Ada and Beyond: Software Policies for the Department of Defense

National Research Council
Committee on the Past and Present Contexts for the Use of Ada in the Department of Defense

December 4, 1996

Study Summary:
Recommendations

- Require Ada for DoD warfighting software
- Drop Ada requirement for other DoD software
- Invest $15M/year for Ada infrastructure
  - or drop Ada requirement entirely
- Embed programming language decisions into a Software Engineering Plan Review process.
Study Sponsor and Charter

- Sponsor: ASD/C3I (Mr. Emmett Paige)
- Review original DoD Ada goals and strategy
- Compare and contrast original situation with current situation
- Consider current and future alternatives
- Propose a refined set of goals and strategies with associated rationale

Committee Membership

Barry Boehm, University of Southern California, Chair
Theodore Baker, Florida State
Wesley Embry, Silicon Graphics
Joseph Fox, Template Software
Paul Hilfinger, University of California at Berkeley
Maretta Holden, Boeing
J. Eliot B. Moss, University of Massachusetts at Amherst
Walker Royce, Rational Software
William Scherlis, Carnegie Mellon University
S. Tucker Taft, Intermetrics
Rayford Vaughn, Electronic Data Systems
Anthony Wasserman, Interactive Development Environments
### Study Committee Background

- **DoD**: Boehm, Scherlis, Vaughn
- **Ada and other languages**: Baker, Embry, Hilfinger, Holden, Moss, Royce, Scherlis, Taft, Wasserman
- **Aerospace industry**: Boehm, Fox, Holden, Royce
- **Commercial industry**: Embry, Fox, Royce, Taft, Vaughn, Wasserman
- **Academia**: Baker, Boehm, Hilfinger, Moss, Scherlis, Wasserman

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### Past and Present Contexts: Ada in General

<table>
<thead>
<tr>
<th>Past</th>
<th>Present</th>
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<tbody>
<tr>
<td>Some chance for Ada to be a leading commercial language</td>
<td>Virtually no chance for Ada to achieve this, except in niche areas</td>
</tr>
<tr>
<td>Some chance that Ada could drive other software practices</td>
<td>Virtually no chance for Ada to achieve this</td>
</tr>
<tr>
<td>Fair chance that Ada could become the leading high-assurance, real-time language</td>
<td>Ada generally considered the strongest language in this area, but others widely used</td>
</tr>
<tr>
<td>New software mostly custom, requirements-driven</td>
<td>New software mostly (non-Ada) COTS-driven</td>
</tr>
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Past and Present Contexts: Ada and DoD

<table>
<thead>
<tr>
<th>Past</th>
<th>Present</th>
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</thead>
<tbody>
<tr>
<td>DoD a dominant software player</td>
<td>DoD a large software player</td>
</tr>
<tr>
<td>Secondary role in DoD for software</td>
<td>Primary role: key to DoD goal of information dominance</td>
</tr>
<tr>
<td>No DoD Ada legacy code</td>
<td>50 million lines of DoD weapon systems Ada legacy code</td>
</tr>
<tr>
<td>DoD committed to major Ada development investment</td>
<td>DoD preparing to drop its Ada sustainment investment</td>
</tr>
</tbody>
</table>

DoD Goal: Information Dominance

[...our warfighting strategy sustains and builds on...] the application of information technology to gain great military leverage to continue to give us [an] unfair competitive advantage.

Secretary of Defense William J. Perry
NAE Bueche Award Acceptance Address
October 2, 1996
Ada Today: Overall Demand for Programmers

C 23%  Java 4%
C++ 23%  PowerBuilder 10%
COBOL 11%  Visual Basic 13%
Ada 5%

(Newspaper classified advertisements, Spring 1996)

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Ada Today: DoD Weapon Systems Software

CMS-2 19
Ada 83 50
Jovial 14
Fortran 20
C 33

C++ 5

Millions of source lines of code (IDA, 1995)

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NASA-SEL Development Error Rates

Ada Business-case Analysis

- Factors comparison vs. across-the-board return on investment comparison
  - Focus on DoD competitive advantages vs. adversaries
- Factors that influence cost
  - Size, process, environment, personnel
- Factors that influence quality
  - Support for high-assurance, real-time capability
  - Ease of change
- Socio-technical infrastructure factors
DoD Software Applications

**Areas**

**Warfighting Software**
- Weapon control, electronic warfare, real-time sensor processing, battlefield-unique communications
- Domain expertise mostly within DoD community
- Mostly custom software
- Plurality of software in Ada

**Commercially Dominated Software**
- Office and management support, routine operations support, asset status monitoring, logistics, medicine, backbone communications
- Domain expertise mostly commercial
- Mostly COTS-driven software
- Very little software in Ada

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**Criteria for Determining “Warfighting Software”**

- Relatively little commercial software and expertise available (ex: Window GUI vs. heads-up display).
- Needed quality levels not supported by commercial software (ex: real-time performance, reliability, survivability).
- Apply criteria at subsystem vs. system level (ex: AEGIS weapons control vs. Window GUI).
### Business Case Summary

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Warfighting SW</th>
<th>Commercially Dominated SW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Environment</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Personnel</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>HA/RT</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Ease of Change</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Sociotechnical</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>Infrastructure</td>
<td></td>
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</tr>
</tbody>
</table>

HART: high-assurance/real-time capability
++: using Ada a significant advantage
-->: using Ada a significant disadvantage

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### Recommendations for DoD

1. Continue vigorous promotion of Ada for warfighting software
2. Require Ada for DoD warfighting software; consider Ada for other DoD software
3. Broaden policy focus to integrate Ada and other key software-engineering concerns
4. Integrate the Ada decision process with an overall Software Engineering Plan Review process
5. Invest ~ $15M/year with Ada technology and infrastructure suppliers, or drop the Ada requirement entirely
6. Establish a sustained commitment to collect and analyze consistent software metrics data

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Recommended DoD Ada Policy

**Study Recommendation**
IF these conditions hold:
- Application subsystem is in the warfighting sector
- DoD-directed maintenance
- Subsystem highly critical or larger than 10 KLOC
- No better COTS, NDI, 4GL solution
- No life-cycle cost justification to use another language
THEN Use 95 percent Ada solution

**Current Policy**
IF these conditions hold:
- All DoD software systems, all sectors
- Same
- Entire system
- Use COTS, NDI, 4GLs where cost effective
- Same
THEN Use 100 percent Ada solution

Draft Revision of DoD Directive 3405.1

- States conditions of recommended DoD Ada policy
  - Establishes principles for language choice
- Reinforces preference for COTS, NDI, and 4GL solutions when appropriate
- Establishes policy on software best practices
  - Tradeoff and business-case analysis
  - Product-line frameworks, open architectures
  - Process maturity and metrics-based improvement
- Establishes Software Engineering Plan Review process
- Exempts research and technology programs (6.1.6.2.6.3)
  - Study recommends transition planning for 6.3 software

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Recommended Ada Investment Elements

- Contracts (mostly cost-shared): $11.3M/year
  - $8.0M: Warfighting critical tools and technology
  - $1.0M: API/Binding development and maintenance
  - $0.6M: Language maintenance and evolution experts
  - $0.4M: Validation suite maintenance and enhancement
  - $0.4M: Ada and software-engineering curriculum, particularly for high-assurance, real-time performance

- Centralized Ada support functions: $3.5M/year
  - $1.0M: Information clearinghouse and website
  - $1.0M: DoD training and technology insertion
  - $0.5M: Compliance monitoring and analysis
  - $0.5M: Ada experience data collection and analysis

Conclusions of Study

- Study recommendations are supported from several perspectives
  - Technical and business-case analysis
  - Analysis of alternatives
  - Extensive external review process
  - Experience of highly diverse committee

- Further study is not necessary
Implications of Study for DoD

- Timely implementation of recommendations is important to sustain DoD software momentum
  - Draft revision of DoDD 3405.1 provided in report
  - $15M/year needed for DoD Ada support

Frequently Asked Questions

- What is "warfighting software"?
  - Definition given above.

- If using Ada correlates with higher productivity and quality, why not use Ada for all DoD software?

- If DoD has trouble managing an unconditional Ada mandate, how can it manage a more selective one?
Why Not Use Ada for All DoD Software?

- Productivity and quality data cover custom software
can often do better via COTS integration with non-Ada glue code.
- Other criteria are important: cycle time, commercial interoperability
  - Ex: DoD logistics often uses commercial carriers
  - Commercial logistics software generally in C/C++
  - Infrastructure upgrades automatically furnished for C/C++
  - Ada bindings to infrastructure upgrades incur logistics delays

How Can DoD Manage a Selective Mandate?

- DoD manages its complex standard business practices well
  - Ex: Milestone reviews; acquisition contracting
- Current Ada waiver process not a standard business practice
  - Similar to international travel, technical paper clearance
- Aligning Ada decisions with Software Engineering Plan Reviews makes them part of a standard business practice
  - Ada decisions connected with plans, architecture, build-or-buy decisions at subsystem level

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Study Summary: Rationale I

1. Perry: Key criterion is support of information technology for warfighting competitive advantage

2. COTS, commercial trends make Ada less competitive for most non-warfighting applications

3. Ada provides DoD with basis for sustainable competitive advantage for warfighting software
   - Technical advantages
   - Large installed asset base
   - Sociotechnical infrastructure

Study Summary: Rationale II

4. DoD investment required to sustain Ada advantage
   - Ada vendors can't do it alone
   - $15M/year at the margin makes a big difference
   - Enhances DoD warfighting software capability

5. Ada installed base a liability without support
   - Investment repaid by savings on installed base

6. Weak Ada waiver process best strengthened by integration with software-engineering best practices
   - Architecture review boards

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Study Overview

- Computer Science and Telecommunications Board (CSTB)
  - Unit of National Research Council (NRC)
  - NRC is arm of National Academy complex
- Committee empaneled April 1996
- High standards: reviewed by
  - CSTB
  - External experts

Data Sources

- Briefings and position papers
  - DoD, aerospace, commercial, academia
  - Broad representation across levels/sectors
- Technical literature
- Experience data and summaries
- Committee expertise
- Reviewer expertise
Programming Languages (PLs) and Software Engineering (SE)

- PL decisions unavoidably bound to SE decisions
  - Risk, architecture, COTS, reuse, staffing

- PL features can enable better SE practices
  - 4GLs: Rapid prototyping, evolutionary development
  - Ada: Integration prior to coding via package specifications

- DoD Ada waiver process isolates the PL decision from SE decisions
  - Can result in suboptimal, rigid decisions; unevenly implemented

- Commercial best practices enable integration of PL and SE decisions
  - Architecture review boards (AT&T/Lucent, NASA, Citibank)

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Programming Language Comparisons

- Language feature analysis
  - Pro: Based on specific language differences
  - Con: Can miss interaction effects on projects

- Empirical data collection
  - Pro: Based on actual project experience
  - Con: Hard to normalize for counting rules, effects of other variables; available data largely incommensurate

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Language Feature Comparisons

<table>
<thead>
<tr>
<th>Programming Language Features Critical to Warfighting SW</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-assurance criteria</td>
</tr>
<tr>
<td>- Enforcement of modularity</td>
</tr>
<tr>
<td>- Support for user-defined abstraction</td>
</tr>
<tr>
<td>- Management of pointers</td>
</tr>
<tr>
<td>- Management of software faults</td>
</tr>
<tr>
<td>Real-time criteria</td>
</tr>
<tr>
<td>- Safe static data allocation</td>
</tr>
<tr>
<td>- Predictability of meeting deadlines</td>
</tr>
<tr>
<td>- Interaction among threads of control</td>
</tr>
</tbody>
</table>

Sources: SEI (Weinmann, 1991), FAA (IBM, 1985)

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## Technical Comparison of Ada 95, C, C++, and Java

<table>
<thead>
<tr>
<th>Language</th>
<th>High-assurance</th>
<th>Real-time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ada 95</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>C</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>C++</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Java</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

Conclusion: Ada 95 technically superior for high-assurance, real-time systems.

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## Language Comparisons: Empirical Data
Determinants of National Competitive Advantage

- Production factor endowment and creation
  - Human resources, infrastructure, knowledge resources, physical and capital resources
- Domestic demand conditions
  - Buyer sophistication, anticipatory demand, demand size
- Related and supporting industries
  - Competitive, compatible domestic suppliers
- Firm strategy, structure, and rivalry


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### Business Case: Cost Factors I

<table>
<thead>
<tr>
<th>Warfighting Software</th>
<th>Commercially Dominated Software</th>
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<tbody>
<tr>
<td><strong>Size:</strong> Ada advantage (+)</td>
<td>Ada disadvantage (-)</td>
</tr>
<tr>
<td>Mostly custom</td>
<td>Mostly non-Ada COTS-driven</td>
</tr>
<tr>
<td>Large Ada installed base</td>
<td>Small Ada installed base</td>
</tr>
<tr>
<td>Some Ada reuse investments</td>
<td>Non-Ada reuse investments</td>
</tr>
<tr>
<td><strong>Process:</strong> About even</td>
<td>About even</td>
</tr>
<tr>
<td>Some Ada advantage via early interface verification</td>
<td>Some Ada disadvantage in COTS-based rapid development</td>
</tr>
</tbody>
</table>

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**Business Case: Cost Factors II**

**Warfighter Software**
- Environment: About even
  - DoD investment required for Ada parity
  - Some Ada advantage in domain tools
- Personnel: Ada advantage (+)
  - DoD community has dominant Ada domain skill base

**Commercially Dominated Software**
- Environment: Ada disadvantage (-)
  - Non-Ada tools much stronger
- Personnel: Ada disadvantage (-)
  - Non-Ada domain skill base dominant

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**Business Case: Quality Factors**

**Warfighter Software**
- HA/RT: Ada advantage (+)
  - Ada technically superior
  - Attributes are success-critical
- Ease of change: Ada advantage (+)
  - Ada somewhat superior
  - More so for high assurance changes

**Commercially Dominated Software**
- HA/RT: Ada advantage (+)
  - Ada superiority diluted by COTS
  - Attributes less success-critical
- Ease of change: Ada disadvantage (-)
  - Ada custom advantages outweighed by non-Ada COTS advantages

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### Business Case: Socio-Technical Infrastructure

<table>
<thead>
<tr>
<th>Warfighting Software</th>
<th>Commercially Dominated Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socio-technical: Ada advantage (+)</td>
<td></td>
</tr>
<tr>
<td>- Existing infrastructure provides for sustainable competitive advantage</td>
<td></td>
</tr>
<tr>
<td>- Continued DoD investment required to sustain</td>
<td></td>
</tr>
<tr>
<td>Socio-technical: Ada disadvantage (-)</td>
<td></td>
</tr>
<tr>
<td>- Existing Commercial infrastructure much stronger than Ada-based infrastructure</td>
<td></td>
</tr>
</tbody>
</table>

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### Business Case: Conservative Economic Analysis

- Only consider sustaining existing 50MLOC of DoD Ada warfighting software
  - Excludes current and future development
- Only 8% percent of software changes per year (usually 11-20 percent)
- Only $40 per charged line of code (usually over $75)
- Only 8% percent cost improvement from $15M investment in tools and experience
  - Cost models include other factors, higher percentages
- Cost without investment = (50 MLOC) (0.08 change/year) ($40) = $160M/yr
- Cost with investment = ($160M/yr) (0.92) (0.92) = $135M/yr
- Annual ROI = ($160M-$135M)/$15M = 1.67

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Findings and Recommendations

- **Finding #1**: Ada provides DoD with a sustainable competitive advantage for warfighting software
- **Recommendation #1**: Continue vigorous promotion of Ada for warfighting software
- **Rationale**: Sustained by business-case analysis, language feature analysis, available project data

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- **Finding #2**: The current Ada requirement is over-applied to all DoD-maintained software
- **Recommendation #2**: Require Ada for DoD warfighting software; consider Ada for other DoD software
- **Rationale**: Sustained by business-case analysis; requirement necessary to avoid language proliferation in warfighting software

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Findings and Recommendations

• **Finding #3:** The current Ada requirement over-emphasizes programming language considerations

• **Recommendation #3:** Broaden policy focus to integrate Ada and other key software-engineering concerns

• **Rationale:** Other concerns (requirements, architecture, process, source selection) are more success-critical; isolation of Ada decision has caused premature or non-optimal commitments

Findings and Recommendations

• **Finding #4:** The current Ada requirement and its waiver process have been weakly implemented

• **Recommendation #4:** Integrate the Ada decision process with an overall Software Engineering Plan Review process

• **Rationale:** Based on commercially successful Software Architecture Review Board process; eliminate "waiver" concept

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### Software Engineering Plan

#### Review Content

- **Software/system concept of operation and requirements**
  - Including anticipated directions of change
- **Software/system architecture (product plan)**
  - Components, connectors, constraints, style, interfaces
  - Compliance with DoD architecture frameworks
  - Relation to DoD product line architectures
  - Choice of COTS, NDI components, programming language
- **Software life-cycle plan (process plan)**
  - Life-cycle responsibilities, milestones, increments, phases, cycles
  - Budgets, schedules, other key resources, risk management plan
- **Rationale demonstrating feasibility of plan and architecture**
  - Results of prototypes, simulations, analyses

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### Software Engineering Plan

#### Review Process

- Review approval required for passage of DAB and MAISR Milestone I and II reviews
- Approval authority delegated through Service Acquisition Executives to PEOs or equivalent product-line managers
  - Results periodically reviewed by ASD/C1
- Review representation from:
  - Experienced peer software program managers
  - Key stakeholders and technical experts
- Review focus: adequacy of rationale
  - Feasibility and consistency of plans and specifications

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Findings and Recommendations

• Finding #5: Ada infrastructure needs a level of support beyond the incentives for or capability of Ada vendors to finance

• Recommendation #5: DoD should invest roughly $15M/year at the margin with Ada technology and infrastructure suppliers, or drop the Ada requirement entirely

• Rationale: With ongoing investment (similar to warfighting-critical materials investments), DoD creates a sustainable warfighting competitive advantage; otherwise, Ada is at risk of becoming marginalized, like Jovial or CMS-2.
Findings and Recommendations

• **Finding #6:** DoD's inadequate software metrics database weakens its software policy and management decision capability

• **Recommendation #6:** Establish a sustained DoD commitment to collect and analyze consistent software metrics data

• **Rationale:** Recommendations of this study are based on a mix of inadequate data, anecdotal evidence, and expert judgment; DoD-endorsed Capability Maturity Model emphasizes such data collection and analysis; metrics efforts realized returns in several areas of DoD, NASA

Analysis of Alternatives

• **Summary of alternatives considered**

• **Elaboration for three primary alternatives**

  1. Ada requirement; no Ada investment
  2. Ada investment; no Ada requirement
  3. Phase-out of Ada
Summary of Alternatives

Ada Requirement; No Ada Investment

- Ada investment needs do not go away
  - Not covered by Ada vendor capital resources

- DoD-wide needs must be covered by individual programs
  - More Ada waivers based on life cycle cost
  - Piecemeal Ada solutions

- DoD competitive advantage undermined
  - Inability to leverage prior/related DoD investment
  - Ada will become more like Jovial, CMS-2
Ada Investment; No Ada

Requirements

- Ada decisions made program by program
  - Often with little software expertise in program office
  - Tendency to go for cheap, fragile non-Ada solutions

- DoD competitive advantage undermined
  - Often produces weaker warfighting software
  - Language proliferation weakens sociotechnical infrastructure
  - Inability to leverage related DoD investment

Phase-Out of Ada

- Creates large Ada legacy conversion challenge
  - Diverts resources from warfighting improvements
  - Creates transition period with weak Ada operational software

- Lessens warfighting software capability
  - High-assurance, real-time systems are more difficult to develop in other languages

- Eliminates source of DoD competitive advantage
  - Discards Ada technical and infrastructure superiority for warfighting software

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Current Status

- Study just published
  - National Academy Press, Ada and Beyond, 1997
  - ISBN 0-309-05597-0
  - Can order copies from 800/624-6242 or http://www.nap.edu
  - Electronic version at web site soon

- Balanced objections to recommendations
  - Crafts et al.: Continue to mandate Ada everywhere
  - AIA et al.: Drop Ada mandate completely

- Paige preparing to endorse, implement study recommendations
  - Except Ada mandate for warfighting systems
  - Continue to support Ada as preferred language for weapon systems, C3I systems
  - Implement via Paige/Kaminski joint memo
  - Rationale: DoD minimizing how-to mandates