTWARE ENGINEERING LABORATORY — SEL

Ada (and OOD) Impacts on Cost



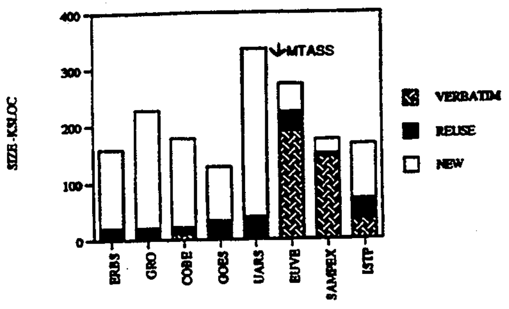
*Ada : Developed Size = 100% New + 30% Old Statements
FORTRAN: Developed Size = 100% New + 20% Old Statements

- Development cost per statement has been no cheaper for Ada
- Resue potential of Ada is significant
- Reuse cost factor has changed in Ada systems

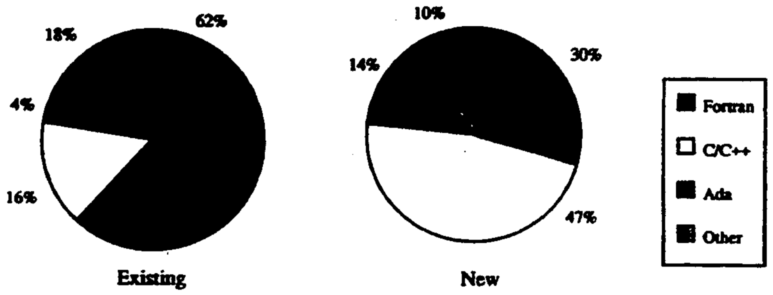
Slide 2-33
10000284-g051

SOFTWARE ENGINEERING LABORATORY — SEL

But FORTRAN reuse is also growing



Language use in Code 500 at Goddard



NASA IBM mainframe Ada evaluation

- Need more development and testing support
  - Two compilers evaluated
  - Multiple source file compilation limited
  - Ada library can be corrupted
  - Inflexible Ada library manager
  - Need better debugger
  - One compiler failed to even compile some modules
- Need improvement in error handling and error messages
- Need improvement in performance
- Result: Could not use IBM mainframe for large-scale NASA Goddard development

Onboard embedded Ada application

- Goal: Dual 1750A processors with shared memory to handle onboard navigation
- Environment: TI 1750A hardware, Tartan cross compiler system on VAX
- Problems: Intermittent communication and shared memory problems. Hardware and software vendors could not solve problems.
- Resolution: Had to fly uniprocessor system with reduced functionality.

Positive attributes of Ada

- Language syntax and semantics are in mainstream language design – an outgrowth of FORTRAN, ALGOL and Pascal
- Language features to aid in large system design, reuse and maintenance (e.g., packages, tasking, exceptions, generics)
- Over 250 validated compilers
- University use growing – 14 Ada textbooks and use at perhaps 10% of U.S. universities (from: November, 1992 Comm. of the ACM)
- Millions of lines of Ada code for commercial non-military applications – Examples: Shell Oil for exploration, Motorola for cellular telephones, Boeing for 747-400, GE for automated steel manufacturing, NTT (Japan) for commercial telecommunications applications, Nokia SoftPlan (Finland) for a banking system, plus others
- Ada-9X revision to solve many of the lingering problems

Negative attributes of Ada

- Hard to learn to use well
- Lack of production quality compilers
- Performance penalty in certain critical applications
- Doesn't handle object oriented design – Impact of C++

Observations

After 10 years of development ...

- Growth of courses and textbooks in Ada seems very slow.
- Does not seem to be a large scale movement to Ada within non-DoD segments of the industry. Most examples are anecdotal.
- Ada does not yet seem ready within the large mainframe environment at Goddard.
- Yet, seems to be a natural attraction to C and C++. Both have attained huge unsupported growth.

Will there be supported Ada products in 10 years?

Summary of issues

- "Many of the perceived problems with Ada were due to the immaturity of early implementations, rather than flaws of the language itself. Some of these perceptions linger, even though mature Ada implementations are available today and most of the previously identified shortcomings have disappeared." – Erhard Ploedereder, Comm. of the ACM, Nov., 1992
- Is Ada today an economically viable language for building software systems?
- If so, for what class of projects is it appropriate?
- If not, what criteria are needed for determining the economic viability of Ada (and when should they be met)

Panel organization

- Opening statements:
  - What is your position and why?
  - What are the objective or subjective criteria supporting your position?
  - What actions should the principles be taking (i.e., DoD, NASA, contractors) and what will Ada be in the next century?

- Each panelist will talk for up to 10 minutes; then a 5 minute comment by panelists on other statements; then general comments or questions from workshop attendees

Feldman 1

Uses and Future

Niche	1980	⇒	2000
Commercial	COBOL	+4GL	+QUERY LANGUAGE
+ C++			
Scientific/Engineering	FORTRAN	+C	FORTRAN 90, C++
Systems	ASM, C	C	C++
Prototyping	LISP, SMALLTALK	C, PROLOG ...	
Embedded/Real Time	ASM, ADA	C, ADA	C++, ADA
S/W Engineering	ADA		C++, ADA, ...?
CS Research	C, LISP	C++, CLOS, ML	

Feldman 2

Sociology

Lifecycle
- Born/Stillborn
- Born Again?

Nurture
- Phoenix/Bride of Frankenstein?

Kinship
- None Allowed

Support System
- Ada Industry $\propto \frac{d^n}{dt^n}$ Defense Budget

Ecology
- Niches and Competition

Feldman 3

Unproven Comparisons

Software Maintainability

Ada > C
Ada > C++

$C \left\{ \begin{matrix} > \\ ? \\ < \end{matrix} \right\} C{+}{+}$

Language Complexity

Ada 9X > FORTRAN 90 > C++ >> C ~ FORTRAN 77

Simple - Compiler Difficulty

Ada 9X > Ada >> C++ >> C

Excellent - Compiler Difficulty

C++ $\gtrsim$ C >> Adas > FORTRAN

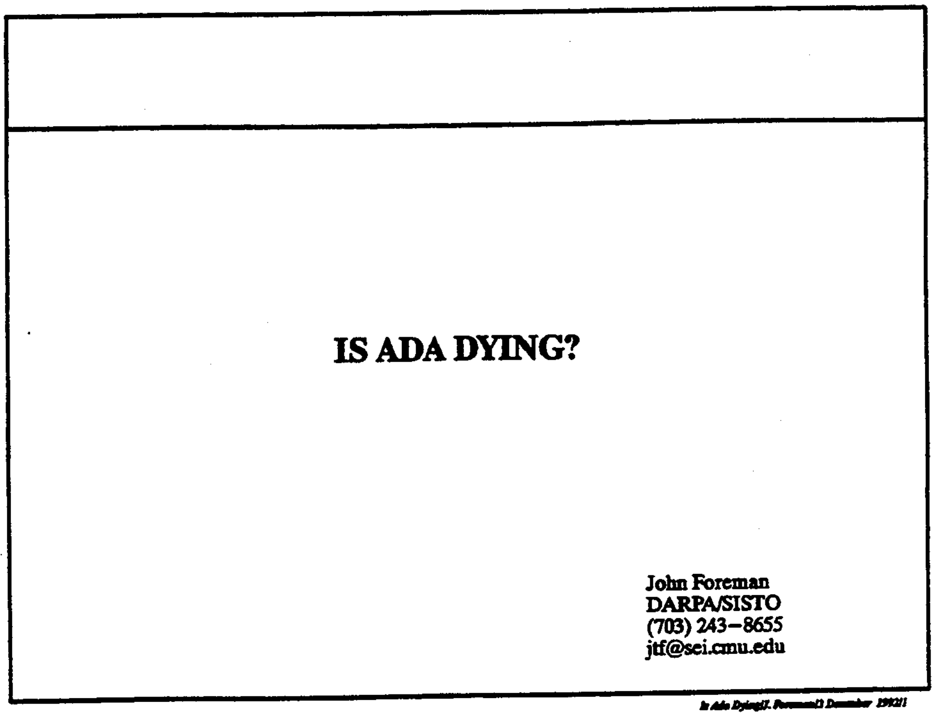
Feldman 4

Ada Properties

+ Complete
+ Supported
+ Sponsored
+ Real-Time
+ Software-Engineering

? Configuration Support

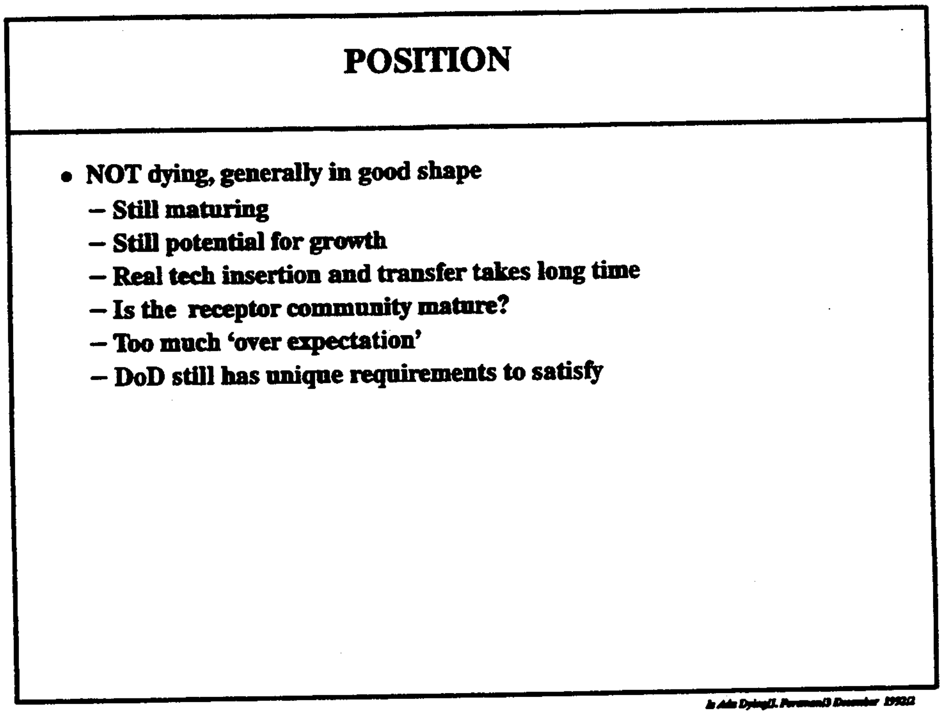
- Syntax
- Garbage Collection
- Complexity
- Software Support
- Use in Systems ("open")
- Love



IS ADA DYING?

John Foreman
DARPA/SISTO
(703) 243–8655
jtf@sei.cmu.edu

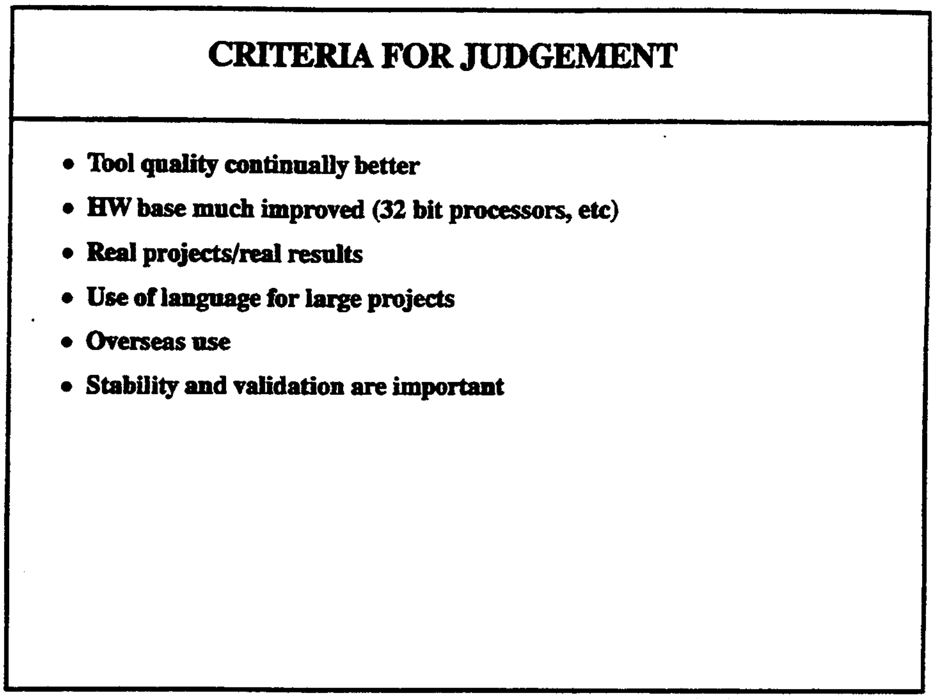
Is Ada Dying?/J. Foreman/3 December 1992/1



POSITION

- NOT dying, generally in good shape
  - Still maturing
  - Still potential for growth
  - Real tech insertion and transfer takes long time
  - Is the receptor community mature?
  - Too much 'over expectation'
  - DoD still has unique requirements to satisfy

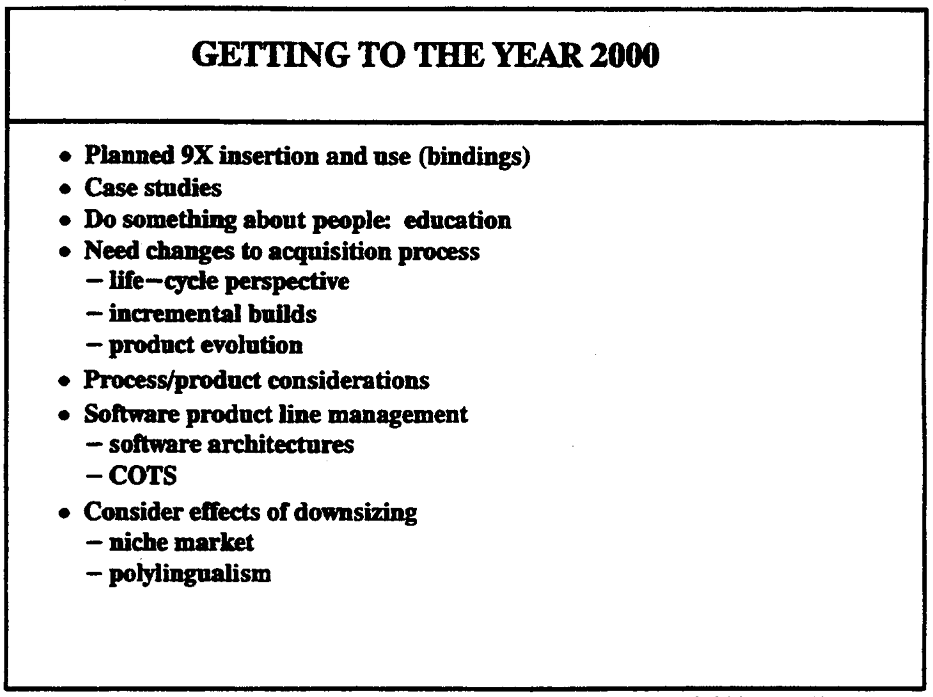
Is Ada Dying?/J. Foreman/3 December 1992/2



CRITERIA FOR JUDGEMENT

- Tool quality continually better
- HW base much improved (32 bit processors, etc)
- Real projects/real results
- Use of language for large projects
- Overseas use
- Stability and validation are important

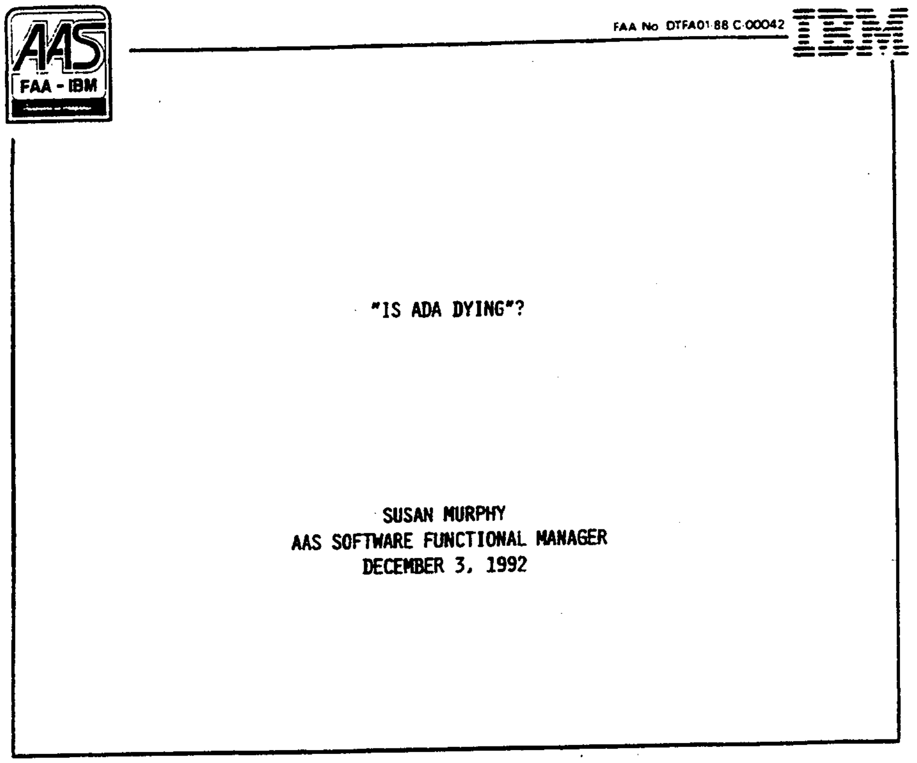
Is Ada Dying/J. Foreman/3 December 1992/13



GETTING TO THE YEAR 2000

- Planned 9X insertion and use (bindings)
- Case studies
- Do something about people: education
- Need changes to acquisition process
  - life–cycle perspective
  - incremental builds
  - product evolution
- Process/product considerations
- Software product line management
  - software architectures
  - COTS
- Consider effects of downsizing
  - niche market
  - polylingualism

Is Ada Dying/J. Foreman/3 December 1992/14

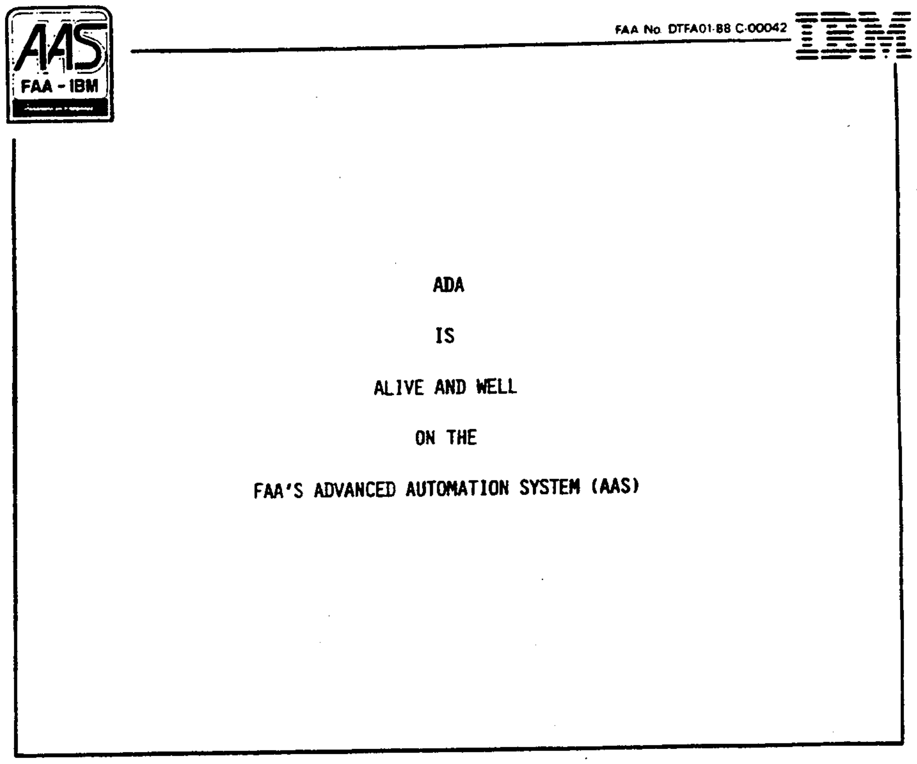


AAS FAA - IBM

FAA No DTFA01-88-C-00042 IBM

"IS ADA DYING"?

SUSAN MURPHY
AAS SOFTWARE FUNCTIONAL MANAGER
DECEMBER 3, 1992



AAS FAA - IBM

FAA No DTFA01-88-C-00042 IBM

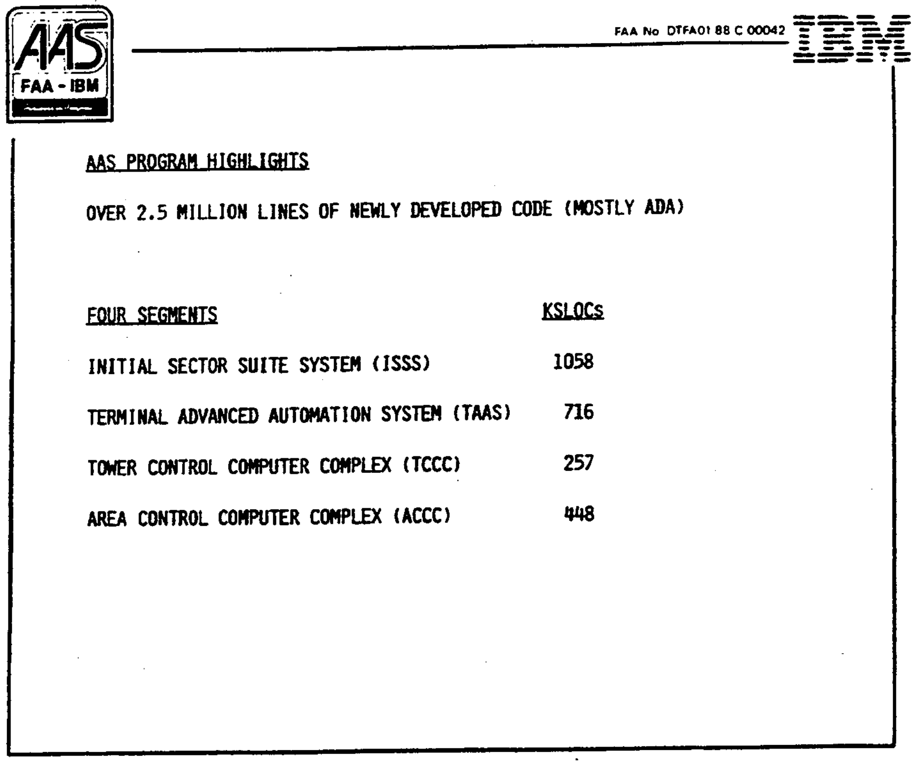
ADA

IS

ALIVE AND WELL

ON THE

FAA'S ADVANCED AUTOMATION SYSTEM (AAS)

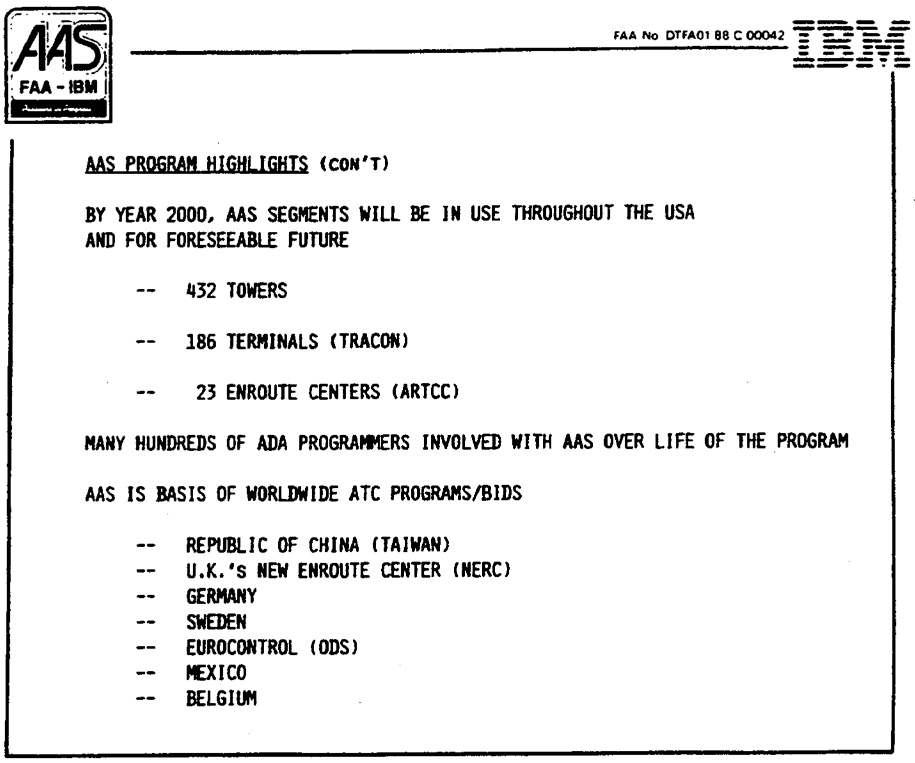

AAS FAA - IBM

FAA No DTFA01 88 C 00042 IBM

AAS PROGRAM HIGHLIGHTS

OVER 2.5 MILLION LINES OF NEWLY DEVELOPED CODE (MOSTLY ADA)

FOUR SEGMENTS	KSLOCs
INITIAL SECTOR SUITE SYSTEM (ISSS)	1058
TERMINAL ADVANCED AUTOMATION SYSTEM (TAAS)	716
TOWER CONTROL COMPUTER COMPLEX (TCCC)	257
AREA CONTROL COMPUTER COMPLEX (ACCC)	448


AAS FAA - IBM

FAA No DTFA01 88 C 00042 IBM

AAS PROGRAM HIGHLIGHTS (CON'T)

BY YEAR 2000, AAS SEGMENTS WILL BE IN USE THROUGHOUT THE USA
AND FOR FORESEEABLE FUTURE

-- 432 TOWERS

-- 186 TERMINALS (TRACON)

-- 23 ENROUTE CENTERS (ARTCC)

MANY HUNDREDS OF ADA PROGRAMMERS INVOLVED WITH AAS OVER LIFE OF THE PROGRAM

AAS IS BASIS OF WORLDWIDE ATC PROGRAMS/BIDS

-- REPUBLIC OF CHINA (TAIWAN)
-- U.K.'S NEW ENROUTE CENTER (NERC)
-- GERMANY
-- SWEDEN
-- EUROCONTROL (ODS)
-- MEXICO
-- BELGIUM

FOR ADA TO GROW:

ADA 9X MUST BE FULLY DOWNWARD COMPATIBLE WITH ADA 83
(NO CODING CHANGES REQUIRED)

ELSE

- THESE PRODUCTION SYSTEMS WILL NOT TRANSITION TO ADA 9X
- HUNDREDS OF ADA PROGRAMMERS WILL NOT EVOLVE TO USE OF ADA 9X FEATURES

CTA INCORPORATED

AIR FORCE ADA PROJECTION

MAJOR TOM CROAK, USAF

	1991 SURVEY*	1995 PROJECTION
COBOL	40%	20%
ADA	10%	40%
FORTRAN/ JOVIAL	30%	25%
C	3%	10%
OTHER	17% (450 LANG'S.)	5% (250 LANG'S.)

THERE HAVE BEEN NO ADA WAIVERS SINCE JULY 1990

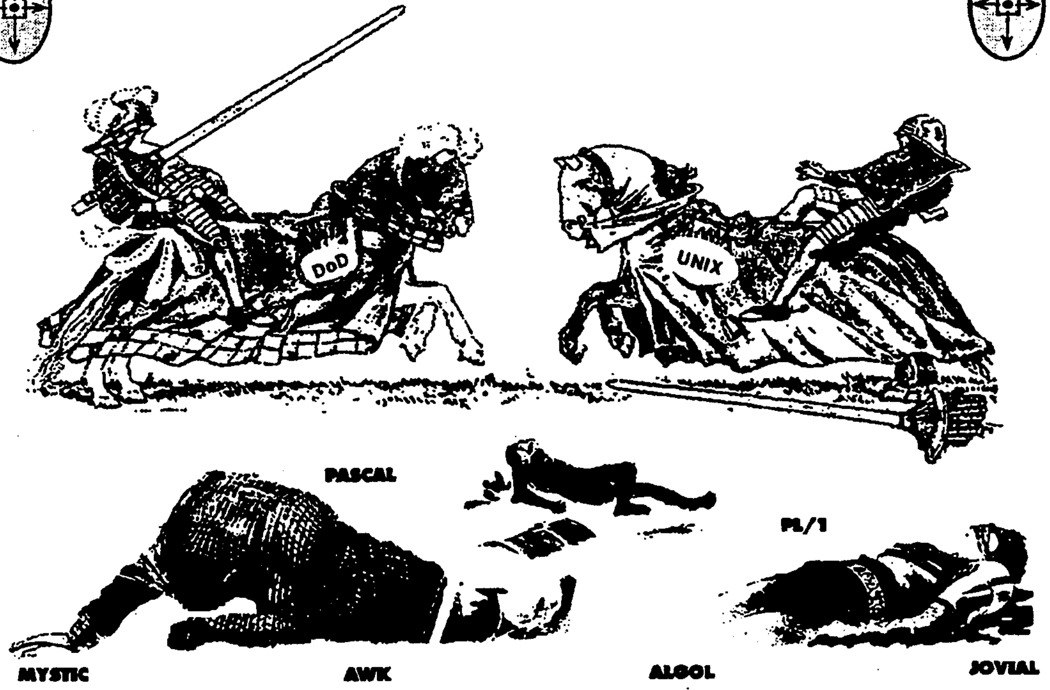
*ALL OPERATIONAL SYSTEMS; ADDITIONAL 32M OF ADA CODE UNDER DEVELOPMENT

CTA INCORPORATED

ADA INFORMATION CLEARINGHOUSE

ADA PROJECTS		EXAMPLES
• ACADEMIA	4	"SUB-SIM" ATTACK SUB SIMULATOR
• ARMY	62	ADVANCE FIELD ARTILLERY TACTICAL DATA SET (AFATDS)
• NAVY	220	ADVANCE SURVEILLANCE WORKSTATION
• MARINE CORPS	41	NAVAL FLIGHT RECORD SUBSYSTEM
• AIR FORCE	151	ADVANCED TACTICAL FIGHTER (F22)
• COMMERCIAL	111	BOEING 777
• GOV'T. (NON-DoD)	58	ADVANCED AUTOMATION SYSTEM (AAS)
• INTERNATIONAL	68	NETHERLANDS TELEPHONE CONTROL & MONITORING SYSTEM
• OTHER DoD	7	SINGLE CHANNEL OBJECTIVE TACTICAL TERMINAL (SCOTT)
TOTAL	722	

Ada vs C++



ADA & C++ - BUSINESS CASE ANALYSIS*

ADA		C++
28 COMPANIES W/VALIDATED PRODUCTS	MARKET AVAILABILITY	18 VENDORS OFFER C++
GOV'T. CONTROLLED/ANSI & ISO STANDARDS	STRONG STADARDIZATION	NO VALIDATION OR STANDARD EXIST
YES	CROSS COMPILATION	NO
22 UNIVERSITIES & 13 DoD INSTALLATIONS	EDUCATION/TRAINING	4 UNIVERSITIES
78.8	FEATURE COMPARISON** (OUT OF 100)	63.9
210 (SLOC/MM) (153 DATA POINTS)	PRODUCTIVITY (NORM: 183 ALL LANG.	187 (SLOC/MM) (38 DATA PTS.)
65 ($/SLOC) (153 DATA POINTS)	COST (NORM: 70 ALL LANGUAGES)	55 (23 DATA PTS.)
	AVG. ERROR RATES (PER KSLOC)	
24 (153 DATA PTS.)	INTEGRATION (33: NORM ALL LANGUAGES)	31 (23 DATA PTS.)
1 (153 DATA PTS)	FORMAL QUAL TEST (3: NORM ALL LANGUAGES,)	3 (23 DATA PTS.)
	ADA COCOMO COST ANALYSIS	
1631 (23% HIGHER)	MIS	1324
1738 (24% HIGHER)	C3 SYSTEMS	1401

* BASED ON U.S. AIR FORCE STUDY
** BY SEI FOR APPLICATIONS INFORMATION/C3 SYSTEMS

CTA INCORPORATED

ADA AN EIGHTEEN YEAR SCOREBOARD

OBJECTIVE	RESULT	SCORE
SINGLE (DoD-1) HOL	WE (CTA) SEE ADA MANDATED IN VIRTUALLY 100% OF DoD RFPs	+
SUPPORT MODERN SOFTWARE ENGINEERING TECHNIQUES	YES: THROUGH STRONG TYPING PACKAGING, AND OTHER FEATURES	+
PROVIDE AN "ADA" ORIENTED PROGRAMMING ENVIRONMENT	NO: CLEARLY, THE PROMISES OF CAIS, APSE, NOT REALIZED	-
INCREASE OF PRODUCTIVITY	NO CLEAR, CONCLUSIVE RESULTS - APPARENT RESULT IS SAME AS OTHER LANGUAGES	NEUTRAL
DECREASE LC SOFTWARE MAINTENACE (EVOLUTION) COST	EVIDENCE IS POSITIVE - LESS ERRORS IN O&M	+
STANDARDIZATION	YES: ANSI & ISO	+
CONTROLLED, STABLE COMPILER IMPLEMENTATION	YES: THROUGH GOV'T. SUPPORT	+
CLEAR "GRASS ROOTS" USAGE (IN COMMERCE, ACADEMIA)	NO: CERTAINLY NOT LIKE "C"	-

<u>OVERALL RESULT: POSITIVE</u>

Appendix A: Attendees

Abd-El-Hafiz, Salwa K., University of Maryland
Addelston, Jonathan D., Planning Research Corp.
Agresti, Bill W., MITRE Corp.
Aikens, Stephen D., DoD
Allen, Julia, Software Engineering Institute
Allen, Russ, IRS
Anderman, Al, Rockwell SSD
Anderson, Barbara, Jet Propulsion Lab
Anderson, Jim, IRS
Angier, Bruce, Institute for Defense Analyses
Arnold, Robert S., Sevtec
Astill, Pat, Centel Federal Services
Austin, James L., IRS
Ayers, Everett, Ayers Associates

Bachman, Scott, DoD
Bacon, Beverly, Computer Sciences Corp.
Bailey, Carmine M., McDonnell Douglas
Bailey, John, SEL
Balick, Glenn, DoD
Barbara, Edward K., U.S. Air Force
Barbour, Ed, U.S. Air Force
Barnes, Bruce H., National Science Foundation
Barnette, Randy, Hughes STX
Barnhart, Don, Boeing Aerospace Co.
Basch, Bill, Boeing Computer Support Services Co.
Basili, Vic, University of Maryland
Bates, Bob G., Lockheed Space Operations
Baumert, John H., Computer Sciences Corp.
Bearchell, Deborah J., Computer Sciences Corp.
Beatty, Kristin, IIT Research Institute
Belle, Jeffery C., Logicon, Inc.
Beswick, Charlie A., Jet Propulsion Lab
Billick, Ron, Bell Atlantic
Binegar, Scott, Computer Sciences Corp.
Biondi, Marisa, IRS
Bishop, Steven, Naval Air Warfare Center
Bisignani, Margaret, MITRE Corp.
Bissonette, Michele, Computer Sciences Corp.
Blackwelder, Jim, Naval Surface Warfare Center
Blagmon, Lowell E., Naval Center for Cost Analysis
Blankenship, Donald D., U.S. Air Force
Blankenship, Gordon, U.S. Air Force
Bloodgood, Pete, IRS
Blough, Lyn, Computer Sciences Corp.
Blum, Bruce I., Applied Physics Lab
Bogdan, Robert J., Computer Sciences Corp.
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