APPENDIXES FOR THE TRA DESKBOOK

APPENDIX A
VARIOUS POINTS OF CONTACT (POCs)

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APPENDIX B
SUMMARY OF GENERAL ACCOUNTING OFFICE (GAO) REPORTS AND DEPARTMENT OF DEFENSE (DoD) IMPLEMENTATION

Several GAO reports addressed the DoD acquisition system and made recommendations that influenced the DoD 5000 series of publications. In particular, these reports influenced the involvement of the Component Science and Technology (S&T) communities on the acquisition review process and the use of Technology Readiness Assessments (TRAs).

The following presents a brief summary of GAO-related work, along with references for the source documents.

B.1 GAO REPORTS

The subcommittee on Readiness and Management Support of the Committee on Armed Services, U.S. Senate, which has oversight on acquisitions policy, enlisted the GAO in a study of best commercial practices as related to defense acquisition. A series of GAO reports and related testimony assessed how best commercial practices could improve the way DoD incorporates new technology into weapon system programs and reduces risk. These reports, issued from 1996–2000 (the principal of which are listed as Refs. 1, 2, 3), offered DoD some guidance and resulted in many of the changes in the current issues of the DoD 5000 series of documents [Department of Defense Directive (DoDD) 5000.1, Department of Defense Instruction (DoDI) 5000.2, and DoD 5000.2-R] (Refs. 4, 5, 6).

The weapon system acquisition cycle for DoD major weapon systems before the issuance of References 4, 5, and 6 could be illustrated as shown in Figure B-1. Technology, design, and manufacturing knowledge was obtained concurrently.

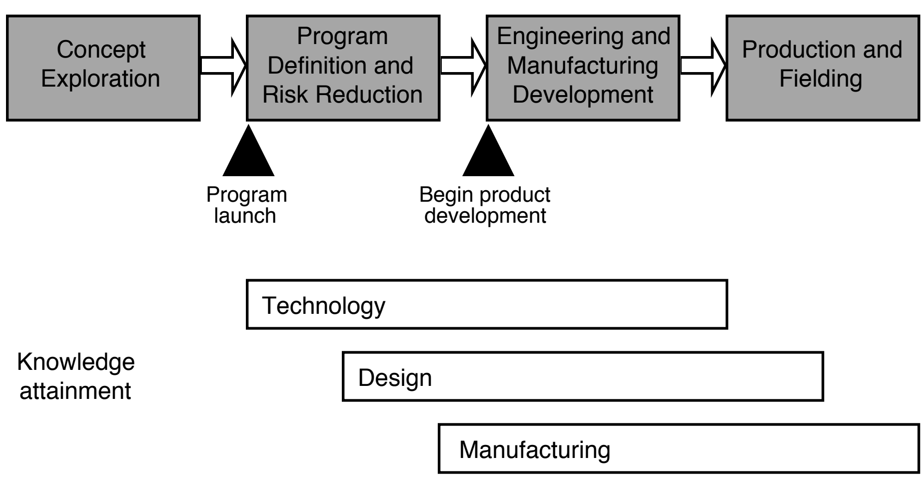

Figure B-1. DoD's Current Weapon System Acquisition Cycle

The major GAO recommendation that followed best commercial practice was to minimize technology development during product development and match requirements with technological capability before product development is launched. Proof that the technology will work and can be demonstrated to a high level of maturity is critical to lowering risk and avoiding large cost overruns. Associated with this principle are the needs to develop high standards for finding the maturity and readiness of technology, to establish disciplined paths that technology must take to be included in products, and to provide strong gatekeepers to decide when to allow the technology into a product development program. GAO recommended that DoD not launch a program until the technologies needed to meet a new weapons requirement are mature. To separate this technology development from the program, GAO best practices recommendations suggest that a technology and concept maturation phase follow concept exploration and precede program launch, as illustrated in Figure B-2.

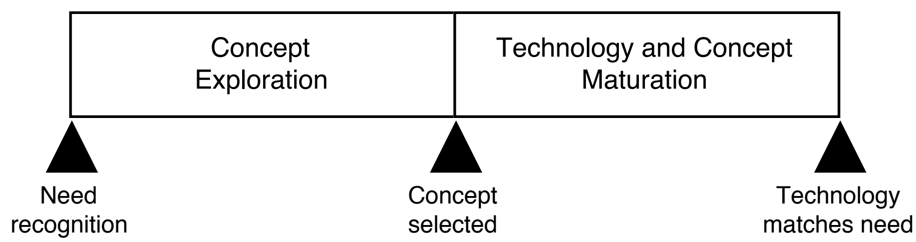

Figure B-2. Weapon Acquisition Phases That Should Precede the Launch of a New Program

The GAO review of best practices for including new technology in products (see Ref. 2) applied a scale of Technology Readiness Levels (TRLs) pioneered by the National Aeronautics and Space Administration (NASA) and adapted by the Air Force Research Laboratory (AFRL). "TRLs proved to be reliable indicators of the relative maturity of the 23 technologies reviewed, both commercial and military, and their eventual success after they were included in product development programs" (Ref. 2, p. 22)

To show that design is mature, the GAO studies suggest that a product development phase should include a distinct system integration effort *before* the system demonstration effort to demonstrate the effectiveness of the product and processes. See Figure B-3.

Figure B-4 shows GAO's final proposal for a potential DoD technology and product development process based on commercial best practices. It should be noted that leading commercial firms launch a new product later than DoD—after technology is

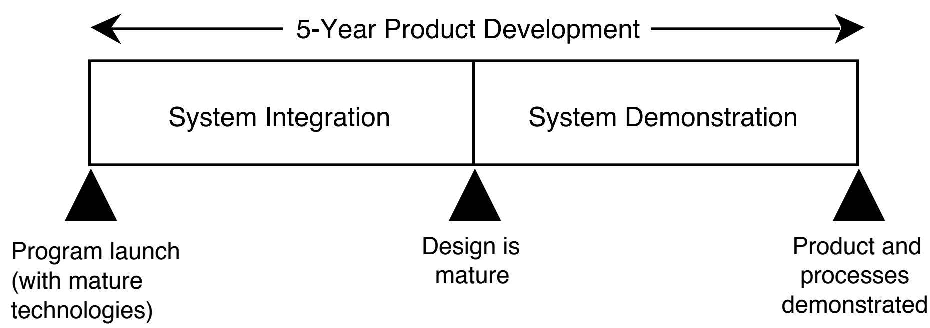

Figure B-3. Product Development Phase To Deliver a Mature Design and Key Processes

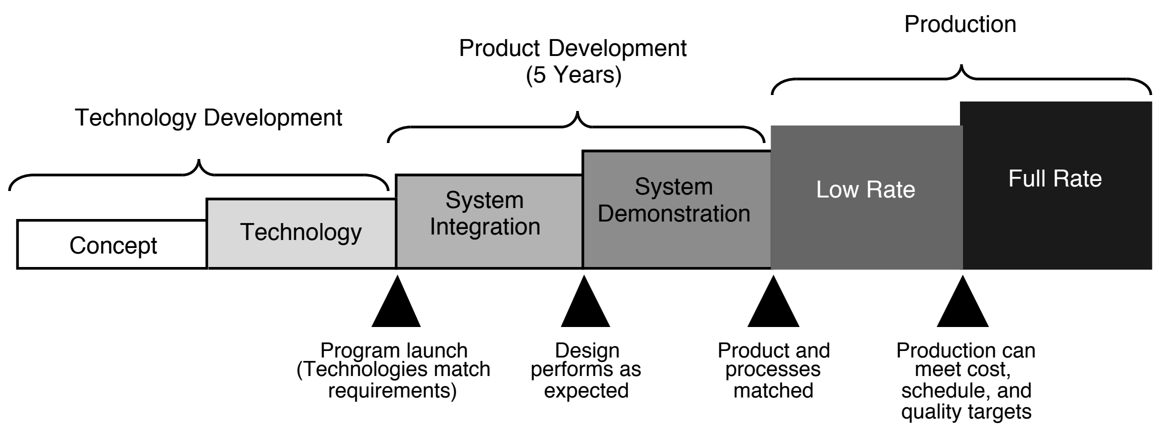

Figure B-4. Potential DoD Technology and Product Development Process Incorporating Best Practices

complete. Paragraphs B.2 and B.3 of this appendix provide the GAO recommendations for DoD management of Technology Development and the DoD response as reported in Reference 2. DoD did not agree entirely with GAO's recommendations and is willing to accept more risk. DoD considered TRL 6 as an acceptable readiness-level risk for a weapon system entering the program definition stage (see Figure B-1) and TRL 7 as an acceptable readiness-level risk for the Engineering and Manufacturing Development (EMD) stage. GAO accepted this.

Figure B-5 shows the process initially proposed by the TRA Working Group (see Appendix A) for accomplishing a TRA.[1] This would occur before Milestone B (MS B) and

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1 This is in the context of the acquisition process established by DoDI 5000.2

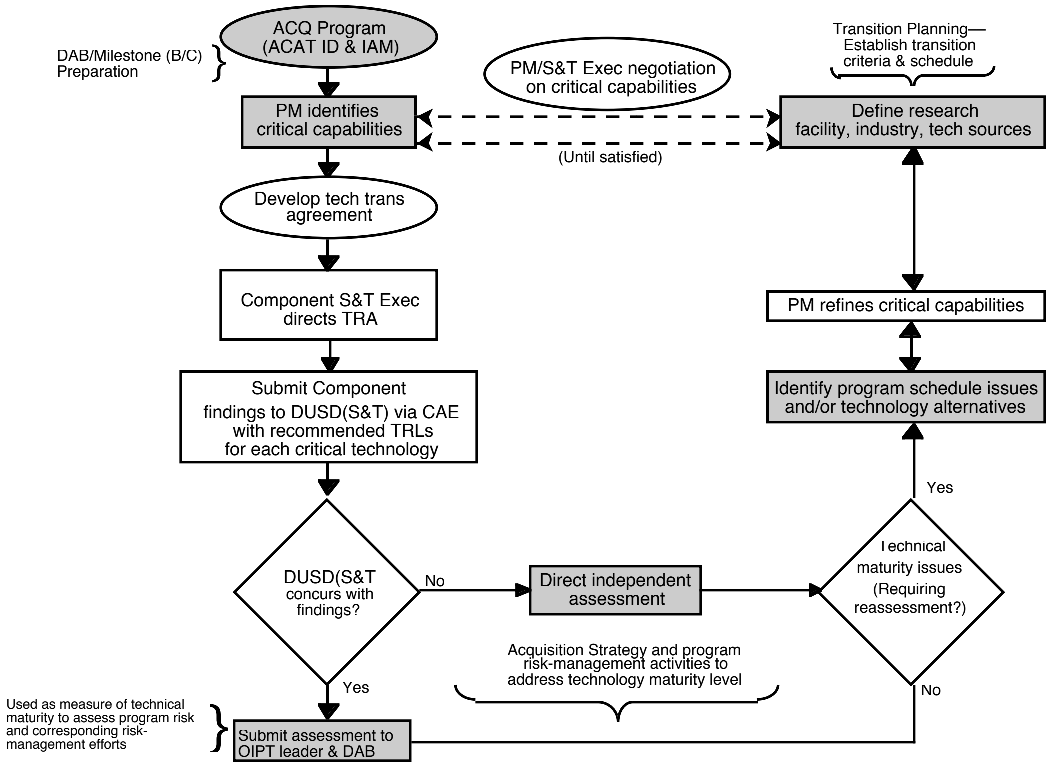


Figure B-5. Proposed TRA Process

Milestone C (MS C). Figure B-6 outlines the associated Defense Acquisition Management Framework presented in DoD 5000.2-R.

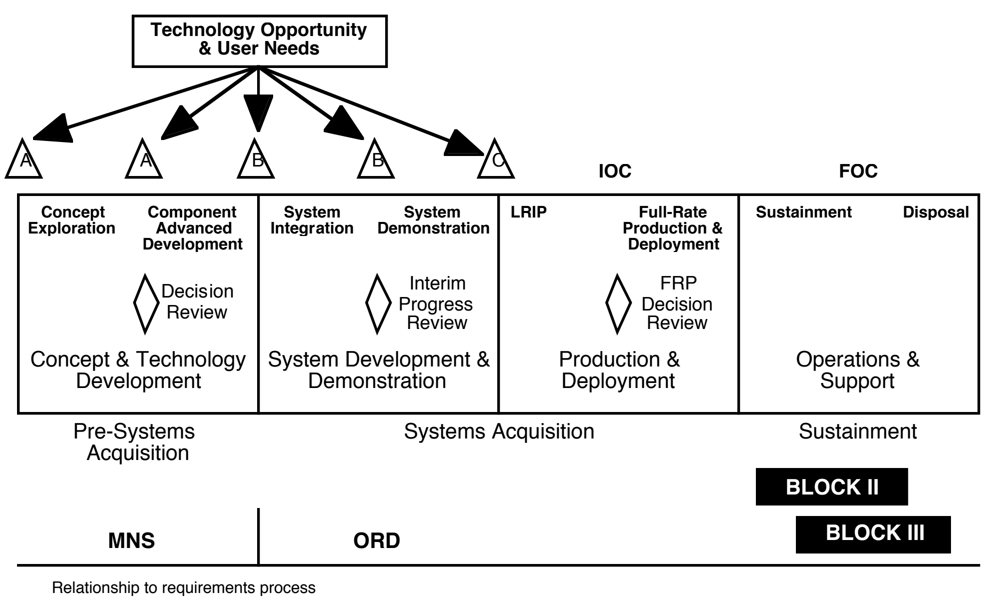


Figure B-6. Defense Acquisition Management Framework

B.2 GAO RECOMMENDATIONS

The following paragraphs are direct quotations from Reference 2: GAO/NSIAD-99-162, *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes*.

> We have previously recommended that DOD separate technology development from weapon system programs. That recommendation was made without prejudice toward the necessity of technology development but rather with the intent that programs could be better managed if such development was conducted outside of a program manager's purview. Similarly, the recommendations that follow are made without prejudice toward-or the intention of compromising-the basic research and other activities that S&T organizations perform. We recognize that implementation of these recommendations will have organizational, funding, and process implications and will require the cooperation of the Congress (p. 62).
>
> To help ensure that new technologies are vigorously pursued and successfully moved into weapon system programs, we recommend that the Secretary of Defense adopt a disciplined and knowledge-based method for assessing technology maturity, such as TRLs, DOD-wide. This practice should employ standards for assessing risks of handoff to program managers that are based on a technology's level of demonstration and its criticality to meeting the weapon system's requirements (p.63).
>
> With these tools in hand, we recommend that the Secretary (1) establish the place at which a match is achieved between key technologies and weapon system requirements as the proper time for committing to the cost, schedule, and performance baseline for developing and producing that weapon system and (2) require that key technologies reach a high maturity level—analogous to TRL 7-before making that commitment. This would approximate the launch point for product development as practiced by leading commercial firms (p. 63).
>
> We recommend that the Secretary find ways to ensure that the managers responsible for maturing the technologies and designing weapon systems before product development are provided the more flexible environment that is suitable for the discovery of knowledge, as distinct from the delivery of a product. Providing more flexibility will require the cooperation of requirements managers and resource managers so that rigid requirements or the threat of jeopardizing the funding planned to start product development will not put pressure on program managers to accept immature technologies. Such an environment may not be feasible if the program definition and risk reduction phase remains the effective launch point for an entire weapon system program (p. 63).
>
> An implication of these recommendations is that S&T organizations will have to play a greater role in maturing technologies to higher levels and should be funded accordingly. Therefore, we recommend that the Secretary of Defense evaluate the different ways S&T organizations can play a greater role in helping technologies reach high levels of maturity before product

development begins. For example, given that a technology has sufficient potential for application to a weapon system, at a minimum, an S&T organization should be responsible for taking a technology to TRL 6 before it is handed off to a program office at the program definition and risk reduction phase. During this phase, the program manager would be responsible for maturing the technology to TRL 7 before it is included in an engineering and manufacturing development program. In a situation where a single, design-pacing technology is to be developed for a known application—like the nonpenetrating periscope—an S&T organization should be required to mature that technology to TRL 7 before it is turned over to a product development manager. S&T organizations could play a similar role when a significant new technology is being prepared for insertion into an existing weapon system. Finally, when multiple new technologies are to be merged to create a weapon system, S&T organizations should be required to bring key technologies to TRL 6 and then become part of a hybrid organization with product developers to integrate the technologies and bring them to TRL 7 before handing full responsibility to a product development manager (pp. 63–64).

To help guard against the possibility that the more basic research and technology development activities would be compromised by having S&T organizations routinely take key technologies to TRL 6 or higher, we recommend that the Secretary extract lessons from the nonpenetrating periscope, the AAAV, and the Army's Future Scout programs, and other ATD and ACTD programs. Specifically, the Secretary should assess whether the resources needed to enable S&T organizations to play a leading role in the development of technologies and, in some cases, preliminary system design, detracted from or displaced more basic research and technology development programs (p. 64).

Finally, we recommend that the Secretary empower managers of product development programs to refuse to accept key technologies with low levels of demonstrated maturity. The Secretary can encourage this behavior through supportive decisions on individual programs, such as by denying proposals to defer the development of key technologies and by favoring proposals to lengthen schedules or lessen requirements to reduce technological risk early (p. 64).

B.3 DoD COMMENTS AND GAO EVALUATION

The following paragraphs are direct quotations from Reference 2: GAO/NSIAD-99-162, *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes*.

DOD generally concurred with a draft of this report and its recommendations, noting that the traditional path to new weapon system development is no longer affordable or necessary (see app. I). DOD stated that it has embarked upon a "Revolution in Business Affairs" that will enable new technologies to be developed more efficiently and effectively. It believes that the first steps in this direction have already been taken but agrees that more progress needs to be made. DOD agreed that TRLs are necessary in assisting decision-makers in deciding on when and where to insert new technologies into weapon system programs and that weapon system managers should ensure that technology is matured to a TRL 7 before insertion occurs. DOD concurred that S&T organizations should be involved in maturing technologies to high levels, such as TRL 6, before transitioning to the engineering and manufacturing development phase and agreed to assess the impact of this involvement on other S&T resources. We note that the best practice is to mature technology to at least a TRL 7 before starting the engineering and manufacturing development phase, whether the technology is managed by an S&T organization, a weapon system program manager, or a hybrid of the two organizations (pp. 64–65).

DOD noted that while TRLs are important and necessary, the increasing projected life for new weapon systems, total ownership costs, and urgency based upon threat assessments are also important considerations for system development decisions. We agree and note that our recommendations are not intended to cover all aspects of weapon system development decisions or to suggest that technology maturity is the only factor in such decisions. Rather, the recommendations are in keeping with the purpose of the report, "to determine whether best practices offer methods to improve the way DOD matures new technology so that it can be assimilated into weapon system programs with less disruption." We believe that a knowledge-based approach to maturing technology, such as TRLs, can benefit other considerations as well. For example, decisions on what technologies to include in a weapon system and when to include them can have a significant bearing on its total ownership costs.

DOD stated that there should be an established point for the transition of technologies and that it plans to supplement its milestone review process with additional guidance in the next revisions to DOD 5000.2-R. It also stated that its policy on the evolutionary approach to weapon acquisitions should be developed in consonance with the technology transition strategy. We cannot comment on the revisions to the directive or the evolutionary acquisition policy because they have yet to be published. However, under the current milestone review process, the pressures placed on a program during the program definition and risk reduction phase—when much technology development occurs—can operate against the flexibility and judgments that are needed to mature technologies. If the revisions to the directive supplement the current milestones without relieving the pressures brought to bear on programs as they are launched in the program definition and risk reduction phase, it will remain difficult to discourage the acceptance of immature technologies in the design of new weapon systems. To relieve these pressures, we encourage DOD, as it develops the directive and the evolutionary acquisition policy, to separate technology development from product development and to redefine the launch point for a program as the point at which enough knowledge has been gained to ensure that a match is reached between the maturity of key technologies and weapon system requirements (pp. 65–66).

DOD also stated that program managers already have the ability to reject inappropriately mature technologies, and to the extent technology immaturity affects acquisition baselines, to advise acquisition executives of feasible alternatives. We did not find this to be the case in our review. Rather, we found that the program managers' ability to reject immature technologies is hampered by (1) untradable requirements that force acceptance of technologies despite their immaturity and (2) reliance on tools for judging technology maturity that fail to alert the managers of the high risks that would prompt such a rejection. As noted in the report, once a weapon system program begins, the environment becomes inflexible and deviations to program baselines can attract unwanted attention. This reality limits the program managers' ability to reject immature technologies (p. 66).

B.4 CITED REFERENCES

1. GAO/T-NSIAD 99-116, *Defense Acquisition: Best Commercial Practices Can Improve Program Outcomes*. Statement for the Record by Louis J. Rodrigues, Director, Defense Acquisition Issues, National Security and International Affairs Division. Testimony Before the Subcommittee on Readiness and Management Support, Committee on Armed Services, U.S. Senate, March 1999.
(See Internet Web Site http://www.fas.org/man/gao/nsiad-99-116.htm).

2. GAO/NSIAD-99-162, *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes*. United States General Accounting Office (GAO) Report to the Chairman and Ranking Minority Member, Subcommittee on Readiness and Management Support, Committee on Armed Services, U.S. Senate, July 1999.
(See Internet Web Site http://www.fas.org/man/gao/nsiad-99-162.htm).

3. GAO/T-NSIAD-00-137, *Defense Acquisition: Employing Best Practices Can Shape Better Weapon System Decisions*. Statement of David M. Walker, Comptroller General of the United States. Testimony Before the Subcommittee on Readiness and Management Support, Committee on Armed Services, U.S. Senate, April 26, 2000.
See Internet Web Site http://www.gao.gov/archive/2000/ns00137t.pdf).

4. DoDD 5000.1, *The Defense Acquisition System,* 23 October 2000 (Incorporating Change 1, January 4, 2001).
(See Internet Web Site http://dod5000.dau.mil/index.htm).

5. DoDI 5000.2, *Operation of the Defense Acquisition System*, (Including Change 1), 4 January 2001.
(See Internet Web Site http://dod5000.dau.mil/index.htm).

6. DoD 5000.2-R, *Mandatory Procedures for Major Defense Acquisition Programs (MDAP) and Major Automated Information System (MAIS) Acquisition Programs,* April 5, 2002.
(See Internet Web Site http://dod5000.dau.mil/index.htm).

B.5 UNCITED REFERENCES

USD(AT&L), ASD(C31), and DOT&E Memorandum, "Mandatory Procedures for Major Defense Acquisition Programs (MDAP), and Major Automated Information System (MAIS) Acquisition Programs," dated January 2001.

ODDR&E Memo for ODUSD(S&T) Directors, "Interim Guidance for Implementing TRL," dated July 12, 2001.

ACRONYMS

AAAV	Advanced Amphibious Assault Vehicle
ACAT	Acquisition Category
ACTD	Advanced Concept Technology Demonstration
AFRL	Air Force Research Laboratory
ASD(C3I)	Assistant Secretary of Defense for Command, Control, Communications, and Intelligence
ATD	Advanced Technology Demonstration
CAE	Component Acquisition Executive
DAB	Defense Acquisition Board
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DUSD(S&T)	Deputy Under Secretary of Defense for Science and Technology
EMD	Engineering and Manufacturing Development
FOC	full operational capability
GAO	General Accounting Office
IOC	initial operational capability
LRIP	low rate initial production
MAIS	Major Automated Information System
MDAP	Major Defense Acquisition Program
MNS	Mission Needs Statement
NASA	National Aeronautics and Space Administration
NSIAD	National Security and International Affairs Division (GAO)
ODDR&E	Office of the Director of Defense Research and Engineering
ODUSD(S&T)	Office of the Deputy Under Secretary of Defense for Science and Technology
ORD	Operational Requirements Document
PM	Program Manager
S&T	Science and Technology
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics

APPENDIX C
EXTRACTS FROM THE DEPARTMENT OF DEFENSE (DoD) 5000 SERIES OF DOCUMENTS RELEVANT TO TECHNOLOGY READINESS ASSESSMENTS (TRAs) AND COMMENTS ON THE TRA PROCESS

The DoD 5000 series documents relevant to TRAs are

- Department of Defense Directive (DoDD) 5000.1, *The Defense Acquisition System,* (Incorporating Change 1, January 4, 2001), 23 October 2000
- Department of Defense Instruction (DoDI) 5000.2, *Operation of the Defense Acquisition System,* (Including Change 1); 4 January 2001
- DoD 5000.2-R, *Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information System (MAIS) Acquisition Programs*, April 5, 2002.

For background and reference, the portions of these documents relevant to TRA responsibilities are extracted here. A brief summary of the requirements for the assessments is also provided. These DoD 5000 series documents appear on Internet Web Site http://dod5000.dau.mil/index.htm.

C.1 EXTRACTS FROM DoD 5000 SERIES DOCUMENTS THAT SET TRA PROCEDURES AND POLICY

C.1.1 DoDD 5000.1

- **Paragraph 4.3.1**

  To ensure that the Defense Acquisition System provides useful military capability to the operational user as rapidly as possible, evolutionary acquisition strategies shall be the preferred approach to satisfying operational needs. Evolutionary acquisition strategies define, develop, and produce/deploy an initial, militarily useful capability ("Block I") based on proven technology, time-phased requirements, projected threat assessments, and demonstrated manufacturing capabilities, and plan for subsequent development and production/deployment of increments beyond the initial capability over time (Blocks II, III, and beyond). The scope, performance capabilities, and timing of subsequent increments shall be based on continuous communications among the requirements, acquisition, intelligence, and budget communities. In planning evolutionary acquisition strategies, program managers shall strike an appropriate balance among key factors, including the urgency of the operational requirement; the maturity of critical technologies; and the interoperability, supportability, and affordability of alternative acquisition solutions. To facilitate evolutionary acquisition, program managers shall use appropriate enabling tools, including a modular open systems approach to ensure access to the latest technologies and products, and facilitate affordable and supportable modernization of fielded assets. Sustainment strategies must *evolve and be refined throughout the life cycle, particularly during development of subsequent blocks in an evolutionary strategy.*

- **Paragraph 4.3.4**

  Milestone decision authorities shall not commit the Department to the initiation of low-rate initial production (or any production in the case of systems where low-rate initial production is not required) of an acquisition program unless and until certain fundamental criteria have been considered and evaluated. These criteria include, but are not necessarily limited to, demonstrated technology maturity; well-defined and understood user requirements that respond to identified threats; acceptable interoperability, affordability, and supportability; and a strong plan for rapid acquisition using evolutionary approaches as the preferred strategy, open systems designs, and effective competition.

- **Paragraph 4.5.1**

  There is no one best way to structure an acquisition program so that it accomplishes the objectives of the Defense Acquisition System. Decision-makers and program managers shall tailor acquisition strategies to fit the particular conditions of an individual program, consistent with common sense, sound business management practice, applicable laws and regulations, and the time-sensitive nature of the user's requirement. Proposed programs may enter the acquisition process at various decision points, depending on concept and technology maturity. Tailoring shall be applied to various aspects of the acquisition system, including program documentation, acquisition phases, the timing and scope of decision reviews, and decision levels. Milestone decision authorities shall promote flexible, tailored approaches to oversight and review based on mutual trust and a program's dollar value, risk, and complexity.

C.1.2 DoDI 5000.2

- **Paragraph 4.7.2.3.2.6**

  [Component S&T Executive shall] conduct independent technology assessments and assist in determining the maturity of critical system technologies for transition to the System Acquisition process, during System Development and Demonstration and at Milestone C.

- **Paragraph 4.7.2.3.3.1**

  ATDs shall be used to demonstrate the maturity and potential of advanced technologies for enhanced military operational capability or cost effectiveness.

- **Paragraph 4.7.2.4.5**

  The practical result of a preference for more mature technology is initiation of individual programs at later stages of development, after determination of technology maturity. As a consequence, most MDAPs will be initiated at Milestone B. On the rare occasions when an earlier program initiation is appropriate, it will take place at entry to or during Component Advanced Development. At program initiation in advance of Milestone B, the MDA shall approve the acquisition strategy, the acquisition program baseline, IT certification for MAISs (reference (u)), and exit criteria for the Component Advanced Development work effort if not already established.

- **Paragraph 4.7.3.2.1.2**

  This phase [System Development and Demonstration] can be entered either directly out of technology opportunity and user need activities or from Concept Exploration. The actual entry point depends on the maturity of the technologies, validated requirements (including urgency of need), and affordability. The MDA shall determine the appropriate entrance point, which shall be Milestone B. There shall be only one Milestone B per program, or evolutionary block.

- **Paragraph 4.7.3.2.2.1**

  Entrance into System Development and Demonstration is dependent on three things: technology (including software) maturity, validated requirements, and funding. Unless some other factor is overriding in its impact, the maturity of the technology will determine the path to be followed. Programs that enter the process at Milestone B shall have a system architecture and an operational architecture for their relevant mission area.

- **Paragraph 4.7.3.2.2.2**

  Technology is developed in S&T or procured from industry. Technology must have been demonstrated in a relevant environment (reference (c) for a discussion of technology maturity) or, preferably, in an operational environment (using the transition mechanisms) to be considered mature enough to use for product development in systems integration. If technology is not mature, the DoD Component shall use alternative technology that is mature and that can meet the user's needs. The determination of technology maturity is made by the DoD Component S&T Executive, with review of the determination for MDAPs by the DUSD(S&T). If the DUSD(S&T) does not concur with the determination, the DUSD(S&T) will direct an independent assessment. To promote increased consideration of technological issues early in the development process, the MDA shall, at each acquisition program decision, consider any position paper prepared by a Defense research facility *on a technological issue relating to the major system being reviewed; and any technological assessment made by a Defense research facility (reference(w)). A defense research facility is a DoD facility that performs or contracts for the performance of basic research or applied research known as exploratory development.*

- **Paragraph 4.7.3.2.3.1.1**

  Prior to approving entry into System Development and Demonstration at Milestone B, the MDA shall consider the validated ORD, System Threat Assessment, independent technology assessment and any technology issues identified by DoD research facilities, any early operational assessments or test and evaluation results, analysis of alternatives including compliance with the Department of Defense's strategic plan (based on the Government Performance and Results Act (GPRA), reference (x)), the independent cost estimate or, for MAISs, component cost analysis and the economic analysis, manpower estimate (if applicable), whether an application for frequency allocation has been made (if the system will require utilization of the electromagnetic spectrum), system affordability and funding, the program protection for Critical Program Information, anti-tamper provisions, the Delegation of Disclosure Authority Letter (DDL) concerning foreign disclosure of program information vis-à-vis foreign participation in the program and/or sales of the system, the proposed acquisition strategy, cooperative opportunities, and infrastructure and operational support.

- **Paragraph 4.7.3.2.3.1.2**

  At Milestone B, the MDA shall confirm the acquisition strategy approved prior to release of the final Request for Proposal and approve the development acquisition program baseline, low-rate initial production quantities (where applicable), and System Development and Demonstration exit criteria (and exit criteria for interim progress review, if necessary). For shipbuilding programs, the lead ship engineering development model shall be authorized at Milestone B. Critical systems for the lead and follow ships shall be demonstrated given the level of technology maturity and the associated risk prior to ship installation. Follow ships may be initially authorized at Milestone B, to preserve the production base, with final authorization dependent on completion of critical systems demonstration, as directed by the MDA.

- **Paragraph 4.7.3.2.3.1.3**

  The DOT&E and the cognizant Overarching Integrated Product Team Leader shall approve the Test and Evaluation Master Plan (TEMP) (including the LFT&E strategy, if applicable) for all OSD test and evaluation oversight *programs. If full-up, system-level LFT&E is unreasonably expensive and impractical, a waiver shall be approved by the USD(AT&L), for programs where he or she is the MDA, or by the CAE, for programs where he or she is the MDA, and an alternative LFT&E plan shall be approved by the DOT&E before entry into System Development and Demonstration (reference (y)).*

- **Paragraph 4.7.3.2.3.1.4**

  For MDAPs, a Milestone B decision shall be the occasion for submission of a revised Selected Acquisition Report (DoD 5000.2-R, reference (h)). IT intended for use by non-military users shall be accessible to people with disabilities (reference (v)).

- **Paragraph 4.7.3.3.2**

  Regardless of the entry point, approval at Milestone C is dependent on the following criteria being met (or a decision by the MDA to proceed):

- **Paragraph 4.7.3.3.2.1**

  Technology maturity (with an independent technology readiness assessment), system and relevant mission area (operational) architectures, mature software capability, demonstrated system integration or demonstrated commercial products in a relevant environment, and no significant manufacturing risks …

C.1.3 DoD 5000.2-R

- **Paragraph C7.5.1**

  Technology maturity shall measure the degree to which proposed critical technologies meet program objectives. Technology maturity is a principal element of program risk. A technology readiness assessment shall examine program concepts, technology requirements, and demonstrated technology capabilities to determine technological maturity.

- **Paragraph C7.5.2**

  The PM shall identify critical technologies via the WBS (see paragraph C5.3.1.). Technology readiness assessments for critical technologies shall occur sufficiently prior to milestone decision points B and C to provide useful technology maturity information to the acquisition review process.

- **Paragraph C7.5.3**

  The DoD Component Science and Technology (S&T) Executive shall direct the technology readiness assessment and, for ACAT ID and ACAT IAM programs, submit the findings to the CAE, who shall submit his or her report to the DUSD(S&T) with a recommended technology readiness level (TRL) (or some equivalent assessment) for each critical technology. When the

Component S&T Executive submits his or her findings to the CAE, he or she shall provide the DUSD(S&T) an information copy of those findings. In cooperation with the Component S&T Executive and the program office, the DUSD(S&T) shall evaluate the technology readiness assessment and, if he/she concurs, forward findings to the OIPT leader and DAB. If the DUSD(S&T) does not concur with the technology readiness assessment findings, an independent technology readiness assessment, under the direction of the DUSD(S&T), shall be required.

- **Paragraph C7.5.4**

  TRL descriptions appear at Appendix 6. TRLs enable consistent, uniform, discussions of technical maturity, across different types of technologies. Decision authorities shall consider the recommended TRLs (or some equivalent assessment methodology (e.g., Willoughby templates) when assessing program risk. TRLs are a measure of technical maturity. They do not discuss the probability of occurrence (i.e., the likelihood of attaining required maturity) or the impact of not achieving technology maturity.

- **Paragraph C7.6.4.4**

  For ACAT ID decision points, the OIPT leader shall provide the DAB chair, principals, and advisors an integrated assessment using information gathered through the IPT process. The leader's assessment shall focus on core acquisition management issues and shall consider independent assessments, including technology readiness assessments, which the OIPT members normally prepare. These assessments typically occur in context of the OIPT review and shall be reflected in the OIPT leader's report. There shall be no surprises at this point—all team members shall work issues in real time and shall be knowledgeable of their OIPT leader's assessment. OIPT and other staff members shall not require the PM to provide pre-briefs independent of the OIPT process.

- **Paragraph C7.6.7**

  Assessments, independent of the developer and the user, ensure an impartial evaluation of program status. Consistent with statutory requirements and good management practice, the Department of Defense shall require independent assessments of program status (e.g., the independent cost estimate or technology readiness assessment). Senior acquisition officials shall consider these assessments when making acquisition decisions. Staff offices that provide independent assessments shall support the orderly and timely progression of programs through the acquisition process. IPTs shall have access to independent assessments to enable full and open discussion of issues.

C.2 EXTRACTS FROM DoD 5000 SERIES DOCUMENTS THAT ASSIGN TRA RESPONSIBILITIES

C.2.1 Program Manager (PM)

- **DoD 5000.2-R (C7.5.2)**

  The PM shall identify critical technologies via the WBS (see paragraph C5.3.1.). Technology readiness assessments for critical technologies shall occur sufficiently prior to milestone decision points B and C to provide useful technology maturity information to the acquisition review process.

- **DoD 5000.2-R (C7.3.1.4)**

  The PM shall brief the acquisition program to the DAB and specifically emphasize technology maturity, risk management, affordability, critical program information, technology protection, and rapid delivery to the user. The PM shall address any interoperability and supportability requirements linked to other systems, and indicate whether those requirements will be satisfied by the acquisition strategy under review. If the program is part of a system-of-systems architecture, the PM shall brief the DAB in that context. If the architecture includes less than ACAT I programs that are key to achieving the expected operational capability, the PM shall also discuss the status of and dependence on those programs.

- **DoD 5000.2-R (C7.3.2.3)**

  Principal participants at DoD CIO reviews shall include (as appropriate to the issue being examined) the following department officials: the Deputy DoD CIO; IT OIPT Leader; ACAT ID OIPT Leaders; Cognizant PEO(s) and PM(s); Cognizant OSD PSA, CAEs and CIOs of the Army, Navy, and Air Force. Participants shall also include (as appropriate to the issue being examined) executive-level representatives from the following organizations: Office of USD(AT&L); Office of the Under Secretary of Defense (Comptroller); Office of the Joint Chiefs of Staff; Office of DOT&E; Office of the Director, PA&E; and Defense Information Systems Agency.

- **DoD 5000.2-R (C7.6.4.1)**

  All ACAT ID and IAM programs shall have an OIPT to provide assistance, oversight, and review as the program proceeds through its acquisition life cycle. An appropriate official within OSD, typically the Director of Strategic and Tactical Systems or the Principal Director, Command, Control, Communications, Intelligence, Surveillance, and Reconnaissance & Space, shall lead the OIPT for ACAT ID programs. The Deputy DoD CIO or designee shall lead the OIPT for ACAT IAM programs. The OIPT for ACAT IAM programs is called *the IT OIPT. OIPTs shall comprise the PM, PEO, Component Staff, Joint Staff, and OSD staff involved in oversight and review of the particular ACAT ID or IAM program.*

- **DoD 5000.2-R (C7.6.5.1)**

  The PM, or designee, shall form and lead an IIPT to support the development of strategies for acquisition and contracts, cost estimates, evaluation of alternatives, logistics management, training, cost-performance trade-offs, etc. The PM, assisted by the IIPT, shall develop and propose to the OIPT, a WIPT structure. The IIPT shall coordinate the activities of the WIPTs and review issues they do not address. WIPTs shall meet as required to help the PM plan program structure and documentation and resolve issues.

- **DoD 5000.2-R (C7.7.1)**

  It shall be Department policy to keep reporting requirements to a minimum. Nevertheless, complete and current program information is essential to the acquisition process. Consistent with the tables of required regulatory and statutory information appearing in DoD Instruction 5000.2 (reference (a)), decision authorities shall require PMs and other participants in the defense acquisition process to present only the minimum information necessary to understand program status and make informed decisions. The MDA shall "tailor-in" program information case-by-case, as necessary. IPTs shall facilitate the management and exchange of program information.

- **DoD 5000.2-R (C7.14.1)**

  PMs shall implement internal management controls in accordance with DoD Directive 5000.1 (reference (jjjjj)), DoD Instruction 5000.2 (reference (a)), this Regulation, and DoD Directive 5010.38 (reference (kkkkk)). APB parameters shall serve as control objectives. PMs shall identify deviations from approved APB parameters and exit criteria as materiel weaknesses. PMs shall focus on results, not process.

- **DoD 5000.2-R (C7.15.1.1)**

  Program plans describe the detailed activities of the acquisition program. In coordination with the PEO, the PM shall determine the type and number of program plans needed to manage program execution.

- **DoDD 5000.1 (4.3.1)**

  To ensure that the Defense Acquisition System provides useful military capability to the operational user as rapidly as possible, evolutionary acquisition strategies shall be the preferred approach to satisfying operational needs. Evolutionary acquisition strategies define, develop, and produce/deploy an initial, militarily useful capability ("Block I") based on proven technology, *time-phased requirements, projected threat assessments, and demonstrated manufacturing capabilities, and plan for subsequent development and production/deployment of increments beyond the initial capability over time (Blocks II, III, and beyond). The scope, performance capabilities, and timing of subsequent increments shall be based on continuous communications among the requirements, acquisition, intelligence, and budget communities. In planning evolutionary acquisition strategies, program managers shall strike an appropriate balance among key factors, including the urgency of the operational requirement; the maturity of critical technologies; and the interoperability, supportability, and affordability of alternative acquisition solutions. To facilitate evolutionary acquisition, program managers shall use appropriate enabling tools, including a modular open systems approach to ensure access to the latest technologies and products, and facilitate affordable and supportable modernization of fielded assets. Sustainment strategies must evolve and be refined throughout the life cycle, particularly during development of subsequent blocks in an evolutionary strategy.*

C.2.2 Deputy Under Secretary of Defense for Science and Technology DUSD(S&T)

- **DoD 5000.2-R (C7.5.3)**

  The DoD Component Science and Technology (S&T) Executive shall direct the technology readiness assessment and, for ACAT ID and ACAT IAM programs, submit the findings to the CAE who shall submit his or her report to the DUSD(S&T) with a recommended technology readiness level (TRL) (or some equivalent assessment) for each critical technology. When the Component S&T Executive submits his or her findings to the CAE, he or she shall provide the DUSD(S&T) an information copy of those findings. In cooperation with the Component S&T Executive and the program office, the DUSD(S&T) shall evaluate the technology readiness assessment and, if he/she concurs, forward findings to the OIPT leader and DAB. If the DUSD(S&T) does not concur with the technology readiness assessment findings, an independent technology readiness assessment, under the direction of the DUSD(S&T), shall be required.

- **DoD 5000.2-R (C7.6.7)**

  Assessments, independent of the developer and the user, ensure an impartial evaluation of program status. Consistent with statutory requirements and good management practice, the Department of Defense shall require independent assessments of program status (e.g., the independent cost estimate or technology readiness assessment). Senior acquisition officials shall consider these assessments when making acquisition decisions. Staff offices that *provide independent assessments shall support the orderly and timely progression of programs through the acquisition process. IPTs shall have access to independent assessments to enable full and open discussion of issues.*

C.2.3 Component Acquisition Executive (CAE)

- **DoD 5000.2-R (C7.5.3)**

  The DoD Component Science and Technology (S&T) Executive shall direct the technology readiness assessment and, for ACAT ID and ACAT IAM programs, submit the findings to the CAE who shall submit his or her report to the DUSD(S&T) with a recommended technology readiness level (TRL) (or some equivalent assessment) for each critical technology. When the Component S&T Executive submits his or her findings to the CAE, he or she shall provide the DUSD(S&T) an information copy of those findings. In cooperation with the Component S&T Executive and the program office, the DUSD(S&T) shall evaluate the technology readiness assessment and, if he/she concurs, forward findings to the OIPT leader and DAB. If the DUSD(S&T) does not concur with the technology readiness assessment findings, an independent technology readiness assessment, under the direction of the DUSD(S&T), shall be required.

C.2.4 Component Science and Technology (S&T) Executive

- **DoD 5000.2-R (C7.5.3)**

  The DoD Component Science and Technology (S&T) Executive shall direct the technology readiness assessment and, for ACAT ID and ACAT IAM programs, submit the findings to the CAE who shall submit his or her report to the DUSD(S&T) with a recommended technology readiness level (TRL) (or some equivalent assessment) for each critical technology. When the Component S&T Executive submits his or her findings to the CAE, he or she shall provide the DUSD(S&T) an information copy of those findings. In cooperation with the Component S&T Executive and the program office, the DUSD(S&T) shall evaluate the technology readiness assessment and, if he/she concurs, forward findings to the OIPT leader and DAB. If the DUSD(S&T) does not concur with the technology readiness assessment findings, an independent technology readiness assessment, under the direction of the DUSD(S&T), shall be required.

C.2.5 Defense Acquisition Board [Chaired by the Under Secretary of Defense for Acquisition Technology and Logistics (USD(AT&L))]

- **DoD 5000.2-R (C7.3.1.1)**

  The DAB shall advise the Under Secretary of Defense (Acquisition, Technology, and Logistics) on critical acquisition decisions. The Under Secretary of Defense (Acquisition, Technology, and Logistics) shall chair the DAB, and the Vice Chairman of the Joint Chiefs of Staff shall serve as vice-chair. DAB membership shall comprise the following executives: Under Secretary of Defense (Comptroller); Under Secretary of Defense (Policy); Under Secretary of Defense (Personnel & Readiness); Assistant Secretary of Defense (Command, Control, Communications, and Intelligence)/Department of Defense Chief Information Officer; Director, Operational Test and Evaluation; and the Secretaries of the Army, Navy, and the Air Force. United States Joint Forces Command shall be available to comment on interoperability and integration issues that the JROC forwards to the DAB. The DAE may ask other department officials to participate in reviews, as required.

C.2.6 Defense Acquisition Executive (DAE)

- **DoD 5000.2-R (C7.3.1.3)**

  The Defense Acquisition Executive shall conduct DAB reviews at major program milestones and at the Full-Rate Production Decision Review (if not delegated to the CAE), and at other times, as necessary. An ADM shall document the decision(s) resulting from the review.

C.2.7 DoD Chief Information Officer (CIO) Reviews

- **DoD 5000.2-R (C7.3.2.1)**

  DoD CIO Reviews shall provide the forum for ACAT IAM milestones, for deciding critical ACAT IAM issues when they cannot be resolved at the OIPT level, and for enabling the execution of the DoD CIO's acquisition-related responsibilities for IT, including NSS, under the Clinger-Cohen Act and Title 10 USC (references (ppp) and (eeeee)). Wherever possible, these reviews shall take place in the context of the existing IPT and acquisition milestone review process. Where appropriate, an ADM shall typically document the decision(s) resulting from the review.

C.2.8 Overarching Integrated Product Team (OIPT)

- **DoD 5000.2-R (C7.6.4.1)**

  All ACAT ID and IAM programs shall have an OIPT to provide assistance, oversight, and review as the program proceeds through its acquisition life cycle. An appropriate official within OSD, typically the Director of Strategic and Tactical Systems or the Principal Director, Command, Control, Communications, Intelligence, Surveillance, and Reconnaissance & Space, shall lead the OIPT for ACAT ID programs. The Deputy DoD CIO or designee shall lead the OIPT for ACAT IAM programs. The OIPT for ACAT IAM programs is called the IT OIPT. OIPTs shall comprise the PM, PEO, Component Staff, Joint Staff, and OSD staff involved in oversight and review of the particular ACAT ID or IAM program.

- **DoD 5000.2-R (C7.6.4.2)**

  The OIPT shall form upon departmental intention to start an acquisition program. The OIPT shall charter the IIPT and WIPTs. The OIPT shall consider the recommendations of the IIPT regarding the appropriate milestone for program initiation and the minimum information needed for the program initiation milestone review. OIPTs shall meet, thereafter, as necessary over the life of the program. The OIPT leader shall act to resolve issues when requested by any member of the OIPT, or when so directed by the MDA. The goal is to resolve as many issues and concerns at the lowest level possible, and to expeditiously escalate issues that need resolution at a higher level. The OIPT shall bring only the highest-level issues to the MDA for decision.

- **DoD 5000.2-R (C7.6.4.3)**

  The OIPT shall normally convene two weeks before a planned decision point. It shall assess the information and recommendations that the MDA will receive, in the same context, and to the same ACAT level. It shall also assess family-of-system or system-of-system capabilities within mission areas in support of mission area operational architectures developed by the Joint Staff. If the program includes a pilot project, such as TOC Reduction, the PM shall report the status of the project to the OIPT. The OIPT shall then assess progress against stated goals. The PM's briefing to the OIPT shall specifically address interoperability and supportability (including spectrum supportability) with other systems, anti-tamper provisions, and indicate whether those requirements will be satisfied by the acquisition strategy under review. If the program is part of a family-of-systems architecture, the PM shall brief the OIPT in that context. If the architecture includes less than ACAT I programs that are key to achieving the expected operational capability, the PM shall also discuss the status of and dependence on those programs. The OIPT leader shall recom-

mend to the MDA whether the anticipated review should go forward as planned.

- **DoD 5000.2-R (C7.6.4.4)**

  For ACAT ID decision points, the OIPT leader shall provide the DAB chair, principals, and advisors an integrated assessment using information gathered through the IPT process. The leader's assessment shall focus on core acquisition management issues and shall consider independent assessments, including technology readiness assessments, which the OIPT members normally prepare. These assessments typically occur in context of the OIPT review, and shall be reflected in the OIPT leader's report. There shall be no surprises at this point—all team members shall work issues in real time and shall be knowledgeable of their OIPT leader's assessment. OIPT and other staff members shall not require the PM to provide pre-briefs independent of the OIPT process.

C.2.9 Integrated Product Teams (IPTs)

- **DoD 5000.2-R (C7.6.2)**

  IPTs are an integral part of the defense acquisition oversight and review process. For ACAT ID and IAM programs, there are generally two levels of IPT: the OIPT and WIPT(s). Each program shall have an OIPT and at least one WIPT. WIPTs shall focus on a particular topic such as cost/performance, test, or contracting. An Integrating IPT (IIPT) (which is a WIPT) shall coordinate WIPT efforts and cover all topics not otherwise assigned to another IPT. IPT participation is the primary way for any organization to participate in the acquisition program.

C.2.10 Authority of Key Acquisition System Officials

- **DoDD 5000.1 (Paragraph 5)**

  The Under Secretary of Defense (Acquisition, Technology, and Logistics) (USD(AT&L)), the Assistant Secretary of Defense (Command, Control, Communications, and Intelligence) (ASD(C3I)), and the Director of Operational Test and Evaluation (DOT&E) are key officials of the Defense Acquisition System. They may jointly issue DoD Instructions, DoD publications, and one-time directive-type memoranda, consistent with DoD 5025.1-M (reference (h)), that implement the policies contained in this Directive. Any such issuance shall be jointly signed by the USD(AT&L), the ASD(C3I), and the DOT&E.

C.3 COMMENTS ON THE TRA PROCESS

C.3.1 DoDD 5000.1, Change 1 (January 2001)

DoDD 5000.1, Change 1 (January 2001), in discussing "Rapid and Effective Transition From Acquisition to Deployment and Fielding" (Section 4.3 under the topics of "Evolutionary Acquisition and Departmental Commitment to Production" and "Effective Management" and Section 4.5 under the topic of "Tailoring") sets forth the following:

- Evolutionary acquisition strategies are the preferred approach to satisfying operational needs. Maturity of critical technologies is one of the key factors to be considered in planning evolutionary acquisition strategies. Milestone Decision Authorities (MDAs) shall not commit the Department to the initiation of low rate initial production (LRIP) (or any production in the case of systems where LRIP is not required) until technology maturity has been demonstrated (among other fundamental criteria).
- In discussing effective management, DoDD 5000.1 emphasizes that no best way exists to structure an acquisition program and that proposed programs may enter the acquisition process at various decision points depending on concept and technology maturity.

C.3.2 DoDI 5000.2, Change 1

DoDI 5000.2, Change 1, in listing criteria for approval at Milestone B (MS B) and Milestone C (MS C), requires that "technology maturity" (with an independent TRA) be ascertained. Technology maturity is only one of the many considerations in MS B and MS C approval and what constitutes desired maturity is not indicated.

C.3.3 DoD 5000.2-R (April 5, 2002)

Chapter C7 of DoD 5000.2-R (April 5, 2002) establishes the mandatory policies and procedures for making major program decisions for Acquisition Category (ACAT) ID and ACAT IAM programs. Sections C7.5 and C7.6 deal specifically with technology maturity and the responsibilities of various action and decision-making entities, including the Program Manager (PM), the DoD Component Science and Technology (S&T) Executive, the Component Acquisition Executive (CAE), the Deputy Under Secretary of Defense for Science and Technology (DUSD(S&T)), the Overarching Integrated Product Team (OIPT), the Defense Acquisition Board (DAB), and the Working Integrated Product Team (WIPT). Section C7.6 allows for independent assessments and invites industry participation.

Appendix 6 of DoD 5000.2-R lists 9 TRLs and their definitions.[2] The specific level for passing MS B and MS C is not directed. Nonetheless, the wording "… in an appropriate simulated environment, or preferably in an operational environment" strongly suggests TRL 6 or TRL 7 at MS B.

ACRONYMS

ACAT	Acquisition Category
ADM	Acquisition Decision Memorandum
APB	Acquisition Program Baseline
ASD(C3I)	Assistant Secretary of Defense for Command, Control, Communications, and Intelligence
ATD	Advanced Technology Demonstration
CAE	Component Acquisition Executive
CIO	Chief Information Officer
DAB	Defense Acquisition Board
DAE	Defense Acquisition Executive
DDL	Delegation of Disclosure Authority Letter
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DOT&E	Director of Operational Test and Evaluation
DUSD(S&T)	Deputy Under Secretary of Defense for Science and Technology
GPRA	Government Performance and Results Act
IIPT	Integrating IPT
IPT	Integrated Product Team
IT	Information Technology
JROC	Joint Requirements Oversight Committee
LFT&E	Live Fire Test and Evaluation
LRIP	low rate initial production
MAIS	Major Automated Information System
MDA	Milestone Decision Authority
MDAP	Major Defense Acquisition Program
MS	Milestone

2 These definitions also appear in Section III of this TRA Deskbook.

OIPT	Overarching Integrated Product Team
ORD	Operational Requirements Document
OSD	Office of the Secretary of Defense
PA&E	Program Analysis and Evaluation
PEO	Program Executive Officer
PM	Program Manager
PSA	Principal Staff Assistant
S&T	Science and Technology
TEMP	Test and Evaluation Master Plan
TOC	total ownership cost
TRA	Technology Readiness Assessment
USC	United States Code
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
WBS	Work Breakdown Structure
WIPT	Working Integrated Product Team

APPENDIX D
POLICY STATEMENTS

Various policy statements, directives, and so forth relevant to the Technology Readiness Assessment (TRA) process are provided for reference.

107TH CONGRESS
1st Session

HOUSE OF REPRESENTATIVES

REPORT
107–333

NATIONAL DEFENSE AUTHORIZATION ACT FOR FISCAL YEAR 2002

CONFERENCE REPORT

TO ACCOMPANY

S. 1438

DECEMBER 12, 2001.—Ordered to be printed

SEC. 804. REPORTS ON MATURITY OF TECHNOLOGY AT INITIATION OF MAJOR DEFENSE ACQUISITION PROGRAMS.

(a) REPORTS REQUIRED.—Not later than March 1 of each of years 2003 through 2006, the Secretary of Defense shall submit to the Committees on Armed Services of the Senate and the House of Representatives a report on the implementation of the requirement in paragraph 4.7.3.2.2.2 of Department of Defense Instruction 5000.2, as in effect on the date of enactment of this Act, that technology must have been demonstrated in a relevant environment (or, preferably, in an operational environment) to be considered mature enough to use for product development in systems integration.

(b) CONTENTS OF REPORTS.—Each report required by subsection (a) shall—

(1) identify each case in which a major defense acquisition program entered system development and demonstration during the preceding calendar year and into which key technology has been incorporated that does not meet the technological maturity requirement described in subsection (a), and provide a justification for why such key technology was incorporated; and

(2) identify any determination of technological maturity with which the Deputy Under Secretary of Defense for Science and Technology did not concur and explain how the issue has been or will be resolved.

(c) MAJOR DEFENSE ACQUISITION PROGRAM DEFINED.—In this section, the term "major defense acquisition program" has the meaning given that term in section 139(a)(2) of title 10, United States Code.

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

ACQUISITION, TECHNOLOGY AND LOGISTICS

APR 12 2002

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
CHAIRMAN OF THE JOINT CHIEFS OF STAFF
UNDER SECRETARIES OF DEFENSE
ASSISTANT SECRETARIES OF DEFENSE
INSPECTOR GENERAL, DEPARTMENT OF DEFENSE
GENERAL COUNSEL, DEPARTMENT OF DEFENSE
DIRECTORS OF THE DEFENSE AGENCIES

SUBJECT: Evolutionary Acquisition and Spiral Development

Since the publication of DoD Directive 5000.1 and DoD Instruction 5000.2, in which the Department established a preference for the use of evolutionary acquisition strategies relying on a spiral development process, there has been some confusion about what these terms mean and how spiral development impacts various processes such as contracting and requirements generation that interface with an evolutionary acquisition strategy. The purpose of this memorandum is to address those questions.

Evolutionary acquisition and spiral development are methods that will allow us to reduce our cycle time and speed the delivery of advanced capability to our warfighters. These approaches are designed to develop and field demonstrated technologies for both hardware and software in manageable pieces. Evolutionary acquisition and spiral development also allow insertion of new technologies and capabilities over time. Therefore, these approaches provide the best means of getting advanced technologies to the warfighter quickly while providing for follow-on improvements in capability. Evolutionary acquisition and spiral development are similar to pre-planned product improvement but are focused on providing the warfighter with an initial capability which may be less than the full requirement as a trade-off for earlier delivery, agility, affordability, and risk reduction.

Attached is a set of definitions. My points of contact for further information are Skip Hawthorne in the Acquisition Initiatives office, 703-697-6399, skip.hawthorne@osd.mil, or Ramona Lush in the Acquisition Resources and Analysis office, 703-695-5166, ramona.lush@osd.mil.

E.C. Aldridge, Jr.

Attachment
As stated

DEFINITIONS

Evolutionary Acquisition. An acquisition strategy that defines, develops, produces or acquires, and fields an initial hardware or software increment (or block) of operational capability. It is based on technologies demonstrated in relevant environments, time-phased requirements, and demonstrated manufacturing or software deployment capabilities. These capabilities can be provided in a shorter period of time, followed by subsequent increments of capability over time that accommodate improved technology and allowing for full and adaptable systems over time. Each increment will meet a militarily useful capability specified by the user (i.e., at least the thresholds set by the user for that increment); however, the first increment may represent only 60% to 80% of the desired final capability.

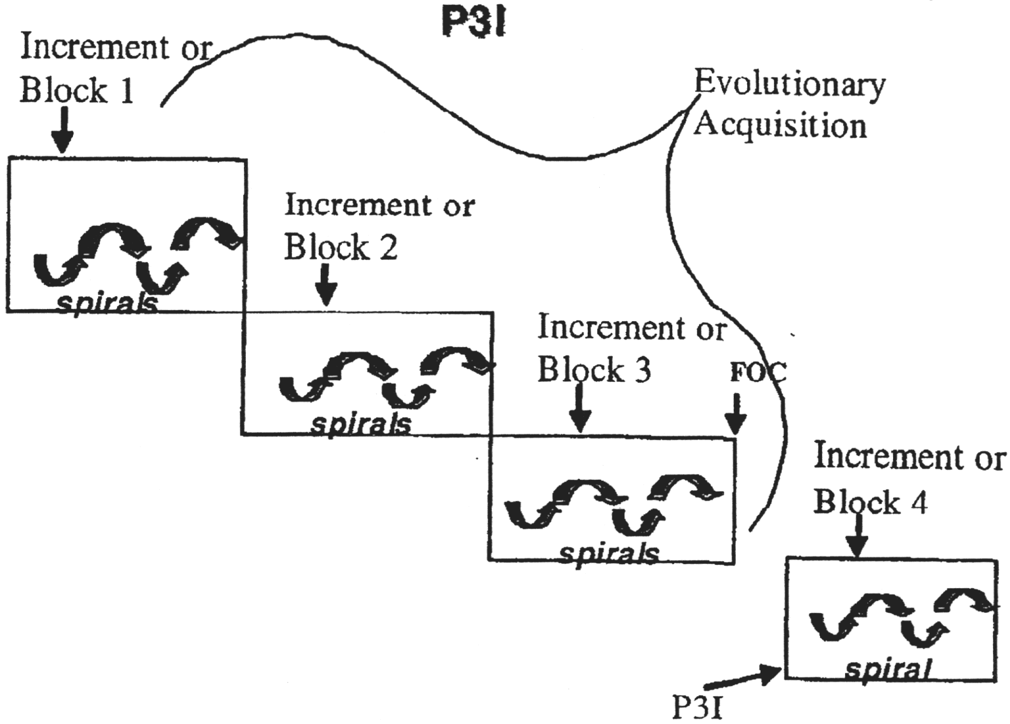
There are two basic approaches to evolutionary acquisition. In one approach the ultimate functionality can be defined at the beginning of the program, with the content of each deployable increment determined by the maturation of key technologies. In the second approach the ultimate functionality cannot be defined at the beginning of the program, and each increment of capability is defined by the maturation of the technologies matched with the evolving needs of the user.

Spiral Development. An iterative process for developing a defined set of capabilities within one increment. This process provides the opportunity for interaction between the user, tester, and developer. In this process, the requirements are refined through experimentation and risk management, there is continuous feedback, and the user is provided the best possible capability within the increment. Each increment may include a number of spirals. Spiral development implements evolutionary acquisition.

Increment or Block. A militarily useful and supportable operational capability that can be effectively developed, produced or acquired, deployed, and sustained. Each increment of capability will have its own set of thresholds and objectives set by the user.

Pre-Planned Product Improvement (P3I). A traditional acquisition strategy that provides for adding improved capability to a mature system.

Evolutionary Acquisition, Spiral Development, & P3I



OFFICE OF THE DIRECTOR OF
DEFENSE RESEARCH AND ENGINEER
3040 DEFENSE PENTAGON
WASHINGTON, D.C. 20301-3040

JUL 12 2001

MEMORANDUM FOR ODUSD(S&T) DIRECTORS

SUBJECT: Interim Guidance for Implementing Technology Readiness Levels

The new June 10, 2001 updated Department of Defense Regulation 5000.2R, Mandatory Procedures for Major Defense Acquisition Programs (MDAPs) and Major Automated Information System (MAIS) Acquisition Programs reflects the Science and Technology (S&T) role in the acquisition process. The S&T community must be actively engaged in enabling the rapid transition of mature technologies to product developers and actively participate in acquisition system integrated product teams. The regulation requires that the Component Science and Technology Executives conduct a technology readiness level (TRL) assessment (or some equivalent assessment) for critical technologies identified in ACAT ID and ACAT IAM programs prior to Milestone B and C. In cooperation with the Component S&T Executive and program office, the DUSD (S&T) must evaluate this assessment (including the Technology Readiness Level for each critical technology) and forward a concurrence with these findings to the Overarching Integrated Product Team Leader and the Defense Acquisition Board. It should be noted that TRL assessments are the preferred approach for all new programs unless DUSD (S&T) approves an equivalent assessment method.

The DSTAG recommended that a TRL IPT be established to define the guidelines and framework for implementing and applying TRLs in a consistent manner throughout the Department. The IPT developed guidelines for the S&T community to use in implementing TRL during the process. The attached interim guidelines include:

- Technology Readiness Assessment Process (Attachment 1)
- Definitions of Technology Readiness Levels (Attacment 2)
- Elements for a Technology Readiness Agreements including a sample (not mandatory) (Attachment 3)

Your active leadership and participation in your technical area plays a significant role in the implementation of TRLs across the Department. As shown in the TRL Process chart, we will be required to validate TRL assessments conducted by the Component S&T Executives. Attachment 4 is an example of a format that can be used in reviewing the TRL assessment of an acquisition program. Note that our review needs to be signed by both the technical action offices and his/her director. As a recognized partner in the acquisition process, we must insert ourselves much earlier in the process. I personally encourage each of you and your staffs to be actively involved during the identification of critical technologies process and in the Working Integrated Product Teams (WIPTs) for ACAT ID and ACAT IAM programs.

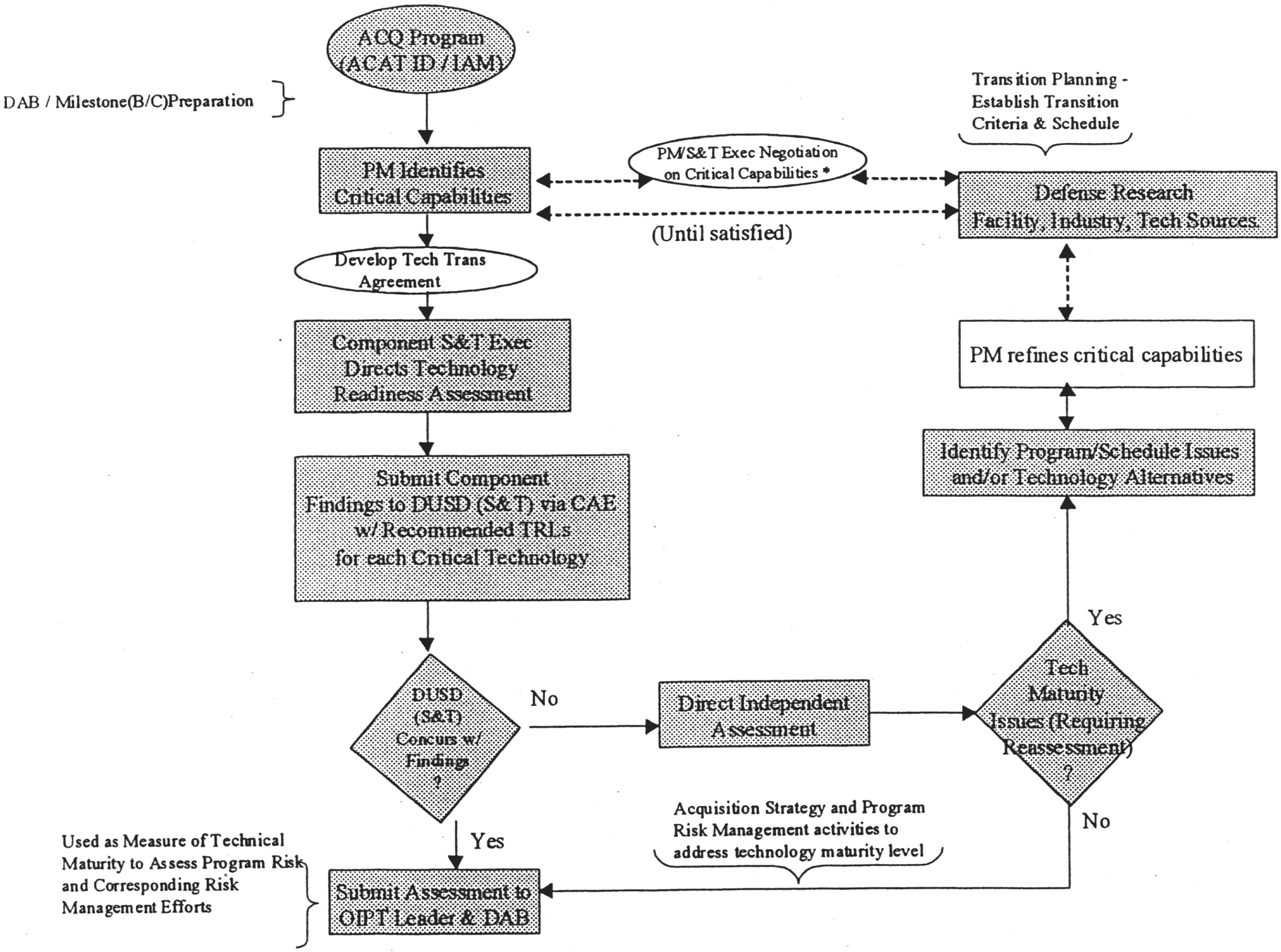
The S&T Plans and Programs office is responsible for maintaining a list of all ACAT ID AND acat iam programs requiring technology assessments and maintaining a copy of DUSD(S&T)'S review of TRL assessments. If you have any questions or comments, please contact Mr. Al Shaffer, Director, S&T Plans and Programs at (703) 695-9604.

Delores M. Etter

Delores M. Etter
Deputy Under Secretary of Defense
(Science and Technology)

Attachments:
As stated.

TECHNOLOGY READINESS ASSESSMENT PROCESS



* NO NEGOTIATION ON TRL ASSESSMENT

DEFINITIONS OF TECHNOLOGY READINESS LEVEL

The following table lists the various technology readiness levels and descriptions from a systems approach for both HARDWARE and SOFTWARE.(Components may provide additional clarifications for Software)

Technology Readiness Level	Description
1. Basic principles observed and reported.	Lowest Level of Technology Readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there is no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3. Analytical and experimental critical functions and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard validation in laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.
5. Component and/or breadboard validation in relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment, or in a simulated operational environment.
7. System prototype demonstration in an operational environment.	Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment, such as an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.
8. Actual system completed and "flight qualified" through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9. Actual system "flight proven" though successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of system development. Examples include using the system under operational mission conditions.

<u>**DEFINITIONS**</u>:

BREADBOARD: Integrated components that provide a representation of a system/subsystem and which can be used to determine concept feasibility and to develop technical data. Typically configured for laboratory use to demonstrate the technical principles of immediate interest. May resemble final system/subsystem in function only.

"HIGH FIDELITY": Addresses form, fit and function. High fidelity laboratory environment would involve testing with equipment that can simulate and validate all system specifications within a laboratory setting.

"LOW FIDELITY": A representative of the component or system that has limited ability to provide anything but first order information about the end product. Low fidelity assessments are used to provide trend analysis.

MODEL: A reduced scale, functional form of a system, near or at operational specification. Models will be sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system.

OPERATIONAL ENVIRONMENT: Environment that addresses all of the operational requirements and specifications required of the final system to include platform/packaging.

PROTOTYPE: The first early representation of the system which offers the expected functionality and performance expected of the final implementation. Prototypes will be sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system.

RELEVANT ENVIRONMENT: Testing environment that simulates the key aspects of the operational environment.

SIMULATED OPERATIONAL ENVIRONMENTAL: Environment that can simulate all of the operational requirements and specifications required of the final system or a simulated environment that allows for testing of a virtual prototype to determine whether it meets the operational requirements and specifications of the final system.

ELEMENTS OF TECHNOLOGY TRANSITION AGREEMENT

The following elements should be considered for inclusion in a technology agreement between an acquisition program, the intended receiver of a technology or capability development, and a science and technology activity, the developer and provider of the technology. Not every one of these elements is appropriate for every agreement, but each agreement should have considered these for inclusion.

Agreements, to be effective, must be reviewed periodically with both S&T management and program office management representatives participating. These reviews should address technical progress and future directions.

Elements to be provided by the Program Office:

a. **Target Acquisition Program.** A brief description of the acquisition program intended to receive the technology that is to be transitioned. Include major program objectives, current phase of acquisition life cycle, and projected initial operational capability date.

b. **Program Manager/Project Officer.** Program manager and individual in program office responsible for day-to-day management with contact information.

c. **Acquisition Program Technology Need.** Brief description of the benefit that this technology will bring to the acquisition program, or need satisfied. Where possible, relate benefit to ORD, KPP, etc. Include need dates for specific capabilities.

d. **Integration Strategy.** Describe the process for integrating the technology into the acquisition program. Include elements of acquisition strategy – evolutionary acquisition, block upgrade, etc., as well as required contractor to contractor agreements

Elements to be provided by S&T Activity

a. **Description of Technology or Capability to be Delivered.** Brief description of what the S&T activity intends to develop for transition to the acquisition program. Include capability delivery dates.

b. **Technology Manager.** Individual designated by the S&T activity to be the coordinator and day-to-day manager of the development of the needed technology.

c. **Current Status of Technology.**

   1. **Status Summary.** Summarize current state of development. Identify primary areas where additional development is required. Provide estimate of current TRL.

2. **Risk Analysis.** Major areas of risk, prioritized, with planned mitigation activities. Include technical (e.g., producibility, affordability, sustainability) cost, and schedule risks.

d. **Technology Development Strategy**. Outline approach planned. Efforts required beyond those currently underway; integration plans if multiple projects are planned. Planned ATD or ACTD developments, if applicable

e. **Key Technical Measures of Readiness to Transition**. Identify the key parameters or attributes that will be used to measure whether or not the technology development effort is proceeding appropriately. Include parameter to be tracked, current state, interim progress estimates, and final objective. Technology Readiness Levels are a measure of technical maturity and can be used to assess readiness to transition.

f. **Program Plan.** Show major activities/efforts comprised by the technology development activity with milestones.

Signatures. Technology transition agreements should be signed as required to commit the participating organizations to the plan outlined in the agreement. The program manager(s) of the acquisition program(s) involved and the S&T project manager, should sign.

- SAMPLE -

TECHNOLOGY TRANSITION AGREEMENT

Basic Transition Agreement

1. **Description of Technology or Capability to be Delivered.**

2. **Target Acquisition Program.**

3. **Acquisition Program Technology Need**

4. **Integration Strategy**

5. **Program Manager/Project Officer**

6. **Technology Manager**

Technical Details and Programmatics

1. **Technology – Current Status**

   a. **Summary – Status**

   b. **Risk Analysis**

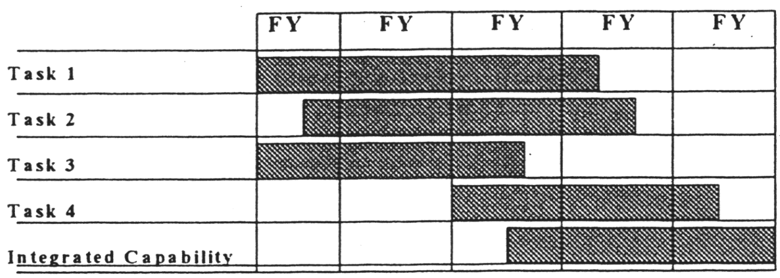
Top Risks	Brief Description	Mitigation Strategy

2. **Technology Development Strategy.**

3. **Key Measures of Transition Readiness**

Attribute/Parameter	Current	Interim (w/Est Date)	Final Objective

4. **Program Plan**



SIGNATURES:

Acquisition PM

S&T Project Manager

ODUSD (S&T)/WS UH-60M Program
Technology Readiness Level Assessment

The UH-60M Program TRL assessment is grouped into three categories. They are Cockpit Digitization, Propulsion, and Airframe. These categories are subdivided into 16 individual TRL assessments. Source information for this appraisal includes direct knowledge of specific supporting science and technology (S&T) activities, documentation provided by the SAALT staff, and information derived from the DOT&E website on Black Hawk modernization at http://www.dote.osd.mil/reports/FY00/army/00blackhawkuh60.html.

Category 1 - Cockpit Digitization

Element 1 - Stormscope

- Army Assessment: 8 DUSD (S&T) Assessment: Concur
- Supporting Rationale: Commercial-off-the-Shelf (COTS) item, already fielded on the UH-60Q and HH-60L

Element 2 - Dual Embedded GPS Inertial (EGI) Navigation System

- Army Assessment: 7 DUSD (S&T) Assessment: Concur
- Supporting Rationale: EGI has flown on CH-47 and MH-60K. Apache Program is currently demonstrating/qualifying an updated version.

Element 3 - Cockpit Voice Recorder (CVR)/Flight Data Recorder (FDR)

- Army Assessment: 7 DUSD (S&T) Assessment: Concur
- Supporting Rationale: COTS component. Technology demonstrated on the MH-60K Program and civil aviation aircraft. Qualification efforts ongoing for MH-60K and MH-47E fleets.

Element 4 - Advanced Flight Control Computer (AFCC)

- Army Assessment: 7 DUSD (S&T) Assessment: Concur
- Supporting Rationale: Based upon SH-60 and S-92 architecture. Qualification testing is ongoing.

Element 5 - Improved Data Modem (IDM)

- Army Assessment: 7 DUSD (S&T) Assessment: Concur
- Supporting Rationale: IDM currently in use on OH-58D and AH-64 platforms.

Category 2 - Propulsion

Element 1 - Crashworthy External Fuel System (CEFS)

- Army Assessment: 7 DUSD (S&T) Assessment: Concur
- Supporting Rationale: Product of a Cooperative Research and Development Agreement intended to improve the crashworthiness and reduce the ballistic vulnerability of the existing Extended Range Fuel System (ERFS). Airworthiness Qualification Testing ongoing.

ODUSD (S&T)/WS UH-60M Program
Technology Readiness Level Assessment (cont'd)

Category 2 – Propulsion (cont'd)

Element 2 - Wide Chord Blade (WCB)
- Army Assessment: 7 DUSD (S&T) Assessment: Concur
- Supporting Rationale: DoD Dual Use Application Program COSSI effort to qualify a commercially developed main rotor blade for use in the military environment. Airworthiness Qualification Testing ongoing.

Element 3 - T700-GE-701C Engine
- Army Assessment: 9 DUSD (S&T) Assessment: Concur
- Supporting Rationale: Currently fielded on the UH-60L with over 400 A/C, 2 engines per A/C

Element 4 - Improved Durability Gearbox (IDGB), Rotorhead & Control
- Army Assessment: 9 DUSD (S&T) Assessment: Concur
- Supporting Rationale: Currently fielded on the UH-60L with over 400 A/C

Element 5 - Improved Infrared (IR) Suppressor
- Army Assessment: 7 DUSD (S&T) Assessment: Concur
- Supporting Rationale: Discrete Design Modifications to HIRSS currently installed on the UH-60 fleet. System flight demonstrations completed with no significant issues noted.

Category 3 - Airframe

Element 1 - Refurbishment
- Army Assessment: 9 DUSD (S&T) Assessment: Concur
- Supporting Rationale: No new technologies or materials being used in refurbishment efforts.

Element 2 - Standardization
- Army Assessment: 9 DUSD (S&T) Assessment: Concur
- Supporting Rationale: Using existing Maintenance Work Orders for the current version of the UH-60L aircraft.

Element 3 - Tailcone & Stabilator
- Army Assessment: 9 DUSD (S&T) Assessment: Concur
- Supporting Rationale: Being accomplished already on the UH-60A/L aircraft.

Element 4 - Transition Access Door
- Army Assessment: 9 DUSD (S&T) Assessment: Concur
- Supporting Rationale: Same modification being accomplished on the UH-60Q.

ODUSD (S&T)/WS UH-60M Program
Technology Readiness Level Assessment (cont'd)

Category 3 – Airframe (cont'd)

Element 5 - Electro Magnetic Interference (EMI) Wiring

- Army Assessment: 9 DUSD (S&T) Assessment: Concur
- Supporting Rationale: No new technologies or materials required. Material solution for the UH-60M is currently fielded wiring or that used on MH-60K.

Element 6 - External Stores Support System (ESSS)

- Army Assessment: 9 DUSD (S&T) Assessment: Concur
- Supporting Rationale: No new technologies required. Currently fielded on the UH-60L.

Action Officer:______>>Signed<<______________________________ Date:_______________

Paul F. Piscopo, Staff Specialist for Aircraft Systems

Director:____________>>Signed<<______________________________ Date:_______________

George Ullrich, Director, Weapons Systems Directorate

OFFICE OF THE DIRECTOR OF
DEFENSE RESEARCH AND ENGINEERING
3040 DEFENSE PENTAGON
WASHINGTON, D.C. 20301-3040

SEP 6 2001

MEMORANDUM FOR DIRECTOR, STRATEGIC AND TACTICAL SYSTEMS
PRINCIPAL DIRECTOR, DASD (C3IISR/SPACE)

SUBJECT: Deputy Under Secretary of Defense (Science and Technology) (DUSD(S&T)) Staff Participation in OIPTs

In light of the recent change to the DoD 5000 series, the expanded role of S&T in the acquisition process requires Science and Technology (S&T) staff officers become active members of Overarching Integrated Product Teams (OIPT) for ACAT ID and ACAT IAM programs. The regulation requires that the Component Science and Technology Executives conduct a technology readiness level (TRL) assessment (or some equivalent assessment) for critical technologies identified in ACAT ID and ACAT IAM programs prior to Milestone B and C. In cooperation with the Component S&T Executive and program office, the DUSD(S&T) must evaluate this assessment and forward a concurrence with these findings to the Overarching Integrated Product Team Leader and the Defense Acquisition Board. Through active participation in OIPTs, the S&T staff officer can make informed recommendations to the DUSD(S&T).

I have attached a list of known major programs that identifies an S&T staff member for each program. The S&T Plans and Programs office is responsible for maintaining the master list. My point of contact for this effort is Beth Foster who can be reached at (703)614-9442, beth.foster@osd.mil.

Alan R. Shaffer
Director, S&T Plans and Programs

Attachment

ACAT ID AND ACAT IAM LIST
As of September 4, 2001

Service/Program	S&T Directorate	S&T Staff Officer
ARMY		
ATACMS-BAT – Army Tactical Missile System-Brilliant Anti-Armor Submunition	Weapon Systems	Mr. Art McGregor (703)588-7406 arthur.mcgreor@osd.mil
COMANCHE – Reconnaissance Attack Helicopter	Weapon Systems	Dr. Lew Sloter (703)588-7405 lewis.sloter@osd.mil
CRUSADER – Advanced Field Artillery System/Future Armored Resupply Vehicle	Weapon Systems	Mr. Jack Taylor (703)588-7405 jack.taylor@osd.mil
FBCB2 – Force XXI Battle Command Brigade and Below Program	Information Systems	Maj Jim Sweeney (703)588-7412 james.sweeney@osd.mil
IAV – Interim Armor Vehicle	Weapon Systems	Mr. Jack Taylor (703)588-7405 jack.taylor@osd.mil
MCS (ATCCS) – Maneuver Control System	Information Systems	Dr. Eric Landree (703)588-7415 eric.landree@osd.mil
NAVY		
AAAV – Advanced Amphibious Assault Vehicle	Weapon Systems	Mr. Jack Taylor (703)588-7405 jack.taylor@osd.mil
ALAM – Advanced Land Attack Missile	Weapon Systems	Mr. Art McGregor (703)588-7406 arthur.mcgreor@osd.mil
CEC – Cooperation Engagement Capability	Information Systems	CAPT Frank Garcia (703)588-7411 frank.garcia@osd.mil
CVN(X) – Next Generation Nuclear Aircraft Carrier	Weapon Systems	Mr. Jack Taylor (703)588-7405 jack.taylor@osd.mil
DD 21 – 21st Century Destroyer Program	Weapon Systems	Mr. Jack Taylor (703)588-7405 jack.taylor@osd.mil
JSOW/UNITARY – Joint Stand-Off Weapon with Unitary Warhead variant	Weapon Systems	Mr. Art McGregor (703)588-7406 arthur.mcgreor@osd.mil
LPD 17 – Amphibious Assault Ship	Weapon Systems	Mr. Jack Taylor (703)588-7405 jack.taylor@osd.mil
MIDS-LVT – MultiFunctional Information Distribution System-Low Volume Terminal	Information Systems	Maj Jim Sweeney (703)588-7412 james.sweeney@osd.mil
SSN 774 – VIRGINIA CLASS Submarine	Weapon Systems	Mr. Jack Taylor (703)588-7405 jack.taylor@osd.mil

T-AKE – Auxiliary Dry Cargo Ships	Weapon Systems	Mr. Jack Taylor (703)588-7405 jack.taylor@osd.mil
USMC H-1 Upgrades – Marine Corps Mid-life Upgrade to AH-1W Attack Helicopter and UH-1N Utility Helicopter	Weapon Systems	Dr. Lew Sloter (703)588-7405 lewis.sloter@osd.mil
AIR FORCE		
ABL – Airborne Laser	Weapon Systems	Mr. Keith Truesdell (703)588-7408 keith.truesdell@osd.mil
AEHF – Advanced Extremely High Frequency Program	Information Systems	Dr. Steve King (703)588-7414 steven.king@osd.mil
C-130 AMP – C-130 Aircraft Avionics Modernization Program	Sensor Systems	Mr. Jeff Paul (703)588-7442 jeffrey.paul@osd.mil
C-5 RERP – C5 Aircraft Reliability and Reengining Program	Weapon Systems	Mr. Mike Richman (703)588-7430 michael.richman@osd.mil
EELV – Evolved Expendable Launch Vehicle	Sensor Systems	Mr. Andy Culbertson (703)588-7407 andy.culbertson@osd.mil
F-22 – Advanced Tactical Fighter	Weapon Systems	Dr. Lew Sloter (703)588-7405 lewis.sloter@osd.mil
GBS – Global Broadcast Service	Information Systems	Maj Jim Sweeney (703)588-7412 james.sweeney@osd.mil
JASSM – Joint Air-to-Surface Standoff Missile	Weapon Systems	Mr. Art McGregor (703)588-7406 arthur.mcgreor@osd.mil
JDAM – Joint Direct Attack Munition	Weapon Systems	Mr. Art McGregor (703)588-7406 arthur.mcgreor@osd.mil
MP RTIP – Multi-Platform Radar Technology Insertion Program	Sensor Systems	Mr. Jeff Paul (703)588-7442 jeffrey.paul@osd.mil
MILSTAR – Satellite Low Data Rate/Medium Data Rate Communication System	Information Systems	Mr. John Grosh (703)588-7413 john.grosh@osd.mil
NAVSTAR GPS – Global Positioning System	Sensor Systems	Mr. Jeff Paul (703)588-7442 jeffrey.paul@osd.mil
RTIP – Radar Technology Insertion Program for JSTARS Aircraft	Sensor Systems	Mr. Jeff Paul (703)588-7442 jeffrey.paul@osd.mil
SBIRS – Space-Based Infrared System Program	Information Systems Sensor Systems	CAPT Frank Garcia (703)588-7411 frank.garcia@osd.mil Mr. Andy Culbertson (703)558-7407 andrew.culbertson@osd.mil

WIDEBAND GAPFILLER – Wideband communications satellite system to fill the gap between DCS/GBS and Advanced Wideband System	Sensor Systems	Mr. Jeff Paul (703)588-7442 jeffrey.paul@osd.mil
DoD		
PATRIOT PAC-3 – Patriot Advanced Capability	Weapon Systems	Mr. Art McGregor (703)588-7406 arthur.mcgreor@osd.mil
Navy Area TBMD – Navy Area Theater Ballistic Missile Defense	Weapon Systems	Mr. Art McGregor (703)588-7406 arthur.mcgreor@osd.mil
NMD – National Missile Defense Program	Sensor Systems	Mr. Andy Culbertson (703)588-7407 andrew.culbertson@osd.mil
THAAD – Theater High Altitude Area Defense	Weapon Systems	Mr. Art McGregor (703)588-7406 arthur.mcgreor@osd.mil
NTW – Navy Theater Wide Ballistic Missile Defense	Weapon Systems	Mr. Art McGregor (703)588-7406 arthur.mcgreor@osd.mil
MEADS – Medium Extended Air Defense System	Weapon Systems	Mr. Art McGregor (703)588-7406 arthur.mcgreor@osd.mil
JSF – Joint Strike Fighter	Weapon Systems	Dr. Lew Sloter (703)588-7405 lewis.sloter@osd.mil
JSIMS – Joint Simulation System	DMSO	CAPT Mike Lilienthal (703)988-0660 mlilienthal@dmso.mil
NPOESS – National Polar-Oribiting Operational Environmental Satellite System	Information Systems	CAPT Frank Garcia (703)588-7411 frank.garcia@osd.mil

TERMS OF REFERENCE
FOR
TECHNOLOGY READINESS LEVEL (TRL)
INTEGRATED PRODUCT TEAM (IPT)

PURPOSE:

DoD 5000.2-R requires technology readiness assessments for critical technologies occur prior to milestone decision point B and C to provide useful technology maturity information to the acquisition review process. It states further that technology readiness assessments shall examine program concepts, technology requirements, and demonstrated technology capabilities to determine technology maturity. To ensure this is accomplished in a consistent manner throughout DoD, the Defense Science and Technology Advisory Group established this TRL IPT to define guidelines and a framework for implementing and applying TRLs.

SCOPE:

The IPT will conduct the following actions:

- Develop guidelines for implementing and applying TRLs consistently throughout DoD for both hardware and software.
- Establish a repeatable process to the extent possible for assessing technology readiness consistently across the Services and Agencies.
- Identify impediments and issues for applying TRLs and conducting technology readiness assessments.
- Identify funding issues associated with the transition between TRL 6 and TRL 7.
- Define the application of TRLs to the insertion of commercial technology in new and/or legacy systems.
- Identify training requirements in support of TRL implementation strategy.

ROLES AND RESPONSIBILITIES:

The IPT is sponsored by the Deputy Under Secretary of Defense (Science and Technology) in conjunction with the Defense Science and Technology Advisory Group. Mr. Alan Shaffer will serve as IPT Chair. The IPT membership will be composed of Service and Agency Representatives identified by the S&T Executives as well as Service Acquisition Representatives. The current membership is contained in attachment 1.

The IPT Chair will provide status briefings to the Defense S&T Advisory Group biweekly.

DELIVERABLES:

The IPT deliverable will include a set of guidelines for applying TRLs and a notional process flowchart for implementing TRLs consistently throughout DoD.

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, D.C. 20301-3010

ACQUISITION AND TECHNOLOGY

MEMORANDUM FOR SERVICE ACQUISITION EXECUTIVES
DIRECTOR, ACQUISITION INITIATIVES
DEPUTY ASSISTANT SECRETARY OF THE ARMY (RESEARCH AND TECHNOLOGY)
CHIEF OF NAVAL RESEARCH
DEPUTY ASSISTANT SECRETARY OF THE AIR FORCE (SCIENCE, TECHNOLOGY AND ENGINEERING)
CHIEF SCIENTIST, MISSILE DEFENSE AGENCY
DIRECTOR, DEFENSE ADVANCED RESEARCH PROJECTS AGENCY
DIRECTOR, DEFENSE THREAT REDUCTION AGENCY

SUBJECT: Technology Readiness Assessment (TRA) Policy

The 5000 series acquisition policy documents require technology readiness assessments prior to Milestone B and C decisions. The purpose of these assessments is to provide information to the Defense Acquisition Board on the maturity of critical technologies. Following a recommendation by the Business Initiative Council to revise the TRA procedures, the Office of the Director of Defense Research and Engineering led an Integrated Product Team (IPT) review of the process. Based on this review, we remain committed to conducting TRAs for all ACAT ID and ACAT IAM programs.

The effectiveness of the TRA process relies upon early and continuous communication between the acquisition and science and technology communities—especially in the determination of a program's critical technologies. To facilitate collaboration, the IPT recommended that technology maturity agreements (TMAs) be prepared for all ACAT 1D and ACAT IAM programs. I support the recommendation and request the acquisition community develop TMAs for all programs. This process is intended to eliminate unnecessary reviews by having an up front agreement on which, if an, critical technologies require more extensive assessment. The attached policy guidance is effective immediately and will be incorporated in the next update to the 5000 series.

E.C. Aldridge

Attachments:
As stated

Changes to DoD 5000.2-R

Insert new paragraph after C7.5.4 requiring formal technology maturity agreements as follows:

C7.5.5. The PM responsible for the acquisition of a system shall work with the Component S&T community and provide the technical information required for assessing the maturity of critical technologies. To facilitate the technology readiness assessment process, the PM and Component S&T Executive shall jointly prepare a Technology Maturity Agreement (TMA). TMAs shall include all relevant parties, i.e., activities that are essential in the identification, assessment and maturation of critical technologies, as signatories, and may suffice for the TRA if all critical technologies are mature. The primary purposes of the agreement are to provide early determination of critical technologies and to initiate the necessary collaboration between the acquisition and S&T communities. The agreements will serve as a baseline for the decisional assessment required for Milestones B and C. The TMA should be prepared as early as possible, but at least 120 days prior to the DAB. The DDR&E shall review all TMAs for ACAT ID and ACAT IAM programs. The PM shall keep the agreement current and in a validated status. There is no mandatory format for the TMAs, however, a recommended format is at Appendix __.

Change paragraph C7.5.3 as follows to eliminate unnecessary TRAs:

C7.5.3. The DoD Component Science and Technology (S&T) Executive shall direct the technology readiness assessment and, for ACAT ID and ACAT IAM programs, submit the findings to the CAE who shall submit his or her report to the DDR&E with a recommended technology readiness level (TRL) (or some equivalent assessment) for each critical technology. When the Component S&T Executive submits his or her findings to the CAE, he or she shall provide the DDR&E an information copy of those findings. In cooperation with the Component S&T Executive and the program office, the DDR&E shall evaluate the technology readiness assessment and, if he/she concurs, forward findings to the OIPT leader and DAB. The Component S&T Executive's assessment can be based on the TRA conducted by the PM or any other assessment, developed separately by the Component S&T or be a combination of both. If the DDR&E does not concur with the technology readiness assessment findings, an independent technology readiness assessment, under the direction of the DDR&E, shall be required.

ACRONYMS/GLOSSARY

AAAV	Advanced Amphibious Assault Vehicle
ABL	Airborne Laser
ACAT	Acquisition Category
ACQ	Acquisition
ACTD	Advanced Concept Technology Demonstration
AEHF	Advanced Extremely High Frequency
AFCC	Advanced Flight Control Computer
ALAM	Advanced Land Attack Missile
ATACMS-BAT	Army Tactical Missile System-Brilliant Anti-Armor Submunition
ATCCS	Army Tactical Command and Control System
ATD	Advanced Technology Demonstration
C-130 AMP	C-130 Avionics Modernization Program
C3	command, control, and communications
C-5 RERP	C-5 Aircraft Reliability and Reengining
CAE	Component Acquisition Executive
CEC	Cooperation Engagement Capability
CEFS	Crashworthy External Fuel System
COMANCHE	Reconnaissance Attack Helicopter
COSSI	Cost and Operation and Support Savings Initiative
COTS	commercial off-the-shelf
CRUSADER	Advanced Field Artillery System/Future Armored Resupply Vehicle
CVN(X)	Next Generation Nuclear Aircraft Carrier
CVR	Cockpit Voice Recorder
DAB	Defense Acquisition Board
DASD	Deputy Assistant Secretary of Defense
DCS	Defense Communications System
DD 21	21st Century Destroyer Program
DDR&E	Director of Defense Research and Engineering
DoD	Department of Defense
DOT&E	Director of Operational Test and Evaluation
DSTAG	Defense Science and Technology Advisory Group
DUSD(S&T)	Deputy Under Secretary of Defense for Science and Technology

EELV	Evolved Expendable Launch Vehicle
EFRS	Extended Range Fuel System
EGI	Embedded GPS Inertial
EMI	electromagnetic interference
ESSS	External Stores Support System
F-22	Advanced Tactical Fighter
FBCB2	Force XXI Battle Command Brigade and Below Program
FDR	Flight Data Recorder
FY	Fiscal Year
GBS	Global Broadcast Service
GPS	Global Positioning System
HIRSS	Hover Infrared Suppression System
IAV	Interim Armor Vehicle
IDGB	Improved Durability Gearbox
IDM	Improved Data Modem
IPT	Integrated Product Team
IR	Infrared
JASSM	Joint Air-to-Surface Standoff Missile
JDAM	Joint Direct Attack Munition
JSF	Joint Strike Fighter
JSIMS	Joint Simulation Program
JSOW/UNITARY	Joint Stand-Off Weapon With Unitary Warhead Variant
JSTARS	Joint Surveillance Target Attack Radar System
KPP	Key Performance Parameter
LPD	Amphibious Assault Ship
MAIS	Major Automated Information System
MCS	Maneuver Control System
MDAP	Major Defense Acquisition Program
MEADS	Medium Extended Air Defense System
MIDS-LVT	MultiFunction Information Distribution System-Low Volume Terminal
MILSTAR	Military Strategic, Tactical & Relay (Satellite Low Data Rate/Medium Data Rate Communication System)
MP RTIP	Multi-Platform Radar Technology Insertion Program
NAVSTAR GPS	Navigation Satellite Timing & Ranging Global Positioning System

NMD	National Missile Defense
NPOESS	National Polar-Orbiting Operational Environmental Satellite System
NTW	Navy Theater Wide
ODUSD(S&T)	Office of the Deputy Under Secretary of Defense for Science and Technology
OIPT	Overarching Integrated Product Team
ORD	Operational Requirements Document
P3I	Pre-Planned product Improvement
PAC	PATRIOT Advanced Capability
PM	Program Manager
RTIP	Radar Technology insertion Program (for JSTARS Aircraft)
S&T	Science and Technology
SAALT	Secretary of the Army for Acquisition, Logistics, and Training
SBIRS	Space-Based infrared System
SSN	VIRGINIA Class Submarine
T-AKE	Auxiliary Dry Cargo Ship
TBMD	Theater Ballistic Missile Defense
THAAD	Theater High Altitude Defense
TMA	Technology Maturity Agreement
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
USMC H-1	Marine Corps Mid-life Upgrade to AH-1 Attack Helicopter and UH-1N Utility Helicopter
WCB	Wide Chord Blade
WIDEBAND GAPFILLER	Wideband communications satellite system to fill the gap between DCS/GBS and Advanced Wideband System
WIPT	Working Level Integrated Product Team

APPENDIX E
TECHNOLOGY READINESS LEVEL (TRL) EXAMPLES

Table III-1 of the TRA Deskbook contains the definitions of the various TRLs and notes some of the information that supports assignment of a technology to specific levels of readiness. To aid in making the definitions more concrete, this appendix contains several examples of readiness levels for technologies as the evolved to full maturity.

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3 Compliments of the Army, in which the evolution of a technology is depicted graphically.

4 Compliments of the Navy, in which the evolution of a materials technology is presented, with a full description at each TRL.

RING LASER GYRO

Technology Readiness Example

Level	Technology Readiness	Example – HG1700 Inertial Measurement Unit Guided Multiple Launch Rocket System (GMLRS)
1	Basic Principles observed and reported	**Basic research** – Invention of Gas Laser
2	Technology concept and/or application formulated.	**Basic research** – Invention of Ring Laser. Theoretical description of Ring Laser Gyro
3	Analytical and experimental critical function and/or characteristic proof of concept.	**Applied research** – Demonstration of Ring Laser as a rate sensor
4	Component and/or breadboard validation in laboratory environment.	**Applied research** – Demonstration of Ring Laser Gyro (RLG)-based Inertial Measurement Unit (IMU) operation under temperature, shock, vibration, and g-loading
5	Component and/or breadboard validation in relevant environment.	**Advanced Technology Demonstration** – Demonstration of HG1700-based guidance set components (IMU, GPS receiver, control system, flight computer) in a high-fidelity hardware-in-the-loop facility
6	System/subsystem model or prototype demonstrated in a relevant environment.	**Advanced Technology Demonstration** – Demonstration of actual flight-ready HG1700-based guidance set in a high-fidelity hardware-in-the-loop facility and under expected levels of shock, vibration, altitude and temperature
7	System prototype demonstrated in an operational environment.	**System Design and Development** – Demonstration of actual Guided MLRS missile in a flight test sequence from an operational launcher. Successful operation in multiple flight demonstrations
8	Actual system completed and "flight qualified" through test and demonstration.	**Low Rate Initial Production** – Developmental Test and Evaluation of GMLRS in its final form under mission conditions.
9	Actual system "flight proven" through successful mission operations.	**Production** – Operational Test and Evaluation of GMLRS by the soldier, airman, or seaman.

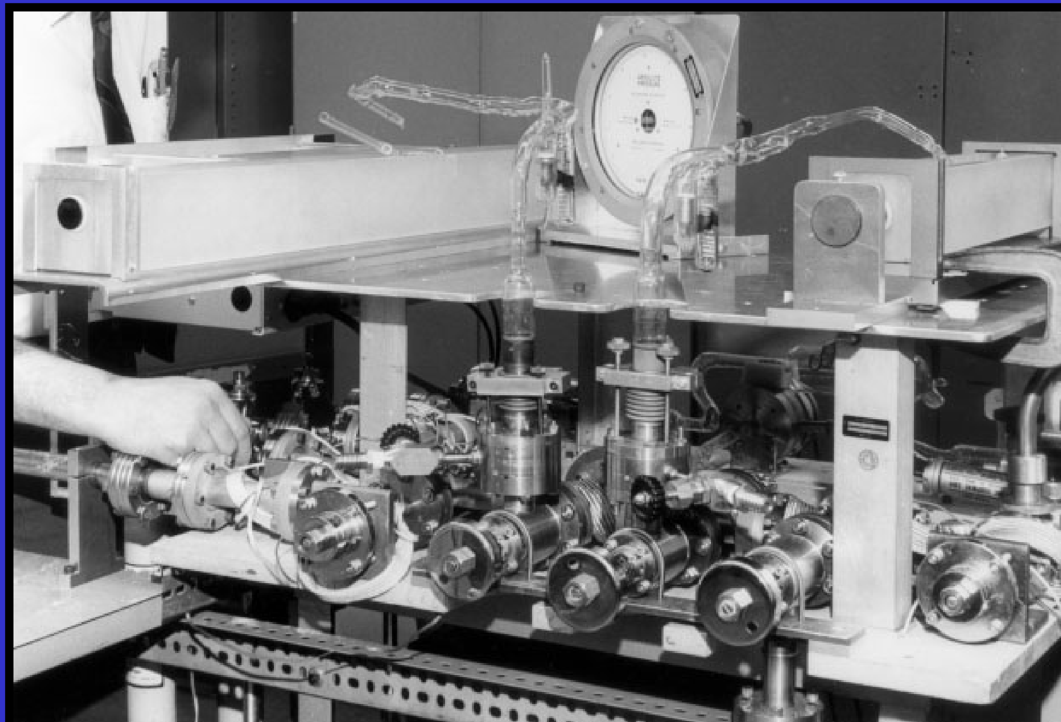
Technology Readiness Example

Level	Technology Readiness	Example – HG1700 Inertial Measurement Unit Guided Multiple Launch Rocket System (GMLRS)
1	Basic Principles observed and reported	**Basic research** – Invention of Gas Laser
2	Technology concept and/or application formulated.	**Basic research** – Invention of Ring Laser. Theoretical description of Ring Laser Gyro

Laser

Research

Facility

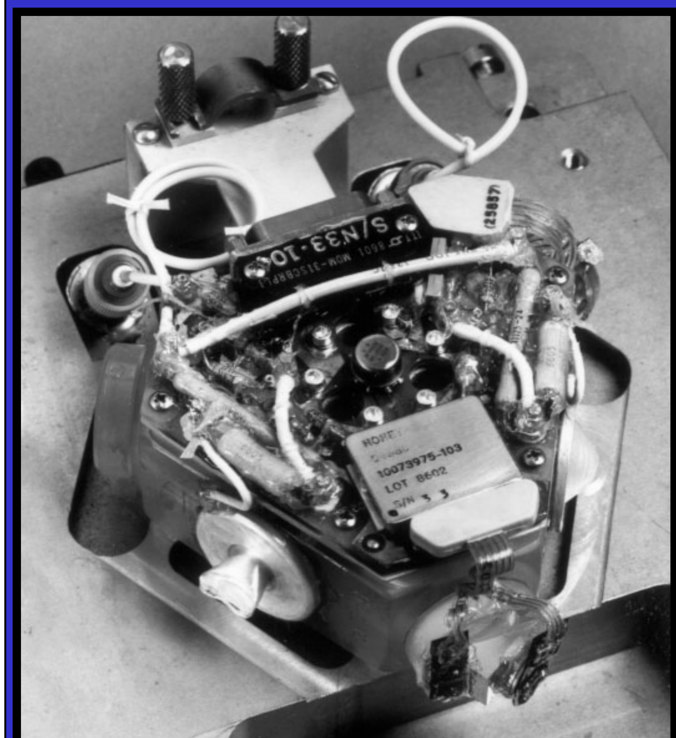


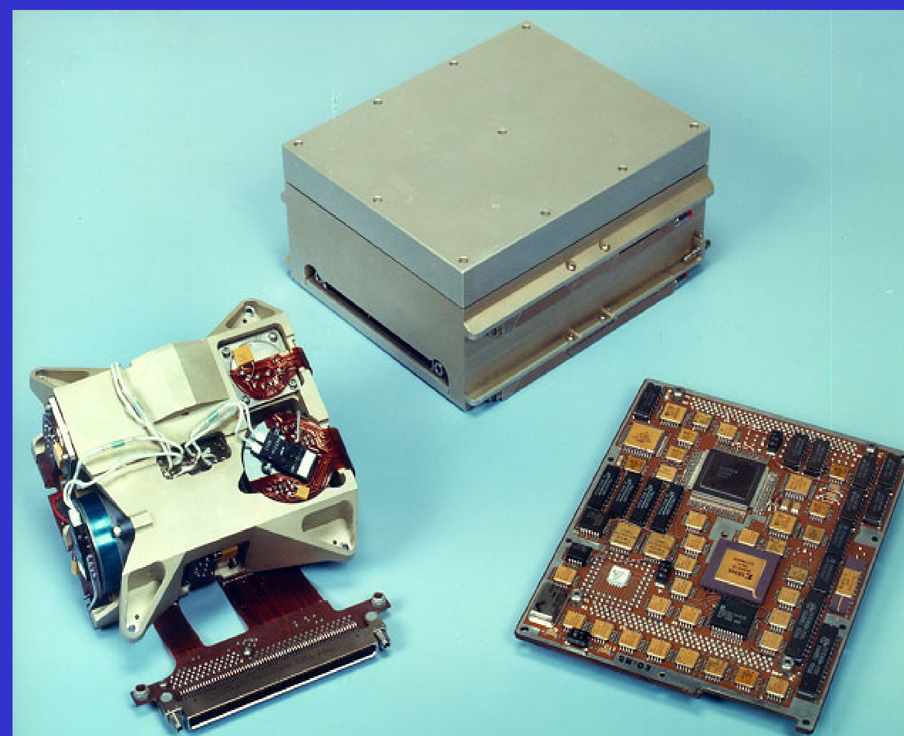
circa 1960

Technology Readiness Example

Level	Technology Readiness	Example – HG1700 Inertial Measurement Unit Guided Multiple Launch Rocket System (GMLRS)
3	Analytical and experimental critical function and/or characteristic proof of concept.	**Applied research** – Demonstration of Ring Laser as a rate sensor

Ring Laser Gyro circa 1975





HG1108 Inertial Measurement Unit circa 1990

Technology Readiness Example

Level	Technology Readiness	Example – HG1700 Inertial Measurement Unit Guided Multiple Launch Rocket System (GMLRS)
5	Component and/or breadboard validation in relevant environment.	**Advanced Technology Demonstration** – Demonstration of HG1700-based guidance set components (IMU, GPS receiver, control system, flight computer) in a high-fidelity hardware-in-the-loop facility

Technology Readiness Example

Level	Technology Readiness	Example – HG1700 Inertial Measurement Unit Guided Multiple Launch Rocket System (GMLRS)
6	System/subsystem model or prototype demonstrated in a relevant environment.	**Advanced Technology Demonstration** – Demonstration of actual flight-ready HG1700-based guidance set in a high-fidelity hardware-in-the-loop facility and under expected levels of shock, vibration, altitude and temperature

Technology Readiness Example

Level	Technology Readiness	Example – HG1700 Inertial Measurement Unit Guided Multiple Launch Rocket System (GMLRS)
7	System prototype demonstrated in an operational environment.	**System Design and Demonstration** – Demonstration of actual Guided MLRS missile in a flight test sequence from an operational launcher. Successful operation in multiple flight demonstrations

Technology Readiness Example

Level	Technology Readiness	Example – HG1700 Inertial Measurement Unit Guided Multiple Launch Rocket System (GMLRS)
8	Actual system completed and "flight qualified" through test and demonstration.	**Low Rate Initial Production** – Developmental Test and Evaluation of GMLRS in its final form under mission conditions.
9	Actual system "flight proven" through successful mission operations.	**Production** – Operational Test and Evaluation of GMLRS by the soldier, airman, or seaman.

TECHNOLOGY STEEL READINESS LEVELS

EXAMPLE: HSLA-100 STEEL FOR AIRCRAFT CARRIER STRUCTURE

MARCH 2002

Technology Readiness Level 1:
Basic Principles Observed and Reported

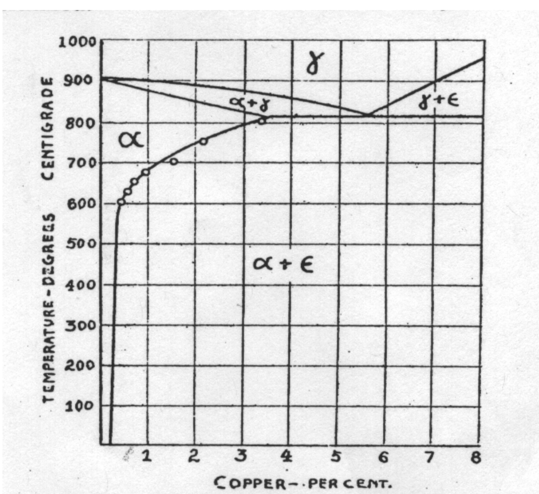
The lowest Technology Readiness Level (TRL), where scientific research begins to be translated into technology's basic properties.

With the mass industrialization of structural steel welding for shipbuilding in World War II, the quest for high-strength steels with good weldability was a motivation for metallurgical research that continued through the post-war era. Carbon strengthening and alloying that resulted in high strength was counter to weldability. The fundamental metallurgical tools for steel alloy design (e.g., phase transformation, phase diagrams, relationship of microstructure to properties, precipitation strengthening, and so forth) were developing at a dramatic rate along with the U.S. steel industry.

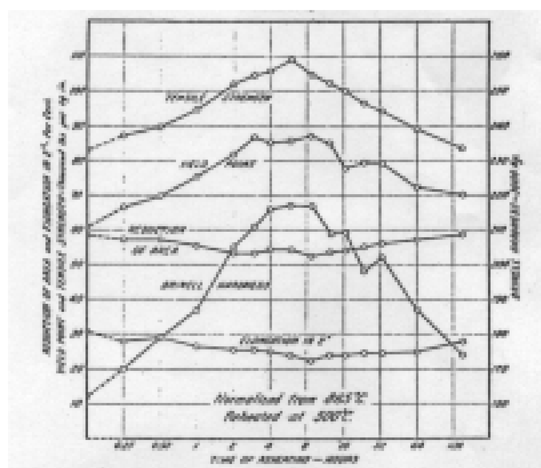
In the 1930s, the unique property of precipitation hardening induced by alloying of copper in steel was established. The phase diagrams for the Fe-Cu system were formulated, the solubility limits of Cu in low carbon steel were explored, and laboratory studies of copper steels were conducted. However, the benefit of Cu-strengthening as a means toward optimum strength, toughness, and weldability was not recognized.

Key References:

Smith, C.S. and E.W. Palmer, "The Precipitation-hardening of Copper Steels," *Trans. AIME*, Vol. 105 (1933).



Fe-Cu Phase Diagram



Precipitation Hardening in Heat Treatment of an 0.27% C, 1% Cu Steel

Technology Readiness Level 2: Invention Begins

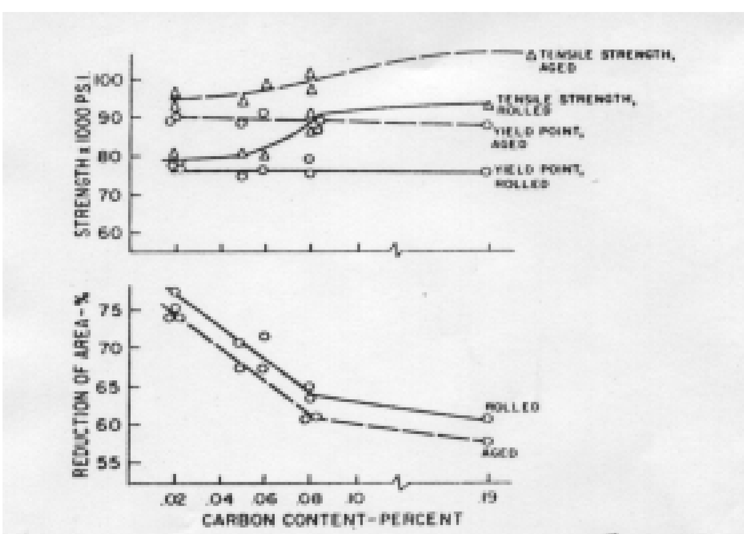
Once basic principles are observed, practical applications can be invented. However, the application is speculative, and no proof or detailed analysis exists to support the assumption.

In the mid-1960s, the laboratories of the International Nickel Company (INCO) initiated the development of a class of low-carbon, age-hardening Ni-Cu-Cb steels called "NiCuAge" steels. The work focused on the very low carbon, with changes in Ni, Cu, and Cb content and processing (hot working schedules and heat treatment) to establish microstructure-mechanical property relationships. The combinations of strength, ductility, and processing characteristics exhibited by the Ni-Cu-Cb steels suggested a variety of applications in transportation, automotive, and oil field construction. Because of the low carbon content, the steel offered excellent formability and weldability in the fully strengthened condition.

The key concepts discovered at this stage were the importance of Ni and Cb additions to the copper steels. The Ni addition and the ratio of Ni-to-Cu were established as a means to prevent cracking during hot working. Researchers discovered that small additions of Cb significantly increased strength, provided grain refinement, and did not degrade any characteristics of the steel. At this stage, small laboratory melts (30 lb) were used for the alloy composition optimization.

Key References:

Hurley, J.L. and C.H. Shelton, "Age-Hardenable Nickel-Copper Steels," *Metals Engineering Quarterly,* ASM, May 1966.



Tensile Ductility of Ni-Cu Steel as Influenced by Carbon Content

Technology Readiness Level 3:
Active Research and Development (R&D) Is Initiated

This includes analytical and laboratory studies to validate physically the analytical predictions of separate elements of the technology.

INCO continued the development of improved "NiCuAge" steel for improved weldability and low-temperature toughness in heavy section plates and forgings and, in 1972, marketed the steel designated IN-787 for offshore platforms and ship hull plates. The American Society for Testing and Materials (ASTM) Standard Specification A710, Grade A, based on IN-787 steel, was issued in 1975. Armco Steel Corporation produced a plate to ASTM A710, Grade A, under the trade name "NI-COP" steel.

The primary reason for preheat in the welding of High Yield Strength (HY)-80 and HY-100 steels is to mitigate underbead cracking (hydrogen related) in the hard, martensitic heat-affected zone (HAZ). The Navy High-Strength Low-Alloy (HSLA)-80, an optimized version of ASTM A710, Grade A steel, is a ferritic steel. The microstructure of the quenched and aged HSLA-80 plate product is generally an acicular ferrite. Ferritic steels are widely used in civil construction because of their excellent weldability.

In 1981, the Navy HSLA Steels Exploratory Development Program was initiated at David Taylor Research Center (DTRC), with ASTM A710, Grade A selected as the primary candidate. Because of the positive results emanating from the project, ASTM A710, Grade A, Class 3 steel was authorized as substitute for HY-80 steel on a production trial basis in CVN 71 in selected noncritical, nonwetted areas in 1983. Upon completion of the evaluation of ASTM A710 for Navy requirements, the modifications to ASTM A710 were incorporated in MIL-S-24645(SH), 4 September 1984, for HSLA-80 steel plate, sheet, and coil. The Naval Sea Systems Command (NAVSEA) certified HSLA-80 for surface ship construction and repair in thickness up to 1-1/4 inch, 16 February 1984. The evaluation of HSLA-80 properties, welding, and structural performance demonstrated that the very-low-carbon, copper precipitation-strengthened steel met the requirements of HY-80 steel and was readily weldable with no preheat (32 °F minimum) using the same welding consumables and processes as those used for HY-80 steel fabrication. Since 1985, HSLA-80 steel has been used in CG 47 Class construction in increasing tonnage, in CVN 72 and follow-on ships, and in DDG 51 Class, LHD 1 Class, LSD 41 Class, and FFG 7 Class modifications.

Following the HSLA-80 program, a research and development (R&D) project commenced in 1985 to establish the feasibility of HSLA-100 steel as a replacement for HY-100 to reduce fabrication costs. A contract to AMAX Materials Research Center in 1985 initiated the laboratory alloy development for HSLA-100 steel. The objective for HSLA-100 was to meet the strength and toughness of HY-100 steel but to be weldable without the preheat requirements of HY-100, using the same welding consumables and processes as those used in welding HY-100. The project for the development of HSLA-100 steel in the laboratory alloy design phase used the principles of very low carbon, copper-precipitation strengthened steel successful for HSLA-80.

Fracture-process research on HSLA-80 steel indicated that a uniformly small grain size and wider distribution of small carbides would reduce the fracture transition temperature. In fact, HSLA-80 plates of 1-inch gage and less were typically a fine-grained, acicular ferrite microstructure with widely dispersed fine carbides and showed excellent low-temperature toughness. The aim of HSLA-100 alloy design was to produce a homogeneous, fine-grained, low-carbon martensite microstructure that dispersed the secondary transformation products. The alloy development effort to modify HSLA-80 steel microstructurally used laboratory-scale heats (50 to 100 lb) to study the effects of Mn, Ni, Mo, Cu, Cr, Cb, and C in hot rolled, quenched, and aged HSLA-100 plate. Laboratory plates in thicknesses of 1/4, 3/4, 1-1/4, and 2 inches of HSLA-100 exceeded the minimum strength and impact toughness requirements.

Microstructural analysis was conducted to develop composition ranges for heavy gage plate, meeting the strength and toughness requirements, where polygonal ("blocky") ferrite microstructures were not present. A regression analysis was conducted on the results for plates from 45 experimental melts to develop composition ranges for an Interim Specification for HSLA-100 Steel Plate. The Interim Specification was then used as the basis for a trial commercial production of HSLA-100 steel by domestic steel plate mills.

The copper content of HSLA-100 steel is higher than that in HSLA-80 [for additional precipitation strengthening (maximum solubility of copper in iron is near 2 percent)], and increased hardenability was achieved by increases in manganese, nickel, and molybdenum. Nickel, the greatest increase over that in HSLA-80, lowers upper shelf impact toughness but also lowers (improves) the impact toughness transition temperature. The microstructure of HSLA-100 steel was identified by optical and scanning electron microscopy as low-carbon martensite or a granular, low-carbon bainite, depending on plate gage—a significantly different metallurgy and microstructure than the ferritic HSLA-80 steel microstructures.

Key References:

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Coldren, A.P. and T.B. Cox, *Development of 100 Ksi Yield Strength HSLA Steel,* DTNSRDC-CR-07-86, July 1986.

Coldren, A.P., T.B. Cox, E.G. Hamburg, C.R. Roper, and A.D. Wilson, *Modification of HSLA-80 Steel to Improve Toughness in Heavy Sections,* DTRC Report SME-CR-04-91, February 1991.

Jesseman, R.J. and G.C. Schmid, "Submerged Arc Welding a Low-Carbon, Copper Strengthened Alloy Steel," *Welding Journal Research Supplement*, Vol. 62, No. 11, November 1983, pp. 321s–330s.

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Kvidahl, L.G., "An Improved High Yield Strength Steel for Shipbuilding," *Welding Journal*, Vol. 64, No. 7, July 1985, pp. 42–48.

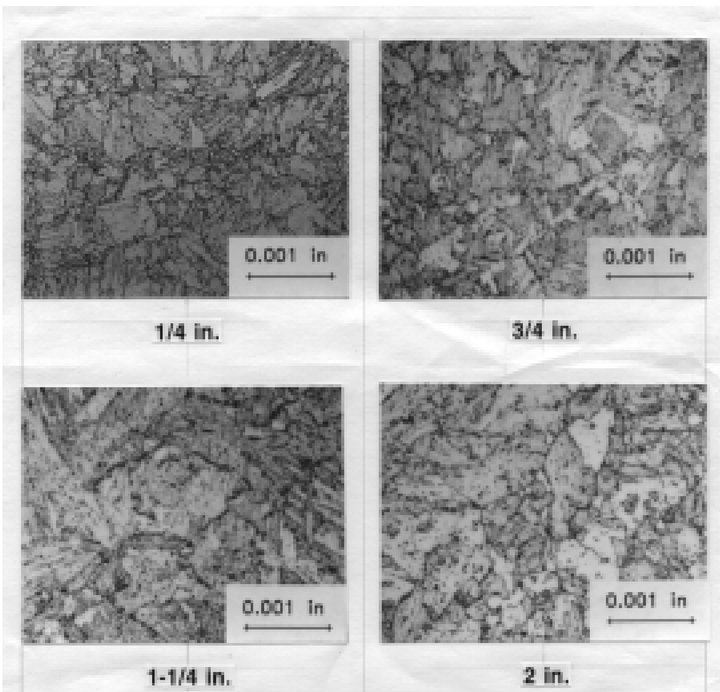
McCaw, R.L. and R.J. Wong, *Welding of HSLA-80 Steel,* DTNSRDC/SME-85/32, June 1985.

Money, K.L., C.H. Shelton, and P.P. Hydrean, "High Strength, Age Hardening Low-Alloy Steel Plate for Offshore Platforms and Hull Plate," *1974 Offshore Technology Conference*, Paper OTC 1952, 1974.

Montemarano, T.W., R.T. Brenna, T.E. Caton, D.A. Davis, R.L. McCaw, L.J. Roberson, T.M. Scoonover, and R.J. Wong, *Results of the Evaluation of ASTM A710, Grade A Steel Under the "Certification of HSLA Steels for Surface Ship Construction Program,"* DTNSRDC TM-28-84-17, January 1984.

Natishan, M.E., *Micromechanisms of Strength and Toughness in a Microalloyed, Precipitation Hardened Steel,* DTRC/SME-89/04, May 1989.

Wilson, A.D., "High Strength, Weldable Precipitation Aged Steels," *Journal of Metals*, March 1987, pp. 36–38.



Experimental HSLA-100 Steel Plate Microstructures for a Range of Plate Thickness

Technology Readiness Level 4: Basic Technology Components Are Integrated

The basic components of the technology are integrated to establish that the pieces will work together.

For the trial plate production phase of the HSLA-100 steel project, an initial 150-ton production of HSLA-100 steel was melted and rolled by Phoenix Steel Corporation in 1986 to the interim specification, using conventional electric furnace and ingot casting practice, conducted to achieve a very-low-carbon composition. The minimum strength and toughness requirements of the interim specification were met in the initial production of HSLA-100 steel plate in gages from 1/4 to 2 inches. Optimum properties in HSLA-100 plate resulted from aging temperatures from 1150 to 1275 °F.

Upon receipt of HSLA-100 plate from the trial productions, an evaluation commenced to evaluate HSLA-100 steel plate and welding using the processes and procedures for HY-100 steel ship and submarine structural applications—but with reduced or no preheat. The evaluation of HSLA-100 steel plate properties and welding demonstrated that HSLA-100 steel met the mechanical property requirements of HY-100 steel and was weldable with reduced preheat requirements, using the same welding consumables as for HY-100 steel fabrication. When compared with HY-100 steel, the tensile and impact toughness properties of the plates met or exceeded the requirements.

The primary reason for preheating when welding the HY-series steels was to mitigate underbead cracking (hydrogen related) in the HAZ. The HSLA-100 precertification evaluation emphasized welding and weldability testing to demonstrate that HSLA-100 was more resistant to hydrogen cracking than HY-100 (to allow a relaxation of preheat requirements). The findings of the HSLA-100 steel welding and weldability evaluations are summarized as follows:

- The strength and toughness of weld metals deposited by the Shielded Metal Arc Welding (SMAW), Submerged Arc Welding (SAW), Pulsed Gas Metal Arc Welding (GMAW-P), and Short Circuiting Gas Metal Arc Welding (GMAW-S) processes, using the welding consumables qualified for HY-100 welding, met the requirements when welded over a broader range of operating conditions (heat inputs ranging from 22 to 65 kJ/in.) than for HY-100. No “hard” microstructures were indicated, and the Charpy V-notch toughness of the HAZ in HSLA-100 weldments was equal to or greater than the weld metal toughness.

- It was demonstrated that HSLA-100 fillet weld strengths were equivalent to HY-100 welds using the same process, filler metal, and fillet size.

- HSLA-100 plate, weld metal, and weld HAZ did not show any susceptibility to stress corrosion cracking exposed at –1,000 mV at or above stress corrosion cracking threshold stress intensity values determined for HY-100, MIL-100S-1, and MIL-120S-1 weld metals.

Key References:

Coldren, A.P. and T.B. Cox, *Phase II Report and Phase III Commercial Plate Documentation for Development of 100 Ksi Yield Strength HSLA Steel,* DTNSRDC-CR-07-87, June 1987.

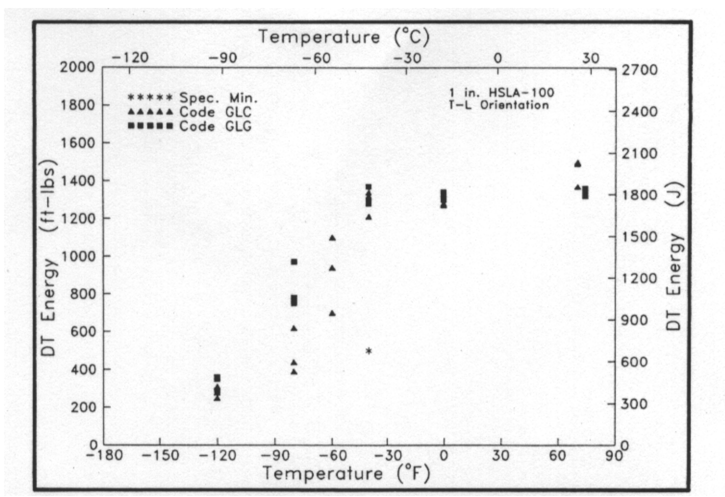
Czyryca, E.J., *Trial Production of HSLA-100 Steel Plate,* DTRC Report SME-87/83, February 1988.

Czyryca, E.J. and R.E. Link, *Physical Properties, Elastic Constants, and Metallurgy of HSLA-100 Steel Plate,* DTRC/SME- 88/62, December 1988.

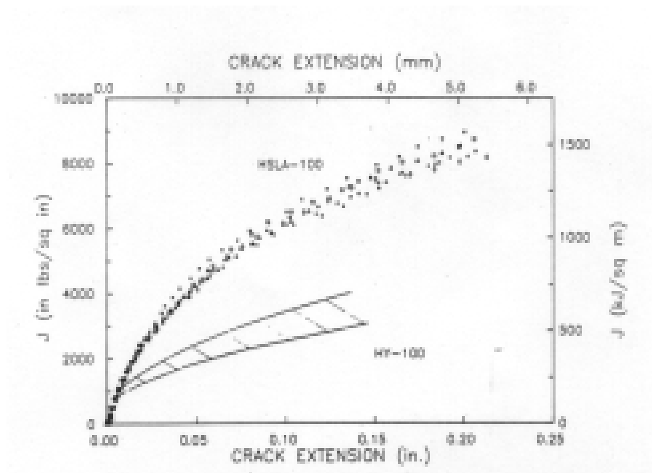
Holsberg, P.W. and R.J. Wong, "Welding of HSLA-100 Steel for Naval Applications," *Weldability of Materials*, ASM International, 1990.

Link, R.E. and E.J. Czyryca, *Mechanical Property Characterization of HSLA-100 Steel Plate,* DTRC/SME-88/38, December 1988.

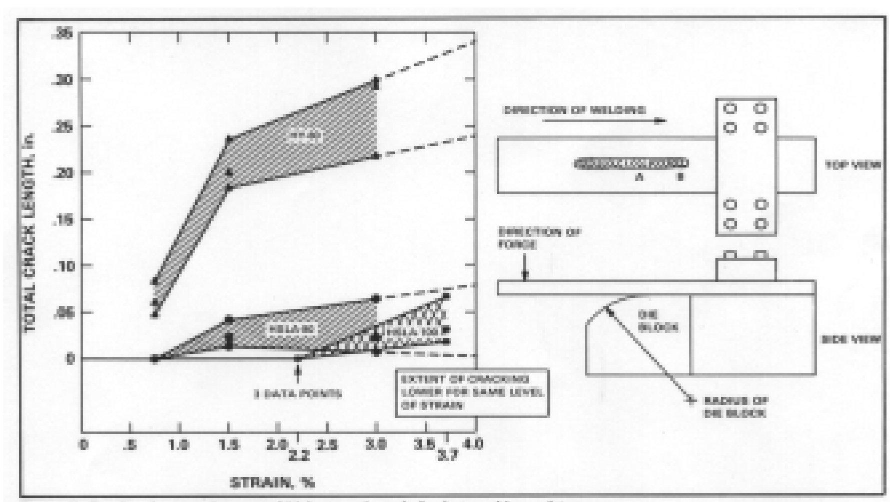
Wong, R.J., *Weldability and Welding Procedure Development for HSLA-100 Steel Non-Pressure Hull Structures,* DTRC/SME-90/40, September 1990.



Dynamic Tear Test Results for HSLA-100 Steel Plates



Fracture Toughness Test Results of HSLA-100 and HY-100



Varestraint Weldability Tests of High-Strength Steels

Technology Readiness Level 5: Technology Sufficiently Advanced For Simulation Tests

The fidelity of breadboard technology increases significantly enough to justify being ready for testing in a simulated environment.

Lukens Steel Company produced a second melt of HSLA-100 steel, again by electric furnace and ingot casting. Most of the plate produced from the heat was greater than 2 inches thick, primarily for ballistic resistance evaluation. The minimum strength and toughness requirements were met in plate thicknesses from 1/2 to 3-3/4 inches. A double austenitization and quench process was used for HSLA-100 steel plate in gages over 1-1/4 inches to refine the heavy-plate grain structure for optimum toughness. HSLA-100 plate from both productions to the interim specification was the primary material used in the certification program.

The certification evaluation included continued characterization of production HSLA-100 steel plate mechanical, physical, and fracture properties. However, the main focus was the evaluation of weldability and welding process limits for structures of high restraint, studies of fatigue properties, and effects of marine environments on HSLA-100.

The results of low-cycle fatigue crack initiation tests of HSLA-100 steel and weldments and high-cycle fatigue tests in air and seawater showed properties equivalent to HY-100 steel in every case. The steels showed similar fatigue crack growth rate properties. General corrosion, crevice corrosion, galvanic corrosion, and high-velocity seawater parallel flow and cavitation tests of HSLA-100 in seawater showed that the corrosion behavior of HY-100 and HSLA-100 steels was comparable.

Key References:

Aylor, D.M., R.A. Hays, R.E. Rebis, and E.J. Czyryca, *Corrosion and Stress Corrosion of HSLA-100 Steel,* DTRC/SME-90/17, May 1990.

Czyryca, E.J., "Development, Qualification, and Certification of HSLA-80 and HSLA-100 Steels for U. S. Navy Ship Construction: The Metallurgy, Welding, and Qualification of Microalloyed (HSLA) Steel Weldments," *Proceedings of the International Conference,* Houston, Texas, November 6–8, 1990, American Welding Society, Miami, Florida, 1991.

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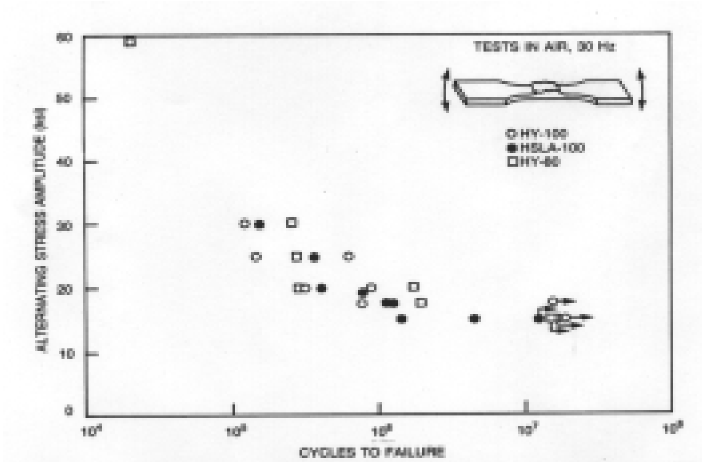
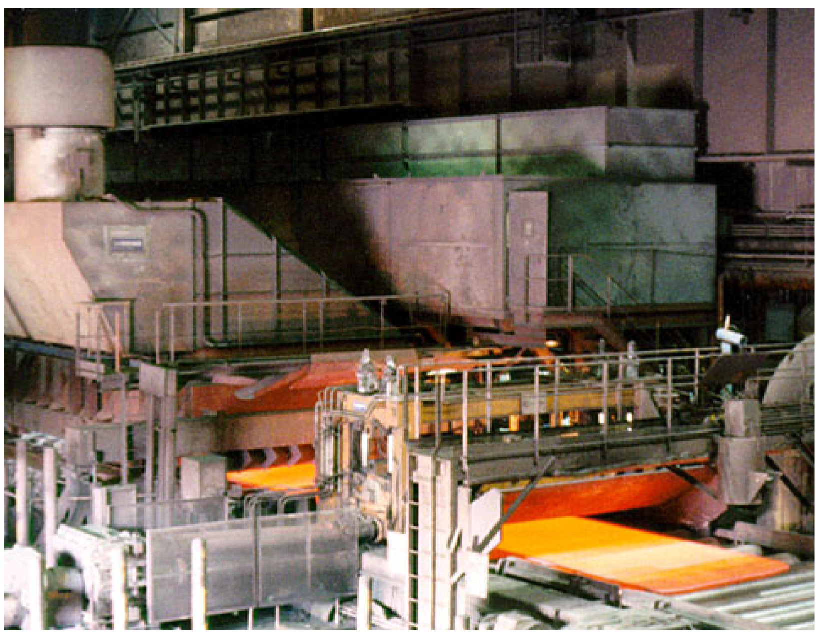
Czyryca, E.J., R.E. Link, and R.J. Wong, *Evaluation of HSLA-100 Steel for Surface Combatant Structural Certification,* DTRC/SME-89/15, August 1989.

Czyryca, E.J., R.E. Link, R.J. Wong, D.M. Aylor, T.W. Montemarano, and J.P. Gudas, "Development and Certification of HSLA-100 Steel for Naval Ship Construction," *Naval Engineers Journal*, May 1990, pp. 63–82.

Werchniak, W., E.J. Czyryca, and D.M. Montiel, *Fatigue Properties of HSLA-100 Steel and Weldments,* DTRC/SME-89/113, September 1990.

Fatigue Test Results for HSLA-100, HY-100, and HY-80 Steel Weldments





Technology Readiness Level 6:
Model/Prototype Tests

Representative model or prototype system, which is well beyond the breadboard tested at TRL 5 and is tested in a relevant environment.

The evaluation of HSLA-100 steel production plates concluded that the mechanical properties of production plate, welding and weldability screening tests, fatigue properties, and corrosion properties demonstrated that the system was viable for certification for combatant ship structure. Evaluation as a system by explosion bulge and crack-starter bulge tests, fragment penetration resistance tests, and ballistic property tests was demonstrated in the next phase.

Explosion bulge and crack starter explosion bulge tests of 2-inch thick weldments by GMAW, SMAW, and SAW of HSLA-100 steel were successfully conducted. The weldments were fabricated within the recommended preheat/interpass temperatures expected for HSLA-100 fabrication, exhibited no indications of hydrogen damage, and passed the explosion bulge test requirements.

In 1987, NAVSEA initiated projects at Electric Boat Corporation and Newport News Shipbuilding (NNS) to evaluate the weldability of HSLA-100 steel under various preheat conditions in a production environment. The results of the weldability evaluation demonstrated that HSLA-100 steel could be welded at up to 1.25-inch thick at 60 °F minimum preheat, with the same processes and consumables being used for HY-80/100 steels.

Based on NNS' welding and weldability evaluations of HSLA-100 using HY-100 welding consumables, welding preheat/interpass temperature limits were established. Preheat was recommended for SAW and SMAW, based on the weld metal cracking tendencies noted for these flux-assisted processes in the weldability testing. For GMAW and SAW, difficulties were experienced in obtaining MIL-100S-2 and MIL-120S-2 wire electrodes (low hydrogen content) with acceptable wire-feed characteristics for elimination of preheat for heavy-gage plate welding. Research projects are in progress to develop welding consumables specifically for HSLA-100 to achieve preheat-free welding in heavy plate, highly restrained welds.

Ballistic evaluations demonstrated that HSLA-100 steel and GMAW (MIL-100S-1) weldments (fabricated without preheat) were equivalent to HY-100 steel and weldments in ballistic resistance. Both steels were comparable to Army Rolled Homogeneous Armor.

NNS completed weld qualification and weldability testing to conduct pulsed-arc GMAW and SAW of HSLA-100 in thicknesses greater than 1 inch through 1-5/8 inch at 60 °F preheat using MIL-100S-2 electrode. NAVSEA approved the procedures. It should also be noted that Ingalls Shipbuilding Division (ISD) conducted weld qualification and weldability tests of HSLA-100 up to 1-inch gage using both HY-100- and HY-80-type welding consumables and processes.

The present material specification for HSLA-80 and HSLA-100 steel strip, sheet, and plate is MIL-S-24645A, with Amendment 1 of 24 September 1990. HSLA-100 was certified by NAVSEA for surface ship construction in thicknesses up to 4 inches, 13 March 1989.

Key References:

Crement, D., *Weldability Study of HSLA-100 Steel, Phase I (HY-100 Welding Consumables),* Ingalls Shipbuilding Division, Welding Engineering Report, August 27, 1987.

Crement, D., *Weldability Study of HSLA-100 Steel, Phase I (HY-80/HSLA-80 Welding Consumables),* Ingalls Shipbuilding Division, Welding Engineering Report, January 29, 1988.

Fairbanks, M., *HSLA-100 Weldability Testing,* Electric Boat Division of General Dynamics Corporation, Report Task 11.1, Contract No. 00024-85-C-2055, September 1987.

Salive, M.L., R.A. Martin, and E.J. Mossi, *Results of Ballistic Tests of 2.25- and 3.75-Inch HSLA Steel (U),* DTRC(C) 89/002, April 1989 (CONFIDENTIAL).

Salive, M.L., R.A. Martin, and E.J. Mossi, *Results of Ballistic Tests on HSLA-100 Steel (U),* DTRC(C)/SSPD-90-174-46, May 1990, (CONFIDENTIAL).

Schwietzer, N.F., *Explosion Test Evaluation of 2-Inch Thick HSLA-100 Weldments Fabricated by Newport News Shipyard Using the Submerged Arc "Twin Wire" and the Gas Metal Arc-Pulsed Welding Processes With Type MIL-100S-1 Filler Metal,* Mare Island Naval Shipyard, Engineering Technical Report, Project 138-74-88A, January 1989.

Schwietzer, N.F., *Explosion Test Evaluation of 2-Inch Thick HSLA-100 Weldments Fabricated by Newport News Shipyard Using the Submerged Arc Welding Process With Type MIL-120S-1 Filler Metal,* Mare Island Naval Shipyard, Engineering Technical Report, Project 138-74-88B, January 1989.

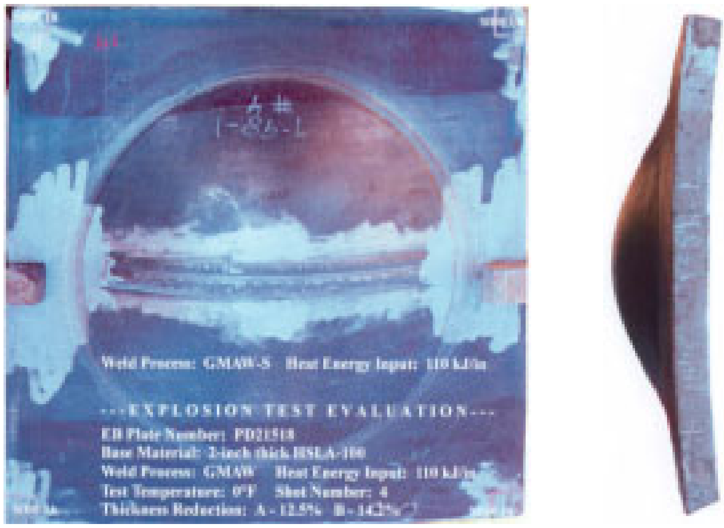
Thomas, P.D., *Evaluation of the Weldability of HSLA-100 as a Substrate for Corrosion-Resistant Cladding and for Joining to Dissimilar Steels,* Newport News Shipbuilding and Drydock Company, Report No. E80(S11D)-2, Contract No. 00024-87-C-2012, Task No. 95, 6 September 1989.

Thomas, P.D., *HSLA-100 Weld Process Development,* Newport News Shipbuilding and Drydock Company, Welding Engineering Technical Report No. ES11D-1, Contract No. 00024-87-C-2012, Task No. 94, 1 May 1990.

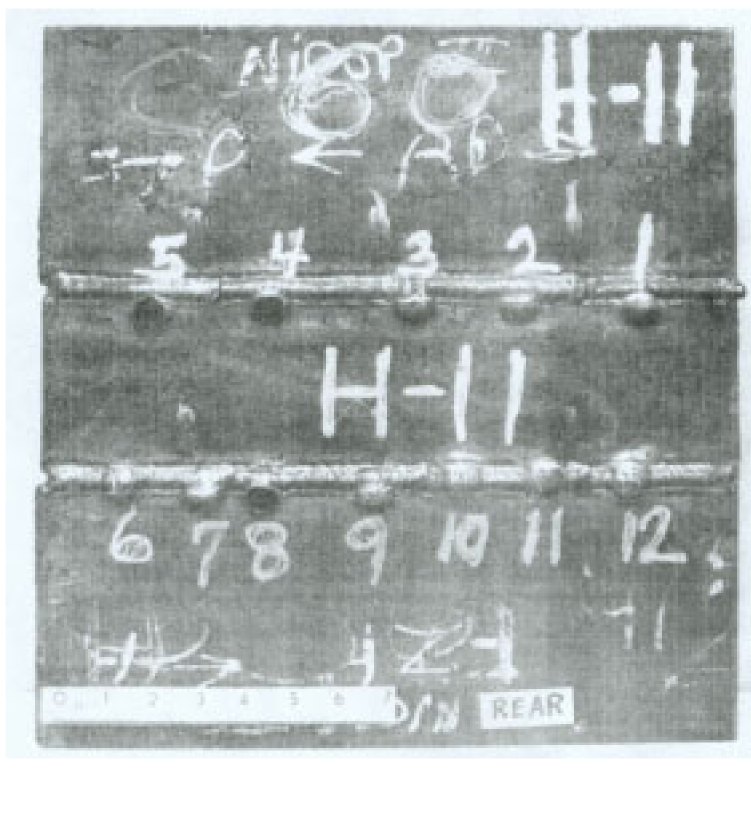
Thompson, R.D., *First Article Qualification Testing of USX Corporation, USS Gary Works Division HSLA-100 Steel to the Requirements of MIL-S-24645A(SH) (DRAFT),* Mare Island Naval Shipyard, Engineering Technical Report, Project 138-23-89, January 1990.

Wallace, D.T., *HSLA-100 Weldability Evaluation,* Newport News Shipbuilding and Drydock Company, Report No. E.80-7, Contract No. N00024- 85-C-2056, June 1988.

Wallace, D.T., *HSLA-100 Weldability Tests for CVN-73 Material Substitution for HY-100 Steel,* Newport News Shipbuilding and Drydock Company, Report No. E.80 (S11D)-1, Contract No. N00024-88-C- 2044, February 1989.



Explosion Bulge Test of HSLA-100 2-inch Thick Weldment



Fragment Penetration Resistance HSLA-100 Test Weldment

Technology Readiness Level 7:
Prototype Near or at Planned Operational System

TRL-7 is a major step from TRL 6, requiring the demonstration of an actual prototype in an operational environment.

The fabrication of a series of structural performance models was completed under shipyard welding conditions. Holding bulkhead panel models, foundation models, and a full-scale foundation were evaluated and demonstrated satisfactory structural performance.

The Electric Boat Division [General Dynamics Corporation] fabricated the full-scale foundation and a small, heavy-gage tank model. NNS partially completed the fabrication of a full-scale hard tank; however, a funding shortage precluded tests. In these shipyard fabrication exercises, all weld cracking was related to SMAW and SAW consumables (where cracking occurred even when HY-100 preheat temperatures were used) or to improper welding practices. No HAZ cracking occurred in HSLA-100.

Hydrostatic tests of full-gage bulkhead panel models are an extreme test of plating-to-stiffener strength and HAZ ductility. The HSLA-100 panel models exceeded anticipated holding pressure levels, withstanding over twice the holding pressure of identical HY-100 panel models. A series of foundation beam elements (full-scale) and the full-scale SSN 688-type AC foundation were installed and tested on a floating shock platform. The structures were subjected to a series of underwater explosion (UNDEX) shock tests. For a series of 3 UNDEX events, the structural response of the HSLA-100 items indicated no cracking or excessive deformation in any structural joint.

Key References:

Czyryca, E.J., *Assessment of HSLA-80 and HSLA-100 Steels for Submarine Non-Pressure Hull Applications,* CARDIVNSWC-TR-61-94/38, Preliminary, February 1995.

Fugate, S.P., *Fabrication of the HSLA-100 Foundation Structure,* Electric Boat Division of General Dynamics Corporation, Report No. 276, Contract No. 00024-86-C-2059, June 1988.

Kenney, D.P., and S.P. Fugate, *Fabrication of an HSLA-100 Model Structure,* Electric Boat Division Report No. PDE-279, NAVSEA Contract No. N00024-86-C-2059, July 1989.

Knight, D.E., and J.R. Carlberg, *Shock Performance Evaluation of HSLA-100 Foundation Structures,* DTRC/SSPD-90-172-1, October 1989.

Spaulding, R.S., P.D. Thomas, and R.A. Spitzer, *HSLA-100 Hard Tank Fabrication and Fatigue Model, Design and Fabrication Report,* Newport News Shipbuilding and Drydock Company, Report G2001- 0059, Contract No. N00024-87-C-2012, 9 September 1988.

Thomas, P.D., *HSLA-100 Hard Tank Fabrication and Fatigue Model Construction,* Newport News Shipbuilding and Drydock Company, Report No. ES10-1, Contract No. 00024-85-C-2056, 29 July 1988.

HSLA-100 Steel/LC-100 Weld Metal
Box-Tank Fatigue Model
Overall View of Model Exterior/End Hatch Open

HSLA-100 Holding Bulkhead Panel Model:
Before Test (Left) and After Hydrostatic Test to Rupture (Right)

Technology Readiness Level 8: Technology Demonstrated In Operation

Technology has been proven to work in its final form and under expected conditions.

In 1989, NAVSEA certified HSLA-100 steel for surface ship construction in thicknesses up to 4 inches. At that time, the *USS JOHN C. STENNIS* (CVN 74) was approved, indicating that HSLA-100 steel was a qualified substitute for HY-80/100 steel in CVN construction. Fabrication was to be conducted in accordance with MIL-STD-1689A(SH), *Fabrication, Welding, and Inspection of Ships Structure*. The experience base for welding HSLA-100 steel was too limited to allow the wholesale substitution for all HY-80/100 steel in the unrestricted areas of the carrier. Therefore, an implementation plan for incorporation was submitted, and NAVSEA approved this plan.

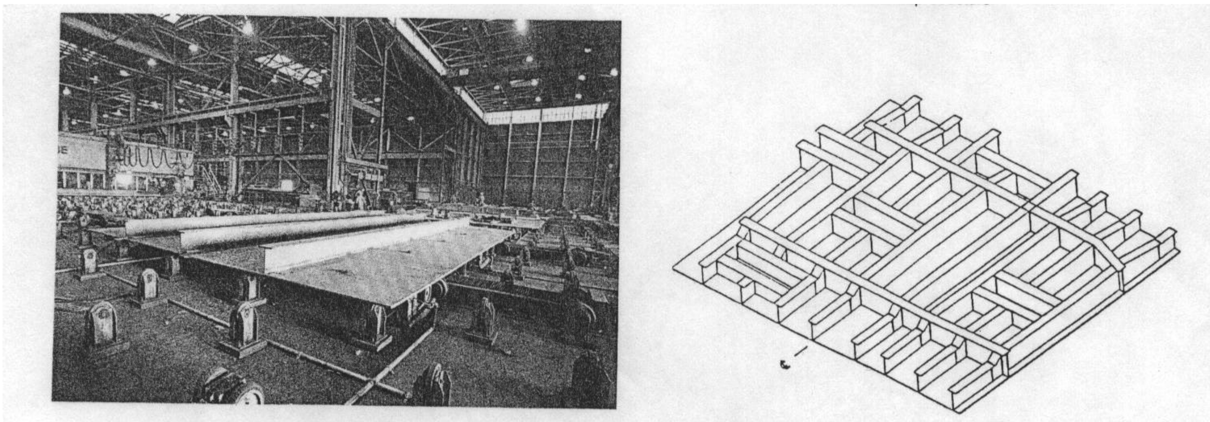
The CVN 74 main deck was the chosen area for HSLA-100, and approximately 770 LT were earmarked. The thicknesses in this area were 7/8-inch and 1-inch thick HSLA-100. The fabrication results were excellent. A total of 16,656 inches of butt joints in the 7/8-inch plate were welded, with only 8 inches requiring repair. In the 1-inch plate, 16,524 inches of butt joints were welded, and no defects were found. Since the ship was under construction at the time of the implementation plan, the total tonnage inserted into CVN 74 was limited to 1,250 LT, mostly above main deck.

NNS used HSLA-100 steel during CVN 74 construction. Approximately 700 tons of HSLA-100 steel plate in 7/8- and 1-inch thicknesses were used for main deck panel assemblies with longitudinal and transverse stiffeners without preheat (65 to 80 °F shop temperature). One hundred percent magnetic particle inspection was performed on all HSLA-100 butt welds. In 1,400 feet of 7/8-inch thick HSLA-100 butt weld inspected by MT, only 2 repairs (8 inches total) were required, not related to hydrogen-type defects. The same length of 1-inch thick HSLA-100 butt weld inspected by magnetic particle inspection showed no defects. A total of 1,250 tons of HSLA-100 were used in CVN 74, with over 4,000 feet of weldment inspection requiring 32 inches total repair (less than 0.01 percent).

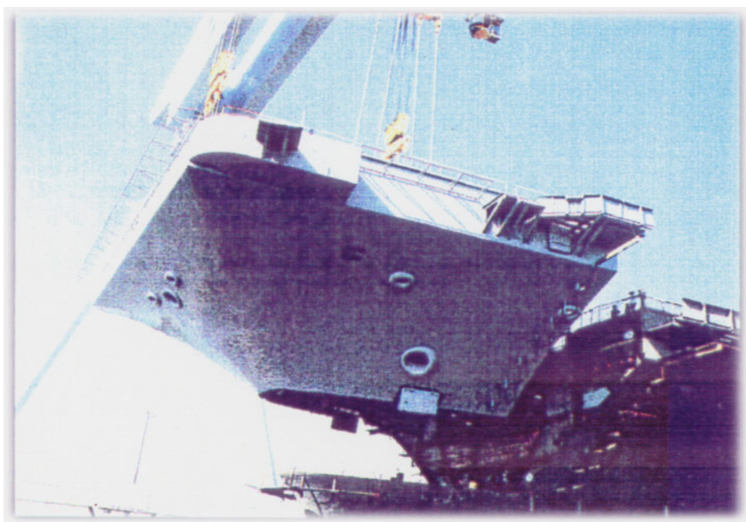
NNS completed weld qualification and weldability testing to conduct pulsed-arc GMAW and SAW of HSLA-100 in thicknesses greater than 1 inch through 1-5/8 inch at 60 °F preheat using MIL-100S-2 electrode. NAVSEA approved the procedures. It should also be noted that ISD conducted weld qualification and weldability tests of HSLA-100 up to 1-inch gage using both HY-100- and HY-80-type welding consumables and processes. The flight deck of the *USS BATAAN* (LHD 5) was successfully fabricated with HSLA-100 plate (in place of HY-100 steel) for cost savings, as were subsequent vessels of the same class.

Key References:

Christein, J.P. and J.L. Warren, “Implementation of HSLA-100 Steel in Aircraft Carrier Construction - CVN 74,” *Journal of Ship Production*, Society of Naval Architects and Marine Engineers, 1994.



CVN 74 HSLA-100 Steel Main Deck Panel Fabrication



Technology Readiness Level 9:
Implementation of the Technology in Service

Actual application of the technology in its final form and under mission conditions.

Because of the experience gained on CVN 74, wholesale changes to HSLA-100 were made on CVN 75. Approximately, 10,500 LT of HSLA-100 were inserted into CVN 75. Most of the replacement was for decks and bulkheads and some built-up stiffeners. The HSLA-100 stiffeners were short spans with heavy web/flange members. HSLA-100 steel was selected to replace HY-100 for fabrication cost reduction, and, as a consequence, HSLA-100 steel has been used in place of HY-100 in the construction of *USS JOHN C. STENNIS* (CVN 74), *USS HARRY S. TRUMAN* (CVN 75), and *USS RONALD REAGAN* (CVN 76).

On CVN 76, NAVSEA 08 approved the substitution of HSLA-100 for HY-80/100 structures outside the primary shield tank, opening another area for substitution. On CVN 77, expended use of HSLA-100 plate continues. NNS expects to qualify reduced preheat for welding up to 2 inches, adding over 4,000 LT of HSLA-100 where significant fabrication cost reduction is gained over HY-100 in this thickness range. Depending on complexity of the structure, estimated cost savings, for HSLA-100 vs. HY-100 fabrication in CVN 74 construction range from $500 to $3,000 per ton of fabricated structure.

The table below summarizes the tonnage of HSLA-100 steel plate used to date in construction of U.S. Navy combatant ships. The continued expansion of the use of HSLA-100 steel is planned for CVNX (CVN 78) design, including the heavy plating and foundation in the propulsion area.

Class	Vessels	LT
CVN 68	CVN 74	2,080
	CVN 75	11,600
	CVN 76	12,500
	CVN 77	12,500
LHD 1	LHD 5	1,180
	LHD 6	1,200

ACRONYMS[5]

ASM	American Society for Metals International
ASTM	American Society for Testing and Materials
CG	Carrier Group
CVN	Aircraft Carrier, Nuclear
CVNX	Aircraft Carrier, Nuclear, Experimental
DDG	Guided Missile Destroyer
DTNSRDC	David Taylor Naval Ships Research and Development Center
DTRC	David Taylor Research Center
FFG	Guided Missile Frigate
GMAW-P	Pulsed Gas Metal Arc Welding
GMAW-S	Short Circuiting Gas Metal Arc Welding
GMLRS	Guided Multiple Launch Rocket System
HAZ	heat-affected zone
HSLA	High-Strength Low-Alloy
HY	High Yield Strength (steel)
IMU	Inertial measurement Unit
INCO	International Nickel Company
ISD	Ingalls Shipbuilding Division
LHD	Amphibious Assault Ship
LSD	Dock Landing Ship
LT	long ton
NAVSEA	Naval Sea Systems Command
NNS	Newport News Shipbuilding
OTC	Offshore Technology Conference
RLG	Ring Laser Gyro
SAW	Submerged Arc Welding
SMAW	Shielded Metal Arc Welding
SME	Society for Mining, Metallurgy, and Exploration
TM	Technical Manual
TRL	Technology Readiness Level
UNDEX	underwater explosion

5 These acronyms are for Appendix E (pp. E-1 through E-32).

APPENDIX F
SERVICE TECHNOLOGY READINESS ASSESSMENT (TRA) PROCEDURES AND FORMATS

This appendix provides procedures used and documented by the Services.

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6 In light of the change to DoD 5000.2-R contained in the pending USD(AT&L) memorandum (see Appendix D of this document), this is the recommended format for Technology Maturity Agreements (TMAs). The reader will notice that the Army refers to a TMA as a "Technology Maturity Assessment."

Sample Technology Maturity Assessment Format
This is a sample format for a Technology Maturity Assessment (TMA).

TITLE PAGE

(SYSTEM TITLE)

TECHNOLOGY MATURITY ASSESSMENT

Date

AUTHENTICATION PAGE

Prepared By:

__________ DATE:_________________ ___________ DATE: ________________

Name Name
Job Title Job Title
Organization Organization

Approved By:

__________ DATE:_________________

Name
Job Title (APM or higher)
Organization

TABLE OF CONTENTS PAGE

(SYSTEM TITLE)
Technology Maturity Assessment

TABLE OF CONTENTS

ASSESSMENT BODY

(SYSTEM TITLE)
Technology Maturity Assessment

1.0 PURPOSE

This document provides a TMA for the (SYSTEM TITLE) program in support of the Milestone (MS) (B or C, as appropriate) acquisition decision process. The assessment will identify and demonstrate the degree to which critical technologies are mature and capable of meeting the program objectives.

A listing of acronyms is found at the end of this document.

2.0 PROGRAM OVERVIEW

The following paragraphs briefly define the (SYSTEM TITLE) program, its objectives, and the detailed program and system descriptions.

2.1 Objective

The (SYSTEM TITLE) program will achieve (desired capability/result) by fielding advanced technology to (brief description of desired capability)…

2.2 Program Description

The (SYSTEM TITLE) mission is to …

The proposed technology transition/upgrade began because (describe why the proposed effort was conducted) …

The current proposal is to field (describe performing organization(s), what is to be done, and when, where, and how it will be done)…

Future modifications/block upgrades are expected to provide…

2.3 System Description

The (upgraded or proposed new SYSTEM TITLE) is based on (describe system/technology heritage) … . Note: Heritage technology may or may not be the basis for pursuing the new system.

The current fielded system/technology status is …

Subsystems, components, and proposed technical advancements are described as follows [system Work Breakdown structure (WBS) at Attachment 1]:

(include figures and tables as necessary).

3.0 Assessment

This section details the process used for the TMA of the (SYSTEM/TITLE) program… .

3.1 Process Definition

Describe process to identify critical technologies and systems, define appropriate Technology Readiness Levels (TRLs) and standards corresponding to those levels and assess technologies (conduct analyses, show qualification by similarity, or demonstrate maturity to desired standards). Provide justification that analyses and/or tests conducted do in fact demonstrate attainment of desired performance. (Introduction here provides context and overview for following sub-sections.)

a. Define critical technologies: Those vehicle technologies, components, or subsystems, the success or failure of which most significantly affect the ability of a (SYSTEM TITLE) to meet the system requirements as identified by [the Operational Requirements Document (ORD), the System Performance Specification, and so forth].

b. Identify critical technologies, components, or subsystems in the (SYSTEM/TITLE) WBS (see Attachment 1).

c. Define levels to be used in TRL Assessment per DoD 5000.2-R and extracted from Government Accounting Office (GAO) Report NSIAD-99-162, *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes,* as shown in Appendix A: select desired TRL range (5–7, 6–8, and so forth) under consideration, justify choice of this range as appropriate for this phase of the program.

d. Assess critical technologies and assign readiness levels desired and achieved to date (see Figure x). (This is an overview. Provide detail in following section.)

Subsystem Title	**Critical Technologies**	**TRL Desired at Current Decision Point**	**TRL Achieved at Current Decision Point**
Subsystem A	… …	…. ….	…. ….
Subsystem B	…	….	….
Subsystem C	…	….	….
….	…	….	….

Figure x. (SYSTEM TITLE) Critical Technologies

3.2 Evaluation

Based on the previous steps for the TMA, the following sections briefly describe the levels desired and achieved by each critical element.

Appendix A provides the current TRL definitions used by the Army. Augmenting this list are the following accepted definitions for brassboards and breadboards.

Breadboard *- An experimental device (or group of devices) used to determine feasibility and to develop technical data. It normally will be configured for laboratory use only to demonstrate the technical principles of immediate interest. It may not resemble, nor be intended for use, as the projected end item.*

Brassboard *- An experimental device (or group of devices) used to determine feasibility and to develop technical and operational data. It normally will be a model sufficiently hardened for use outside of laboratory environments to demonstrate the technical and operational principles of immediate interest. It may resemble the end item, but is not intended for use as the end item.*

Critical information for each technology is to be summarized in a Technology Maturity Chart (TMC). Appendix B provides an illustrative TMC. More detail is expected in its preparation, using the ORD, System Performance Specification, or other such documentation that specifies what the warfighter expects (Best Estimated Need). The TMC in Appendix B has two main columns: Attributes and Objectives. The "Attributes" column is broken down into four major categories: Performance (e.g., for an inertial sensor, bias stability, drift rate, scale factor, accelerometer dynamic range), Physical (e.g., size, weight, volume, required power), Environmental (e.g., temperature range, vibration/power spectrum density; shock; humidity range; waterproof; immersion depth), and Programmatic (e.g., test/measurement environment, affordability). The Objective column is subdivided into four columns: Best Estimated Need, Current, Program Mid-Point, and Program End. The first and second columns under Objectives have space for the insertion of numbers/metrics. The third and fourth columns under Objectives have space for the insertion of numbers/metrics and a qualitative risk assessment (Low, Medium and High) of the program's ability to meet each respective attribute. The bottom of the chart will have an overall TRL assessment for the second, third, and fourth columns under Objectives, respectively. The purpose of this chart is to provide information on the component/subsystem quality necessary to achieve the cited TRL level, as a function of program deadlines. Individual technology charts will be inserted into the report at the end of section 3.2.

The report text in the following sections provides background and defends the selected attributes and objectives. The technology proponent is expected to attach supporting technical documentation (e.g., test results) to validate the assessments provided in this attachment.

3.2.1. Subsystem A

Technology A1:

Justify selected attributes and objective TRLs
Defend selection of TRL performance standards/tests/environment
Discuss results achieved
Evaluation result: The TRL is therefore assessed as (number rating). (Discussion as required)

Technology A2:

3.2.2. Subsystem B

....

3.2.3. Subsystem C

….

3.3. System-Level Technology Readiness

This section should address the technology readiness of the entire system, incorporating the individual technologies discussed in Section 3.2, to include the implications of integration with existing/legacy systems. This section must provide confidence that the entire system can meet its specified requirements for the program decision point under consideration.

3.4 Summary

The *(SYSTEM TITLE)* program has performed a TRL Assessment for all of the critical technologies identified in the WBS, with results summarized in Figure xx. *(IF APPLICABLE, as for upgrades)* All other elements of the *(SYSTEM TITLE)* were assessed at the readiness level nine since there is no change from the current fielded *(SYSTEM TITLE)*.

Technology	Assessment
(Subsystem Title) (Technology/Component A) (Technology/Component B) …	(Overall rating) (number rating) (number rating) …
(Subsystem Title) (Technology/Component C) (Technology/Component D) …	(Overall rating) (number rating) (number rating) …
(Subsystem Title) (Technology/Component E) (Technology/Component F) …	(Overall rating) (number rating) (number rating) …
Overall System Rating	(Overall Rating)

Figure xx. Summary

4.0 CONCLUSIONS

(State conclusions regarding technology readiness – briefly summarize justifications above)

ACRONYMS

DoD	Department of Defense
GAO	Government Accounting Office
MS	Milestone
NSIAD	National Security and International Affairs Division (GAO)
ORD	Operational Requirement Document
R&D	research and development
TMA	Technology Maturity Assessment
TMC	Technology Maturity Chart
TRL	Technology Readiness Level
VV&A	Verification, Validation and Accreditation
WBS	Work Breakdown Structure

Attachments

Attachment 1
(SYSTEM TITLE) WBS

WBS Level	Description
1	**...**
1.1....	**...**
2	**...**
3...	**...**

APPENDIXES

Appendix A. TRL Definitions

TRL	Description
1. **HW/S**: Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.
SW: Functionality conjectural	Lowest level of software readiness. Basic research begins to be translated into applied R&D. Examples might include a concept that can be implemented in software or analytic studies of an algorithm's basic properties.
2. **HW/S/SW**: Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications may be speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3. **HW/S**: Analytical and experimental critical functions and/or characteristic proof of concept	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
SW: Analytical and experimental critical functions and/or characteristic proof of concept	Active R&D is initiated. This includes analytical studies to produce code that validates analytical predictions of separate software elements. Examples include software components that are not yet integrated or representative but satisfy an operational need. Algorithms are run on a surrogate processor in a laboratory environment.
4. **HW/S:** Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.
SW: Functionality demonstrated in a laboratory environment	Basic software components are integrated to establish that they will work together. They are relatively primitive with regard to efficiency and reliability compared with the eventual system. System software architecture development is initiated to include interoperability, reliability, maintainability, extensibility, scalability, and security issues. Software is integrated with simulated current/legacy elements as appropriate.

Appendix A. TRL Definitions (Continued)

TRL	Description
5. **HW/S**: Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that it can be tested in a simulated environment. Examples include "high- fidelity" laboratory integration of components.
SW: Functionality and performance demonstrated in a relevant environment	Reliability of software ensemble increases significantly. The basic software components are integrated with reasonably realistic supporting elements so that it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of software components. System software architecture is established. Algorithms are run on a processor(s) with characteristics expected in the operational environment. Software releases are “Alpha” versions and configuration control initiated. Verification, Validation and Accreditation (VV&A) initiated.
6. HW/S: System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in technology’s demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment, or in a simulated operational environment.
SW: Functionality and performance demonstrated in a realistic simulated (live/virtual) operational environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in software-demonstrated readiness. Examples include testing a prototype in a live/virtual experiment or in simulated operational environment. Algorithm is run on a processor or in the simulated operational environment. Software releases are “Beta” versions and are configuration controlled. Software support structure in development. VV&A in process.
7. HW/S: System prototype demonstration in an operational environment	Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment, such as an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.
SW: Functionality and performance demonstrated in an operational test environment	Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as a command post or air/ground vehicle. Algorithms are run on processor of the operational environment integrated with actual external entities. Software support structure in place. Software releases are in distinct versions (e.g., Version 2.0). Frequency and severity of software deficiency reports do not significantly degrade functionality or performance. VV&A completed.

Appendix A. TRL Definitions (Continued)

TRL	Description
8. **HW/S:** Actual system completed and "flight qualified" through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, TRL 8 represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
SW: Functionality, performance and quality attributes* validated in an operational	Software has been demonstrated to work in its final form and under expected conditions. In most cases, this TRL represents the end of system development. Examples include test and evaluation of the software in its intended system to determine whether it meets design specifications. Software releases are production versions and are configuration controlled in a secure environment. Software deficiencies are resolved rapidly through the support structure.
9. HW/S: Actual system "flight proven" though successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of system development. Examples include using the system under operational mission conditions.
SW: Functionality, performance, and quality attributes* proven in an operational environment through successive successful accomplishment of mission operations	Actual application of the software in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of system development. Examples include using the system under operational mission conditions. Software releases are production versions and are configuration controlled. Frequency and severity of software deficiencies are at a minimum.

*Quality attributes include reliability, maintainability, extensibility, scalability and security

TRL Definitions

Breadboard: Integrated components that provide a representation of a system/subsystem and can be used to determine concept feasibility and to develop technical data. Typically configured for laboratory use to demonstrate the technical principles of immediate interest. May resemble final system/subsystem in function only.

"High Fidelity": Addresses form, fit, and function. High-fidelity laboratory environment would involve testing with equipment that can simulate and validate all system specifications within a laboratory setting.

"Low Fidelity": A representative of the component or system that has limited ability to provide anything but first-order information about the end product. Low-fidelity assessments are used to provide trend analysis.

Model: A reduced scale, functional form of a system, near or at operational specification. Models will be sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system.

Operational Environment: Environment that addresses all the operational requirements and specifications required of the final system to include platform/packaging.

Prototype: The first early representation of the system that offers the expected functionality and performance expected of the final implementation. Prototypes will be sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system.

Relevant Environment: Testing environment that simulates the key aspects of the operational environment.

Simulated Operational Environmental: Environment that can simulate all of the operational requirements and specifications required of the final system or a simulated environment that allows for testing of a virtual prototype to determine whether it meets the operational requirements and specifications of the final system.

Technology Maturity

Technology Title: Inertial Sensors

POC
Name: John Doe
Phone #: XXX-YYY-ZZZZ

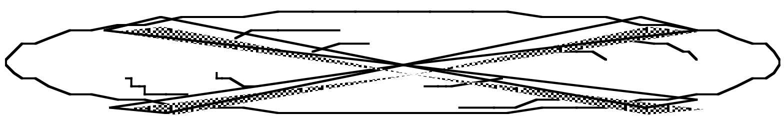
Attributes	Objectives					
	Best Estimated Need	**Current**	**Program Mid-Point Status**	**Program Mid-Point Risk**	**Program End Status**	**Program End Risk**
Performance						
Rate Gyro drift	10^0/hr	500^0/hr	200^0/hr	L	50^0/hr	H
Accelerometer Dyn. Range	1E+07	1E+03	1E+05	L	1E+06	H
Physical						
Gyro size	2 cu.in.	4 cu.in.	3 cu.in.	M	3 cu.in.	M
Environmental						
Temperature Max/Min.	-25 - 115^0C	RM	RM - 100^0C	L	0 - 115^0C	L
G-Load	1000	10	100	L	500	L
Vibrations (Power spectrum)	Unknown	Untested	Untested		50% power Spectrum Test	M
Programmatic						
Test Environment	Field Test	Lab	Lab		Simulated Field	
Unit Cost (By calculation)	$3K/unit	$15K/unit	$15K/unit		$5K/unit	
Overall TRL Level	NA	3	4		5	

APPENDIX G
TECHNOLOGY READINESS ASSESSMENT (TRA) EXAMPLES

Several actual TRAs that have been submitted for milestone decisions are provided for information and reference.

UH-60M

TECHNOLOGY READINESS LEVEL ASSESSMENT



Utility Helicopters

6 March 2001

Prepared By:

______________________DATE:___________________DATE:_

MELLISA BARNETT
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Prod Eng Div, ED, AMCOM RDEC

ERIC EDWARDS
UH-60M Project Engineer
UH-60M RECAP/UPGRADE

Approved By:

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LTC, IN
APM, UH-60M RECAP/UPGRADE

Table of Contents

UH-60M
Technology Readiness Level Assessment

1.0 PURPOSE

This document provides a Technology Readiness Level (TRL) Assessment for the UH-60M program in support of the Milestone (MS) B acquisition decision process. The TRL Assessment will identify and demonstrate the degree to which critical technologies are mature and capable of meeting the program objectives.

2.0 PROGRAM OVERVIEW

The following paragraphs briefly define the UH-60M program: its objectives and the detailed program and system descriptions.

2.1 Program Objective

The UH-60M program will recapitalize/upgrade the existing fleet of UH-60A/L aircraft to meet Block 1 requirements identified in the Operational Requirements Document (ORD) for Recapitalization of the UH-60 Black Hawk Utility Helicopter Fleet. The ORD requirements provide capabilities for digitization/situational awareness, provide for increased lift and range requirements over the UH-60A model, extend the service life of the aircraft, and increase operational readiness over the current UH-60A model. The Utility Helicopters Program Manager's Office (UH PMO) will meet these requirements by recapitalizing the airframe and qualifying, testing, and integrating mature technologies into the UH-60 helicopter. UH-60 aircraft designated to perform the Medical Evacuation (MEDEVAC) mission will integrate the UH-60Q/HH-60L medical Mission Equipment Package (MEP) into the UH-60M platform. New-production UH-60 helicopters will incorporate the UH-60M Engineering Change Proposal (ECP).

2.2 Program Description

The UH-60 Black Hawk mission is to project and sustain the force by providing air assault, general support, command and control (C2), and MEDEVAC capabilities. It was designed to replace the Vietnam-era UH-1 and to fill the need for a utility helicopter that would transport an entire infantry squad or carry double the UH-1's external load at higher airspeeds, with greater survivability, and in adverse weather and more severe climatic conditions. The Black Hawk is a twin turbine engine, single rotor, semi-monocoque fuselage, rotary wing helicopter capable of transporting cargo, 11 combat troops, and weapons during day, night, visual, and instrument conditions. The main and tail rotor systems consist of four blades each, with the capability to fold the main rotor blades manually, scissor the tail rotor paddles, and fold the tail pylon assembly for deployment, transport, or storage. A movable, horizontal stabilator assembly is located on the lower portion of the tail rotor pylon to enhance flight characteristics.

Twenty-two percent of the UH-60A helicopters in the fleet were over 20 years old at the end of FY00 and 66 percent had exceeded their service half life. Increased operational tempo and the technological age of the airframe, components, and systems are adversely impacting the UH-60 and resulting in increased operation and support (O&S) costs and decreased reliability and maintainability. The UH-60 does not have the necessary digital avionics architecture to meet interoperability communication requirements. Existing communication and navigation suites do not meet evolving International Civil Aviation Organization (ICAO) and Federal Aviation Administration (FAA) traffic management requirements planned for implementation beginning in 2003. Current UH-60A/L navigation systems do not provide the precision required to insert troops and equipment during future combat (land and over water) operations, especially in darkness and adverse weather conditions.

In 1998, the U.S. Army Aviation Center Director of Combat Developments began the development of an ORD for UH-60 Black Hawk Recapitalization/Upgrade. During this same time frame, the U.S. Army Aviation and Missile Command (AMCOM) chartered a utility helicopter fleet modernization study to address how to best meet the challenges faced by the aging fleet. The Utility Helicopter Fleet Modernization Analysis, which concluded in January 1999, was led by a General Officer Steering Committee (GOSC), which reached a consensus recommendation for the path ahead. The GOSC consensus was that while a pure UH-60 modernized fleet is the desired approach, it is currently unattainable because of affordability constraints. Therefore, an evolutionary tiered modernization approach should be pursued. Elements of the recommended strategy, specific to the UH-60 Black Hawk fleet, are synopsized as follows:

- Modify 255 UH-60A/L aircraft to meet the UH-60 Modernization ORD Block 2 requirements (digitized cockpit, increased lift, reduced O&S) for Force Package (FP) 1 air assault units
- Modify 860 UH-60A/L aircraft in FP 1, FP 2–4, and Table of Distribution and Allowance (TDA) units to a UH-60M configuration, to meet the Block 1 requirements of the UH-60 Modernization ORD
- Modify 357 UH-60A/Q and HH-60L aircraft to the UH-60M MEDEVAC Black Hawk (UH-60M platform with medical MEP).

The ORD for Recapitalization/Upgrade of the UH-60 Black Hawk Utility Helicopter Fleet, signed in January 2000 and updated in September 2000, calls for increased capabilities as technology matures through the use of tiered, evolutionary requirements. In the near term, Block 1 requirements address immediate operational challenges associated with the aging UH-60 fleet. Requirements include digitization/situational awareness, extension of the aircraft life, reduction of fleet O&S costs, and increased operational readiness. Block 2 requirements address additional increases in lift and range, digitization, reductions in O&S costs, and increased survivability. Meeting Block 2 requirements is dependent on technology advances.

Block 1 takes advantage of existing aeronautical and digital technologies to recapitalize/upgrade the fleet. Existing UH-60A/Ls are recapitalized/modernized into UH-60M aircraft that include airframe structural improvements, a propulsion upgrade for the UH-60A, and a digital cockpit. Immediate payoff is realized by maintaining the average fleet age at about 15 years while reducing O&S costs. The O&S payback is a result of replacing the UH-60A T700-GE-700 engines (about 60 percent of the fleet) with more reliable UH-60L T700-GE-701C engines. The UH-60L engine also provides significant lift capability improvement over the UH-60A. Digital avionics and communications will allow the Black Hawk to operate on the digital battlefield and will reduce pilot fatigue while improving situational awareness.

Block 2 is initiated once the advanced propulsion capabilities of the common engine program are available. The common engine program, an advanced technology program executed by the Aviation Applied Technology Directorate (AATD), will provide 3,000 shaft horsepower (shp) with reduced fuel consumption. The Army's Apache program and the Navy's Sea Hawk program may also procure these engines. Along with the increased lift and range, the Block 2 aircraft will contain increased digitization and improved aircraft survivability. The Block 2 program will be pursued when technology becomes available to meet performance requirements under a separate acquisition process.

While technology constrains the ability to meet the ORD Block 2 lift/range requirements in the near term, the need exists now to modify existing Black Hawks to meet digitization/situational awareness requirements, extend the life of the aircraft, reduce O&S costs, and increase operational readiness.

2.3 System Description

The UH-60M can be produced from the assembly line or recapitalized/upgraded from an UH-60A or UH-60L aircraft. The UH-60M is based on the UH-60L Lot 21 configuration, with additional improvements to the airframe, electrical system, main rotor blades, Flight Control Computer (FCC), and cockpit/avionics. Specifically, the UH-60M configuration will have the following improvements.

a. The avionics incorporate the following components: communications/navigation MIL-STD-1553 data bus, Control Display Unit (CDU), Multi-Function Displays (MFDs), stormscope, and hardware and software to allow the crew to communicate digitally via the Improved Data Modem (IDM). The cockpit improvements include a moving map and the ability to present the data of primary flight instruments on the MFDs.

b. The UH-60M includes a Cockpit Voice Recorder (CVR)/Flight Data Recorder (FDR). The CVR/FDR will record all crew intercom voice, radio voice, and data messages. The CVR/FDR will be equipped with crash protection and a locator beacon.

c. The current Stability Augmentation System (SAS)/Flight Path Stabilization (FPS) computer is replaced with the Dual-Use Application Program (DUAP) digital Advanced Flight Control Computer (AFCC). The analog components of the flight control system remain unchanged. Figure 1 illustrates UH-60M cockpit improvements and benefits of items a–c.

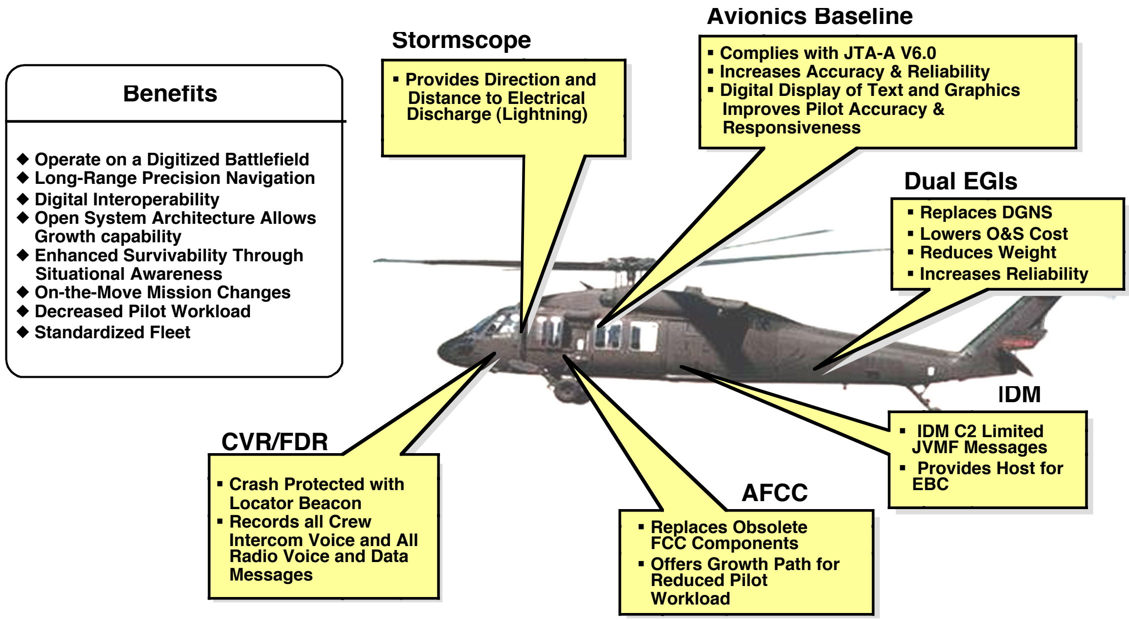


Figure 1. Cockpit Improvements

d. The UH-60M will use the Wide Chord Blade (WCB). This blade offers increased lift and will help offset the lift lost because of the increased mission weight of the UH-60M. The advanced composite main rotor blades consist of a graphite/fiberglass spar with a swept anhederal blade tip and have 16-percent wider chord than the current titanium blades.

e. The engine exhaust system includes an improved Hover Infrared Suppression System (HIRSS). The T700-GE-701C engines currently fielded on the UH-60L aircraft will be used for the UH-60M program. An Improved Durability Gearbox (IDGB), rotor-head, and controls will also be incorporated from the UH-60L program.

f. The UH-60M includes the Crashworthy External Fuel System (CEFS). The Extended Range Fuel System (ERFS) delivers fuel from external fuel tanks into the main fuel tanks, thereby providing any External Stores Support System (ESSS)-capable UH-60 helicopter a substantially larger range of operation. The ERFS consists of two 230-gallon crashworthy external, ballistic-resistant fuel tanks; two BRU-22A ejection racks for each ESSS-removable provisions kit; a jettison subsystem; and the necessary adapter, electrical harnesses, and tube assemblies to complete the interface with the ESSS. The fuel system consists of the lines from the main fuel tanks, firewall-mounted selector valves, prime/boost pump and fuel tanks, and engine-driven suction boost pumps. In each tank, the UH-60M also contains electrically operated submerged fuel boost pumps that provide pressurized fuel if the engine fuel pressure drops below the minimum operating pressure. Figure 2 illustrates the propulsion improvements and benefits of items d–f.

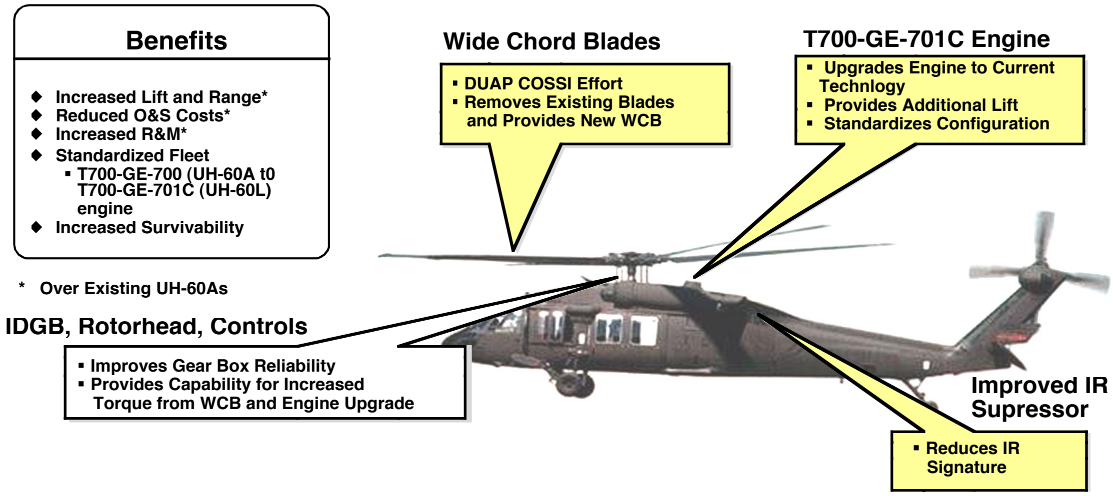


Figure 2. Propulsion Improvements

g. Airframe improvements include refurbishment or replacement of cabin components and troop seats and refurbishment of tailcone, stabilator, vertical pylon, airframe tuning devices, and crew seats. Major airframe load paths are strengthened to accommodate the increased WCB capability and the aircraft usage spectrum modified to reflect growth in mission weight. For those aircraft not currently equipped, the ESSS will be added to incorporate hard points for external stores and an improved ESSS fuel system. The transition access door will be used for the UH-60M program.

h. Electrical wiring is replaced to meet the Electromagnetic Environmental Effects (E3) requirements and accommodate new electrical systems design. Figure 3 illustrates airframe improvements and benefits of items g and h.

3.0 TECHNOLOGY ASSESSMENT

This section details the process used for the TRL Assessment of the UH-60M Recapitalization/Upgrade program.

3.1 Process Description

The TRL Assessment examines the UH-60M program concepts and defines the technology requirements of the program in order to determine technology maturity. As part of the program risk determination, technology maturity is defined as the degree to which critical technologies have been demonstrated as capable of meeting the program objectives. As part of the UH-60M Milestone B documentation for System Development and Demonstration, the UH PMO has performed an Integrated Risk Assessment, which is based on similar principles identified by program documentation, inputs from experienced acquisition personnel, and the application of widely accepted Department of Defense (DoD) risk management techniques. Using the IRA process approach as a basis, the TRL Assessment consists of the following steps:

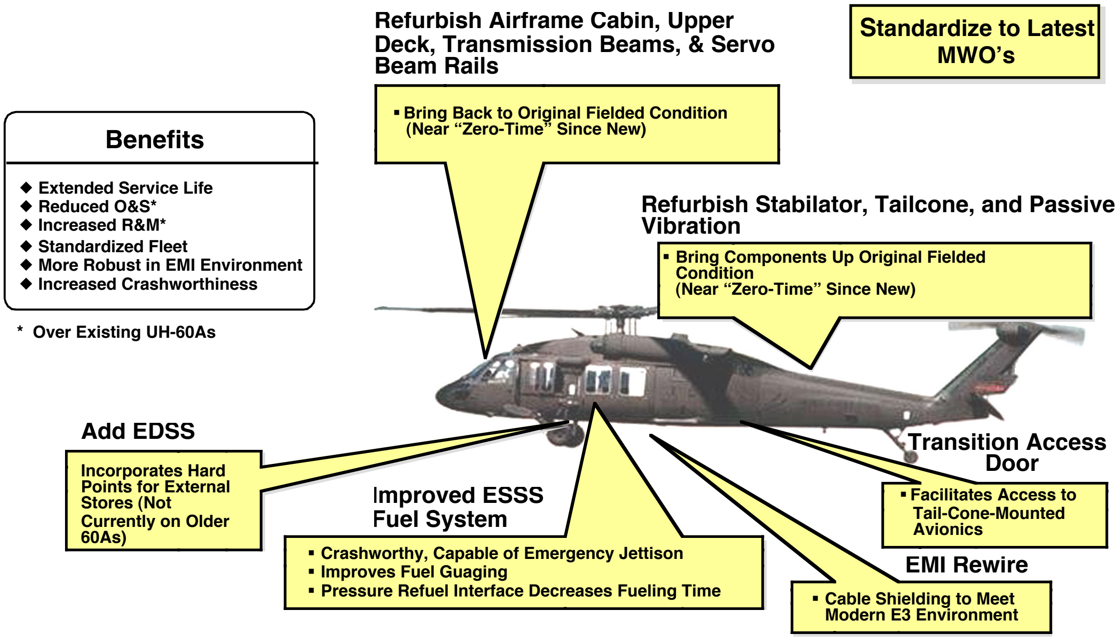


Figure 3. Airframe Improvements

a. Define Critical Technology

Those vehicle technologies, components, or subsystems whose success or failure most significantly affect the ability of a fully integrated UH-60M to meet the Block 1 key performance parameters (KPPs) as identified by the ORD and the System Performance Specification AVNS-PRF-10002.

b. Identify critical technologies in the UH-60M Work Breakdown Structure (WBS), (see Attachment 1)

Based on the objectives of the UH-60M program, improvements to the airframe, propulsion system, cockpit digitization, and cockpit integration (hardware and software) were chosen as the critical technology elements as shown in Figure 4.

c. Define levels to be used in TRL Assessment per October 2000 draft version of DoD 5000.2-R and extracted from Government Accounting Office (GAO) Report NSIAD-99-162, *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes*, as shown in Figure 5

d. Assess critical technologies and assign readiness levels.

3.2 Evaluation

Based on the above steps for the TRL Assessment, the following sections briefly describe the levels assigned to each critical element according to these definitions:

- TRL 7: Assigned to components that are currently undergoing qualification testing for an Army rotorcraft program but have not been fielded on the UH-60 platform except for qualification and testing.

Cockpit Digitization	Stormscope Dual EGIs CVR/FDR AFCC IDM
Propulsion	CEFS WCB T700-GE-701L Engine IDGB, Rotorhead, and Controls Improved HIRSS
Airframe	Standardization Refurbishment Refurbishment of Tailcone, Stabilator, and Passive Vibration Transition Access Door Electromagnetic Interference (EMI) Rewire Improved ESSS

Figure 4. UH-60M Critical Technologies

TRL	Definition	Description
1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples include paper studies of a technology's basic properties.
2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof of detailed analysis to support the assumption. Examples are still limited to paper studies.
3	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology.
4	Component and/or breadboard validation in a laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory.
5	Component and/or breadboard validation in a relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.

Figure 5. TRL Definitions

TRL	Definition	Description
6	System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.
7	System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.
8	Actual system completed and "flight qualified" through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this is the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9	Actual system "flight proven" through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.

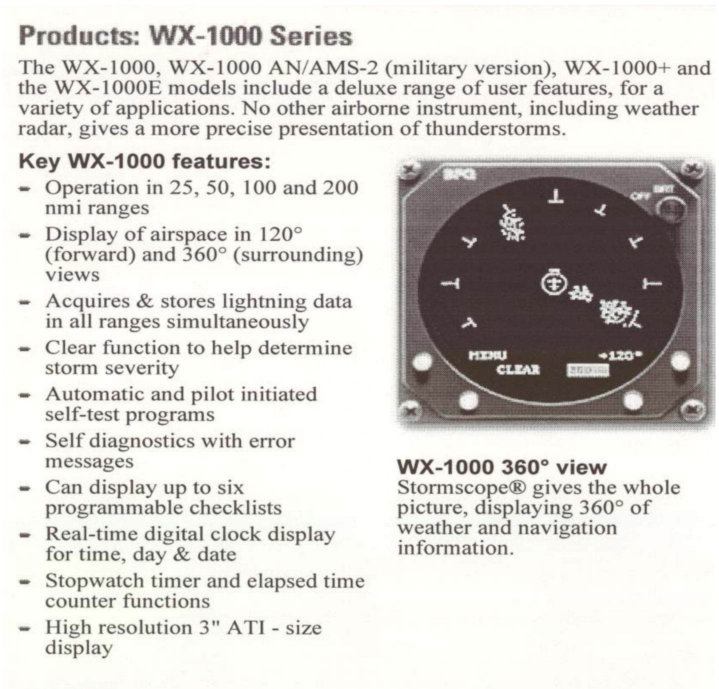
Figure 5. TRL Definitions (Continued)

- TRL 8: Assigned to qualified components of other fielded UH-60 systems (UH-60Q).
- TRL 9: Assigned to components currently fielded on UH-60L platform.

3.2.1 Cockpit Digitization

The stormscope (see Figure 6) provides relative direction and distance to electrical discharge. The stormscope consists of an antenna that is mounted on the bottom of the aircraft, a receiver computer that continuously monitors itself through built-in test features, and a display screen on the instrument panel of aircraft. Modes of operation include 360- and 120-degree weather mapping, time and date, and navigation display. The current designation for the stormscope is the BF Goodrich WX 1000, which is fielded on the UH-60Q and the HH-60L. The WX 1000 is a commercial off-the-shelf (COTS) item that satisfies the performance specification requirements of the UH-60M and has been approved for inclusion in the UH-60Q. Therefore, the TRL is 8.

The Embedded GPS/INS (EGI) is a tri-Service effort (led by the United States Air Force). The objective is to provide an integrated navigation solution for aircraft equipped



Products: WX-1000 Series

The WX-1000, WX-1000 AN/AMS-2 (military version), WX-1000+ and the WX-1000E models include a deluxe range of user features, for a variety of applications. No other airborne instrument, including weather radar, gives a more precise presentation of thunderstorms.

Key WX-1000 features:

- Operation in 25, 50, 100 and 200 nmi ranges
- Display of airspace in 120° (forward) and 360° (surrounding) views
- Acquires & stores lightning data in all ranges simultaneously
- Clear function to help determine storm severity
- Automatic and pilot initiated self-test programs
- Self diagnostics with error messages
- Can display up to six programmable checklists
- Real-time digital clock display for time, day & date
- Stopwatch timer and elapsed time counter functions
- High resolution 3" ATI - size display

WX-1000 360° view
Stormscope® gives the whole picture, displaying 360° of weather and navigation information.

Figure 6. Stormscope Characteristics

with a MIL-STD-1553 digital data bus. The EGI embeds a five-channel GPS receiver into a ring laser gyro Inertial Navigation System (INS), making the total system lightweight and low mean time to failure. The EGI is the objective, fully digitized Global Positioning System (GPS) solution for scout/attack helicopters and has successfully flown on the CH-47 and the MH-60K. The AH-64 program is currently demonstrating/qualifying an updated version of the EGIs. For these reasons, the TRL for Dual EGIs is 7.

The CVR/FDR provides recording of crew internal and external communication (voice and data) and aircraft systems in-flight data, which can be used to analyze flight mishaps. The CVR/FDR is a COTS component that will be tailored to meet the system requirements of the UH-60M. The CVR/FDR technology is mature and well demonstrated in helicopters. A wide selection of commercially available CVR/FDR component solutions has been tailored to the rotary wing environment, and the technology has been demonstrated on the MH-60K and countless civil aviation aircraft. Performance requirements for the UH-60M program are equivalent to minimum FAA requirements for commercial aircraft CVR/FDR components. Qualification efforts are currently ongoing for the MH-60K and MH-47E fleets of aircraft. Therefore, the TRL is 7.

The AFCC is a product of the Department of Defense (DoD) Cost and Operation and Support Savings Initiative (COSSI) program to qualify a commercially developed FCC for use in the military environment. The AFCC is a form, fit, and function replacement to the existing flight control computer, which contains obsolete components no longer available from the manufacturer. These obsolete components are replaced with plastic encapsulated modules, which are based on mature technology. The new AFCC architecture is based on the SH-60 and S-92 commercial systems. Design modifications include cooling fins to replace fans, reduced power requirements, lighter weight, plug in cards reduced from five to three, and alphanumeric displays replace "fault ball" fault indicators. ECP cut-in of the AFCC for the new production UH-60 aircraft is scheduled for calendar year 2001 following completion of qualification testing. The TRL is 7.

The IDM provides an interface between tactical radios and the aircraft's MFDs or the CDUs. The IDM provides four half-duplex radio channels and is compatible with several digital data protocols. PM-AEC is further enhancing the capability of the IDM to include hosting of a Joint Variable Message Format (JVMF) parser and, eventually, the Embedded Battle Command (EBC) software. The former will provide the UH-60M with the capability to send and receive C2 messages over the Tactical Internet (TI), whereas the latter will provide situational awareness from TI servers located on the digital battlefield. The benefit of using the IDM in this fashion on Army Aviation platforms is that the mission equipment processors within the respective Army aircraft will not be burdened with the overhead of parsing the message traffic and converting it from their various protocols. The IDM has been flown on the UH-60Q and the HH-60L but has not been used for interoperability. It is currently flying on the OH-58D and the AH-64. Qualification of the IDM 303 is ongoing. The TRL is 7.

3.2.2 Propulsion

The CEFS is a product of a Cooperative Research and Development Agreement (CRADA) intended to improve the crashworthiness capability and reduce the ballistic vulnerability of the existing ERFS. The CEFS is based upon a noncrashworthy fuel system that is fielded on rotary aircraft. Vehicle integration/flight test demonstration is planned. Qualification efforts are ongoing, with functional testing scheduled to begin in February 2000. The TRL is 7.

The WCB (see Figure 7) is the product of a DoD DUAP COSSI program to qualify a commercially developed main rotor blade for use in the military environment. The WCB consists of a composite spar, 16-percent increase in blade chord over current UH-60 blade, improved airfoils/anhedral tip, and cross section and strike protection identical to S-92. Qualification testing is ongoing. The TRL is 7.

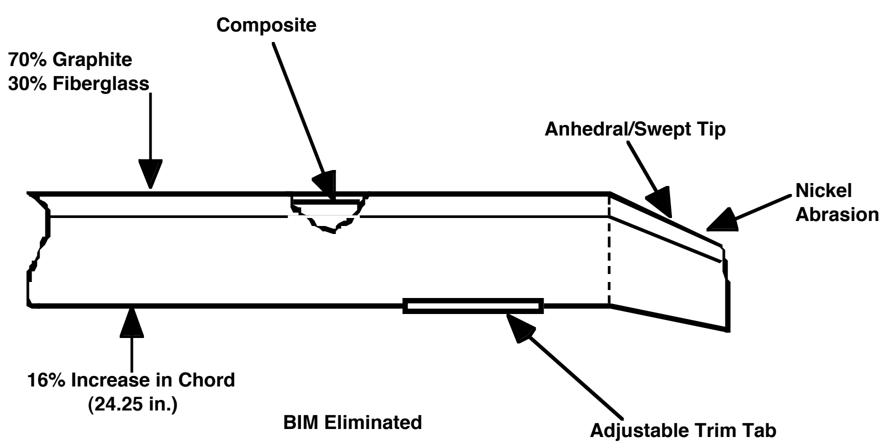


Figure 7. Wide Chord Blade

The T700-GE-701C engine is currently fielded on the UH-60L with over 400 aircraft fielded (each with 2 engines). For the UH-60M program, engines on the UH-60A aircraft will be upgraded from 700 engines to 701C engines. This statement is also true for the IDGB, rotorhead, and controls. The TRL is 9.

The improved HIRSS is the product of a CRADA to establish IR performance improvements realized with the implementation of advanced materials and discrete design modifications to the HIRSS currently installed on the UH-60 fleet. Development test and analysis efforts have been completed and establish the system IR suppression performance, demonstrate the positive impact of the design modifications on installed engine horsepower performance, and evaluate favorable reductions in engine back pressure. The material and suppression technologies resulting in the improved suppressor performance have been demonstrated and applied to a currently fielded product. Although the ORD does not require this capability, the currently fielded HIRSS meets performance requirements. System flight test demonstrations have been completed, with no significant issues noted. System evaluation for the General Electric HIRSS 2000 and the Sikorsky Aircraft Advanced Infrared System. The TRL is 7.

3.2.3 Airframe

The refurbishment of the airframe cabin, upper deck, transmission beams, servo beam rails, and potentially a new cabin section use no new technologies and to minimize schedule risks, the UH-60M program is avoiding use of any exotic material or new technology. Upper deck refurbishment and replacement of the transmission beams are required to correct the history of cracking in this area of UH-60 fielded aircraft. Whether there will be a new cabin section or refurbishment of the old cabin will be decided during System Development and Demonstration. The TRL is 9.

Standardization to Lot 21 Maintenance Work Orders (MWOs) is, by definition, being done on the current version of the UH-60L aircraft. These MWOs have been incorporated into new production units of the Lot 21 configuration. The TRL is 9.

The refurbishment of the tailcone, stabilator, and passive vibration is currently being done on UH-60A/Ls. The TRL is 9.

The transition access door will facilitate the access to the avionics equipment installed in the tail pylon area of the aircraft. Currently, the maintenance personnel must access this equipment through the crew cabin aft bulkhead on the UH-60A/Ls. This modification is being done on the UH-60Q. The TRL is 9.

EMI rewire requires no new technology, and the materiel solution for the UH-60M is currently fielded wiring or that on the MH-60K. The TRL is 9.

Improved ESSS provides new crashworthy fuel tanks with jettisonable capability and improved gauging and control. The ESSS provides hardpoints to older UH-60As to allow installation of the ESSS. The improved ESSS incorporates no new technology and is currently fielded on the UH-60L. The TRL is 9.

3.3 Summary

The UH-60M program has performed the TRL Assessment for the critical technologies identified in the WBS. Figure 8 summarizes the results. All other elements of the UH-60M WBS were assessed at the readiness level TRL 9 since there is no change from the current fielded UH-60 aircraft.

Technology	TRL Assessment
Cockpit Digitization	
Stormscope	8
Dual EGIs	7
CVR/FDR	7
AFCC	7
IDM	7
Propulsion	
CEFS	7
WCB	7
T700-GE-701C	9
IDGB, Rotorhead, and Controls	9
Improved HIRSS	7
Airframe	
Standardization	9
Refurbishment	9
Refurbishment of Tailcone, Stabilator, and Passive Vibration	9
Transition Access Door	9
EMI Rewirine	9
Improved ESSS	9

Figure 8. Summary

A complete history of documentation to support these TRL levels can be found in matrix format in Attachment 2. [**Editor's Note:** *Attachment 2 is not included in this appendix*.]

4.0 CONCLUSIONS

The UH-60M program has been structured to reduce program risk to the extent considered practical and without compromising requirements defined by the user. Significant risk reduction has been accomplished in the early stages of the UH-60M program, and much more is required during the System Development and Demonstration (SDD) phase of the program. These activities have been considered in early stages of the UH-60M program and are thoroughly documented in the Integrated Risk Assessment (IRA) and the Risk Management Plan (RMP) for the program.

To minimize the overall program risks, the UH-60M program has planned and performed risk-mitigation activities in the following areas:

- System Integration Laboratory
- Leveraging other UH-60 efforts (Digital Map and CDU)
- Software Engineering Institute (SEI) Capability Maturity Model (CMM) Level III capability
- Integrated schedules/Critical Path Analysis (CPA)
- Trade studies
- Risk-reduction contract
- IRA
- Combined Test Team
- Modeling and simulation (M&S)
- Early user demonstrations
- Cost as an independent variable/award fee structure
- Depot Partnership Study
- Earned Value Management System
- Service Life Assessment Program
- Low rate initial production (LRIP), which allows additional schedule ramp-up to full-rate production (FRP).

Through early identification and the use of these tools and activities, the UH-60M program has minimized risk through the use of demonstrated capabilities.

The UH-60M program has been defined and structured to identify and control risk. Extensive program planning has been accomplished, which involved the appropriate representatives from the UH PMO, the contractor, and the user. Contract requirements and management plans define a process that will ensure success. The TRLs identified in this assessment are well within the acceptable range to proceed into the System Integration and Demonstration phase.

ACRONYMS

AATD	Aviation Applied Technology Directorate
AFCC	Advanced Flight Control Computer
AFCS	Advanced Flight Control System
AM	amplitude modulation
AMCOM	Aviation and Missile Command
ANVIS	Aviator's Night Vision Imaging System
C2	command and control
CDU	Control Display Unit
CEFS	Crashworthy External Fuel System
CMM	Capability Maturity Model
COSSI	Cost and Operation and Support Savings Initiative
COTS	commercial off-the-shelf
CPA	Critical Path Analysis
CRADA	Cooperative Research and Development Agreement
CVR	Cockpit Voice Recorder
DoD	Department of Defense
DUAP	Dual-Use Application Program
E3	Electromagnetic Effects Environment
EBC	Embedded Battle Command
ECP	Engineering Change Proposal
EGI	Embedded GPS Inertial Navigation System
EMI	electromagnetic interference
ERFS	Extended Range Fuel System
ESSS	External Stores Support System
FAA	Federal Avionics Administration
FCC	Flight Control Computer
FDR	Flight Data Recorder
FLIR	forward-looking infrared
FM	frequency modulation
FP	Force Package
FPS	Flight Path Stabilization
FRP	full-rate production
FY	Fiscal Year
GAO	Government Accounting Office
GFE	government-furnished equipment
GOSC	General Officer Steering Committee
GPS	Global Positioning System
HF	high frequency
HIRSS	Hover Infrared Suppression System
HUD	Heads Up Display
HUMS	Health and Usage Monitoring System
ICAO	International Civil Aviation Organization
IDGB	Improved Durability Gearbox
IDM	Improved Data Modem

IFF	identification friend or foe
ILS	Instrument Landing System
INS	Inertial Navigation System
IR	Infrared
IRA	Integrated Risk Assessment
JVMF	Joint Variable Message Format
KPP	Key Performance Parameter
LRIP	low rate initial production
M&S	modeling and simulation
MEDEVAC	Medical Evacuation
MEP	Mission Equipment Package
MFD	Multi-Function Display
MS	Milestone
MWO	Maintenance Work Order
NSIAD	National Security and International Affairs Division (GAO)
O&S	operation and support
ORD	Operational Requirements Document
R&M	reliability and maintainability
RMP	Risk Management Plan
SAS	Stability Augmentation System
SDD	System Development and Demonstration
SEI	Software Engineering Institute
shp	shaft horsepower
TACAN	Tactical Air Navigation
TDA	Table of Distribution and Allowance
TI	Tactical Internet
TRL	Technology Readiness Level
UH PMO	Utility Helicopters Program Management Office
UHF	ultrahigh frequency
VADR	Voice And Data Recorder
VHF	very high frequency
VOR	VHF Omni-directional Radio-range
WBS	Work Breakdown Structure
WCB	Wide Chord Blade

Attachment 1

UH-60M Work Breakdown Structure

WBS Level	Description
1	UH-60M
1.1	Air Vehicle
1.1.1	Air Frame
1.1.1.1	Fuselage
1.1.1.2	Landing Gear
1.1.1.3	Transmission
1.1.1.4	Life Support/Environmental Systems
1.1.1.5	Flight Controls
1.1.1.6	Secondary Power Systems
1.1.1.7	Electrical System Integration
1.1.1.8	Hoist/Cargo System
1.1.1.9	Propulsion Systems
1.1.1.A	Rotor Systems
1.1.2	Communications/Identification
1.1.2.1	Intercom
1.1.2.2	Radio Systems
1.1.2.3	IFF Transducer
1.1.2.4	Communication Security
1.1.2.5	Improved Data Modem (IDM)
1.1.2.6	VHF-FM Radio
1.1.2.7	UHF-AM Radio
1.1.2.8	HF Radio
1.1.2.9	VHF-AM Radio
1.1.2.A	Emergency Control Panel
1.1.3	Navigation/Guidance
1.1.3.1	Radar Navigation
1.1.3.2	TACAN Navigation Set
1.1.3.3	VORs/ILS Navigation
1.1.3.4	Electronic Altimeter Set
1.1.3.5	INS
1.1.3.6	Stormscope
1.1.3.7	Low Freq Auto Direction Finder System
1.1.3.8	Personnel Locator System
1.1.3.9	GPS
1.1.4	Automatic Flight Control System
1.1.4.1	AFCS Avionics
1.1.4.2	AFCS Servos
1.1.5	Survivability Equipment
1.1.6	Data Displays and Controls

UH-60M Work Breakdown Structure (Continued)

1.1.6.1	Multi-Function Display
1.1.6.2	CDU
1.1.6.3	Data Concentrator Unit
1.1.6.4	Data Transfer System
1.1.6.5	Multifunction Slew Controller
1.1.6.6	ANVIS HUD
1.1.6.7	FLIR
1.1.6.8	Fuel Management System Controls
1.1.7	Armament
1.1.8	Auxiliary Equipment
1.1.9	Integration/Assy/Test/Checkout
1.1.A	Propulsion-GFE Engine
1.1.B	Air Vehicle Application Software
1.1.B.1	MFD Software
1.1.B.2	CDU Software
1.1.B.3	Data Concentrator Unit Software
1.1.C	Air Vehicle System Software
1.1.C.1	MFD Display
1.1.C.2	CDU
1.1.C.3	Data Concentrator Unit
1.1.D	Aircraft Data Recorders
1.1.D.1	FDR
1.1.D.2	CVR
1.1.D.3	HUMS
1.1.E	Non-Recurring Avionics Sys Integration
1.2	Training
1.3	Data
1.4	System Test and Evaluation
1.5	System Engineering/Management
1.5.1	Program Management
1.5.2	Systems Engineering
1.5.3	Integrated Manufacturing
1.6	Logistics
1.7	Aircraft Kits

COOPERATIVE ENGAGEMENT CAPABILITY (CEC) TECHNOLOGY READINESS LEVEL ASSESSMENT

Performed by: Office of Naval Research (ONR-35)

3 January 2002

Prepared by: CAPT A. J. Cetel, USN Date: 27 December 2001

Approved by: Dr. Eli Zimet, ONR 35 Date: 28 December 2001

Table of Contents

Cooperative Engagement Capability (CEC) Technology Readiness Level Assessment

1.0 PURPOSE

This document articulates the results of the Technology Readiness Assessment (TRA) performed by the Office of Naval Research (ONR-35) on the critical technologies embedded in the CEC Program. In accordance with DoD 5000.2-R, dated June 2001, and Deputy Under Secretary of Defense for Science and Technology (DUSD(S&T)) Memo, dated 5 July 2001, this assessment was based upon the Technology Readiness Level (TRL) descriptions and the technology maturity associated with each critical technology.

2.0 PROGRAM OVERVIEW

The CEC has been evaluated in a series of stressing demonstrations and certified by the Operational Test and Evaluation Force (OPTEVFOR) as operationally effective and operationally suitable through one of the most complex operational evaluations ever performed by the U.S. Navy. In addition, prior at-sea evaluations in operational environments have also been successful in reducing the risk and preparing for operational evaluation (OPEVAL) (see Figure 2-1).

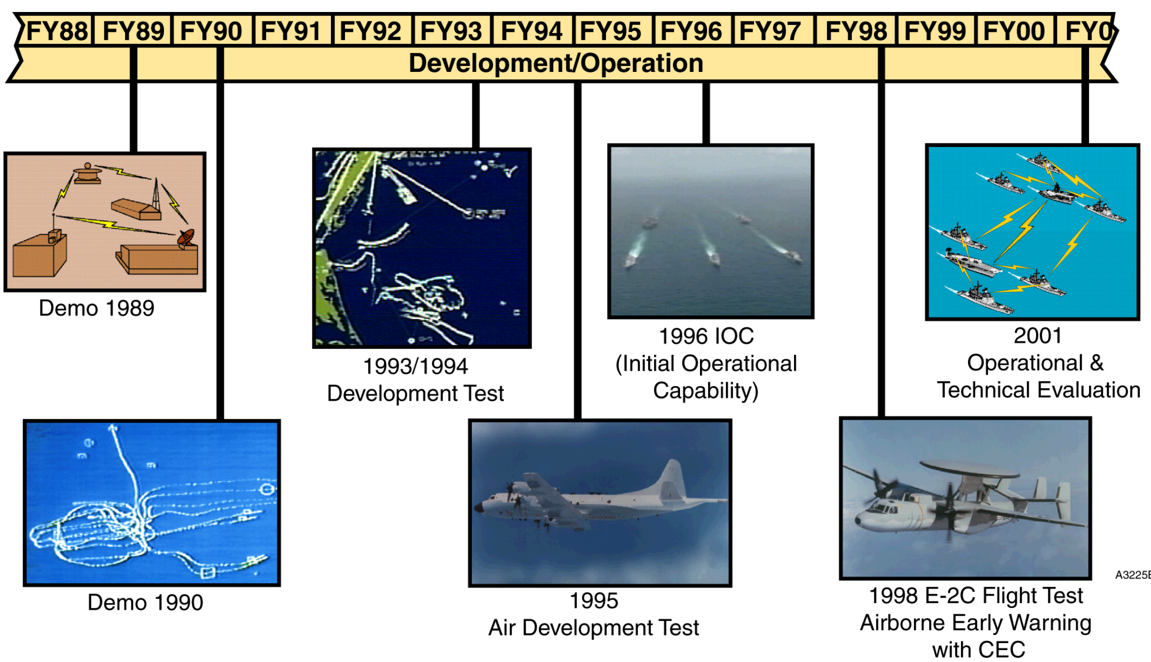


Figure 2-1. Preparations for Operational Evaluation

2.1 Program Objective

The CEC system has demonstrated its capability to develop a coherent, composite view of the battlespace that is shared by all network participants in real time. In addition, the system has shown its ability to facilitate buying back the battlespace lost to the evolving threats that were envisioned in the initial days of CEC. Each of these demonstrations has involved stressing threats in adverse environments consistent with the wartime environment in which the system was designed to operate. The results of each of these demonstrations have shown an ability to maintain a coherent view of the battlespace on each CEC node while facilitating the engagement and destruction of threats that have not previously been achievable. The introduction of CEC into operational units will significantly enhance the ability of Naval forces to engage a wide range of threats, with a high probability of negation in the open ocean and littoral environments.

2.2 Program Description

CEC is a system of hardware (see Figure 2-2) and software that allows ships to share radar data on air targets. Radar data from individual ships and E-2C aircraft within a battle group (BG) are transmitted to other ships in the group via a line-of-sight (LOS) Data Distribution System (DDS). Each ship uses similar data processing algorithms resident in its cooperative engagement processor (CEP), resulting in a composite aircraft and missile track on each ship—a track that is essentially the same. An individual ship can launch a surface-to-air missile (SAM) at a threat aircraft or antiship missile (ASM) within its engagement envelope, based on composite track data resident within the CEC system, even though that ship may not have that track within its organic air search radar system. CEP-equipped units, connected via the DDS network, are known as Cooperating Units (CUs).

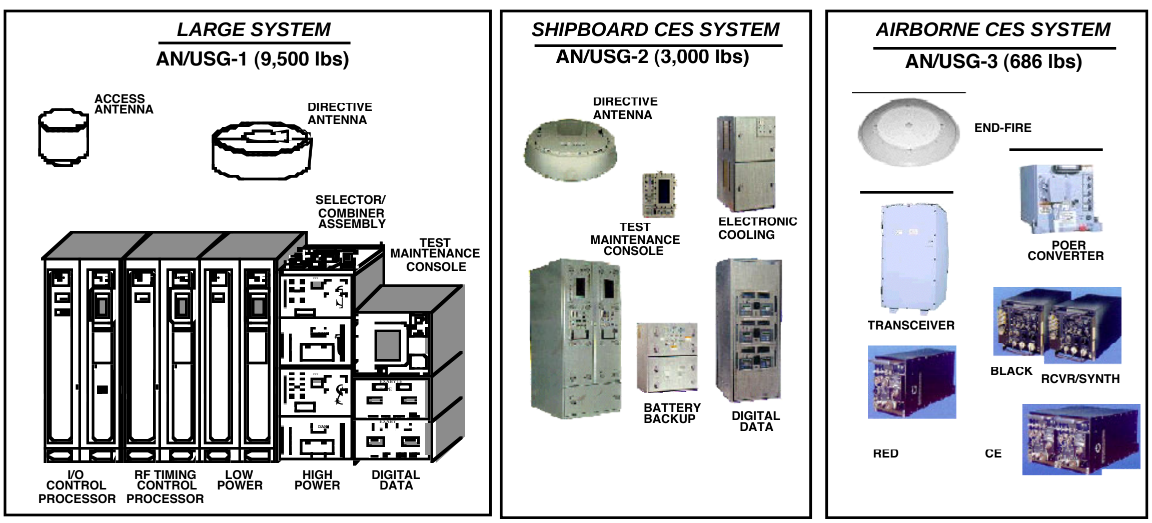


Figure 2-2. CEC Hardware System

2.3 System Description

The shipboard CEC terminal consists of the CEP subsystem and the DDS, which includes an antenna subsystem, receiver/synthesizer subsystem, red processor subsystem, and a black processor subsystem. A CEC terminal also has ancillary equipment, such as:

- A data processing cabinet to house the below-decks subsystems and power conditioners
- An environmental control unit to power and cool the antenna subsystem
- A test maintenance console (TMC) for remote status and maintenance monitoring
- A battery backup converter (BBC) to maintain certain functions during power interruptions
- A digital data recorder to record system events for off-line analysis
- CEP input/output (I/O) converters to interface with various platform-unique weapon systems and sensors.

Figure 2-3 is a block diagram of a CEC terminal's major subsystems. In this figure, solid line arrows represent data flow and dotted line arrows represent control flow. Figure 2-4 illustrates the physical characteristics of the CEC equipment.

a. The shipboard CEC implements a Shipboard Active Aperture Antenna (SBAA) for data transmission and reception. The shipboard CEC also includes direct current/direct current (DC/DC) converters, Cesium time standard, receiver/ synthesizer, CEP I/O converter, BBC, and the Data Processing Terminal (DPT) cabinet containing the CEP and DDS red and black processor subsystems and receiver/synthesizer subsystem. Figure 2-4 depicts the typical shipboard CES equipment configuration's interfaces to the auxiliary subsystems.

b. The DPT provides a centralized common equipment suite (CES) equipment location, which houses the CES' main processing subsystems. The DPT is physically configured into a split layout. The left drawer contains the equipment on the red side of the TEMPEST boundary (i.e., the CEP main and I/O circuitry, the CEP expansion logic, and DDS red processor). The right drawer contains the receiver/synthesizer, black processor, Cesium time standard, and a designated growth rack. The foundation base plate contains the Power Conditioner subsystem. The ship's cooled water system provides primary cooling water at 40–50 °F. flowing at 8.0 gpm with a pressure drop of 10 psig.

c. The CEP obtains sensor data and mission control data and shares this information with other network CEPs. Using this collective information, the CEP produces a composite air/surface picture for the area surrounding the BG. The interface between the CEP and DDS red processor is an Ethernet connection. All host combat system interfaces with the CEP, including sensor and combat

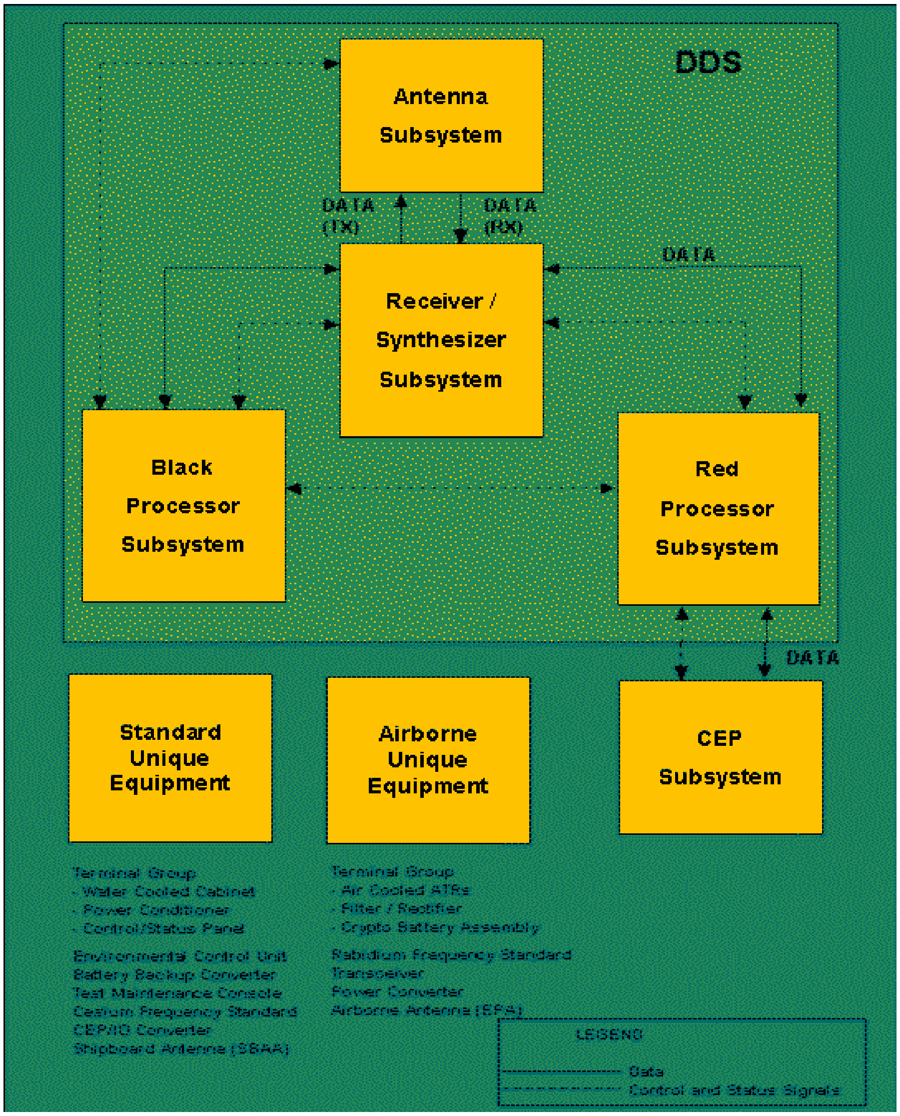


Figure 2-3. CEC System Block Diagram

system, are routed through a CEP I/O Converter (CIOC) box. The CIOC provides the translation between the multiple host combat system interface and the CEP's Ethernet interface. CEP display and operator controls are provided at the combat system's operator consoles via a separate Ethernet interface. Many of the commands that the CEP issues can also be executed from a touch screen display on the TMC or DPT control panel.

d. The CEP processing architecture is a collection of coupled microprocessor and interface boards, interconnected by a combination of commercial microcomputer buses [Versa Module Europa (VME) and Ethernet]. These functions are divided into "kernel" and "adaptive" processing functions. The kernel processing functions represent those functions present in the CEP for all configurations, and the adaptive processing functions are those specific processing functions that change depending on the platform class for which the CEP is configured.

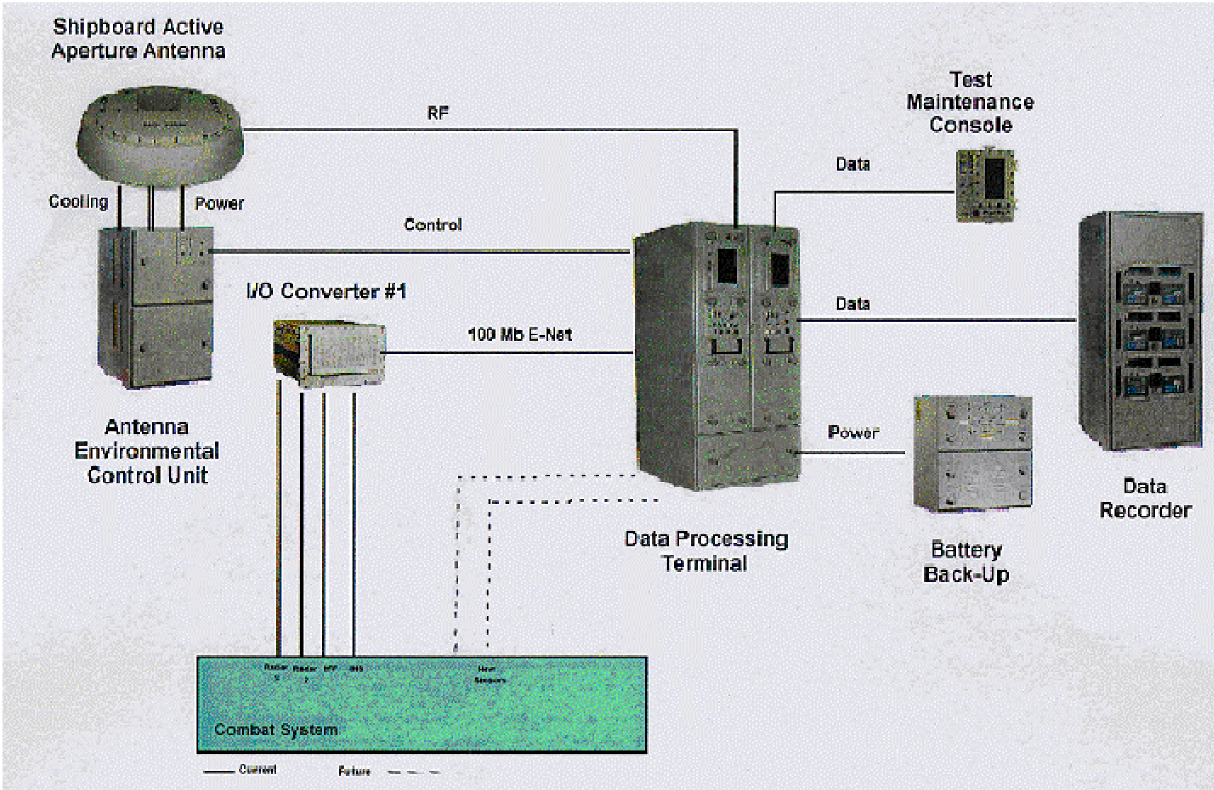


Figure 2-4. Shipboard CES Typical Configuration

e. The CEP has a dedicated capability for future growth designed into the initial manufacturing phase to allow interfacing with additional program applications, weapons system equipment, or sensor features not currently addressed or identified. The first use of this growth capability is to house special Ship Self Defense System (SSDS) components.

f. The DDS red processor provides for processing classified or sensitive data. It has a direct Ethernet interface to the CEP and communicates with the black processor and receiver/synthesizer subsystems through fiber-optic links. The fiber-optic interfaces ensure that classified information held by the red processor memory cannot be transmitted in the clear because of a malfunction of either the equipment or the computer program. Normal data transmissions via DDS are encrypted. An embedded CDH cryptographic chip set physically mounted on the embedded crypto card in the red processor provides encryption and decryption functions and required timing and resynchronization terms. Figure 2-5 is a block diagram of the red processor

g. The black processor provides terminal control for all DDS communications and performs control functions, but it does not process or store any unencrypted classified information. It communicates with the red processor over an optical interface designed to prevent the inadvertent transfer of classified data. The beam controller that provides pointing commands to the antenna is contained in the black processor. Figure 2-6 is a block diagram of the black processor.

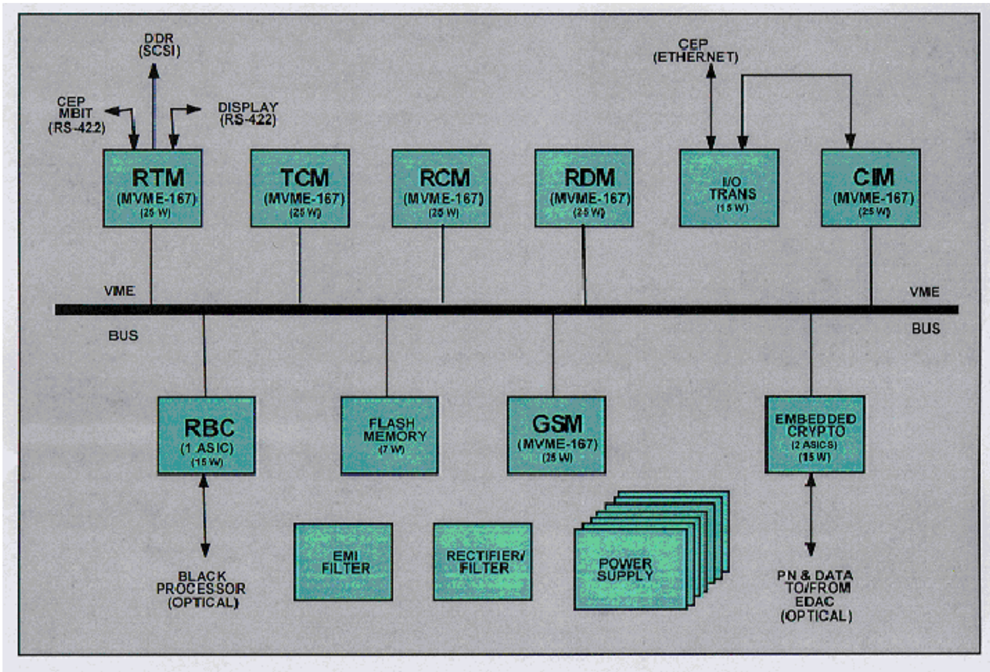


Figure 2-5. Red Processor Block Diagram

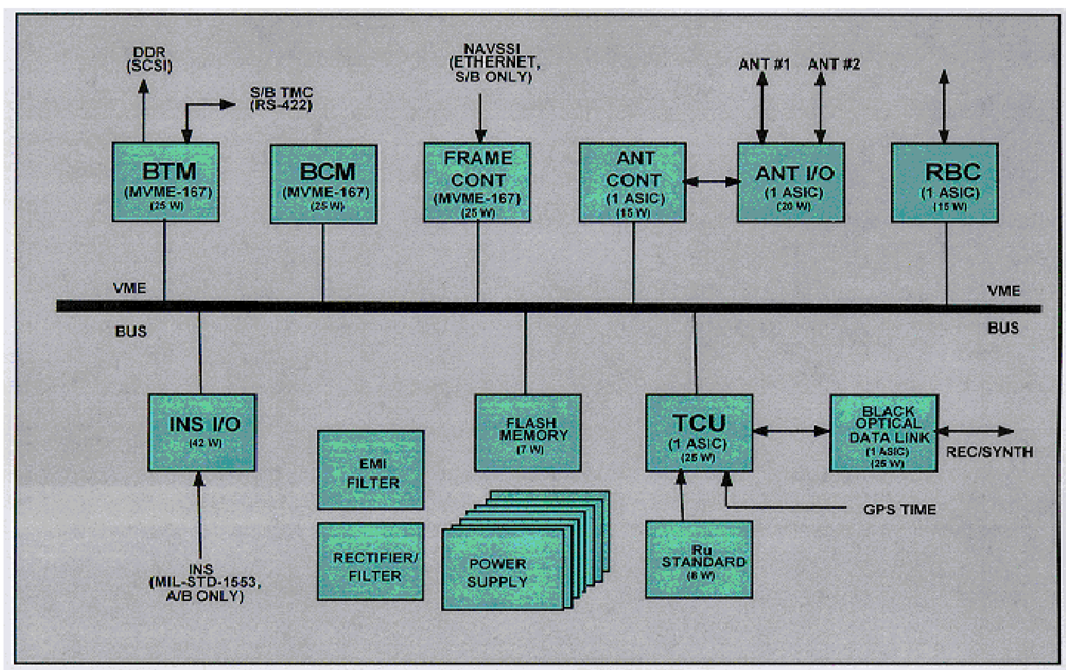


Figure 2-6. Black Processor Block Diagram

h. A Cesium frequency standard is used on shipboard terminals to provide an accurate and stable reference frequency for the DDS's master clock and the time-of-day clock within the Timing and Control Unit (TCU). The Cesium standard is sufficiently stable to meet CEC system timing requirements for extended shipboard missions.

i. The BBC provides full system protection during momentary power loss, fluctuations, or interruptions (100 msec to 8 sec in duration). The BBC uses 270 V DC from the power conditioner for charging and ensuring system protection and provides battery backup to the crypto and time-of-day circuits for up to 1.5 hours. This feature provides increased system reliability and eliminates the need for a separate battery for crypto or the Cesium frequency standard.

j. The SBAA is a cylindrical, polyalphaolefin (PAO) liquid-cooled antenna used for transmitting and receiving normal communications and is designed to be mounted on a standard 17-inch diameter mast. The antenna's radiating elements are configured into five evenly spaced rows of elements around the cylinder. The top row can be used to form an omni-directional receive capability. Normally, a 90-degree sector of the antenna is excited. Commutating the 90-degree sector of the array and "fine tuning" the direction of the beam via electrical phase shifting within the 90-degree sector allows azimuth scanning. Elevation scanning is accomplished by electrical phase shifting within the 90-degree sector. When transmitting, the radio frequency (RF) is divided among the active elements within the 90-degree sector, with different amounts of phase shift injected into the paths of the signals going to those antenna elements. The amount of phase shift and power fed to each element is controlled so that signals radiated by the different elements will reinforce each other in the desired transmission direction but cancel each other in other directions. Most of the radiated power is concentrated and formed into a pencil-like beam.

   The same principle of phase reinforcement and cancellation is used for reception. The received signals from different elements are phase shifted by various amounts before being added together to form a composite signal. The phase shifts applied to the different elements are chosen so that signals arriving from the desired direction reinforce each other and signals arriving from other directions cancel each other.

   To maximize the required radio LOS coverage, the SBAA is mounted as high as possible but generally not less than 120 feet above the ship's waterline. Location (in a single antenna installation) must be such that the radio LOS to the horizon is not blocked for 360 degrees (190 degrees azimuth for each antenna if a dual antenna system is required) and is unobstructed from +70 degrees (up) to –30 degrees (down). The antenna is mounted to within ±1 degree of horizontal for gain and polarization purposes. In addition, mechanical alignment for bearing reference is required to be within 2 degrees of the ship's centerline.

   The SBAA uses a dry air supply to maintain an internal positive operating pressure for corrosion protection. During installation, the internal area is purged for 15 minutes to remove built-up humidity or condensation.

k. The Antenna Environmental Control Unit (AECU) provides conditioned and regulated power, including 270 V DC, to the antenna electronics. It houses the liquid cooling system controller that maintains and controls the antenna internal temperatures using shipboard-supplied cooling water at 40–50 °F flowing at 9.0 gpm with a pressure drop of 10 psig. In addition, the AECU contains electromagnetic interference (EMI) filters, power conditioners and a Liquid Heat Exchanger Assembly (LHEA) consisting of a heat exchanger, pump, isolation valves, and control panel and controller for the AECU. One AECU can supply cooling and power for both antennas in a two-antenna installation if the cable that runs between the SBAAs and the AECU is kept to a specified length.

l. Although primary operational control of the CEC is via combat system console interfaces to the CEP, the TMC is designed as the primary man-to-machine interface for maintenance purposes. The TMC ensures maintenance technicians/operators can communicate via touch screen with the DDS and CEP. The TMC contains system status and fault indications, an audible alarm, control switches, maintenance and recording controls, and battleshort, reload, and reset capabilities.

m. The CIOC provides the ability for the CEP to communicate with numerous systems on different platforms via a 100BaseT Ethernet connection and with the platform's sensors and combat system over various Naval Tactical Data System (NTDS) interfaces (NTDS Types A–E). Although the standard shipboard installation is one unit, the capability exists to accommodate up to six CIOCs, depending on ship requirements.

3.0 TECHNOLOGY ASSESSMENT

This section details the assessment process and summarizes the information associated with the TRA of the CEC. Since the OPEVAL and the acquisition decision is for the USG-2 shipboard CEC system and the CEC System Baseline 2.0, this assessment focused on those shipboard elements. It is clear that the basic technologies of the airborne system, USG-3, are the same as the shipboard system and, thus, would have the same TRL.

The key references used in this assessment were:

- DoD 5000.2-R, dated 10 June 2001
- DUSD(S&T) Memo dated 5 July 2001
- CEC Operational Requirements Document (ORD) (Draft Revision), dated 21 September 2001
- CEC Risk Management Plan for CEC System Baselines 1.0., 2.0, and 2.1
- CEC TECHEVAL(DT-IIH) Analysis Control Board (ACB) Report, dated 31 May 2001
- CEC OPEVAL Report, COMOPTEVFOR ltr 3980 (1415-OT-IIA4) Ser714/S026, dated 7 September 2001
- Acquisition Strategy (PMS-465 Draft), dated 26 November 2001

- CEC System Specifications for Cooperative Engagement Capability – Rev D-WS-32890, dated 21 April 2000
- Independent Assessment of CEC Technology - ASN(RDA) 1998
- Acquisition Strategy for Cooperative Engagement Capability – Approved 16 November 2000.

3.1 Process Description

In determining how to execute this TRA, ONR-35 selected a small group of technical experts. Some had no direct association with the program, and others were the appropriate CEC Program experts. The assessment team was lead by Captain A.J. Cetel, USN from ONR-35, which collected data and assessment inputs from and/or obtained comments on the assessment product from personnel in the following organizations:

- Massachusetts Institute of Technology (MIT)/Lincoln Laboratory (LL)
- Johns Hopkins University/Applied Physics Laboratory (JHU/APL), the CEC Technical Direction Agent (TDA)
- Raytheon Corporation, CEC Prime Contractor
- Office of Naval Research (ONR)
- CEC Program Office, PMS-465
- Anteon Corporation, CEC Technical Support
- Noesis Incorporated, ONR-35 Technical Support.

The first step in this TRA was to define “critical technologies”: those technologies that are imbedded in CEC components or subsystems and that make CEC operate as designed and tested. The following were the determined critical technologies:

CEP	▪ Motorola 5100 series reduced instruction set computer (RISC) processors ▪ Fusion algorithms
DDS	▪ Antenna array – GaAs transmit/receive (T/R) modules ▪ 68040 processors ▪ CDH chipset (CTIC-DS101 Hybrid) ▪ Network algorithms

In reviewing the TRL assessment criteria [stipulated by the Office of the Secretary of Defense (OSD)] that were applicable for a program going through a Milestone III decision, the following were appropriate:

TRL 7. System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle or space. Examples include testing the prototype in a test bed aircraft.
TRL 8. Actual system completed and "flight qualified" through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
TRL 9. Actual system "flight proven" through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.

[Source: DUSD(S&T) Memo, dated 5 July 2001]

It was against these criteria that the TRA concerning the critical technologies was made.

3.2 Evaluation

3.2.1 Operating System Critical Technology Assessment (TRL-9)

Since the CEC system is dominated by computer programs, it is important to ensure initially that the operating system in the DDS and the CEP are stable and are not unique.

The operating system used in the CEP and DDS is VxWorks®. VxWorks® is the fundamental run-time component of the Tornado II embedded development platform and the most widely adopted real-time operating system (RTOS) in the embedded industry. VxWorks® is available on all popular central processing unit (CPU) platforms and, thus, is clearly “off-the-shelf.” The VxWorks® RTOS is found in a multitude of applications and markets, including:

- **Data networking:** Ethernet switches, routers, remote access servers, asynchronus transfer mode (ATM) and frame relay (FR) switches
- **Industrial:** test and measurement equipment, robotics, computer numeric(al) control (CNC) equipment, process control systems
- **Medical:** Magnetic Resonance Imaging (MRI) scanners, Positron Emission Tomography (PET) scanners, radiation therapy equipment, bedside monitors
- **Digital imaging:** printers, digital copiers, fax machines, multifunction peripherals, digital cameras
- **Transportation:** automotive engine control systems, traffic signal control, high-speed train control, anti-skid testing systems
- **Telecommunications:** private branch exchange (PBX) and ACDS, CD switching systems, cellular systems, xDSL and cable modems

- **Aerospace:** avionics, flight simulation, airline cabin management systems, satellite tracking systems
- **Computer peripherals:** X terminals, I/O control, redundant array of inexpensive or independent disks (RAID) data storage systems, network computers
- **Multimedia:** professional video editing systems, video conferencing
- **Consumer electronics:** PCS Data Access Service (PDAS), set-top boxes/ TV, screen phones, audio equipment, car navigation systems, in-flight entertainment systems.

Assessment of each of the major elements of CEC follows.

3.2.2 CEP Critical Technology Assessment

3.2.2.1 Computer, Power PC Processor Card-Power 4B-166-32 (TRL-9)

The Power 4B-166 is a 166-MHz PowerPC-604e-based 6U VME Engine designed for embedded and real-time computing applications in IBM systems. The IBM PowerPC 604e Microprocessor runs at 166 MHz internally and interfaces to the external memory system at 66 MHz. It has 32 to 288 Mbytes of dynamic random access memory (DRAM) and 8 Mbytes of Flash memory[7]. V•I Computer[8] has committed to developing products to support the industry's migration toward "openness." Current products adhere to significant new industry standards (IEEE-1396 PCI/PMC standard for mezzanine cards and IEEE-1275 Boot Firmware Standard), ensuring longevity of design and continued third-party hardware and software support. V•I Computer has issued an End-of-Life Buy (EOLB) letter for that configuration of the Power 4B. EOLB orders must have been placed by 31 July 1998, allowing for spares and full support of the technical evaluation (TECHEVAL) and OPEVAL systems.

The OPEVAL proved the performance of this processor, and, thus, it is assigned TRL-9. As industry upgrades components and processors, so must a commercial off-the-shelf (COTS)-based system such as CEC. This planned upgrade of the CEP processor is to a 5100 series RISC processor and will be implemented for future production.

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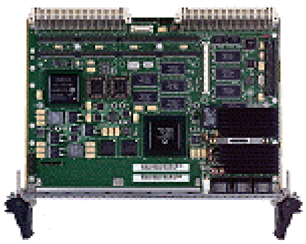
7 Flash memory refers to a memory chip that holds its content without power, but must be erased in bulk. The term comes from its ability to be erased *in a flash*.

8 V•I Computer was acquired by SBS Technologies in 1998.

3.2.2.2 Motorola 5100 series RISC Processors (TRL-9)



The MVME5100 is a high-performance VME processor module with supercomputing levels of performance in a scalable, single-board computer. It is widely used as a replacement for the 68040 processor. This module features the Motorola Computer Group (MCG) PowerPlus II architecture with a Motorola MPC7400 with AltiVec™ technology for algorithmic-intensive computations. Based on an integrated PCI bridge–memory controller application-specific integrated circuit (ASIC) designed by MCG, PowerPlus II has the memory performance of 582 MB/s memory read bandwidth and 640 MB/s burst write bandwidth. The MVME5100 meets the needs of contractors servicing the military and aerospace industry. It is offered in two temperature grades: commercial (with operating temperatures of 0 to 55 °C) and extended (with operating temperatures of –20 to 71 °C). CEC uses the extended version. Other contractors using this processor include:

Product Name	Company Name
Adapters for PMC and PC-MIP Modules	ACT/Technico
Add up to 2 GB on a PMC - PMCStor	ACT/Technico
Architecture and System Design and Integration	ACT/Technico
Conformal Coating for Motorola VMEbus boards	ACT/Technico
Disk and Storage Solutions	RAMiX Incorporated
Embedded Managed Switches (EMS)	RAMiX Incorporated
Fast Ethernet Controllers 10/100 (PMC/CompactPCI)	RAMiX Incorporated
FibreXpress(R) Network	Systran Corporation
Gigabit Ethernet Controllers (PMC/CompactPCI)	RAMiX Incorporated
GoAhead WebServer	GoAhead Software
Green Hills(r) Optimizing Compilers	Green Hills Software, Incorporated
Hard Hat Linux	MontaVista Software, Inc.
High Density VMEbus DSP Resource Board	Voiceboard Corporation
Host Bus Adapters	RAMiX Incorporated
INTEGRITY(tm) Real-Time Operating Systems	Green Hills Software, Incorporated
LynxOS	LynuxWorks, Inc.
Memory Solutions (PMC/CompactPCI/VME)	RAMiX Incorporated
MULTI(r) Integrated Development Environment	Green Hills Software, Incorporated
MultiSpan VMEbus T1/E1 Digital Span Network IF	Voiceboard Corporation
P2 Breakout Boards (BoBs)	ACT/Technico

PMC Expansion Solutions (VME and CompactPCI)	RAMiX Incorporated
Serial Interface (PMC/CompactPCI)	RAMiX Incorporated
TAXI interface	RAMiX Incorporated
ThreadX(r) Real-Time Operating System	Green Hills Software, Incorporated
Tornado Tools 3 for VxWorks AE	Wind River
Unmanaged Embedded Switches	RAMiX Incorporated
VME64x SuperSpan T1/E1 Network Interface	Voiceboard Corporation
VxWorks	Wind River
VxWorks AE	Wind River

3.2.2.3 CEP Fusion Algorithm (TRL-9)

The fusion algorithm in version 2.0 of CEC has evolved over decades. Initial fusion efforts were developed and tested at JHU/APL in the late 1970s and have evolved to the current CEC version developed by Raytheon. Current computer program status is as follows (see Appendix A for details):

	PRI 1	PRI 2	PRI 3	PRI 4	PRI 5
CEP OPEN TRs					
CEP TACTICAL (8.7.0)	0	*3	145 (5)	73 (1)	86 (7)
CEP MAINTENANCE (5.10.0)	0	0	0	0	34
CEP PBIT (5.9.1)	0	0	0	0	19
CEP STARTUP (5.7.0)	0	0	0	0	10

( ) Enhancement TRs
*** Includes 3 AEGIS-only TRs (N/A to CV/CVN/LHD)**

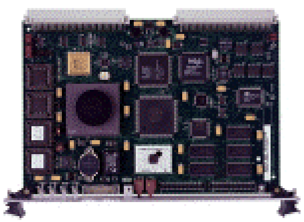
3.2.3 DDS Critical Technology Assessment

3.2.3.1 Antenna Array – GaAs T/R Modules (TRL-9)

The active array SBAA uses state-of-the-practice GaAs T/R modules that are used in high-power military applications, land-based cellular phone relay/substation sites, and point-to-point commercial business communications. Component maturity characteristics of T/R module performance are power, bandwidth, power-added efficiency, and reliability. These all are specified at a given frequency and define the operating maturity of these components. The T/R modules used in the OPEVAL SBAA equipment have mature (not state-of-the-art, but truly "off-the-shelf") characteristics at the CEC operating frequencies.[9]

The Low Cost Planer Array (LCPA), which is planned for cost-reduction purposes, uses the same transistor technology but exchanges the T/R modules for separate transmit and receive devices. By doing this, Raytheon will eliminate the complex circulation issues of T/R modules [e.g. placement on circuit board and loss (attenuation) characteristics]. In a radar-oriented ONR Science and Technology effort (1997/1998), a successful contractor effort (five participating contractors) reduced the production cost of x-band radar T/R modules to $300 each through innovative design. In part, Raytheon built upon this effort for its production of low-cost, high-yield high-power amplifiers (HPAs) used in cellular phones and for the T/R modules in the CEC LCPA.

3.2.3.2 MVME167 (68040) Processor (TRL-9)



Motorola's MC68040 microprocessor offers the combination of functionality, flexibility, and performance for the COTS-based CEC system. It is used widely and forms the basis of the Motorola MVME167 single-board computer, which combines the 68040 microprocessor with the memory management and floating-point units to achieve 26 million instructions per second (MIPS) at 25 MHz and 40 MIPS at 33 MHz.

The list of other contractors using this product follows. It is noteworthy that the other contractors using this product are similar to those using the follow-on Series 5100 processor. This indicates the "normal" evolution from the 68040 processor to the 5100 series.

Product Name	Company Name
ACT/Technico Transition Modules	ACT/Technico
Architecture and System Design and Integration	ACT/Technico
Conformal Coating for Motorola VMEbus boards	ACT/Technico
GoAhead WebServer	GoAhead Software
Green Hills(r) Optimizing Compilers	Green Hills Software, Incorporated
High Density VMEbus DSP Resource Board	Voiceboard Corporation
MULTI(r) Integrated Development Environment	Green Hills Software, Incorporated
MultiSpan VMEbus T1/E1 Digital Span Network IF	Voiceboard Corporation
P2 Breakout Boards (BoBs)	ACT/Technico
ThreadX(r) Real-Time Operating System	Green Hills Software, Incorporated

9 Although "operating maturity" is used here, "production maturity" in terms of IC yield-per-wafer is also an element maturity characteristic. Because they are so closely coupled, entering into production maturity discussion in this document would only be a digression.

Tornado Tools 3 for VxWorks AE	Wind River
VME64x SuperSpan T1/E1 Network Interface	Voiceboard Corporation
VxWorks	Wind River

3.2.3.3 CDH Chipset(CTIC-DS101 Hybrid)(TRL-9)

The CDH Chipset used in the DDS of CEC is a standard National Security Agency (NSA)-approved product designed as part of the Teledyne Microelectronics Hayfield multi-chip module (MCM). Hayfield is a software programmable information security (INFOSEC) MCM designed for description of TRAP Data Dissemination System (TDDS) broadcasts. Hayfield MCMs provide multi-channel decryption, over-the-air rekey (OTAR), power transient detection, built-in test (BIT), an external control status interface, and other features appropriate for the CEC system. Specifications used in development/manufacture/ performance are NSA Standards to include NSA DS-101E, *Interface Protocol of Electronically Keyable INFOSEC Equipment/System*, and CSESD-11, *Communications Security Equipment System Document for Fill Devices KYK-13, KYX-15, KOI-18*. This chipset is widely used with NSA-controlled specification drawings, thus clearly indicating a high level of technology readiness.

3.2.3.4 DDS Network Algorithms (TRL-9)

The fusion algorithm in version 2.0 of CEC has evolved over decades. Initial fusion efforts were developed and tested at JHU/APL in the late 1970s and have evolved to the current CEC version developed by Raytheon. Current computer program status is as follows (see Appendix A for details):

	PRI 1	PRI 2	PRI 3	PRI4	PRI 5
OPEN TRs					
DDS TACTICAL (8.3.1)	0	*5	12	0	39
DDS MAINTENANCE (6.9.1)	0	0	0	0	27
DDS STARTUP (4.0.0)	0	0	0	0	6

( ) Enhancement TRs
*** Includes 3 AEGIS-only TRs (N/A to CV/CVN/LHD)**

3.3 Evaluation Summary

The overall TRA was based upon USG-2 surface system technologies that were tested in the OPEVAL system. The USG-3 airborne system has the same mature foundation technologies and, thus, will have the same TRL if that system passes OPEVAL next year.

The dominant factor that resulted in the TRL-9 assessment was the successful completion of OPEVAL as specified by the Commander, Operational Test and Evaluation

Force (COMOPTEVFOR) in the final OPEVAL Report. The background information stated in this assessment indicates how widely the technology elements are used in the commercial and military sectors.

The final assessment is as follows:

CEP Assessment

Data Processors – V•I Computer Power PC Processor Card Power 4B-166-32	– OPEVAL successful – Standard COTS product for IBM Power PCs	TRL-9
Data Processors – Motorola 5100 series RISC Processors	– OPEVAL successful – Standard COTS replacement product for 68040 processors	TRL-8
Fusion Algorithms	– OPEVAL successful – Proven design; low number of Trouble reports remaining	TRL-9

DDS Assessment

CDH Chipset (CTIC-DS101 Hybrid)	– OPEVAL successful – Standard NSA product used for COMSEC	TRL-9
Antenna Array GaAs T/R Modules	– OPEVAL successful – Mature designs for T/R modules	TRL-9
Data Processors DDS-68040	– OPEVAL successful – Standard COTS product using industry standard chip sets	TRL-9
Network Algorithms	– OPEVAL successful – Proven design; low number of Trouble reports remaining	TRL-9

4.0 CONCLUSIONS

CEC was developed based upon an excellent concept: a COTS baseline coupled with a regularly scheduled COTS refresh. Through the successful OPEVAL of this system with COTS technology embedded and the COTS evolution that has already taken place, it is clear that this is being effectively executed.

ACRONYMS

ACB	Analysis Control Board
AECU	Antenna Environmental Control Unit
ASIC	application-specific integrated circuit
ASM	antiship missile
ATM	asynchronus transfer mode
BBC	battery backup converter
BG	battle group
BIT	built-in test
CDH	COMSEC/TRANSEC Integrated Circuit (CTIC) DS-101 Hybrid
CEC	Cooperative Engagement Capability
CEP	cooperative engagement processor
CES	common equipment suite
CIOC	CEP I/O Converter
CNC	computer numeric(al) control
COMOPTEVFOR	Commander, Operational Test and Evaluation Force
COMSEC	communications security
CPU	central processing unit
CTIC	COMSEC/TRANSEC Integrated Circuit
CU	Cooperating Unit
DC	direct current
DDS	Data Distribution System
DPT	Data Processing Terminal
DRAM	dynamic random access memory
DUSD(S&T)	Deputy Under Secretary of Defense for Science and Technology
EMI	electromagnetic interference
EOLB	End-of-Life Buy
FR	frame relay
gpm	gallons per minute
HPA	high-power amplifier
I/O	input/output
IC	integrated circuit
IEEE	Institute of Electrical & Electronics Engineers
INFOSEC	information security
IOC	initial operational capability
JHU/APL	Johns Hopkins University/Applied Physics Laboratory
LCPA	Low Cost Planer Array
LHEA	Liquid Heat Exchanger Assembly
LL	Lincoln Laboratory
LOS	line-of-sight
MCG	Motorola Computer Group
MCM	multi-chip module
MHz	megahertz

MIPS	million instructions per second
MIT	Massachusetts Institute of Technology
MRI	Magnetic Resonance Imaging
NSA	National Security Agency
NTDS	Naval Tactical Data System
ONR	Office of Naval Research
OPEVAL	operational evaluation
OPTEVFOR	Operational Test and Evaluation Force
ORD	Operational Requirements Document
OSD	Office of the Secretary of Defense
OTAR	over-the-air rekey
PAO	polyalphaolefin
PBX	private branch exchange
PDAS	PCS Data Access Service
PET	Positron Emission Tomography
psig	pounds per square inch gauge
RAID	redundant array of inexpensive or independent disks
RF	radio frequency
RISC	reduced instruction set computer
RTOS	real-time operating system
SAM	surface-to-air missile
SBAA	Shipboard Active Aperture Antenna
SSDS	Ship Self Defense System
T/R	transmit/receive
TCU	Timing and Control Unit
TDA	Technical Direction Agent
TDDS	TRAP Data Dissemination System
TECHEVAL	technical evaluation
TMC	test maintenance console
TRA	Technology Readiness Assessment
TRANSEC	transmission security
TRL	Technology Readiness Level
VME	Versa Module Europa

APPENDIX A:
COMPUTER PROGRAM TROUBLE REPORTS – "OPEN"

The following are descriptions of the key "open" Computer Program Trouble Reports (TRs) for the CEC System.

CEP:

TR No.	Short Title	Status
12883/ CEP-4404 TOR 4165	Message drops in CGAI lead to processor (DDS_IF) being declared down	Under investigation. Unable to reproduce.
12351/ CEP-3713 TOR 3702	CND if track number reassignment premature	AEGIS only. Scheduled for B/L 2.0.16 delivery. Safety issue.
13843/ CEP-5230	BL6PH3 DDG integration requires change in navigational interface	AEGIS only. Scheduled for B/L 2.0.16 delivery.

DDS:

TR No.	Short Title	Status
12767/ 4475 DSTac01744	Net control traffic shut off after a DIR ACQ to node already in network	Fixed in 9.7.0. Will be delivered as part of B/L 2.0.16.
12813/4490 12815/1350 DSTac01745	Fatal error building transmit frame causes HC to fall out of network	Fixed in 9.7.0. Will be delivered as part of B/L 2.0.16.
12814/ 4491 DSTac01746	HC locks up in nonactive test state	Fixed in 9.7.0. Will be delivered as part of B/L 2.0.16.
13795/ 4646 DSTac01760	In battleshort, DDS (BL 2.1) cannot bootup with NAVSSI interface active	Fixed in 9.7.0. Will be delivered as part of B/L 2.0.16.
13959/ 4694 DSTac01763	Add processing of the FODMS NAVSSI INS Message to DDS Tactical 2.0	AEGIS only. Fixed in 9.7.0. Will be delivered as part of B/L 2.0.16.