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Report to the Subcommittee on Seapower, Committee on Armed Services, U.S. Senate

July 2008

DEFENSE ACQUISITIONS

Cost to Deliver Zumwalt-Class Destroyers Likely to Exceed Budget

GAO Accountability * Integrity * Reliability

GAO-08-804

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Cost to Deliver Zumwalt-Class Destroyers Likely to Exceed Budget

GAO Highlights
Accountability·Integrity·Reliability

Highlights of GAO-08-804, a report to Subcommittee on Seapower, Committee on Armed Services, U.S. Senate

Why GAO Did This Study

In October 2008, the U.S. Navy will begin construction of the first of two lead DDG 1000 Zumwalt-class destroyers—at an expected cost of $6.3 billion. Given the history of cost growth on shipbuilding programs, as well as the Navy's request for approval of a third ship, GAO was asked to assess the progress of the program. GAO examined (1) whether key systems can be delivered on time and work as intended (2) design maturity (3) shipyard readiness and (4) whether lead and follow-on DDG 1000 ships can be built within budget. To accomplish this, our work included analysis of schedules, ship progress reviews and cost estimates; interviews with Navy and other officials; and our own past work.

What GAO Recommends

GAO is recommending

- the design be completed before starting ship construction,
- award of contracts for the third ship be delayed until costs of the lead ship are better understood, and
- the production milestone review be held before contracts for the third ship are awarded.

The Department of Defense concurred or partially concurred with the first and third recommendations. It did not agree to delay the third ship, citing potential cost and other impacts.

This report also contains a matter for congressional consideration aimed at providing additional insight into the program.

To view the full product, including the scope and methodology, click on GAO-08-804. For more information, contact Paul Francis at (202) 512-4841 or francisp@gao.gov.

What GAO Found

From the outset, DDG 1000 has faced a steep challenge framed by technical sophistication, demanding mission requirements, and a somewhat unforgiving schedule. The Navy conceived a thoughtful strategy to meet these demands and has had success with several technologies and its design approach. Yet, the program did not proceed as planned and the Navy recently realigned the construction schedule for the first two ships to provide more time to finish key systems and software. Still, the Navy will produce—and in some cases install—key systems on the ship before fully demonstrating and testing them. Software development has proven challenging; the Navy certified the most recent software release before it met about half of its requirements. At this point—the first year of a 6-year construction schedule for the lead ships—the Navy may have exhausted its options for solving future problems without adding money and time.

The Navy expects to achieve a greater degree of design maturity before starting construction than has been the case on previous surface combatant programs. To meet this goal, the Navy will be pressed to complete a large amount of design work by October 2008 when construction will begin. From August 2007 through May 2008, the shipbuilders finished work on 16 of the 100 design "zones" that make up the ship, leaving 84 zones to finish the final design phases in the 5 months leading up to the start of construction.

Both shipyards that will build DDG 1000 are preparing for construction through facility enhancements and production improvements. However, uncertainty remains. The ship's deckhouse will be built primarily from composite rather than steel and the shipbuilder is still refining the process for large scale composite manufacturing and assembly. Workforce instability could also prevent shipbuilders from fully realizing expected efficiencies.

The full costs of constructing the two lead ships have not been entirely recognized or funded. The risk of cost growth is high in part because of the potential for late delivery of key systems and software and difficulties in constructing and integrating sections of the ship, like the deckhouse. Remaining funds may not be sufficient to buy key components and pay for other work not yet under contract. The Navy has already requested funding for a third ship and plans to contract for this ship with options for four more ships in fiscal year 2009. The Navy will not have enough data then on the actual costs of the lead ships to develop realistic prices for follow-on ships. As currently planned, all ships will be under contract and all but one under construction before the Department of Defense holds the production milestone review in 2013.

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Abbreviations

DOD	Department of Defense
RDT&E	Research, Development, Test, and Evaluation

United States Government Accountability Office
Washington, DC 20548

July 31, 2008

The Honorable Edward M. Kennedy
Chairman
The Honorable Mel Martinez
Ranking Member
Subcommittee on Seapower
Committee on Armed Services
United States Senate

The U.S. Navy aims to begin construction of the first lead Zumwalt-class destroyer (DDG 1000) this year—a major step in its shift to the next generation of warships. DDG 1000 is a multimission surface ship designed to provide advanced land attack capability and contribute to military dominance in the shallow coastal waters known as the littorals. To meet its objectives, DDG 1000 will employ a revolutionary hull design (known as the tumble-home form) and an array of cutting-edge technologies, including a missile launch system lined in the ship's hull, an advanced gun system that fires long-range precision-guided munitions, and highly capable sensors integrated into the sides of a deckhouse made primarily of composite material—not steel. Many of these innovations contribute to making DDG 1000 significantly less detectable than current ships. The Navy plans to achieve these advances while also reducing the crew size to less than half of the predecessor Arleigh Burke-class destroyer (DDG 51) through extensive computer automation. The Navy is investing significantly in the DDG 1000 program—almost $9 billion in research and development and almost $20 billion to design and deliver the seven ships of the class.

Given the challenges associated with developing, designing, and constructing a ship as complex as DDG 1000—including the potential for cost growth, you asked us to examine the program's progress, particularly in light of the start of construction of the two lead ships (DDG 1000 and DDG 1001) and the Navy's request for authorization of the third ship (DDG 1002) in its fiscal year 2009 budget. Specifically, we assessed (1) the Navy's ability to deliver key systems when needed to support lead ship construction and whether these systems will work as intended, (2) the level of design maturity and the obstacles to completing the ship's design as planned, (3) the shipyards' readiness to build DDG 1000, and, finally, (4) the challenges of building the ships (lead and follow-ons) within budget.

To address the first objective, we analyzed key documents, including test plans, test reports, and production schedules and supplemented our analysis by visiting contractors and test sites where the ship's major systems are being developed and tested. To assess design maturity and obstacles to completing the ship's design, we examined the Navy's plans and guidelines for design management and evaluated the program's design progress. We analyzed design maturity metrics captured in the program's integrated master schedule and assessed design performance by analyzing shipbuilder cost performance reports. To examine shipyard readiness, we reviewed key shipyard data, including past construction performance and facility improvement and investment plans. Finally, we examined ship costs by analyzing the budget, Navy and independent cost estimates, and contractor costs. To address all of the above objectives, we held discussions and attended briefings with the Office of the Secretary of Defense, Navy, and DDG 1000 program officials; contractors for the mission systems; and the shipbuilders. We conducted this performance audit from September 2007 to July 2008 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives. Appendix I further discusses our scope and methodology.

Results in Brief

A recent decision to restructure and add 1 year to the program's schedule will provide more time to produce and test key combat systems that will be installed on the lead ships, but calls for doing more work later in construction and after ship delivery. The Navy planned to demonstrate the capabilities of production-representative units of the ship's major systems before installation, an approach aimed at minimizing cost and schedule risk on the lead ship. It has been able to do so for a number of systems. The restructure does not delay the completion of the hull, mechanical, and electrical systems but does delay verifying the performance of the integrated power system, the dual band radar, and software before producing—and in some cases installing—them on the ship. Specifically:

- Land-based testing of the integrated power system will not finish until 2011, over a year after units are installed on the first ship.
- Delays in land-based testing have slipped installation of the dual band radar by at least 3 years. Moreover, the Navy will not demonstrate the full-power output of the radar needed to meet requirements until after testing of the first production unit sometime after 2010.

- Software development—crucial to the automation that enables reduced manning of the ship—has proved challenging. For the most recent software release, the contractor had difficulty coding the ship's command and control component. The Navy certified the release without it meeting about half of the software system requirements, moving work to later releases. Yet the most challenging phases of software development lie ahead. Delays would disrupt plans for activating the ship's critical systems, as well as its combat systems.

The DDG 1000 program is positioned to achieve a greater degree of design maturity before starting construction than has been the case on previous surface combatant programs. However, the shipbuilders may face challenges completing the later, more complex phases of design on schedule. Since August 2007, the shipbuilders finished work for approximately 16 of 100 zones (the individual units that make up the ship's design). The shipbuilders believe that they will complete another 84 design zones by October 2008, when construction of the first ship begins. According to the shipbuilders, a revised schedule allows them to complete design tasks more efficiently. However, delays in the delivery of final technical information for the ship's key systems could prevent the shipbuilders from completing the design according to plan. If the shipbuilders cannot achieve their design goals according to plan, the program may experience design-related cost growth as have previous shipbuilding programs.

Although the shipbuilders are preparing for construction of the lead ships by investing in facilities, uncertainty remains. Both shipyards are preparing for DDG 1000 construction through facility enhancements and production improvements that they believe will increase efficiency. For example, one shipbuilder is building a facility to produce larger steel panels. The other shipbuilder built a new facility that will allow construction of DDG 1000 from fewer, larger units. However, achieving the full benefit of these improvements will depend in part on successful execution of the shipbuilders' optimal construction strategy—which includes the right mix of facilities, workforce, and manufacturing capability. Continued labor instability and potential problems manufacturing the deckhouse could lead to increases in the amount of work involved in lead ship construction. Because DDG 1000 requires a new manufacturing method, projected efficiencies may not be fully realized on the lead ships. In particular, the facility that will manufacture the composite deckhouse was damaged by Hurricane Katrina, and the shipbuilder is still refining the process for large-scale composite manufacturing and assembly. Problems discovered during construction would likely disrupt the ship's construction sequence.

Costs of the DDG 1000 ships are likely to exceed current budgets because the true costs necessary to deliver fully operational ships have not been fully recognized or funded.[1] The lead ships are at risk of cost growth for a number of reasons—including late delivery or problems with the performance of key systems or issues constructing or integrating sections of the ship. For example, if composite manufacturing for the deckhouse takes longer than expected, ship construction would be delayed and costs associated with manufacturing as well as integrating the deckhouse would likely rise. Since there is little margin in the budget, Navy officials have said that funds reserved for buying components of the dual band radar and certain communications antennas in later fiscal years may be needed to support ship construction. If this occurs, additional funds would need to be approved in fiscal year 2010 or later. The Navy has requested funding for the third ship and plans to contract for this ship with options for follow-on ships during fiscal year 2009. By this time, the Navy will have limited data on actual costs for the lead ships and their combat systems. Finally, the program's production decision is slated for 2014—after all but one ship is under construction. Thus, its timing does not allow for insight that could better inform decision makers about follow-on ship costs.

We are making recommendations to the Secretary of Defense aimed at reducing risk in the DDG 1000 program by (1) requiring that the ship's detail design is completed as planned before the start of construction and (2) deferring contract award for follow-on ships until the costs of the lead ship are better understood. We are also recommending that the program hold a Milestone C review in advance of awarding a contract for the third ship. The Department of Defense (DOD) agreed with our first recommendation, reiterating the importance of achieving design maturity. DOD did not agree to hold a Milestone C review, stating that such a review would not provide any additional benefit for the program. We believe that a milestone review provides a consistent framework and documentation that will help decision makers recognize and make any needed adjustments to the program.

[1] Current budgets refer to the Navy's fiscal year 2009 President's budget submission for the DDG 1000 program.

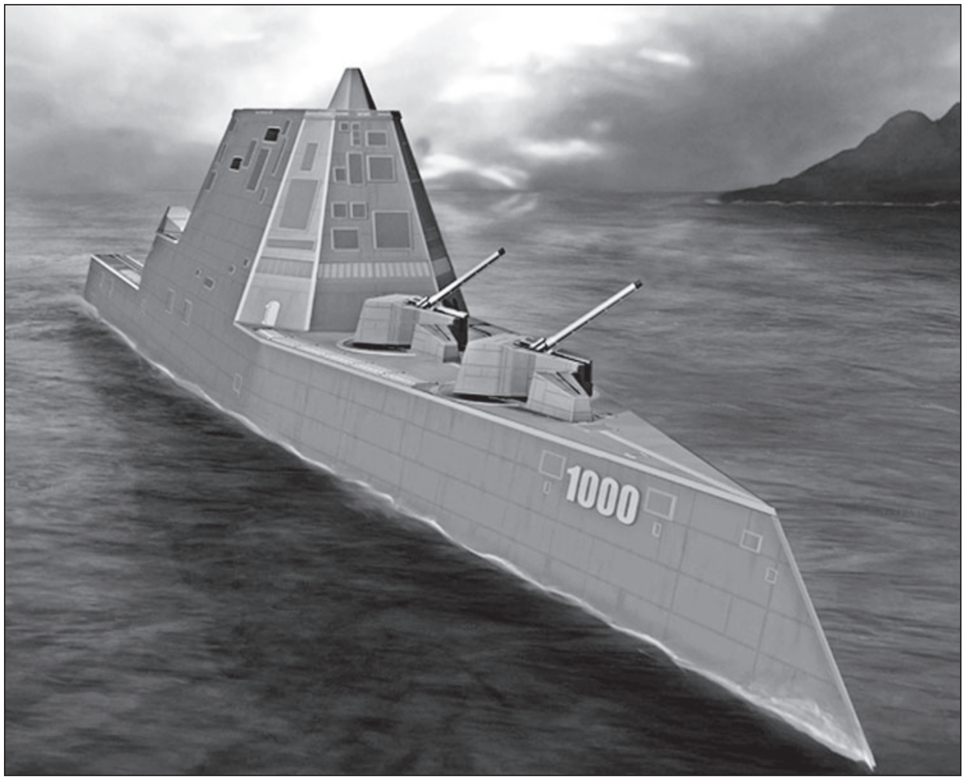
DOD also did not agree with our recommendation to defer the contract award for the follow-on ships, stating that such as delay will impact warfighting capability gaps, cost, and the shipbuilding industrial base. We note that the Navy and DOD are currently considering canceling the third and follow-on ships. This notwithstanding, we believe that the risks of prematurely awarding follow-on ship contracts are considerably higher than any potential cost increase or industrial base effects that could occur as a result of delaying funding for a follow-on ship.

Given the risk of cost growth in the program, this report also contains a matter for congressional consideration to provide more insight into potential cost increases as the DDG 1000 program progresses.

Background

The Zumwalt-class destroyers are designed as multimission surface combatant ships to provide advanced land attack capability to support forces ashore and contribute to military dominance in shallow coastal water environments. Along with nine new ship classes over the next 5 years, the Zumwalt-class destroyers are part of the Navy's planned shift to the next generation of warships intended to complete future mission objectives. The Navy will take ownership of the first two Zumwalt-class destroyers—DDG 1000 and DDG 1001—in 2013 and 2014, respectively. Figure 1 depicts an artist's rendition of the Zumwalt-class ship (commonly referred to as DDG 1000).

Figure 1: DDG 1000 Destroyer Currently in Development



Source: Navy.

The DDG 1000 program has been framed by challenging multimission requirements, resultant numerous technologies, and a tight construction schedule driven by shipyard workloads. The Navy's acquisition strategy for DDG 1000 has changed significantly since the initial concept for the ship in 1997. Over its development cycle, the cost of the DDG 1000 program has increased considerably, while the quantities have been reduced. Currently, the Navy plans for a class of seven ships. The Congress has limited the procurement cost of the fifth ship to $2.3 billion, plus adjustments for inflation and other factors.[2] For a more complete accounting of DDG 1000 program events see appendix III.

[2] National Defense Authorization Act for Fiscal Year 2006, Pub. L. No. 109-163, Div. A § 123 (2006).

Technology Development Approach

Detail design and construction of DDG 1000 was preceded by a technology development phase that continues today. The Navy sees DDG 1000 as the technology driver for the fleet and a bridge to future ship capability. The Navy plans to incorporate 12 new technologies to meet the ship's demanding requirements. To reduce program risk and demonstrate the ship's technologies, the Navy planned to build and test 10 prototypes (referred to as engineering development models) representing the ship's most critical subsystems. Table 1 describes the prototypes.

Table 1: DDG 1000 Critical Technologies

System	Description
Advanced gun system	Will provide long-range fire support for forces ashore through the use of unmanned operations and the long-range land attack projectile.
Integrated deckhouse and apertures	A composite structure that integrates apertures of radar and communications systems.
Dual band radar	Horizon and volume search improved for performance in adverse environments.
Integrated power system	Power system that integrates power generation, propulsion, and power distribution and management.
Total ship computing environment	Provides single computing environment for all ship systems to speed command while reducing manning.
Peripheral vertical launch system	Multipurpose missile launch system located on the periphery of the ship to reduce damage to ship systems.
Integrated undersea warfare system	System for mine avoidance and submarine warfare with automated software to reduce workload.
Infrared mock-up	Seeks to reduce ship's heat signature in multiple areas.
Hull form	Designed to significantly reduce radar cross section.
Autonomic fire suppression system	Intended to reduce crew size by providing a fully automated response to fires.

Source: Navy data.

Prototype development and testing helped to give the Navy confidence in a technology's ability to operate as intended. For example, the Navy successfully demonstrated the advanced gun system through initial guided flight and testing on land. In other cases, such as for the integrated power system, tests brought to light technical problems that the Navy was able to address by going to an alternate technology. However, not all prototypes were completed as planned and development continues even as the Navy prepares for construction of the lead ships. Table 2 provides a status of DDG 1000 prototype development efforts.

Table 2: Prototype Development and Results

Technology	Results
Advanced gun system	Verified gun and magazine response time, rate of fire, range, and pallet unloading rate, and demonstrated complete firing sequence during 2004 through 2005. Separate flight tests demonstrated the long-range land attack projectile munitions to be used by the gun. The gun and munitions were not tested together because of test facility limitations.
Autonomic fire suppression system	Successfully tested on two Navy test ships during 2004 through 2005. Demonstrated system's ability to detect damage and control fires in specific ship environments. With these tests, the Navy designated this technology as fully mature at critical design review.
Integrated deckhouse and apertures	An integrated deckhouse test article was tested in 2005 for radar cross section and to verify that signals from apertures do not interfere with one another. Fire and shock testing of a large-scale test article to verify deckhouse strength was postponed because of uncertainties about the composite material's strength and safety as well as facility delays. This test is currently scheduled to be completed by late 2008, and, if it is successful, the deckhouse will be considered fully mature following analysis of the test.
Dual band radar	Multifunction radar proved clutter rejection and firm track range—key functions required for demonstration—during land-based and at-sea tests from 2004 through 2006; the radar was designated as fully mature following these tests. Volume search radar encountered difficulties with transmit-receive unit; "string" tests demonstrated radar at lower power output than required in 2007 after 1-year delay. Tests of the fully assembled dual band radar were delayed almost 2 years and are currently planned to begin in 2009.
Integrated power system	Turbine generators were factory tested in 2004 and 2005. Permanent magnet motor failed 2005 tests and was replaced by its backup, the advanced induction motor, which was then successfully tested at land-based facility in 2005, allowing the program to pass Milestone B.
Total ship computing environment	First three releases—24 percent of total code—were successfully developed during 2003 through 2005. These releases included critical computing infrastructure functionality needed for the total ship computing environment, as well as limited ship mission functionality.
Peripheral vertical launch system/MK57 vertical launch system	The 2004 test resulted in destruction of the test article, requiring redesign. A second test in 2005 replicated the same conditions with the new design and materials and was successful. Restrained firing tests—proving that the enclosure and launcher can survive an explosion—were postponed and successfully performed in 2006.
Integrated undersea warfare system (acoustic sensor suite element)	Array interference tests were conducted in 2004 at the Navy's Seneca Lake test facility. In 2005, the Navy verified mine avoidance capability during at-sea tests and automated submarine warfare detection and tracking in lab tests, and designated the technology as fully mature by late 2005.
Infrared signature mock-ups	At-sea materials and panel tests followed by design tests were conducted in 2004. Design trade-offs for performance, weight, and cost led to changes in infrared materials used to reduce ship's heat signature. A sheeting water system for the hull was replaced with an alternate system.
Hull form	Scale models were tested during 2004 thorough 2005 for factors like resistance, propeller efficiency, and capsize probability. Scale model tests in 2006 led to design changes to reinforce the hull and deckhouse. Tests continued into 2007 and 2008 and further development is planned through 2015 to develop a "safe operating envelope" to help safely operate the ship in high sea states.

Source: GAO analysis of Navy and contractor data.

Detail Design and Construction

The Navy awarded contracts for detail design in August 2006 and negotiated contract modifications for construction of two lead ships in

February 2008. Construction of the first ship is scheduled to begin in October 2008, followed by the second ship in September 2009.

To build a ship efficiently and stay within budget, the lead ships need to be constructed following an optimal construction sequence. This cost-efficient approach calls for designing and building the ship in modules, maximizing the amount of construction, test, and outfitting completed in shipyard shops and in the dry dock while minimizing work to be performed once the ship is in the water, which tends to be costlier than tasks on land. This sequence is outlined in the shipbuilders' integrated master schedule, which links all of the detailed construction tasks based on key event dates. Shipbuilders try to install the ship's systems in order to take advantage of construction efficiencies. If equipment is not ready in time for installation, the shipbuilder will have to work around the missing equipment. Once units are installed, access to internal ship compartments becomes more difficult. Additional labor hours may be needed because spaces will be less accessible and equipment may require more time for installation.

Contracting Strategy

The Navy's approach to the DDG 1000 program is complex. Since 2006 the Navy has been managing the DDG 1000 program through contracts with four different prime contractors—two shipbuilders are jointly designing and constructing the ships and two system developers are providing combat, communications, and weapon systems as well as the software that will operate and integrate these systems:

- Bath Iron Works is designing the fore and aft of the ship, equaling about 50 percent of the individual design units of the ship, known as design zones. This includes the distributive systems—such as cables and pipes—that pass through the zones. Bath Iron Works will build the first lead ship (DDG 1000) and will build the forward middle section to be integrated on the second lead ship (DDG 1001).
- Northrop Grumman Shipbuilding is designing the deckhouse and ship center (50 percent of the design zones), including the distributive systems that pass through the zones. Northrop Grumman Shipbuilding will build the deckhouse (at its composite facility in Gulfport, Mississippi), hangar, and aft launch system sections to be integrated on DDG 1000 and all ships in the class. Northrop Grumman Shipbuilding will also build the second lead ship (DDG 1001).
- Raytheon is providing most of the ships' electronic systems (combat and communications), including development of the radars and antennas. Raytheon is also responsible for developing the ship's

software system (known as the total ship computing environment)—including defining requirements, design, code, test, and integration.
- BAE is responsible for development, design, testing, and production of the advanced gun system, including gun, automated magazine, and long-range land attack munitions.

Under this contracting arrangement, the Navy is essentially acting as the overall program integrator. Since the shipyards are sharing the design of the ship equally, the Navy manages the overall ship configuration and ensures that the ship's baseline design is aligned across all of the contracts. All of the products produced by the program's prime contractors (including the major systems, as well as sections of the ship) are government-furnished equipment—meaning equipment purchased by the Navy for installation and integration on the ship. As such, the Navy is responsible for the receipt of sections of the ship (such as the deckhouse or mid-fore body) from one shipbuilder and the delivery to the other shipbuilder for integration with the rest of the ship. As a result, the Navy is also responsible for managing the thousands of interface points between the ship's sections to ensure that they are correctly defined.

Delays in Technology and Software Development Pose Risk to Successful Program Execution

Although recent restructuring of the program allows more time for producing, installing, and testing key combat systems and the software that supports these systems, it calls for doing more work later in construction and after ship delivery. While additional time is beneficial, unexpected difficulties in producing systems or getting them to operate as expected would likely result in additional delays and increased costs. Some key systems, including the dual band radar, have not been fully demonstrated as planned. The integrated power system will be produced and installed before land-based testing is complete. This approach increases the risk that problems discovered during testing will require expensive rework to incorporate fixes later on. The most challenging phases of the software development—crucial to the automation that enables reduced manning of the ship—lie ahead, presaged by problems encountered in testing the most recent software release. Delays in software delivery would disrupt plans for activating the ship's critical systems as well as its combat systems and delay delivery of the ship and its combat systems to the Navy.

Recent Adjustments Provide Additional Time, but Many Events Need to Come Together for Success

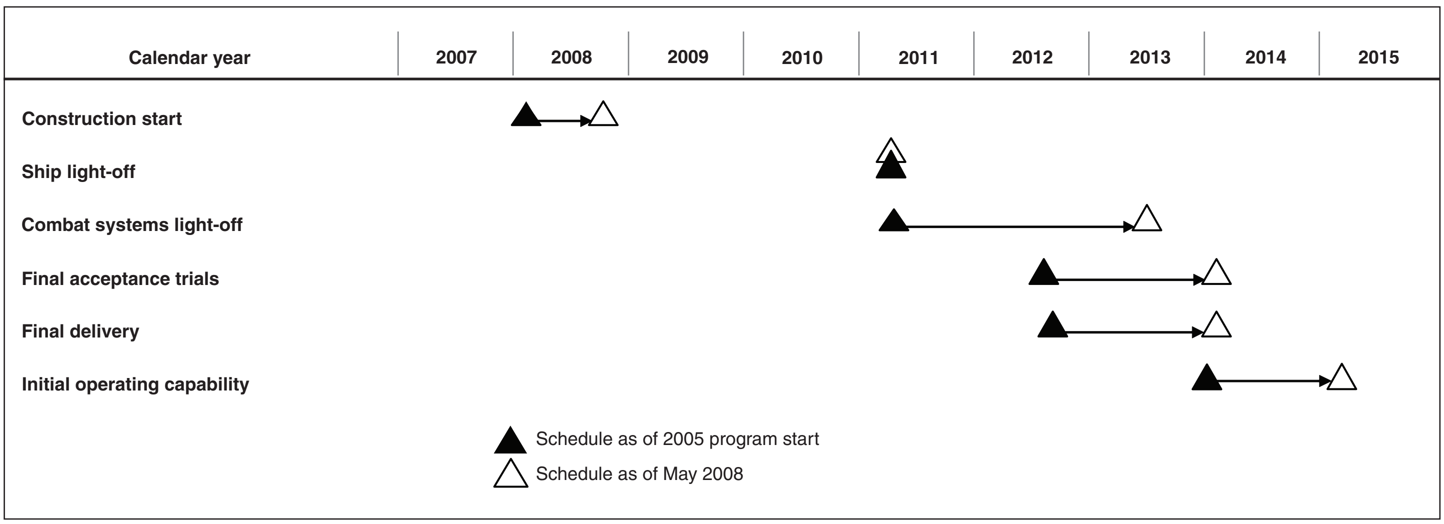
Until recently, Navy plans called for delivery of the first ship in 2012, with initial fielding of the ship (known as initial operational capability) in 2014. According to this schedule, the shipbuilders would begin construction of the first ship in 2008. According to the Navy, this was an important step in managing shipyard workloads as starting later would have caused shipyard workload to drop too low. In order to reduce the risk of cost growth and schedule delay during construction, the Navy planned to demonstrate mature systems before installation on the lead ship. To meet this schedule the Navy laid out a two-stage approach to maturing the key systems. First, the Navy planned to build and test almost all of its 10 prototypes of the key systems before beginning detail design of the ship and, second, planned to transition from development of prototypes to systems integration test and qualification of production units after the program's critical design review in 2005. While this approach was successful on several key systems, the Navy has not been able to develop all key systems as planned—some prototypes still have not completed testing. The Navy chose to move forward into detail design of the ship before demonstrating all technologies. In fact, the Navy continues to shift work—in the form of testing, developing software, integrating subsystems, and actual fabrication—until later stages of design and even ship construction. In these stages, the cost of work and delays is much higher and the schedule less forgiving than in earlier stages of the program.

Following negotiations of the contract modifications for constructing the lead ships, the Navy realigned the program's schedule. While the timing of the start of ship construction remains roughly the same, the Navy changed the definition of what constitutes ship delivery. Rather than delivering a fully mission-capable ship, the Navy stated that it will take ownership of just the vessel and its mechanical and electrical systems—including the power system—in April 2013.[3] At that point, the Navy will have activated and tested the power, mechanical, and electrical systems aboard ship. Under the restructured schedule, the Navy will delay work that typically occurs during construction until after the ship is initially delivered. Specifically, the Navy will light off—that is activate and shipboard test—the combat systems, including the radars, antennas, guns, and the missile launch systems, in May 2013—more than 2 years later than originally planned (see fig. 2). Following combat systems light-off, the Navy will

[3] The Navy describes the delivery in April 2013 as transfer of ownership and hull delivery; for purposes of this report, we refer to this as initial delivery. We use the term final delivery to indicate when ship construction is complete—including the installation and integration of the combat systems.

begin acceptance trials of the combat systems—inspecting these systems and noting any deficiencies that should be corrected. Only at the conclusion of combat system acceptance trials in February 2014 will all of the ship's systems be fully integrated and final ship delivery complete.

Figure 2: DDG 1000 Lead Ship Schedule



Source: GAO analysis based on Navy data.

According to the Navy, conducting light-off in phases allows the program to test and verify the ship's major systems, in particular the integrated power system, in isolation before conducting simultaneous tests with the combat and communication systems. Navy officials stated that this approach will help to reduce the risk that problems with the ship's systems, such as power load or cooling, could damage the combat systems. By delaying these events until after delivery of the vessel, the Navy is using this time to test, produce, and install key combat systems, as well as the software that supports these systems.

Although this approach gives the Navy additional time to mature the ship's combat systems before installation, it may limit its ability to address any problems that may occur as a result of light-off and shipboard testing. Since the Navy will only test and inspect the hull prior to taking ownership of the vessel, it will not have a full understanding of how the ship operates as a complete and integrated system until after final shipboard testing of the combat systems in 2014. Moreover, final delivery of all the ship's software will now occur right before final acceptance trials—compressing the time to address any integration problems prior to initial operation of the ship.

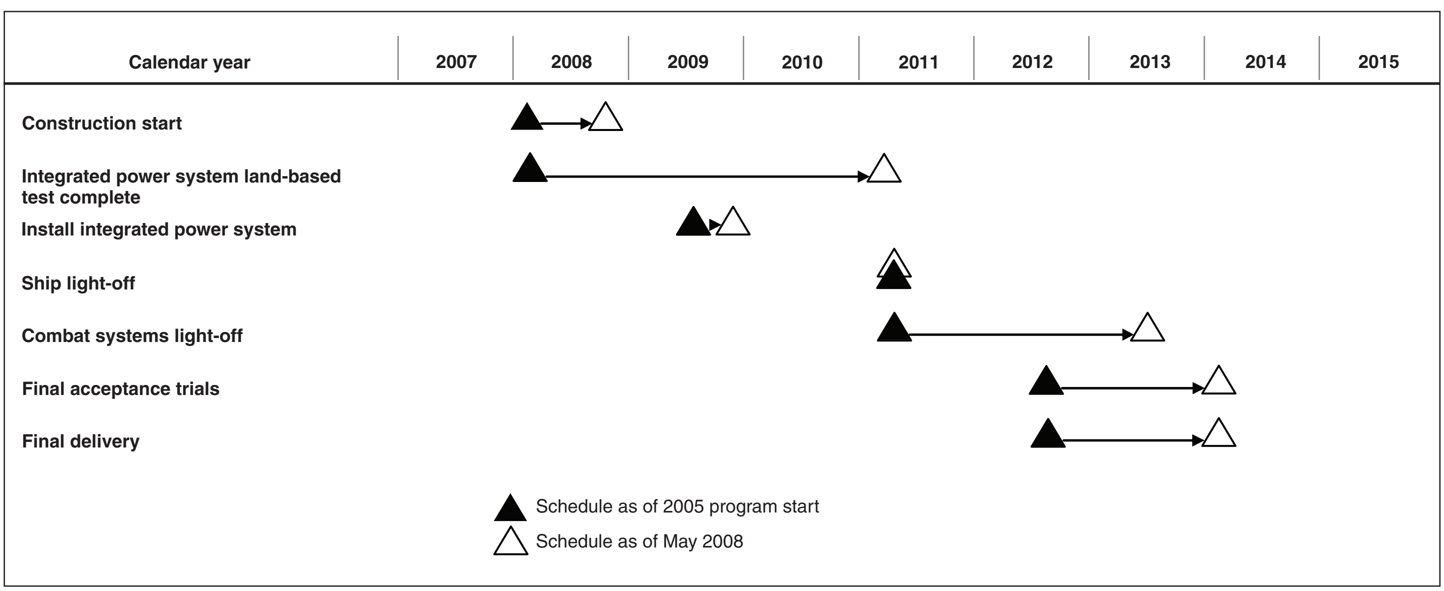
The Navy Will Not Demonstrate All Key Systems Prior to Producing and in Some Cases Installing These Systems

Because of delays in the development of several ship systems, particularly the integrated power system, the dual band radar and the electronic surveillance system, the Navy will not demonstrate integrated systems before installing them on the lead DDG 1000 ship, increasing the risk that problems discovered during testing will require expensive and/or time-consuming rework to incorporate fixes later on.

Integrated Power System

The integrated power system will centrally generate and distribute power for all ship functions, allowing greater flexibility in power use. While the Navy has demonstrated the basic capability of the power generation and distribution systems, tests of a complete integrated power system with the control system will not occur until 2011—nearly 3 years later than planned (see fig. 3).

Figure 3: Integrated Power System Schedule



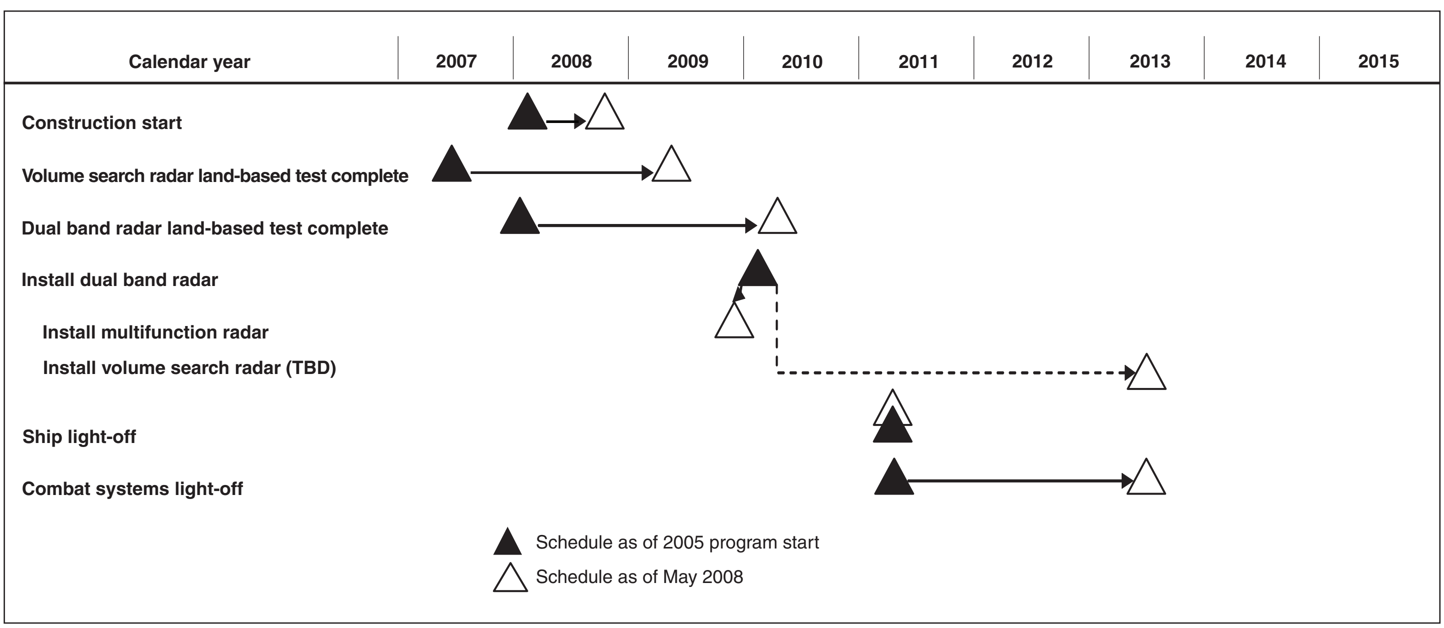
Source: GAO analysis based on Navy data.

The Navy initially planned to verify power system performance through integration tests with the first production unit at a land-based test facility in 2008 before installing the power system on DDG 1000. However, delays in developing the ship's software led the Navy to postpone integration tests by over a year. To deliver the power system on time to meet the shipyard's schedule, the Navy will buy a power system intended for the third ship and use this unit in upcoming tests. As a result, the integrated power system will not be demonstrated until the completion of land-based tests that will occur over a year after the power systems have been produced and installed on the two lead ships.

Dual Band Radar

The dual band radar is made up of two major radar systems, the multifunction radar and the volume search radar. Development and testing of the multifunction radar have progressed further than for the volume search radar. Through testing on land and at sea, the Navy demonstrated the multifunction radar's key functions. In contrast, the volume search radar experienced difficulties during development that still continue. Land-based demonstrations of the volume search radar prototype and the integrated dual band radar originally planned to be done before starting ship construction will not be completed until 2010—almost 2 years later (see fig. 4).

Figure 4: Dual Band Radar Schedule



Source: GAO analysis based on Navy data.

Development difficulties center on the radar's radome and transmit-receive units. The contractor has not yet successfully manufactured the volume search radar's radome—a composite shield of exceptional size and manufacturing complexity—that is necessary to meet radar stealth requirements. The first radome constructed for the volume search radar prototype experienced cracking and delaminating problems stemming from a faulty design. After conducting analysis to determine the root cause, the contractor's second attempt in late 2007 appeared to have solved the initial problems, but new internal cracks were noted, apparently caused by machining difficulties. The Navy is now funding a parallel effort with a second manufacturing source—one that supplied the radome for the much smaller multifunction radar—and will make a decision on the path forward after a June 2008 review. Upcoming land-based tests will be conducted without a radome, and a replacement will not be available until the first production unit of the volume search radar is tested at the factory.

The transmit-receive units—the individual radiating elements that are the essence of the volume search radar—experienced failures during component testing, never reliably operating at the voltage needed to meet range requirements despite multiple design iterations and different suppliers. According to the contractor, the latest test results from January 2008 met performance requirements, but subsequent tests revealed a new issue concerning the heat generated by a component of the transmit-receive unit. The Navy believes that the voltage problem has been resolved and that the fix has been validated in recent tests. However, land-based tests of the volume search radar prototype and the integrated dual band radar will not incorporate the redesigned transmit-receive unit and will not demonstrate the higher-voltage output necessary to meet ship requirements. The contractor does not anticipate testing the volume search radar at the necessary voltage until it produces and tests the first unit at the factory.

Problems with the volume search radar and in constructing the land-based test facility delayed and compressed the production schedule for the dual band radar. Land-based testing of the volume search radar started late and is scheduled to be complete in May 2009. Following the conclusion of these tests, the volume search radar and multifunction radar prototypes will be integrated and tested with their enabling software at the same land-based facility in 2010. However, the multifunction radar will have been produced and delivered to the lead shipyard before the integrated tests are completed. This concurrency introduces additional risk if problems are discovered during testing and components require rework or replacement.

Moreover, delays have led officials to plan for installation of the volume search radar when the first ship is already afloat, a more expensive approach than the original plan of installing the radar as the deckhouse is being completed at the Gulfport facility. Meeting this schedule will also be a challenge; the Navy recently decided to postpone contracting for the major components of the volume search radar until 2010 or later.

Electronic Surveillance System

The Navy has not decided on the electronic surveillance system. This system is part of the deckhouse and will now be installed separately after the first lead ship is initially delivered. The electronic surveillance system provides passive threat detection for ship self-defense and is essential for ship deployment. Existing systems cannot be used because they do not meet the ship's radar cross section requirements. The Navy is hoping to utilize one of two ongoing Navy research and development activities, the multifunction electronic warfare system or the surface electronic warfare improvement plan, but does not currently know when these activities will be completed. Meanwhile, in order to complete deckhouse design, the Navy has allocated space for the electronic surveillance system. The final deckhouse will be delivered with placeholders until a final system is purchased and installed. Continued uncertainty about the electronic surveillance system could ultimately delay ship deployment.

Software Development Faces Challenges and May Not Keep Pace with Ship Integration and Test Schedule

Achieving a high degree of computer automation is crucial to realizing DDG 1000's required manning reductions. Given the risks associated with the ship's software system, referred to as the total ship computing environment, the Navy initially planned to develop and demonstrate all software functionality over 1-year prior to ship light-off, when the ship's systems are turned on for the first time. As a result of changes in the software development schedule, the Navy eliminated this margin. Until recently, the Navy was able to keep pace with its development schedule, successfully completing the first three software releases. However, the Navy is now entering the complex phases of software development, which have proven challenging.

The magnitude and complexity of DDG 1000 software development is unprecedented in Navy ships. Rather than having numerous stand-alone systems, each operated by several sailors, the total ship computing environment will automate and integrate many ship functions. Program officials estimate that the total ship computing environment will consist of 14 million to 16 million lines of code—including about 7 million lines of new and modified code developed in incremental software blocks, currently described as six releases and one spiral. It will be the single most important enabler of the ship's reduced manning requirement. If the ship's software does not work as intended, crew size would need to be increased to make up for any lack of automation.

With release 4, initial functionality of the major ship systems was introduced. While the contractor successfully developed and delivered the first three software releases, it encountered significant problems developing release 4. The contractor delivered release 4 without meeting all requirements and deferred work to release 5, mainly because of issues coding the ship's command and control component—the heart of the ship's decision-making suite. Problems discovered in this release, coupled with the deferred work, may signify larger software issues that could disrupt the development of releases 5 and 6 and prevent the timely delivery of software to meet the ship's schedule.

In fact, the Navy certified release 4 without having met about half of the release's software system requirements. Specifically, approximately 32 percent failed acceptance tests and another 15 percent were not tested in this release.[4] According to the contractor, the main problem area was the command and control component, which represents over one-third of release 4 code. This component repeatedly slipped internal development milestones because of an inability to meet recovery requirements, essentially, the need for software to automatically restart and resume mission activities in the event of a failure. The Navy believes that the causes of the recovery failures are well understood and that fixes to these problems will be incorporated early in release 5 development. However, officials from the Defense Contract Management Agency and the Navy's Operational Test and Evaluation Force believe that the problem is more complicated—the recovery failures were largely driven by problems achieving timely data communication through the Java™ programming language[5] used for much of the ship's software,[6] and were only discovered late in release 4 integration tests when the command and control software was integrated with the rest of release 4 code. The contractor has also

[4] The system requirements are made up of 978 verification items, of which nearly 40 percent either failed acceptance tests or were not tested in this release.

[5] JAVA is a trademark or registered trademark of Sun Microsystems, Inc. in the United States and other countries.

[6] The Defense Contract Management Agency provides contract management and surveillance. The Navy's Operational Test and Evaluation Force provides independent evaluation of the operational effectiveness and suitability of Navy programs. These agencies provide periodic, independent evaluations of the DDG 1000 program's progress.

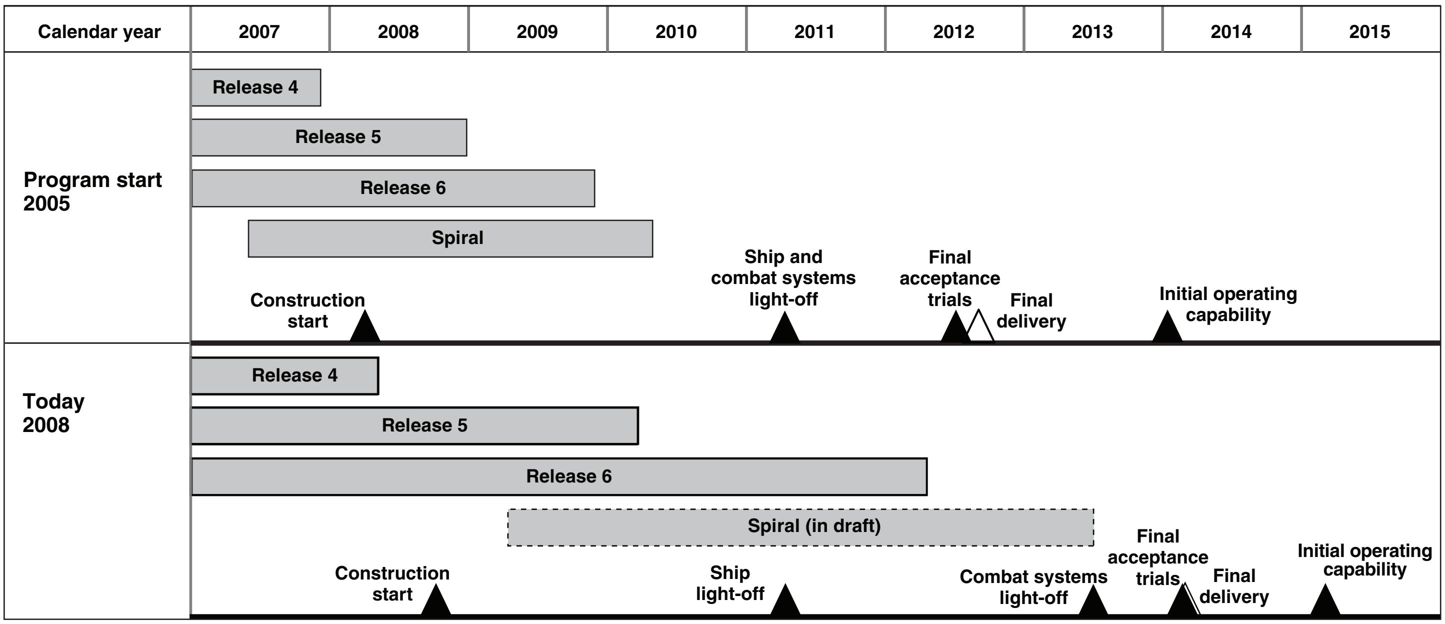
recognized that Java performance problems contributed to the recovery failures. The program has had data communication difficulties with this programming language since 2003.

Initial comments from the Navy's certification panel[7] for release 4 gave the program high marks in several areas, including identifying errors early and building a strong validation and verification capability. At the same time, the certification panel commented that the functionality in the next release will present challenges.

In order to mitigate program risk, the Navy's initial plan from 2005 envisioned developing all ship software by 2010—approximately 1 year before ship light-off. This schedule would give developers time to conduct integration tests to verify that the software would work with the ship's mechanical and electrical systems as well as combat systems before light-off. If any software problems were discovered during testing, the program would have had time to incorporate software fixes before and after ship light-off—but well before delivery. The Navy still plans to conduct integration tests with the ship's software at land-based test facilities. However, as a result of five software schedule revisions over the last 2-1/2 years, the Navy now plans to complete delivery of the software later in the ship's build sequence, as shown in figure 5.

[7] The certification panel is made up of technical experts from within the Navy.

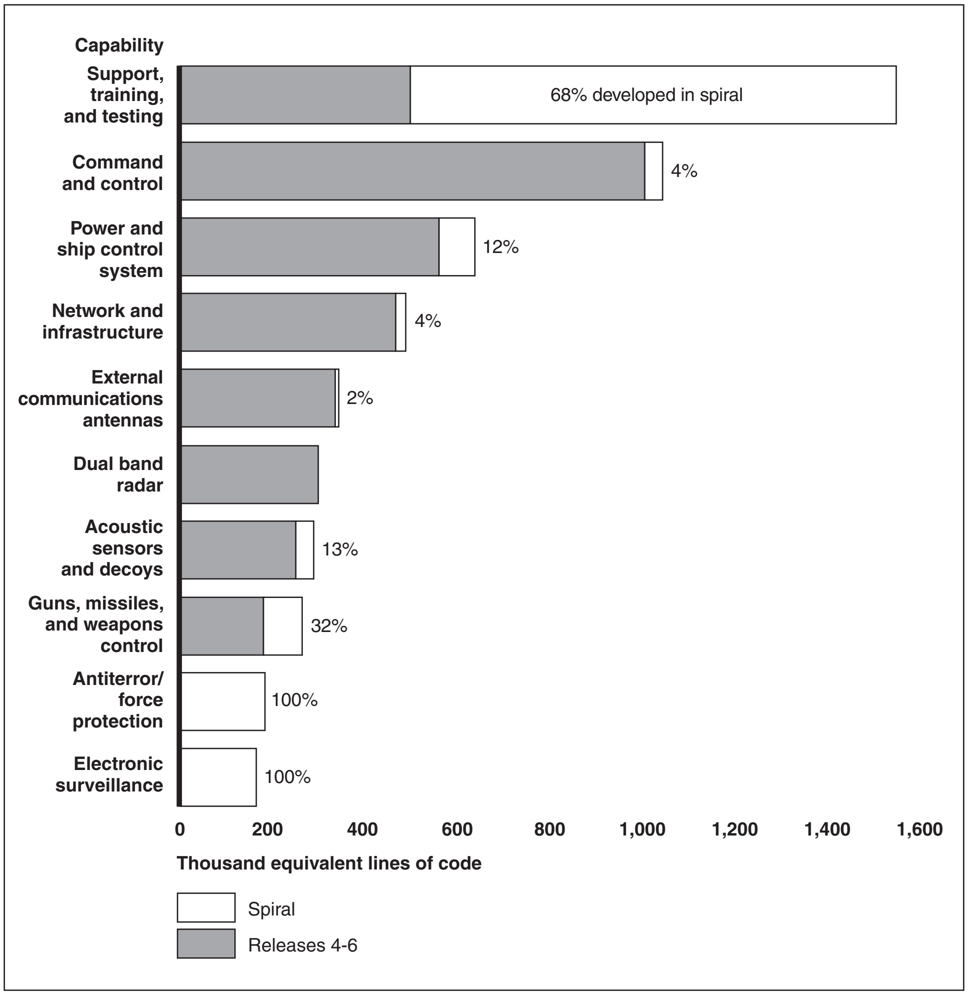
Figure 5: Total Ship Computing Environment Schedule



Source: GAO analysis based on Navy and contractor data.

Release 6, which contains critical engineering control system software, has been delayed by 28 months and will now arrive in 2012, nearly 1 year after ship light-off in 2011 when the ship's power and electrical components are turned on and tested on board the ship. While the engineering control system software will be tested with the power system at a land-based test facility in the months prior to ship light-off, the software will not yet be integrated with the rest of release 6 code at this time. Instead, the Navy plans to conduct ship light-off using interim engineering control system software while concurrently integrating the code into release 6. If problems are discovered in the engineering control system software during release 6 testing, not only could ship light-off be delayed but ultimately delivery of the ship could be delayed as well. Moreover, as early as the program's 2005 critical design review, the Navy recognized that all software code needed to meet requirements would not be completed within the six releases. Instead, the Navy added another block, or "spiral," of software development. According to the Navy, approximately 25 percent of the total software effort will be developed outside of the six software releases. As figure 6 illustrates, a number of important ship functions will not be integrated with the total ship computing environment within the six releases.

Figure 6: Total Ship Computing Environment Releases



Source: GAO analysis based on Navy and contractor data.

For example, software that automates the electronic surveillance and antiterror/force protection systems will be integrated into the ship's software after the ship has already been initially delivered.[8] This software, as well as the final software spiral will not be installed until shortly before combat systems light-off. Further, in 2005, the Navy's Operational Test and

[8]The antiterror/force protection requirement was added in 2005, after the Congress required the Navy to protect ships from close-range terror attacks such as the one on USS *Cole* in Yemen in 2000.

Evaluation Force raised concerns that the Navy would increase the risk that critical defects may go undetected until after the ship is delivered by sacrificing software integration testing for the sake of schedule—concerns that continue to be raised in current assessments of the program. The contractor has reduced software integration test runs by 20 percent in release 4 through consolidating test procedures in an effort to save costs. The Navy, however, believes that this approach appropriately balances these risks and states that these reductions avoid redundant testing.

The Navy Is Emphasizing a Mature Design on DDG 1000, but Timely Completion Will Be Challenging

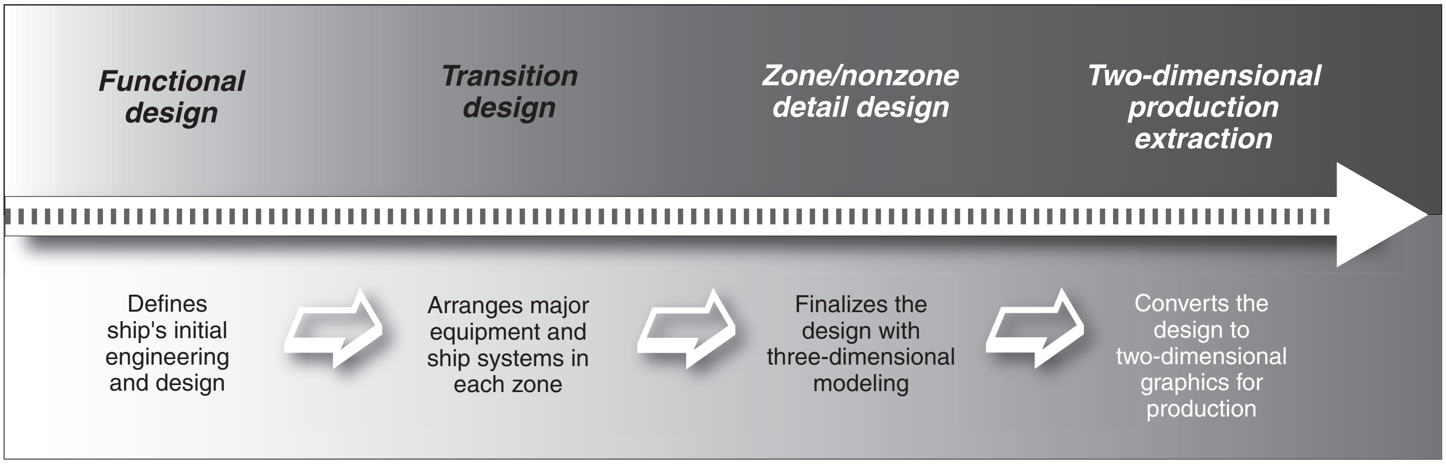
The Navy recognizes the need to mature DDG 1000's design before beginning ship construction and plans to have a more complete design than previous surface combatant programs. The Navy finished the initial phases of design development, and the shipbuilders are currently developing the individual zones of the ship's design. However, the program faces challenges completing the core of detail design: product modeling of the ship's zones. In March 2008 the shipbuilders revised the design schedule to better manage the design work remaining. While the shipbuilders believe they can finish the design of most of the ship's zones by the start of ship construction, there are a number of challenges in meeting this schedule. In particular, delays in the development of the ship's key systems could impede completion of the design and eventually interfere with DDG 1000 construction. If the delays continue, the shipbuilders may not finish all modeling prior to the start of lead-ship construction, placing the program at greater risk for costly rework and out-of-sequence work during construction.

The Navy Is Emphasizing Greater Design Maturity Prior to Starting Construction Than in Previous Shipbuilding Programs

The Navy aims to have 85 percent of all detail and manufacturing drawings complete by the start of lead ship construction—significantly more than in previous surface ship programs. In contrast, the DDG 51 program had only 20 percent of necessary design and manufacturing products finished before the start of construction, and the first Littoral Combat Ship (LCS 1) had less than 25 percent complete. According to the Navy, the DDG 1000 program is modeling the Virginia-class submarine program that had its design matured prior to the start of construction, thereby reducing cost growth related to design immaturity.

The DDG 1000 program has already completed most of the initial two phases of the ship's design (see fig. 7).

Figure 7: DDG 1000 Detail Design Process



Source: Navy and shipbuilder data.

Since 2007, the shipbuilders have been using a computer-aided design product model to work on the details of the 100 individual zones that constitute the ship, the heart of detail design.[9] The product model is shared between both shipbuilders and provides transparency in the designs at both shipyards, as well as access to the Navy to conduct design reviews. The product model generates a detail design, allowing engineers to visualize spaces and test the design. This validates elements of the design prior to construction, thereby avoiding potentially costly rework.

During product modeling, the designers finalize the interfaces between zones, complete the design for shipwide cables and pipes, and add all detail necessary to support manufacturing of the ship. The Navy assesses the progress of each zone when it is 50, 70, and 90 percent complete with product modeling. At these critical reviews, the Navy and other stakeholders review the zone design as it progresses and provide input to ensure that the design meets specifications. At the completion of zone design, the design is converted to drawings used for construction.[10]

[9] The product model uses a shared server managed by Northrop Grumman Shipbuilding with contract requirements for equal server availability at both shipyards.

[10] The two-dimensional drawings include build strategies, construction drawings, and final lists of needed construction materials.

Following the construction contract negotiations, the Navy revised the detail design schedule to better ensure that the design was largely complete by the ship's final production readiness review in October 2008. According to the shipbuilders, the revised schedule moved design work to fit a more achievable timeline and realigned work to recognize that the first ship would be built at Bath Iron Works rather than Northrop Grumman Shipbuilding as initially planned. The program aims to have all but 15 design zones essentially finished with product modeling by construction start in October 2008, which should help to mitigate the risk of the design-related cost growth that has occurred in shipbuilding programs.

Shipbuilders Experienced Design Delays Early in Product Modeling

Thus far, the Navy has not been able to meet its initial detail design schedule. The Navy aimed to have essentially completed 82 zones by March 2008, but only finished 12. The Navy and shipbuilders have cited a number of causes for these schedule delays, discussed in detail in table 3.

Table 3: Challenges Faced by Shipbuilders in Meeting Detail Design Schedule

Challenge	Description
Latency and stability issues with the design tool	The modeling software has not been able to efficiently accommodate the complexity of the design because of the large volume of information it generates. Problems with the modeling software have delayed detail design. For at least 7 months, computer downtime at one shipyard consistently resulted in the loss of at least an hour of work per person per day because of system failures, inconsistent software behaviors, and more than double the anticipated time taken for data to be stored in the database. Since some of the problems are due to the complexity in the design, the shipbuilder estimates that the unfavorable performance with the design tool will likely continue to negatively affect the design schedule as modeling complexity increases. As the models grow in complexity and size they will continue to stress the system. The shipbuilders believe that they are taking actions to improve the latency in the design tool; these actions include software upgrades, hardware upgrades, and process improvements.
Understaffing at one shipyard	One shipyard experienced slow hiring during the beginning of the detail design phase, and it had to outsource some engineering tasks because of its inability to hire.
Delays incorporating changes to the design specifications	The product modeling tool allowed shipbuilders to discover design problems early in design development, but any changes that altered the ship's specifications required formal Navy approval. In addition, a number of interfaces for key systems were not available during initial design phases, so the shipbuilders had to use surrogate data where information did not exist. As the systems matured, any space, weight, power, or cooling changes also required formal Navy approval. The process to receive Navy approval and incorporate the changes into the design took longer than anticipated—sometimes as long as 4 to 6 months.
Missing technical Information for library parts	Late technical diagrams and calculations delayed interface specifications and space dimensions needed for the shipbuilders to issue final library parts—the individual pieces of equipment and material within the design zones. The shipbuilders had to create temporary library parts when none existed in order to proceed with ship design products.

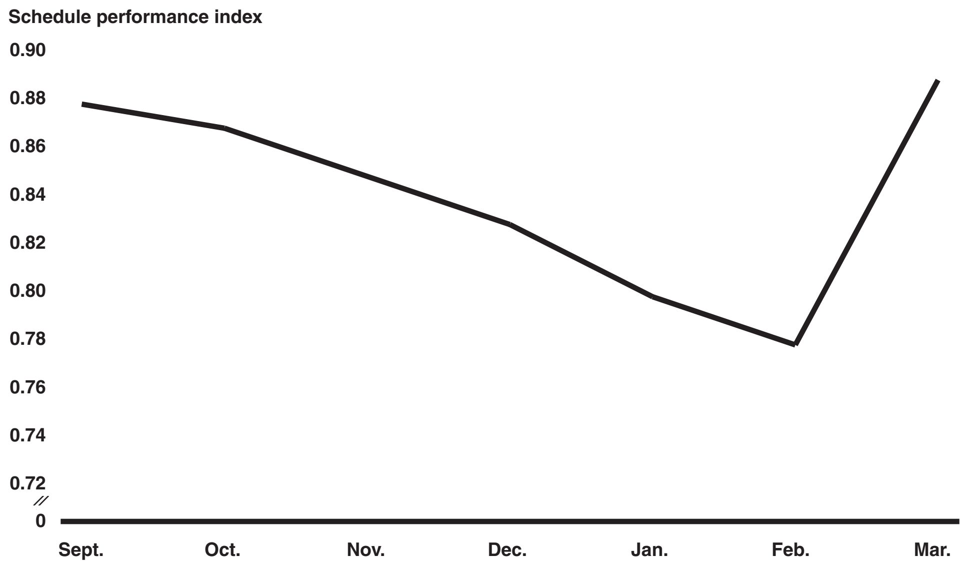
Source: GAO analysis of shipbuilder data.

Cost performance reports from both shipyards indicate that until the recent schedule revision, the shipbuilders have not been able to complete the product modeling work as planned. Performance in product modeling is a leading indicator for the overall detail design effort for two reasons. First, product modeling in zone design accounts for almost half of the total planned labor hours in the detail design contract. Second, of the remaining labor hours in detail design, about 65 percent are planned as "level-of-effort" tasks, for which performance equals scheduled tasks and no schedule variances can occur.[11]

[11] These tasks are general or supportive in nature and do not produce definite end products or results. Performance of these tasks is not an accurate gauge of the overall design effort; since level-of-effort tasks assume that staff will attain expected results, performance equals the scheduled cost for those tasks and no schedule variances can appear to occur. See Department of Defense (DOD) Earned Value Management Implementation Guide § 2.2.3.4.3 (Oct. 2006).

Using data from cost performance reports, we analyzed the shipbuilders' schedule performance in product modeling according to a schedule performance index that measures the value of the work completed against the work scheduled (see fig. 8). If a schedule performance index is less than 1.00, then less than a dollar's worth of work has been completed compared with a dollar's worth of the work that was scheduled.[12] Over a 7-month period, the Navy received an average of less than 84 cents worth of scheduled work for every dollar planned.

Figure 8: Detail Design Schedule Performance



Source: GAO analysis of shipbuilder data.

Note: The shipbuilders believe that performance is understated because work done on changes had not been recognized in the baseline.

The shipbuilders believe that the March 2008 revised schedule will enable them to complete the design according the new schedule. While the progress of the product design model itself has not changed, the revised schedule has realigned the planned work more closely with actual progress, which explains the improvement in the performance index from February to March 2008. A revised schedule will only show a temporary improvement unless it is backed up with sustained progress. Thus, if the

[12] For example, if the scheduled work for a period of time included the tasks leading up to a 90 percent review but not all of these tasks were actually completed during this period, the scheduled performance index would be less than one.

shipbuilders cannot complete design work according to the new schedule, performance will again erode.

The Shipbuilders Will Face Challenges Completing the Design to Meet the Construction Schedule

The shipbuilders will face challenges completing the final complex product modeling stages according to the Navy's plan. The program is now entering the more difficult final product modeling phases—when the details of the design must be finalized to support constructing the ship. Most design zones have passed the 50 percent milestone review, and shipbuilders are now primarily working on the design activities that occur when the zone is from 50 to 90 percent complete. As shown in table 4, the second half of zone product modeling contains more detailed design tasks; in addition to completing all interfaces, detailed system arrangements, and pipe and cable routing, the shipbuilders must finalize and incorporate all outstanding data from the key systems. When the zone is 90 percent complete it is considered essentially finished with detail design—all prior review actions must have been incorporated into the design and the zone must be completely outfitted and considered ready for production.

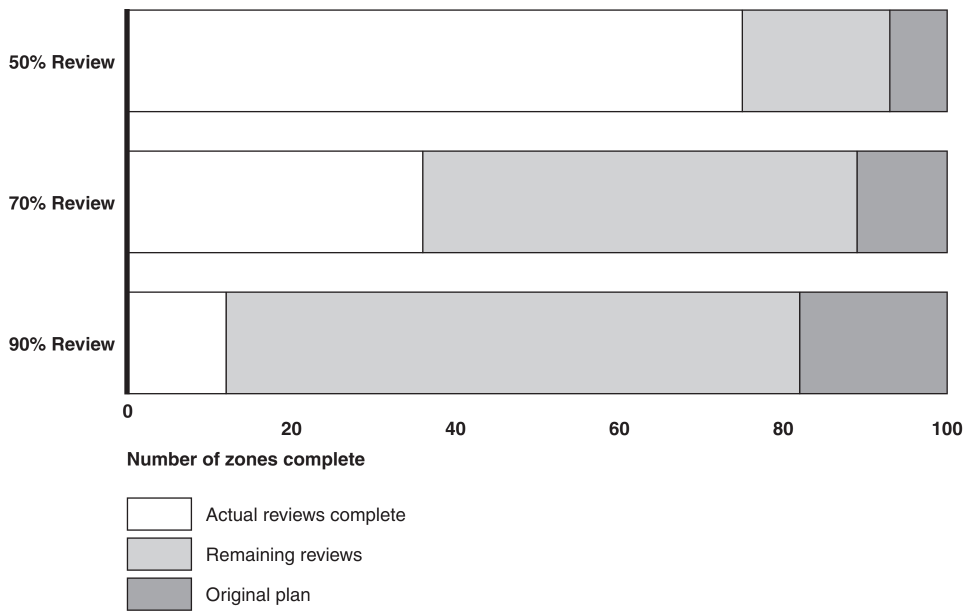
Table 4: Design Activities at Stages of Zone Progress

Percentage complete	Required design activities
50 percent	Major arrangements, primary structure, major distributive systems • Passageways have been defined • Foundational design is complete • Major arrangements are defined
70 percent	Remaining distributive systems • Distributive systems are routed • Large-size pipe work and cableways are identified and modeled • Hull items are modeled • Removal routes are known • Penetration requirements for system interfaces are updated
90 percent	Essentially complete model content • Any remaining distributive systems are fully completed • Design zone is completely outfitted • One hundred percent of all critical system information is delivered • All interfaces are defined • Formal handoff for final quality assurance check before production

Source: Navy and shipbuilder data.

The shipbuilders have had difficulty completing these tasks. In some cases, they did not anticipate the substantial amount of work required after 70 percent of the zone was complete. As shown in figure 9, since starting zone design in August 2007, 70 fewer zones than initially planned had passed the 90 percent review by March 2008.

Figure 9: Zone Milestone Review Progress (as of March 2008)



Source: GAO analysis of shipbuilder and Navy data.

Despite revising the design schedule, the shipbuilders still have a significant amount of design work to complete in a short amount of time. The shipbuilders now aim to complete product modeling in 84 additional design zones by October 2008 to meet the Navy's current schedule.[13] This could be a difficult goal to meet, since the shipbuilders already delayed the same tasks for most design zones by an average of more than 4 months and now have a compressed amount of time in which to complete the final tasks needed in order to meet the target dates for production.

Key System Delays Could Impede Final Design Phases

The Navy is required to deliver technical information to the shipbuilder, including cooling and power needs, space and weight requirements, and electrical interface data of various technology-dependent systems. Without this information, the shipbuilder cannot complete the design of the ship. Because key systems are in development at the same time as the shipbuilders are working on the detail design, the technical information needed for design has not been available when needed and the design schedule may continue to slip if there are delays in the delivery of

[13] As of May 2, 2008, the Navy had completed 16 out of the 100 design zones.

technical information. Since some of the ship's key systems were still immature when detail design began, much specific technical information was not yet known and only general parameters, such as space and weight requirements, could be established. In order to meet the overall ship schedule, the Navy developed a system of incremental "drops" of technology information, in which the shipbuilders and contractors exchange data requirements of increasing complexity at specific times to support design development. However, the development schedule for some key systems has already slipped, resulting in late drops of technical information to the shipbuilders and delays to the design schedule. For example, most design zones have been affected by missing interface data for cables that are attached to key systems. Further delays in completing tests for critical systems, such as the dual band radar, could continue to delay the delivery of technical information about these systems to the shipbuilders. If delays occur, the shipbuilders may not be able to complete the design zones as planned.

Some of DDG 1000's key systems, such as the integrated power system and dual band radar have not completed testing. Problems discovered in testing may lead to redesign, which could result in changes to sections of the ship. For example, testing using models revealed weaknesses in the ship's hull form in extreme sea conditions. According to Navy officials, this led to design changes with additional stiffeners added to the ship for increased stability. In addition, since the Navy has not defined the electronic warfare system, its final interfaces with the ship are not yet known. While the shipbuilders have space reserved for the system, its specifications may change once its physical characteristics are defined. As the technologies continue to mature, these changes and subsequent delays could continue.

Design Maturity Is Essential to Achieving Program's Cost Goals

If the shipbuilders cannot achieve their design goals according to plan, the program may experience the same design-related cost growth that has been common in other shipbuilding programs.[14] Programs that did design work concurrently with construction were later forced to conduct work out of sequence, devote additional labor hours responding to design changes, or perform rework at the shipyard. For example, CVN 77, the final aircraft carrier of the Nimitz class, required concurrent design,

[14] See GAO, *Defense Acquisitions: Improved Management Practices Could Help Minimize Cost Growth in Navy Shipbuilding Programs*, GAO-05-183 (Washington, D.C.: Feb. 28, 2005) and *Defense Acquisitions: Realistic Business Cases Needed to Execute Navy Shipbuilding Programs*, GAO-07-943T (Washington, D.C.: July 24, 2007).

planning, and production activities. Additional labor hours were spent responding to design changes, which ultimately affected cost and schedule. Similarly, when construction of DDG 91 and DDG 92 began, critical technologies were not mature and significant details of the design had not been captured. As a result, workers were required to make significant structural changes to 26 of the ship's 90 design zones. In contrast, the DDG 1000 program is planning to essentially complete detail design before beginning construction, but faces much work ahead to achieve this goal. Moreover, development of key systems such as the dual band radar and integrated power system will continue well into construction, creating the risk of costly design changes later.

Despite Planned Improvements, Shipyard Facility, Labor, and Manufacturing Issues Could Affect Construction of the Lead Ships

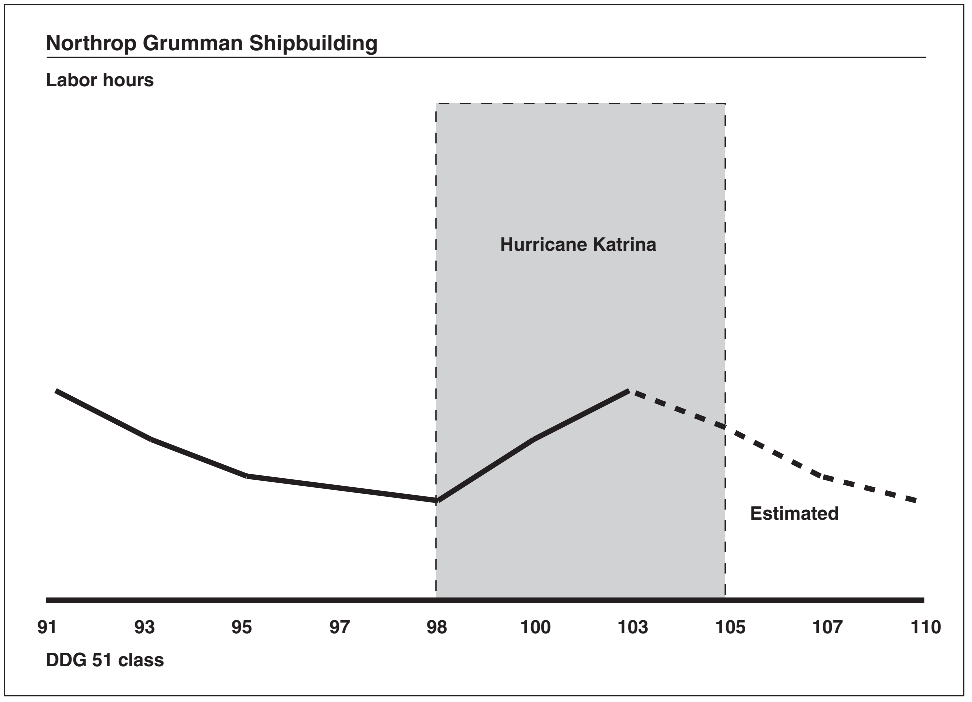
Although the Navy and the shipbuilders are attempting to reduce the risks associated with lead ship construction, considerable uncertainty remains. Both shipyards are preparing for DDG 1000 construction through facility enhancements and production improvements that they believe will increase efficiency. In order to balance the risk associated with constructing the lead ships, the shipyards are building test units designed by each other's yard. While these efforts will certainly build confidence, executing the plan will be challenging. In order to deliver DDG 1000 with its promised capabilities and within planned costs, the shipbuilders need to successfully execute the optimum construction sequence—which includes the right mix of facilities, workforce, and manufacturing capability. Continued labor instability and potential problems manufacturing the deckhouse could lead to increases in the amount of work involved in lead ship construction.

Shipbuilders Expect Investments in Facilities and New Design Features to Improve Efficiency during Construction of DDG 1000

In order to balance the risk associated with constructing the lead ships, the Navy and the shipbuilders are taking steps to prepare for construction. Investments in upgraded facilities, production pilots, and new design features are expected to make DDG 1000 easier to construct than previous ships.

Both shipbuilders have invested in new facilities that the companies believe will improve efficiency during DDG 1000 construction. At Northrop Grumman Shipbuilding, many of the shipyard's facilities were damaged or destroyed by Hurricane Katrina and ships under construction in the yard and labor productivity were affected, including construction of the DDG 51 class (see fig. 10). While estimates indicate that performance has not yet returned to pre-Katrina levels for all DDG 51s currently under construction, the shipbuilder believes that reductions in labor hours will be achieved with construction of its final DDG 51-class ship (see fig. 10).[15]

Figure 10: Northrop Grumman Shipbuilding Productivity Constructing DDG 51 Class (as of January 2008)



Source: Navy data.

Note: Actual labor hours are not computed because data may be proprietary.

According to Navy officials, the shipbuilder is taking advantage of opportunities to improve its facilities as it rebuilds and repairs the shipyard. Expansion of the facility where the shipbuilder manufactures steel panels and other upgrades is underway. The shipbuilder expects to first use these facilities to construct a DDG 1000 test unit in June 2008.

At Bath Iron Works, a new facility known as the Ultra Hall and a new transportation process will allow the shipbuilder to assemble larger manufacturing units than its prior processes. The facility was finished in February 2008, and the shipbuilder believes that efficiencies will be

[15] According to the shipbuilder, DDG 51-class ships currently under construction include 103, 105, 107, and 110.

achieved on construction of its last three DDG 51-class ships. These ships are expected to be erected from just 11 units compared with the 43 units that were erected to build the first DDG 51. Bath Iron Works plans to erect DDG 1000 from 9 units—2 fewer units than the shipbuilder's final DDG 51 ship—which is significantly smaller than DDG 1000.

The Navy and the shipbuilders have recognized that building DDG 1000 using a design shared between shipbuilders carries some risk, and initiated measures to build confidence in preparation for ship construction. The shipbuilders will construct units to test production processes and demonstrate capability to build the other shipyard's design. The test units—called advanced machinery blocks—are intended to demonstrate detail design and production processes, material costs, and craft labor actual costs. While these demonstrations are important tests of DDG 1000's build strategy, the shipbuilders are not scheduled to complete all units until November and December 2008, after they plan to start lead ship construction.

In addition, the shipbuilders and the Navy expect a number of new design features will improve the producibility of DDG 1000 compared to that of previous ships built:

- **Increased rafted machinery**. Machinery will be assembled into a single module (raft) and the raft will be installed on board the ship, instead of attaching individual pieces of machinery directly inside the ship. This allows pre-outfitting and test and supports more efficient installation; a 9,500 labor hour reduction is expected.
- **Increased deck height**. Three-meter deck height allows for less congested outfitting with straighter pipe runs and fewer holes for distributed systems, as well as an easier prefabrication process.
- **Bundled distributed systems**. Use of cableways allows work to be done in the shops instead of on board the ship. In conjunction with increased deck height, the bundling reduces interferences with ship structure; a 46,000 labor hour reduction is expected.

Shipyard Labor Instability and Difficulty in Manufacturing the Composite Deckhouse Could Disrupt the Ship's Optimum Construction Sequence

While capital investments and new design features may result in improved construction efficiency, achieving the full benefit of shipyard improvements will depend on successful execution of the optimal construction sequence, which must be supported by facilities that can manage construction capacity and new manufacturing methods. Labor instability at the shipyards and uncertainties associated with manufacturing the new composite deckhouse may affect execution of an optimum construction sequence.

Labor Instability

Shipbuilders emphasize that an experienced and stable workforce leads to better quality, higher productivity, and ultimately lower production costs. However, if current workforce trends continue, cost and schedule targets for the construction of DDG 1000 may be affected.

Bath Iron Works is a smaller yard, highly dependent on the DDG 51 class. Therefore, the company has less flexibility to absorb workload shifts before needing to initiate layoffs. A number of its most experienced workers are nearing retirement and, thus, if laid off would be less likely to return to the shipyard when business conditions improve.

Northrop Grumman Shipbuilding has made progress in recovering from the effects of Hurricane Katrina, but the shipyard continues to struggle with worker attendance and attrition rates—resulting in a less experienced and less efficient workforce. Trends in attendance and attrition at the Northrop Grumman shipyard have moved in a positive direction; average attendance is up from 34 to 36 hours per week and average monthly attrition rate has improved from 1.7 to 1.0 since 2006. Nevertheless, the workforce is still working at less than 40 hours a week on average and the shipbuilder continues to compete for critical craft labor with rebuilding activities in the region.[16] Less experienced workers require more time to complete tasks with additional labor hours spent on rework. If workforce instability continues, DDG 1000 construction performance will likely be affected, ultimately leading to higher labor hours and increased costs.

Furthermore, Northrop Grumman Shipbuilding may not have enough workers to meet its demand. Including DDG 1000, the shipbuilder will

[16] According to the shipbuilder, the composite facility—located in Gulfport, Mississippi—can compete more effectively in the area economy for workers because it is air-conditioned, providing a favorable environment.

have at least nine hulls (from five different programs) in its shipyard when construction of DDG 1001 is scheduled to begin in September 2009. The choices the shipbuilder will have to make to balance its workload could have negative affects on DDG 1000 construction. In order to manage its construction schedule, Northrop Grumman may choose to make greater use of overtime hours, though in the past, programs that have made significant use of overtime faced additional cost increases because overtime rates are higher than normal hourly wages. The shipbuilder could also decide to outsource work in order to meet demand. Last fall, the shipbuilder (with approval from the Navy) moved construction of portions of the LHA 6 amphibious assault ship from Pascagoula to Northrop Grumman Newport News, illustrating a challenge to managing existing work in the yard.

Composite Deckhouse Manufacturing

The DDG 1000 composite deckhouse design requires an expanded manufacturing capacity and a new manufacturing method that is not yet fully mature. While the Gulfport facility has manufactured composite for several Navy ship classes, the combination of materials that will be used on DDG 1000 is unique.[17] Moreover, the shipbuilder has never built a composite structure to the scale of the deckhouse before. Finalizing deckhouse manufacturing and assembly processes and ensuring that rigorous quality controls are in place are essential to constructing and delivering the deckhouse as planned.

The Gulfport facility was severely affected by Hurricane Katrina and repairs have been extensive. In addition, facility upgrades are necessary to meet DDG 1000 demand. Because of the size of the deckhouse, a large new bay is needed for assembly. Facility and machinery upgrades necessary to construct and assemble the deckhouse are not all scheduled to be complete until March 2010—over a year after the start of construction of the first deckhouse. Northrop Grumman Shipbuilding expects to complete efforts by the time the upgrades are needed in the deckhouse construction schedule. However, if difficulties with composite manufacturing occur, the deckhouses may not be delivered to the shipyards on time, disrupting the construction sequence of the ships.

[17] The facility has previously manufactured the hulls of decommissioned Osprey-class coastal mine hunters and the mast for a Spruance-class destroyer, and is currently manufacturing the masts for the San Antonio-class amphibious ships (LPD 17).

Northrop Grumman Shipbuilding has yet to finalize deckhouse manufacturing and assembly processes. Research and development efforts were undertaken to assess the feasibility of using composite material in the deckhouse. A number of test articles were built, including a section of the deckhouse that was full scale and one face (side) of the deckhouse that represented the most complex panel. Development efforts continue as the shipbuilder has been changing the manufacturing processes for deckhouse production and manufacturing test articles to validate them. These include

- changes to the formula of resin that binds the composite material to improve flow,
- reduction in panel thickness to meet weight specifications, and
- determination of processes to join composite panels together and join them with the steel foundation of the deckhouse.[18]

Process changes are being validated through production and inspection of a series of test units, culminating with the construction test, and inspection of a large-scale prototype. According to the shipbuilder, this prototype is being manufactured to the same thickness and other specifications of the deckhouse. The Navy will not have final validation of the manufacturing processes for deckhouse construction until after construction, inspection, and shock testing of the large-scale prototype. However, test and inspection activities are not scheduled for completion until after the deckhouse production readiness review in September 2008. Problems discovered during testing and inspection may require additional changes to manufacturing methods. Further, the shipbuilder has not finalized the quality assurance standards for production of composite panels manufactured for DDG 1000. The shipbuilder is adapting the quality assurance processes from those established for the manufacturing and assembling of composite masts for the San Antonio-class ships. However, since the composite materials used differ, the shipbuilder may need to develop alternative tests or inspection methods to ensure that quality standards are rigorous enough for DDG 1000.[19] For example, the shipbuilder recently traced apparent panel defects back to errors in

[18] The method for joining composite to steel is particularly important. A joint that uses fasteners only carries risk because properties of the carbon fiber and fasteners may lead to corrosion and the fasteners are expensive.

[19] While both are composite, the DDG 1000 deckhouse contains carbon fiber instead of fabric and a core of balsa wood throughout instead of foam and other materials.

calibrating ultrasonic testing equipment, rather than the panels themselves. Results from testing the large-scale prototype will provide the shipbuilder a final opportunity to refine its quality assurance process prior to actually starting to manufacture panels for the DDG 1000 deckhouse.

The deckhouse represents the Navy's first experience with composite material at this large of a scale, and the Navy's quality assurance procedures are still being developed. The Supervisor of Shipbuilding—the Navy's technical oversight located at the shipyard—recently hired additional staff with composite experience, and quality assurance training has just gotten underway.

The Navy recognizes the challenges of deckhouse manufacturing and the importance of the deckhouse to achieving overall ship construction. Importantly, the contractor is able to earn a special incentive fee for deckhouse construction and delivery, but the criteria and metrics for awarding the fee were not included in the contract and have yet to be established.

Actual Costs of Ships Will Likely Exceed Budget

Costs of the DDG 1000 ships are likely to exceed the Navy's fiscal year 2009 budget. In particular, the total cost to deliver a fully operational ship has not been fully recognized or funded. There is little margin in the budget to fund any cost increases that could occur during construction of the lead ships. However, cost growth during lead ship construction appears likely given technology, design, and construction risks. Independent estimates are higher than the Navy's budget. The Navy does not have adequate funding reserves for these contingencies. Funding problems will not be known until well after the shipyards begin construction of the lead ships. This is particularly true under the restructured program that has moved key events later in the schedule. However, the Navy has already requested funding for the third ship in this fiscal year, with plans to compete and award a contract as early as January 2009, including options to build the remaining four ships. At that time, the Navy will not have enough data on actual lead ship construction performance to confidently price the costs of the follow-on ships. By negotiating prices for the follow-on ships prior to understanding lead ship construction performance, the Navy risks cost growth that will require offsets in the budget in future fiscal years. With the program's production decision milestone scheduled for 2014—after the award of contracts for all of the follow-on ships—decision makers will miss an important opportunity to reevaluate whether DDG 1000 still meets the Navy's needs.

Construction Funds Leave Little Margin for Cost Growth and Do Not Include All Work Necessary for Fully Operational Ships

Based on the contracted costs for construction of the lead ships, the remaining budget is not sufficient to pay for cost growth that will likely occur. The Navy estimates a total shipbuilding budget of $6.3 billion, including almost $2.4 billion for the ships' combat systems, $2.6 billion for building the lead ships, $910 million for detail design, $216 million for other costs (including acquisition support), and $258 million for change orders—that is, funding to compensate for unknowns during design and construction. The Navy already recognizes that there is no additional funding in the budget to pay for any unanticipated costs.

Lead Ship Costs Appear Likely to Increase Given Risks

Construction of the lead ships will likely be challenging and the risk of cost growth is high. If key systems are delivered late or do not function as planned, additional labor hours will be needed to work around missing systems or will be spent reworking defective components. Further, the shipbuilders may have difficulties manufacturing unique ship components. For example, if composite manufacturing for the deckhouse takes longer than expected, ship construction could be delayed and costs associated with manufacturing will likely rise. Added to this are the challenges of integrating sections of the ship built in separate shipyards. Since the Navy is responsible for the delivery of government-furnished equipment, the Navy will bear the costs if there are schedule delays that affect another contractor. However, these problems will not surface until well after the shipyards have begun construction of the lead ships.

Our prior work has shown that cost growth for recent lead ships has been on the order of 27 percent—partly because the total effort needed to build new designs and incorporate new technologies is not yet understood. With ships as expensive as DDG 1000, even a small percentage of cost growth could lead to the need for hundreds of millions of dollars in additional funding.

Some Costs Will Not Be Budgeted until Later in the Construction Phase

As of June 2008, the Navy has approximately $363 million in unobligated funds to cover its outstanding costs and manage any cost growth. Even without cost growth, this appears inadequate to fund work necessary to complete the two lead ships. Table 5 summarizes costs that still need to be funded.

Table 5: Unfunded Lead Ship Expenses

Expense	Status	Estimated value
Deferred ship construction scope	Work removed from scope of construction contract to stay within construction budget. Since this work is necessary to meet ship specifications, the Navy plans to perform and fund work sometime after the lead ships are delivered. Includes the following: • Windows and enclosures for certain sensors • Special hull treatment • Deck coverings that comply with the ship’s radar cross section requirements • Secondary hull sheathing • Anchor handling system	$85 million
Contract price adjustments	Construction contracts structured to allow price adjustments based on future events that were considered largely outside of the shipbuilders’ control. Adjustments reduced the shipbuilders’ risk premium allowing a lower initial contract price. Includes the following: • Shifts in future workload • Escalations in future rates • Changes in the price of raw materials, such as steel and copper	Not available
Deferred procurement of select combat systems	Purchase and installation are not yet under contract for the following systems : • Volume search radar aperture and other components • Vertical launch system electronics, cell adapters, uptakes, and junction boxes • Thirty-four external communications antennas and apertures per ship The contractor estimate of these costs is approximately $763 million; the Navy estimates approximately $200 million for both ships.	$264 million to $767 million
Deferred activation of combat systems	Funds also not obligated toward light-off and final shipboard testing of the combat systems. The Navy estimates as much as $64 million for both ships, including about $4 million in costs for activation to be provided to the shipbuilders. Contractor and shipbuilder estimates may be higher.	

Source: GAO analysis of Navy and contractor data.

Partly to ensure that there was enough funding available in the budget to cover the costs of building the lead ships, the Navy negotiated contracts with the shipbuilders that shifted costs or removed planned work from the scope of lead ship construction and reduced the risk contingency in the shipbuilders’ initial proposals. For example, the Navy stated that it shifted in excess of $100 million associated with fabrication of the peripheral vertical launch system from the scope of ship construction and funded this work separately using research and development funding.[20]

The Navy has not contracted or funded work associated with activating—and in some cases purchasing and installing—many of the ship's key systems. The Navy plans to leave funding uncommitted in order to create a cash reserve to pay for any cost increases that may occur during construction of the lead ships. Officials stated that by not committing all available funding, the Navy will be able to more quickly divert resources if problems occur during construction—thus avoiding disruptions to construction while it obtains additional funding. Even before ship construction is under way, the Navy does not have adequate reserves to pay for work that has been deferred, is not under contract, or is only partially funded. The Navy has $363 million in funding remaining for the two lead ships. However, the Navy's known obligations for the lead ships range from $349 million to $852 million. The main discrepancy is the current estimated cost of the combat systems. The Navy has estimated the cost of the combat system to be around $200 million, while the contractor's estimate is over $760 million. If the agreed-on cost approaches the contractor's estimate, the Navy will not have enough in its remaining funds to cover the cost. To the extent that the lead ships experience cost growth beyond what is already known, more funding will be needed to produce operational ships. Funds could be provided through additional funding to the ships' budget line or, once the ship is initially delivered, using outfitting and post-delivery funding. After delivery, the Navy could also use other types of funds such as support equipment and materials funding that are accounted for separately—outside of the ship's end cost.[21]

[20] By shifting these costs the Navy stated that it could use research, development, test, and evaluation (RDT&E) funding instead of procurement funding. However, this may lead to increases in the RDT&E budget.

[21] This is known as Other Procurement, Navy.

Estimate for the Third Ship Will Not Reflect Knowledge Gained from Construction of the Lead Ships

Cost uncertainty is high for new classes of ships—including early follow-ons.[22] Cost estimates become more certain only as actual costs begin to replace earlier estimates. While the budgets for DDG 1000 ships benefit from a better understanding of class design, lengthy ship construction timelines have led the Navy to request authorization for follow-on ships without sufficient understanding to provide confidence in the lead ships' true cost.

Since the lead ships are not yet under construction, the Navy derives the budget for construction of the follow-on ships from cost estimates of the two lead ships, not actual costs. The Navy initially developed these estimates in 2005 in support of the program's Milestone B decision,[23] updating its current budget submissions to account for inflation changes and residual effects of Hurricane Katrina. The Navy based its construction estimate largely on the experiences of the DDG 51 class—the most closely related ship class, adjusting these costs to account for systems unique to DDG 1000 construction and adding a premium for building the lead ships.[24] Independent cost analysts within DOD estimate that another $878 million will be needed to build the lead ships. The cost of follow-on ship construction is based on the lead ship estimate adjusted downward to account for assumed efficiency gains through building each successive ship at the shipyard. As a result, achieving the budget for the follow-on ships depends on achieving lead ship costs—which appears unlikely.

Navy analyses indicate the potential for cost growth on follow-on ships. The Navy conducted risk and uncertainty analyses to measure the probability of cost growth and established a 50 percent confidence level for the budgets of the follow-on ships, recognizing that there is only a 50 percent chance that these ships will achieve their estimated costs. Independent cost analysts within DOD also estimate higher ship construction costs. According to this estimate, an additional $2.3 billion in total construction costs across all five follow-on ships may be needed.

[22] Recently, the Navy discussed canceling the remaining five ships of the class with members of the Congress.

[23] A Milestone B decision represents DOD's commitment to design and develop a system. The Milestone B estimate was also updated to reflect the decision to procure two lead ships.

[24] Cost analysts adjusted the estimate to account for the integrated power system, peripheral vertical launch system, and composite deckhouse.

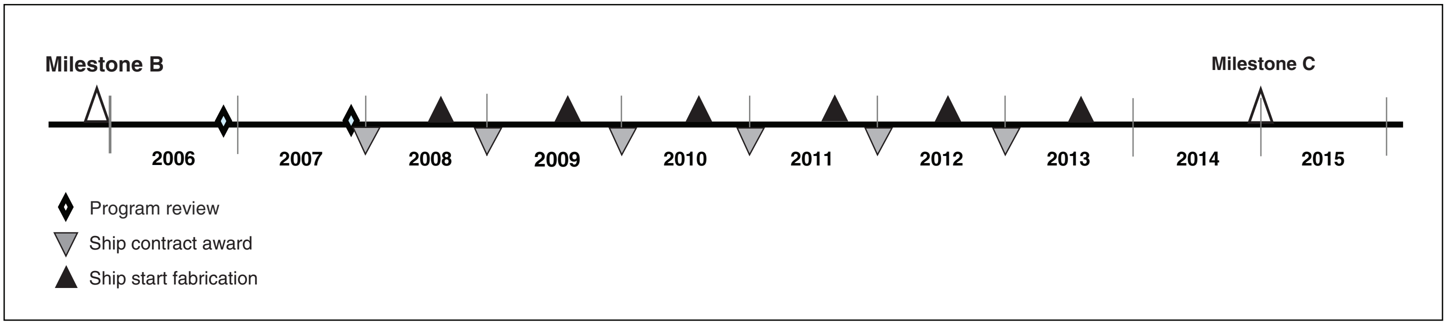
The Navy plans to contract for the follow-on ships before little if any knowledge of actual cost is gained on construction of the lead ships. The Navy intends to compete the award for construction of the next five ships between Bath Iron Works and Northrop Grumman Shipbuilding, with the winning shipyard receiving the larger quantity of ships. Under this approach, the Navy would award fixed-price-type contracts for the third ship (DDG 1002), with priced options for the construction of the remaining four ships. Based on the current schedule, the Navy would award follow-on ship contracts as early as January 2009. At that time, Bath Iron Works will have demonstrated less than 3 months of construction experience and Northrop Grumman Shipbuilding's lead ship will not have even begun construction. If the schedule for construction of the lead ships slips further into fiscal year 2009 and fiscal year 2010, neither shipyard will have demonstrated construction experience prior to contract award. The Navy will not have production cost trends from either shipbuilder until late fiscal year 2009, at the earliest. Consequently, the Navy will have little information on both shipyards' construction performance on which to base not only the cost of the third ship, but that of the remaining follow-ons. We have previously reported that negotiating prices for follow-on ships prior to gaining knowledge of lead ship construction costs contributes to cost growth on follow-on ships.[25]

Timing of Production Decision Milestone Does Not Allow for Meaningful Oversight of Follow-on Ship Costs

A Milestone C decision review is intended to represent DOD's commitment to producing a system. However, in the DDG 1000 program, this review is currently scheduled for 2014 after all ship contracts are awarded and follow-on ship construction is well under way (see fig. 11). Thus, it will have no decision to consider.

[25] See GAO-05-183, p. 23.

Figure 11: DDG 1000 Oversight, Ship Contract Award, and Construction Events after Milestone B



Source: Navy data.

In most weapon system programs, a Milestone C decision review occurs in advance of awarding contracts to begin production.[26] At this review, the Under Secretary of Defense (Acquisition, Technology & Logistics) authorizes the program to begin producing an initial quantity of units (known as low rate initial production). In the DDG 1000 program, the Milestone B decision essentially authorized detail design as well as production. While the Navy anticipates an annual program review with decision makers within DOD, these reviews do not have the same rigor as that associated with a milestone review. Typically, entrance into Milestone C requires that programs prove that they have appropriate knowledge to begin production, which includes demonstrating that

- manufacturing processes are under control,
- software capability is mature,
- the system is affordable throughout its life cycle, and
- the system is realistically funded.

In preparation for the milestone, programs submit documents for well over 10 information requirements, including documentation of readiness for production and updated independent cost estimates. Such documents are intended to help demonstrate that the product (in this case a ship) can be produced within cost and according to requirements. As a result of the program's schedule for DDG 1000, decision makers will not have the advantage of the knowledge gained through these analyses at the time the next five ships are authorized, lessening decision makers' ability to

[26] In most shipbuilding programs, authorization for production of the lead ship occurs at Milestone B.

recognize and make any needed adjustments in the remainder of the program. Officials from DOD point out that Milestone C for ships is normally scheduled after the lead ship passes operational testing. In the case of the DDG 1000, the point occurs in fiscal year 2014 after all key acquisition commitments for the class will be made. DOD acquisition guidance (DOD 5000.2) does not prohibit shipbuilding programs from holding Milestone C earlier in the production phase.

Conclusions

The DDG 1000 program has from the outset faced a steep challenge framed by demanding mission requirements, stealth requirements, less than half the manning levels of predecessor destroyers, and a split construction schedule planned around managing the shipbuilders' workload needs. These requirements translated into significant technical and design challenges. To meet these multiple and somewhat conflicting demands, the Navy conceived a thoughtful acquisition strategy to (1) develop key systems, (2) mature the design before starting to build the ship, and (3) facilitate advance preparation at the shipyards for construction of the lead ships. As the program progressed, the Navy achieved developmental successes and made a number of adroit decisions, such as switching to a more mature power system and changing its contracting strategy. Several of the ship's key systems that depended on new technologies were successfully demonstrated. The design approach, while not yet completed, has already produced more design knowledge than on the LPD 17 and LCS-class ships. Several construction innovations have been sponsored at each of the shipyards.

Yet at this point—the first year of a 6-year construction schedule for lead ships—the Navy may have exhausted its options for solving DDG 1000's potential problems without adding time and money. Recently, the Navy deferred some key efforts, such as demonstrating the combat systems, to later in the construction schedule. While the rescheduling provides benefits with regard to testing the ship systems separately from the mission systems, it was also a necessity given that the power generation system, the dual band radar, and the ship's software are each taking longer than planned. While these may be pragmatic decisions to solve problems while minimizing schedule delays, they are also compromises to original plans that called for systems to be tested before installation. It is not the problems themselves that are of concern, as they are to be expected. Rather, the fact that these compromises are already being made before construction has begun suggests that there is very little margin for solving future problems. Given DDG 1000's complexity and unique features, along with the design work, testing, and actual construction experience yet to come, the discovery of future problems is likely.

Similarly, the $6.3 billion the Navy has budgeted for the two lead ships provides little margin for error and is likely to be inadequate to cover the cost of the first two ships. Cost growth during construction for lead ships has historically been about 27 percent, and an independent estimate already projects the cost of the two lead ships to be $878 million higher than the Navy's budget. Moreover, the Navy's redefinition of ship delivery, including the deferral of combat system work until later in the construction schedule, will delay realization of actual costs and may make it difficult to reconcile the $6.3 billion budget with the actual cost of the ships.

The risks associated with the lead DDG 1000 ships should not carry over to the follow-on ships. While a legitimate debate can be had on how much knowledge should be gained on lead ships before contracting for follow-on ships, in our view, it is not debatable that the current plan to contract for the five remaining DDG 1000s in January 2009 is too soon.[27] Very little construction experience will have been gained at that point to inform the cost estimates for the follow-on ships. At the very least, a review by the Office of the Secretary of Defense, with the same quality of information normally available at a Milestone C decision, is warranted before the commitment and the pricing are set for follow-on ships.

Recommendations for Executive Action

We recommend that the Secretary of Defense take the following three actions:

- Require the Navy to complete product modeling of the ship's design to the level currently planned before the start of construction.
- Defer contract award for follow-on ships until the Navy has completed a substantial amount of construction on the lead ships.
- Hold the Milestone C review in advance of awarding a contract for the third ship.

[27] Recently, the Navy discussed canceling the remaining five ships of the class with members of the Congress.

Matter for Congressional Consideration

To provide insight into the potential for cost growth as the program progresses, the Congress may want to consider requiring the Navy to report on (1) the current production and testing schedule for systems necessary to meet ship light-off, ship delivery, and combat system activation; (2) any changes to this schedule, particularly with the dual band radar and the total ship computing environment; and (3) the cost impact of these changes if the schedule is maintained and if the schedule is stretched out.

Agency Comments and Our Evaluation

Regarding our recommendation to require the Navy to complete product modeling of the ship's design to the level currently planned before the start of ship construction, DOD reiterated that the plan is to be approximately 85 percent complete and noted that this is a higher percentage of design completion than any other surface warship. We agree that the Navy's plan is good, but a plan does not mean actual attainment. The Department should be prepared to react should the program's actual performance lag behind planned performance.

Regarding our recommendation that the Department hold the Milestone C review in advance of awarding a contract for the third ship, DOD stated that a review by the Defense Acquisition Executive is necessary prior to awarding a contract for construction of the third ship, but does not agree that a Milestone C review provides any additional benefit for the program. According to DOD, the Milestone C review will only occur after the lead ships complete operational testing and only if additional ships above the current seven ships are added. While DOD acquisition policy provides some flexibility for shipbuilding programs, the policy applying to most major defense acquisitions calls for the Milestone C review to authorize production of low rate initial quantities. Annual program reviews will certainly enhance program knowledge, but they do not provide the consistent framework and documentation that a Milestone C review would provide, such as an updated independent cost estimate. Nonetheless, it is the quality of the review rather than its title that is important. Thus, the review that precedes awarding the contract for the third ship should provide the framework and documentation of the caliber that a milestone carries.

DOD did not agree with our recommendation to defer contract award for follow-on ships until a substantial amount of construction on the lead ships has been completed. DOD stated that delaying contract award and subsequent procurement of the third and follow-on ships will impact warfighting capability gaps, cost, and the shipbuilding industrial base. We note that the Navy and DOD are currently considering canceling the third and follow-on ships. This notwithstanding, we believe that the risks of prematurely awarding follow-on ship contracts are considerably higher than any potential cost increase that could occur as a result of delaying funding for a follow-on ship. Industrial base effects have likely been offset by the later-than-planned construction start of the lead ships. Moreover, the Navy does not plan to start construction of the third ship before fiscal year 2010 and advanced procurement for its long-lead items has already been funded. The program is moving toward lead ship construction with significant uncertainties. In the past, it has proven costly to award contracts for construction of follow-on ships with little or no actual performance data on the lead ship—especially on a ship that includes so many "firsts" in shipbuilding. With such limited construction planned by contract award, the shipbuilders cannot incorporate lessons learned from the first ship to inform—and reduce the risk premium in—their estimates of follow-on ship costs.

DOD's written comments are reprinted in appendix II. The Department also provided technical comments, which were incorporated into the report as appropriate.

We are sending copies of this report to the Secretary of Defense, the Secretary of the Navy, and interested congressional committees. Copies will also be made available to others on request. In addition, the report will be available at no charge on GAO's Web site at http://www.gao.gov.

If you or your staff have any questions concerning this report, please contact me at (202) 512-4841 or francisp@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made major contributions to this report are listed in appendix IV.

Paul L. Francis

Paul L. Francis
Director
Acquisition and Sourcing Management

Appendix I: Objectives, Scope, and Methodology

This report assesses

1. the Navy's ability to deliver key systems when needed to support lead ship construction and whether these systems will work as intended,

2. the level of design maturity and the obstacles to completing the ship's design as planned,

3. the shipyards' readiness to build DDG 1000, and

4. the challenges of building the ships (lead and follow-ons) within budget.

To address the first objective, we reviewed technology development plans, scope and schedules and compared these against similar documentation for 2005 when the Navy held its Critical Design Review and milestone review. We also analyzed test plans and schedules as well as test reports to determine progress in demonstrating key systems.

We also assessed the degree of testing and hardware and software integration planned prior to installation and identified areas of testing and installation concurrency. We analyzed, among other documents, DDG 1000 Cost Analysis Requirements Description, DDG 1000 Program Review briefings, technology test plans and reports, software development schedules, critical design review findings, risk matrixes, Defense Contract Management Agency reports, and contractor cost performance reports for key technologies. To supplement our analysis, we visited contractors and test sites where the ship's major technologies are being developed and tested.

To address the second objective, we reviewed the Navy's plans and guidelines for design management and completion, evaluated the design progress and schedule, and assessed impacts of the product model on that progress, including schedule delinquencies and key dates. We applied established earned value management techniques to data captured in the shipbuilders' cost performance reports in order to evaluate design performance to date. Further, we analyzed variance reports that accompany the cost performance reports in order to understand the drivers of schedule delays. We compared DDG 1000's design process with our knowledge-based acquisition methodology and past work on shipbuilding programs. We analyzed and compared DDG 1000 design metrics with the experience of previous shipbuilding programs, particularly the DDG 51 class and the Virginia-class submarine. In conducting our analysis, we examined key documents, including the

Integrated Master Schedule, Configuration Management Plan, and Supervisor of Shipbuilding, Conversion and Repair's reports.

To address the third objective, we reviewed key shipyard performance data. We examined recent cost performance reports for the DDG 51 class under construction at both shipyards. We reviewed key indicators of labor productivity, including data on Northrop Grumman Shipbuilding's progress in recovering its labor and facilities from the effects of Hurricane Katrina. We examined both shipyards' plans and progress improving facilities to meet the schedule and manufacturing capacity required to construct DDG 1000. Among other documents, we reviewed facility improvement schedules compared with construction schedules, labor metrics, shipbuilder cost performance reports, contract documentation, and Supervisor of Shipbuilding, Conversion and Repair reports. To supplement our analysis we visited both shipyards and toured their facilities.

To address the fourth objective, we examined the Navy's budget request and cost estimates for the ships in the class. We analyzed the Navy's cost estimates by examining the Program Life Cycle Cost Estimate and updates to that estimate since the Milestone B decision in 2005. We compared the Navy's cost estimates with estimates from the Department of Defense's independent cost analysts. We assessed the potential for lead ship cost growth by analyzing the program's current budget obligations by budget element and contract for each of DDG 1000's prime contractors. We compared total contract estimates of the total cost to complete the ship with the program's total remaining funding. Further, we analyzed the shipbuilders' contracts and the Navy's business clearance memorandums to understand the scope and cost of lead ship construction. We evaluated follow-on ship costs by analyzing the program's acquisition strategy. We compared DDG 1000's strategy with DOD acquisition policy and guidance and our past work on shipbuilding cost growth.

In conducting our analysis, we held discussions and attended briefings with the shipbuilders and contractors responsible for DDG 1000 development; as well as officials from the Naval Sea Systems Command, including the DDG 1000 Program Office; Program Executive Office, Integrated Warfare Systems; Program Executive Office for Ships; Ship Design Integration and Engineering Division; Cost Engineering and Industrial Analysis Division; Contracts Division; Naval Surface Warfare Center, Carderock in Pennsylvania and Maryland; Supervisor of Shipbuilding, Conversion and Repair, Gulf Coast; and Supervisor of Shipbuilding, Conversion and Repair, Bath. In addition, we interviewed officials from the Navy's Commander of Operational Test and Evaluation Force and DOD's Cost Analysis Improvement Group; Defense Contract Audit Agency in Bath, Maine and Pascagoula, Mississippi; and Defense Contract Management Agency in Tewksbury, Massachusetts, and Fort Snelling, Minnesota.

We conducted this performance audit from September 2007 to July 2008 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Comments from the Department of Defense

Note: Page numbers in the draft report may differ from those in this report.

OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION
TECHNOLOGY
AND LOGISTICS

JUL 28 2008

Mr. Paul L. Francis
Director, Acquisition and Sourcing Management
U.S. Government Accountability Office
441 G Street, N.W.
Washington, DC 20548

Dear Mr. Francis:

This is the Department of Defense (DoD) response to the GAO draft report, GAO-08-804, "DEFENSE ACQUISITIONS: Cost to Deliver Zumwalt-Class Destroyers Likely to Exceed Budget," dated June 23, 2008 (GAO Code 120672).

The DoD concurs with recommendation 1, non-concurs with recommendation 2, and partially concurs with recommendation 3. The Department's comments on the recommendations are enclosed.

We appreciate the opportunity to comment on the draft report. Technical comments were provided separately. For further questions concerning this report, please contact Ms. Darlene Costello, Deputy Director, Naval Warfare, at 703-697-2205 or Darlene.Costello@osd.mil.

Sincerely,

David G. Ahern
Director
Portfolio Systems Acquisition

Enclosure:
As stated

GAO DRAFT REPORT DATED JUNE 23, 2008
GAO-08-804 (GAO CODE 120672)

"DEFENSE ACQUISITIONS: COST TO DELIVER ZUMWALT-CLASS DESTROYERS LIKELY TO EXCEED BUDGET"

DEPARTMENT OF DEFENSE COMMENTS TO THE GAO RECOMMENDATIONS

RECOMMENDATION 1: The GAO recommended the Secretary of Defense require the Navy to complete product modeling of the ship's design to the level currently planned before the start of construction. (p. 51/GAO Draft Report)

DOD RESPONSE: Concur. DDG 1000 detail design is currently planned to be approximately 85 percent complete prior to the start of fabrication. The ship's detail design effort will be more complete at the start of construction next year than any other previous surface warship. Detail Design of the zones that will begin fabrication on the start fabrication date will be 100 percent complete and will have undergone 2-dimensional drawing extraction which produces the drawings that are used for actual construction of the ship. All other zones, as they reach their individual start fabrication dates, also will be 100 percent complete with Detail Design.

Design of the Mission Systems now is nearly 100 percent complete and a Production Readiness Review for each system is planned prior to the ship start fabrication date.

In the particular case of DDG 1000, the ship class has been in design and development for almost six years. The Navy successfully built and tested the 10 critical technologies that provide the capabilities that future ships need on cost and schedule.

The DDG 1000 shipbuilders, General Dynamics Bath Iron Works (BIW) and Northrop Grumman Shipbuilding (NGSB), have been involved in the development of the ship design since preliminary design began in 2002. This has contributed to the efficient completion of detail design. In addition, the CATIA V5/ENOVIA Computer Aided Design tool in use at both shipyards has been proven to be mature, complete, and stable and the American Bureau of Shipping Naval Vessel Rules are fully incorporated into the DDG 1000 detail design.

BIW and NGSB have been using a proven set of common Computer-Aided Design (CAD) tools, incorporating design, simulation, visualization and material sourcing capabilities. All vendor furnished information (VFI), a common source of design disruption and rework, already has been delivered. By comparison, DDG 51 design was much less mature at the start of fabrication, much of the VFI was preliminary or not available, and the CAD tool failed early in detail design, forcing the shipbuilder to design by hand.

Start Fabrication is a risk-based assessment of adequate design maturity versus consequences of delaying fabrication. The Government uses design and construction contracts to facilitate the most cost effective design-build sequence to maximize the efficient use of shipyard resources. The consequences of delaying Start Fabrication include:

- Increased cost due to schedule extension.
- Increased inflation escalation costs. Delaying procurement of material generally leads to buying material at inflated price with no benefit gained from delay.
- Disruptions in workforce. Staggered start of zones smoothes the workload manning curves and reduces construction costs. Early start zones are the least complex zones with low risk of cost growth.

RECOMMENDATION 2: The GAO recommended the Secretary of Defense defer contract award for follow-on ships until the Navy has completed a substantial amount of construction on the lead ships. (p. 51/GAO Draft Report)

DOD RESPONSE: Non-concur. Deferring the contract award, and subsequent procurement, of the third and follow DDG 1000 class ships will impact warfighting capability gaps, cost, and the shipbuilding industrial base. The cost of the first two ships, now under contract to General Dynamics Bath Iron Works and Northrop Grumman Shipbuilding, will increase significantly due to the lack of the shipbuilders' ability to spread shipyard overhead cost among multiple ships. Additionally, the cost of the mission systems equipment for the lead ships will increase for a similar reason. The deferral of this workload also would likely impact costs on other Navy contracts at these shipbuilders. Finally, the lack of an FY 2009 ship will impact the shipbuilding industrial base and workforce stability.

Each shipbuilder's lead-ship cost proposal was based on a seven-ship program of record DDG 1000 workload. Deferring follow ship contract awards would affect vendors that currently are under contract and building class-specific systems and components, including systems such as the Dual Band Radar (Raytheon/Lockheed Martin), Advanced Gun System (BAE System), Integrated Power System (Converteam/DRS Technologies), Advanced Vertical Launch System (Raytheon/BAE System) and Total Ship Computing Environment Infrastructure (Raytheon). Hundreds of system and component vendors employing thousands of people in 48 states also would be impacted.

RECOMMENDATION 3: The GAO recommended the Secretary of Defense hold the Milestone C review in advance of awarding a contract for the third ship. (p. 51/GAO Draft Report)

DOD RESPONSE: Partial Concur. The Department agrees that a Defense Acquisition Executive (DAE) review of the program is necessary prior to the Navy awarding the construction contract for the third ship, DDG 1002. An Acquisition Decision Memorandum (ADM) signed on February 13, 2008, requires the Navy to return for a Defense Acquisition Board (DAB) level program review prior to obligating any additional procurement funding for construction of the DDG 1002 ship. The ADM also requires the Navy to demonstrate that the negotiated cost for the DDG 1002 ship is within budget and to propose exit criteria for the DAB reviews for the DDG 1003 and DDG 1004 follow ships.

The Department does not agree that a Milestone C review, as defined in the DoD Instruction 5000.2, provides any additional benefit for a shipbuilding program such as the DDG 1000 program, when timed at the first follow ship. Authorization to enter the production phase of the program was granted by the DAE in an ADM signed on December 22, 2007. This followed an extensive review of the readiness of the program to start production of the lead ships. The program documentation updates required at the Milestone C review will be directed as the DAE deems appropriate during the production phase of the program. The Department believes that conducting annual reviews of the program, prior to awarding the contract for a ship in that year is a more practical approach to oversight of the DDG 1000 program. The Department tailored the Defense Acquisition System in the case of the DDG 1000 program and will use the Milestone C event to authorize construction of any additional ships that might be added above the current program of record of seven ships. That tailored Milestone C review would occur only after the lead ships complete Initial Operational Test and Evaluation and the Director, Operational Test and Evaluation issues its statutory Beyond Low Rate Initial Production report. The Milestone C review would serve as the Full Rate Production Decision Review.

Appendix III: Major Events in the Development of DDG 1000

Year	Events
1994	• Navy identifies need for a new 21st century surface combatant (SC 21) to provide naval surface fire support.
1997	• Plans for DD 21 include 32 ships with an average unit cost not to exceed $921million (FY 1996 dollars) and an initial operating capability of fiscal year 2008.
2001	• DD 21 program restructured to emphasize technology development and affordability and renamed DD(X).
2002	• DD(X) program starts Preliminary Design/Development. • Navy completes its review of requirements for future surface combatants and recommends a force structure of 16 DD(X) each with 2 advanced gun systems, 900 land attack munitions, and 96 missile cells. • Navy recognizes the need for an additional $7.6 billion to complete DD(X) technology development, testing, and evaluation efforts.
2004	• Program restructured to include 8 ships, an average unit cost not to exceed $2.6 billion (FY 1996 dollars) and an initial operating capability of fiscal year 2013. • DD(X) program completes its preliminary design review, initiating system design.
2005	• Navy approves a quantity of 10 ships, an average unit cost not to exceed $3.1 billion (FY 1996 dollars) and an initial operating capability of fiscal year 2014. • The Congress prohibits the Navy from a "Winner Take All" competition in Emergency Supplemental Appropriations Act. • Milestone B review approves system development and demonstration and approves Navy's strategy for purchasing dual lead ships.
2006	• Navy outlines its 30-year shipbuilding plan and lists quantity of seven DD(X) destroyers. • Navy re-names DD(X) program DDG 1000-class destroyer and confirms that the first ship in the class, DDG 1000, is to be named the Zumwalt, in honor of Admiral Elmo R. Zumwalt, the Chief of Naval operations from 1970 to 1974. • The Congress authorizes split funding of two lead ships but states that procurement cannot exceed $6.53 billion. • Navy awards dual lead detail design contracts to Northrop Grumman Shipbuilding and Bath Iron Works.
2007	• Navy resequences construction of the first lead ship from Northrop Grumman Shipbuilding to Bath Iron Works.
2008	• Navy negotiated construction contract modifications with shipbuilders (February 14, 2008). • DDG 1000 construction start (currently scheduled for October 2008). • Contract modification with Raytheon for production of key systems for lead ships (estimated definitization August 2008).
2009	• Navy plans to compete and award construction contract award for the ship with priced options for fiscal year 2010 through 2013 ships. • DDG 1001 construction start (currently scheduled for September 2009).
2013	• DDG 1000 initial delivery (April 2013).
2014	• DDG 1000 final ship delivery. • DDG 1001 delivery (May 2014).
2015	• Initial operating capability (March 2015).

Source: Navy data.

Appendix IV: GAO Contact and Staff Acknowledgments

GAO Contact

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