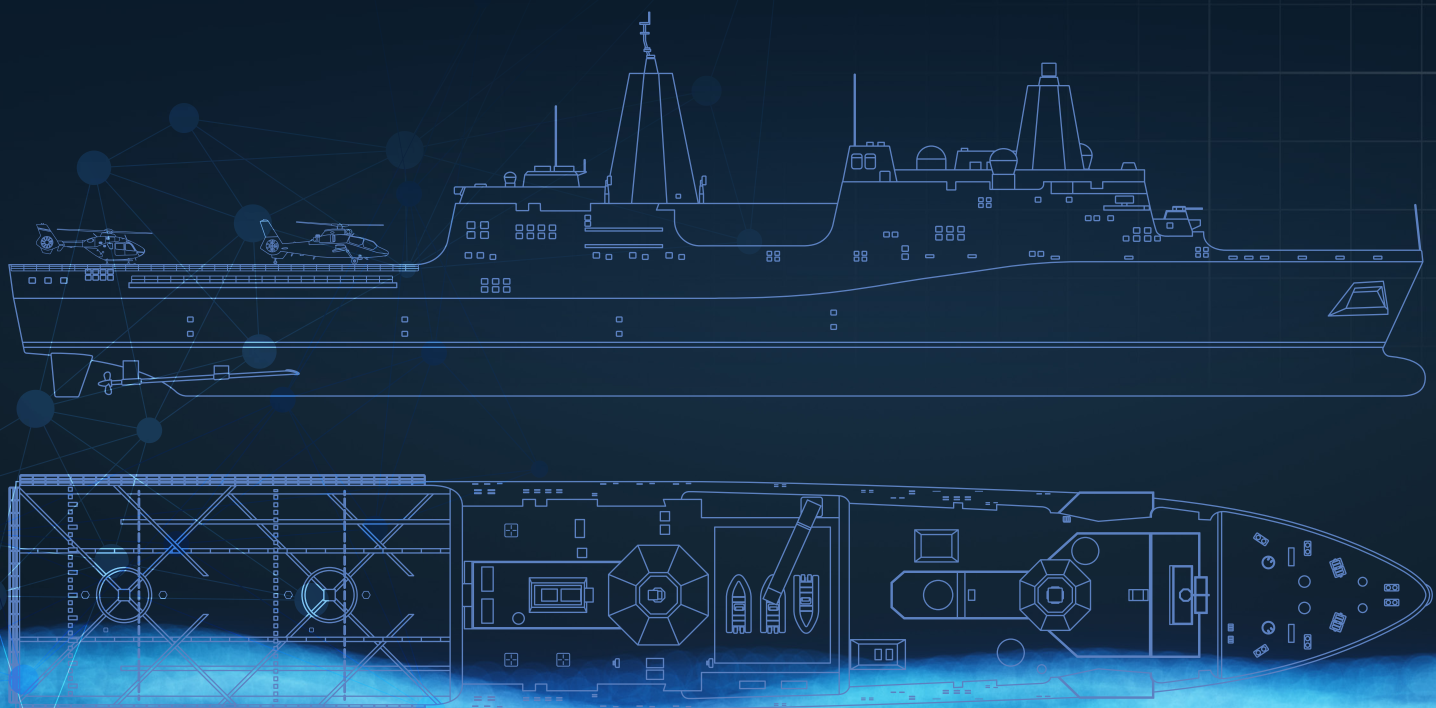
United States Government Accountability Office

May 2024

Report to Congressional Committees

# Navy Shipbuilding

## Increased Use of Leading Design Practices Could Improve Timeliness of Deliveries



GAO-24-105503

Highlights of GAO-24-105503, a report to congressional committees

May 2024

# Navy Shipbuilding

## Increased Use of Leading Design Practices Could Improve Timeliness of Deliveries

### Why This Matters

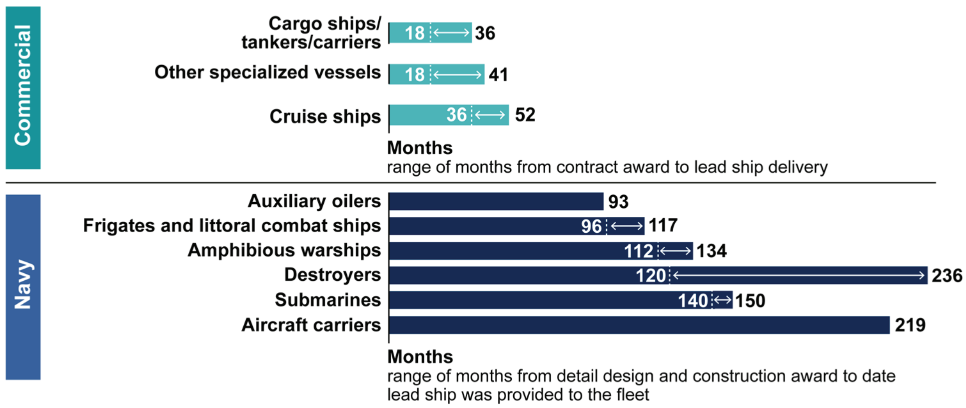
Changing maritime threats are pushing the U.S. Navy to increase its pace for designing and delivering new ships. Since 2009, GAO has used leading practices in commercial shipbuilding to evaluate the plans and execution of Navy shipbuilding programs. GAO's numerous recommendations have spurred Navy action to improve acquisition practices and the use of taxpayer dollars. Yet, the Navy has continued to face persistent challenges in its ability to design and deliver timely, affordable new ships that perform as expected.

Computing power and digital design capabilities have rapidly changed in the 15 years since GAO first identified leading ship design practices. As a result, GAO's examination of commercial industry's current practices helps ensure that the activities and performance of the Navy's shipbuilding programs are evaluated against cutting-edge practices used to design new ships efficiently and effectively.

### Key Takeaways

GAO found that leading commercial ship buyers and builders prioritize shorter, predictable periods for design and construction, which result in delivering timely ships that meet current user needs. In contrast, the Navy's approach often results in significantly longer design and construction cycle times for its shipbuilding programs' lead ships.

**Comparison of Design and Construction Cycles for Selected Commercial and Navy Ships**




Source: GAO analysis of commercial company and Navy information. | GAO-24-105503

**Note:** For commercial ships, the range of months indicates the shortest and longest typical periods for companies to deliver a lead ship after contract award. For Navy ships, the range of months for different ship types indicates the shortest and longest periods for the Navy to provide selected lead ships to the fleet since 2007. For Navy programs with a contract prior to the detail design and construction award, the earlier award date represents the start of the cycle.

Key differences between commercial companies' and the Navy's ship design practices contribute to the slower pace and less predictable cost, schedule, and performance outcomes for Navy shipbuilding programs. Leading design practices involve

- effective management of a ship's business case—a reflection of the balance of customer needs and the resources needed to develop and produce the ship; and
- focus on efficiently maturing new ship designs to better inform decisions on schedule, cost, and performance. This includes using consistent, meaningful design maturity measures to determine readiness to move from design to construction.

## How GAO Did This Study

A conference report directed GAO to examine ship design practices. This report assesses (1) the leading design practices used by commercial ship buyers and builders to inform their understanding of design maturity and readiness for construction, and (2) how the Navy's ship design practices compare to the leading practices in commercial ship design. To address these objectives, GAO interviewed and reviewed documentation from four commercial ship buyers and five shipbuilders—builders generally also design the ships. GAO selected these companies using criteria reflective of commercial success in designing, building, and buying ships relatable to Navy ships. GAO also reviewed its prior work on leading practices for shipbuilding and product development. In addition, GAO reviewed documentation and interviewed representatives from the Navy and selected Navy shipbuilders, as well as reviewed prior work on Navy shipbuilding program efforts. Based on the results of these activities, GAO compared the ship design practices used by the Navy with leading commercial practices.

## What GAO Recommends

GAO is raising to the attention of Congress three matters for its consideration regarding reporting and certification requirements. The matters would enable Congress to gain additional information on design maturity for Navy shipbuilding programs. GAO is also making eight recommendations to the Secretary of the Navy, which are intended to support improvements to the Navy's design approach, decision-making practices, and design capabilities that facilitate more timely, predictable outcomes for its shipbuilding programs. The Navy agreed with seven recommendations and partially agreed with one recommendation. GAO continues to believe that all eight recommendations should be fully implemented.

**For more information, contact Shelby S. Oakley at (202) 512-4841 or OakleyS@gao.gov.**

## GAO Comparison of Leading Ship Design Practices for Commercial Companies and U.S. Navy

### Establish business cases and requirements that support predictable design outcomes

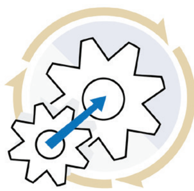
**Commercial**

- Prioritizes timeliness of ship design and delivery
- Avoids overly prescriptive requirements
- Maintains a sound business case through continued reevaluation

**Navy**

- Progresses through an extensive requirements process, with significant time elapsing before detail design and construction contracts
- No regularly required reevaluation of approved requirements to confirm their continued relevance

### Use iterative design to accelerate design maturity



**Commercial**

- Ensures schedule, cost, and requirements expectations are informed by sufficient design knowledge
- Prioritizes user involvement in the ship design process
- Leverages existing ship designs and systems in digital libraries
- Prioritizes timely vendor decisions and information

**Navy**

- Sets expectations for schedule, cost, and operational requirements when design is unstable, resulting in less design knowledge available to inform key decisions and increased program risk
- Generally uses a longer, more linear approach—with less consistent user involvement—focusing on new designs with extensive and novel capability rather than speed to delivery
- Makes some use of existing ship designs, but lacks a robust design library to support iterative design and shorten time needed to mature new designs
- Generally takes extended time to finalize vendor decisions for ship systems and receive vendor-furnished information needed to mature ship designs

### Use efficient ship design collaboration and decision-making practices

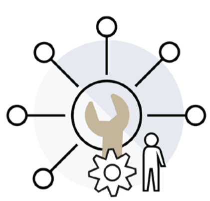
**Commercial**

- Uses processes that support timely design decisions
- Aligns decision-making with design maturity measures

**Navy**

- Lacks streamlined, more time-constrained processes, with numerous stakeholders having decision-making authority and contributing to extended cycle times to finalize designs
- Lacks consistent design maturity measures and a clear connection between those measures and decision-making

### Employ robust in-house ship design capabilities and tools



**Commercial**

- Maintains strong in-house design workforce capabilities
- Uses ship design tools to shorten cycle time

**Navy**

- Evaluating ways to address acknowledged shortfalls in its in-house design workforce and tools
- Adopting modern design tools to varying degrees, with the potential for expanded, more consistent use to provide efficiencies that support shorter, more predictable cycle times for ship design

Source: GAO analysis of commercial company and Navy information; GAO (icons). | GAO-24-105503

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## Abbreviations

| | |
|---|---|
| CDD | capability development document |
| DOD | Department of Defense |
| JCB | Joint Capabilities Board |
| JCIDS | Joint Capabilities Integration and Development System |
| JROC | Joint Requirements Oversight Council |
| JSD | Joint Staffing Designators |
| LCS | Littoral Combat Ship |
| MVP | minimum viable product |
| OWLD | obligation work limiting date |
| VFI | vendor-furnished information |

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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May 2, 2024

Congressional Committees

Changes in the maritime threat environment are compelling the U.S. Navy to find ways to expedite the design and delivery of new and innovative ships. Application of modern ship design practices used by commercial companies provides the Navy with a mechanism for confronting these threats and creating more consistent, predictable outcomes for its shipbuilding programs. This includes application to ongoing programs and major future programs planned for the coming decades, which the Navy expects will provide the next generation of destroyers, attack submarines, and amphibious assault ships, among other new additions to its fleet.

Since 2009, we have applied leading practices in commercial shipbuilding to our work evaluating U.S. Navy shipbuilding programs, recommending numerous actions reflecting those practices and intended to improve outcomes.[1] The practices and our recommendations emphasized the value of applying a knowledge-based framework to manage and oversee Navy shipbuilding investments. The Department of Defense (DOD) and, more specifically, the Navy implemented many of our recommendations, resulting in improved acquisition practices and better use of taxpayer dollars.

Further, the results from our work over the last 15 years demonstrate that leading practices from commercial industry can be applied thoughtfully to Navy shipbuilding acquisition to improve outcomes, even when cultural and structural differences yield different sets of incentives and priorities.[2] Commercial ship buyers and builders continue to employ practices that ensure high levels of knowledge at key junctures throughout their acquisition processes to achieve successful results.[3] However, the rapid rise in computing power and digital design capabilities has fostered some changes in their practices.

The Conference Report 116-333 accompanying the National Defense Authorization Act for Fiscal Year 2020 includes a provision for us to examine the key aspects of ship design practices necessary to provide Congress with confidence in cost, schedule, and

[1]As part of our 2009 analysis on shipbuilding leading practices, we reported on the environments in which commercial and Navy shipbuilding operate. For additional detail on these environments, see GAO, ***Best Practices: High Levels of Knowledge at Key Points Differentiate Commercial Shipbuilding from Navy Shipbuilding***, GAO-09-322 (Washington, D.C.: May 13, 2009).

[2]These differences include the Navy's distinct need for ships to be designed and constructed to operate globally and fulfill warfighting requirements under extreme conditions. The Navy also notes that its shipbuilding efforts are constrained by shipyard limitations, supply chain constraints, and the limited labor pool from which to draw for Navy shipbuilding.

[3]Buyers of large, complex commercial ships typically rely on shipbuilders to design and construct ships that will meet the needs of the buyers' customers and users once delivered.

performance goals for Navy shipbuilding programs. This report examines (1) the leading design practices used by commercial ship buyers and builders to inform their understanding of design maturity and readiness for construction; and (2) how the Navy's ship design practices compare with the leading practices in commercial ship design.

To identify leading design practices used by commercial ship buyers and builders, we interviewed and reviewed documentation from selected leading companies based in the U.S. and internationally—four buyers and five builders.[4] We selected these companies based on criteria that validated their prominence in the design, construction, and acquisition of large, complex, and specialized commercial ships.

As part of reviewing their practices, we gathered quantitative data from the commercial companies related to design and construction cycle times for different commercial ship types and response timelines when reviewing ship design products. We then drafted summaries of each company's key ship design practices, which included data on the general cycle times for design—including review of design products—and construction. We shared these summaries with the companies to review for technical accuracy and exclusion of company proprietary information. We determined the data were sufficiently reliable for the purposes of our reporting. To support our commercial ship design activities, we also reviewed our prior work on leading practices for shipbuilding and commercial product development to evaluate the extent to which those leading practices are relevant to current ship design practices.[5]

To identify the ship design practices used by the Navy and compare them with the leading practices we found in commercial ship design, we reviewed documentation and interviewed Navy officials and representatives from Navy shipbuilding companies about their design practices—shipbuilders generally complete most of the design work. Our review included six Navy shipbuilding programs that undertook significant design activities since 2009 and reflected a range of different ship classes within the fleet. We also interviewed and reviewed documentation from Navy shipbuilders involved in the design and construction of the ships from the six Navy programs included in our scope.

Further, we examined our past findings and recommendations on Navy shipbuilding efforts to assess the Navy's ship design practices and results across its shipbuilding programs.[6]

We used this information to support our analysis of how the Navy's practices compare with the current leading practices we identified in commercial ship design. Additionally, we conducted a roundtable discussion with senior Navy officials involved with ship

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[4]For the purposes of this report, we refer to key practices we identified among commercial ship buyers and builders as "leading ship design practices," or similar language. We distinguish these practices from other leading practices identified in our prior reports on commercial product development, referring to those as "leading practices for product development," or similar language.

[5]GAO, *Leading Practices: Iterative Cycles Enable Rapid Delivery of Complex, Innovative Products,* GAO-23-106222 (Washington, D.C.: July 27, 2023); *Leading Practices: Agency Acquisition Policies Could Better Implement Key Product Development Principles,* GAO-22-104513 (Washington, D.C.: Mar. 10, 2022); and GAO-09-322.

[6]GAO, *Navy Shipbuilding: Past Performance Provides Valuable Lessons for Future Investments,* GAO-18-238SP (Washington, D.C.: June 6, 2018) and GAO-09-322.

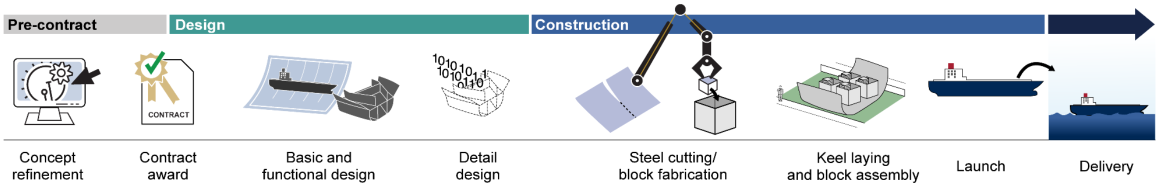
design and construction to obtain feedback on our preliminary findings related to leading ship design practices in commercial ship design. See appendix I for a more detailed description of our objectives, scope, and methodology.

We conducted this performance audit from October 2021 to May 2024 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.

# Background

Shipbuilding is a complex, multistage industrial activity that includes common key events regardless of the type of ship construction or nature of the buyer (Navy or commercial). Commercial ship buyers, such as Carnival Corporation, enter into contracts with shipbuilders, such as Fincantieri, to design and construct new ships. As shown in figure 1, key events are sequenced among three primary stages that move from concept through design and construction to deliver a new ship.

**Figure 1: Notional Ship Design and Construction Process**




Source: GAO analysis of shipbuilding information; GAO (illustration). | GAO-24-105503

Note: This figure depicts a generic shipbuilding process; Navy shipbuilding programs and commercial companies may use different terms to describe their design phases within the overall process.

Though some design work occurs in the pre-contract phase, the design phase continues in earnest after signing a contract for design and construction. As we previously found, the design stage after contract award progresses from outlining the ship's structure to routing systems that are distributed throughout the ship and finalizing design details that facilitate construction.[7] Once the design is sufficiently defined, builders move into the construction phase. This begins with the cutting and welding of large steel plates into the basic building units of ship construction, referred to as "blocks," which form completed or partial compartments, including engine rooms, storage areas, and accommodation spaces. Blocks are generally outfitted in the early stages of construction with pipes, brackets for machinery or cabling, ladders, and any other equipment that may be available for installation. This approach allows a block to be installed as a completed unit with connectors to adjacent blocks. Each block is ultimately welded together with other blocks to form larger sections that compose the ship's structure. Once the shipyard has enough blocks and larger sections assembled, it lays the ship's keel into the drydock, which is where the ship will be erected.[8]

After the keel is laid, other constructed sections are placed in the drydock and welded to the surrounding sections. During this stage, the shipyard also performs outfitting of machinery, engines, propeller shafts, and other large items requiring the use of overhead cranes. When the ship is watertight and the decision is made to float, or

[7]GAO-09-322.

[8]Historically, keel laying coincided with laying the main timber of the ship hull, or keel. Keel laying now generally means landing the first large section of assembled blocks into the drydock.

"launch," the ship in water, the drydock is flooded and the ship is towed into a quay or dock area for final outfitting and testing of machinery and equipment.[9]

## Previously Identified Leading Practices in Ship Design

Our 2009 report on leading practices in shipbuilding identified the foundation for sound design practices.[10] For example, we found that commercial ship buyers and builders address major risk posed by technological advances or new design features prior to signing a contract for the ship. We also found that leading practices for shipbuilding include design phases with specific tasks that ensure increasing degrees of maturity as designs progress to support timely, predictable outcomes, as depicted in table 1.

**Table 1: Ship Design Phases and Key Tasks Identified in Prior Work on Leading Commercial Practices**

| Design phase | Key tasks involved |
| --- | --- |
| Basic and functional design | • Fix ship steel structure and set hydrodynamics<br>• Design safety systems and get approvals from applicable authorities<br>• Route all major distributive systems, including electricity, water, and other utilities<br>• Provide information on position of piping, ventilation, equipment, and other outfitting in each basic unit, or "block," of ship construction<br>• Usually includes 3D modeling of the ship structure and major systems, with vendor-furnished information (VFI) incorporated to support understanding of final system design. VFI reflects the characteristics for ship equipment and components. This includes requirements for space, weight, power, water, and other utilities that feed ship systems |
| *Design stability achieved upon completion of basic and functional design* | |
| Detail design | • Use 3D modeling information to generate work instructions for each block that show detailed system information and support construction, including guidance for subcontractors and suppliers, installation drawings, schedules, material lists, and lists of prefabricated materials and parts |

Source: GAO analysis of commercial ship design information. | GAO-24-105503

Note: Ship buyers and builders may use different terms to denote the design phases. However, the tasks completed are the same regardless of terminology.

Our 2009 work found that Navy shipbuilding programs often did not follow the same leading practices as commercial companies.[11] Based on those findings, we recommended DOD take several actions to improve shipbuilding programs. The

[9]Some shipyards launch ships by sliding them backwards or sideways into the water.

[10]GAO-09-322.

[11]GAO-09-322.

recommendations covered balancing requirements and resources, effectively managing technical risk, stabilizing design before construction, and improving the Navy's in-house management capability, among other topics. In response, DOD took action to implement most of them.[12] These actions included incorporating leading practices in its Defense Acquisition Guidebook and taking steps to increase the size of its acquisition workforce. However, our subsequent reviews and reporting since 2009 indicate that the Navy's actions in response to our recommendations have provided mixed results in helping to improve its ship design and construction outcomes.[13]

In 2018, we summarized our findings on the Navy's acquisition outcomes for ship classes built during the prior decade and outlined the leading practices for addressing risks inherent in shipbuilding.[14] Since that time, the Navy has taken steps to reduce technical risk for new shipbuilding programs by increasing its use of existing ship designs. As we previously found, programs can reduce technical risk by using an existing ship design with characteristics that align with the requirements for a new ship class.[15]

We also found that the use of existing designs presents opportunities to accelerate design maturity and achieve a stable design earlier than what would be possible by pursuing a new design. For example, we found that the Navy's *Constellation* class (FFG 62) guided missile frigate program required prospective contractors to use existing, or "parent" designs—designs demonstrated by ships already at sea—in an effort to help accelerate the design and construction schedule and increase baseline design maturity from the outset.[16] Further, we found that the *Columbia* class (SSBN 826) nuclear-powered ballistic missile submarine program used realistic and reasonable requirements that permitted the Navy to reuse design elements from the *Virginia* class attack submarine instead of requiring new design work (see fig. 2).[17]

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[12]We made seven recommendations to the Secretary of Defense to better align Navy shipbuilding programs with the leading commercial shipbuilding practices we found in 2009. The Navy took action to implement six of those recommendations.

[13]GAO, *Columbia Class Submarine: Program Lacks Essential Schedule Insight amid Continuing Construction Challenges,* GAO-23-106292 (Washington, D.C.: Jan. 24, 2023); and *Guided Missile Frigate: Navy Has Taken Steps to Reduce Acquisition Risk, but Opportunities Exist to Improve Knowledge for Decision Makers,* GAO-19-512 (Washington, D.C.: Aug. 9, 2019).

[14]GAO-18-238SP.

[15]GAO-19-512.

[16]GAO-19-512.

[17]GAO, *Columbia Class Submarine: Immature Technologies Present Risks to Achieving Cost, Schedule, and Performance Goals*, GAO-18-158 (Washington, D.C.: Dec. 21, 2017).

**Figure 2: Navy's FFG 62 *Constellation* Class Frigate and SSBN 826 *Columbia* Class Submarine**

Source: Fincantieri Marinette Marine (left) and General Dynamics Electric Boat (right). | GAO-24-105503

For more recent shipbuilding programs, the Navy has also taken steps to limit the number of technologies requiring development to reduce risk for new ship designs. For example, we previously found that the Navy limited technology development for *Arleigh Burke* class (DDG 51) Flight III destroyers by focusing on four systems needed to incorporate an upgraded radar system and modifying existing technologies.[18]

These examples of using proven systems contrast with the Navy's history of concurrently developing critical technologies while designing and constructing ships. We previously found this overlap contributed to schedule delays, cost growth, and deficiencies in ship performance.[19] For example, we found that the Navy did not sufficiently account for risks of developing critical technologies concurrent with construction of the lead ship for the *Gerald R. Ford* class (CVN 78) aircraft carriers. As a result, CVN 78 was delivered to the Navy over 2 years late, and with significant reliability and performance shortfalls for key technologies, such as aircraft launch and recovery systems, that required several additional years to fully resolve. The program's shortfalls also reverberated into follow-on ship results, with CVN 79 experiencing cost growth and schedule delays. We similarly found immature technologies and significant ship design challenges contributed to schedule, cost, and performance shortfalls for the Littoral Combat Ship and the *Zumwalt* class (DDG 1000) destroyer programs.[20]

## Leading Practices in Product Development

We recently performed work to identify leading practices for product development across different commercial industries, which have applications in ship design. This recent work

[18]GAO, *Arleigh Burke Destroyers: Delaying Procurement of DDG 51 Flight III Ships Would Allow Time to Increase Design Knowledge*, GAO-16-613 (Washington, D.C.: Aug. 4, 2016).

[19]GAO-18-238SP.

[20]GAO, *Littoral Combat Ship and Frigate: Slowing Planned Frigate Acquisition Would Enable Better-Informed Decisions,* GAO-17-279T (Washington, D.C.: Dec. 8. 2016), and *Defense Acquisitions: Zumwalt-Class Destroyer Program Emblematic of Challenges Facing Navy Shipbuilding*, GAO-08-1061T (Washington, D.C.: July 31. 2008).

provides insights on the key principles shown in figure 3, which enable companies to deliver relevant and innovative products with predictable schedule and cost results.[21]

**Figure 3: Key Principles Used by Commercial Companies to Enable Successful Product Development**

**Principle 1**
Attain a sound business case that is informed by research along with collaboration with users

**Principle 2**
Use an iterative design approach that results in minimum viable products

**Principle 3**
Prioritize schedule by off-ramping capabilities when necessary

**Principle 4**
Collect user feedback to inform improvements to the minimum viable product

Source: GAO analysis of company information; GAO (icons). | GAO-24-105503

These principles permeate each stage of product development for leading companies and enable them to develop new and innovative products successfully. Specifically, the four key principles position leading companies to deliver hardware and software products to market with speed, generate returns on their product investment, and satisfy their customers' needs.[22] These principles ensure the business case for a product reflects valid customer needs and resources available to support its development and production. They also off-ramp—intentionally defer or cancel—capabilities based on user feedback, when necessary. With these principles as the foundation, our prior work also found that leading companies employ an iterative process for product development that involves continuous cycles.[23]

This process—like Agile software development—revolves around companies rapidly developing and deploying products. Through the iterative cycles, key practices demonstrated by companies include (1) receipt of continuous feedback from the operators of products, (2) focus on delivering a minimum viable product, and (3) continual updates to product design information in a digital thread.[24] As shown in figure 4, other development activities overlap between cycles as product teams design, validate, and test sub-components and integrated systems.

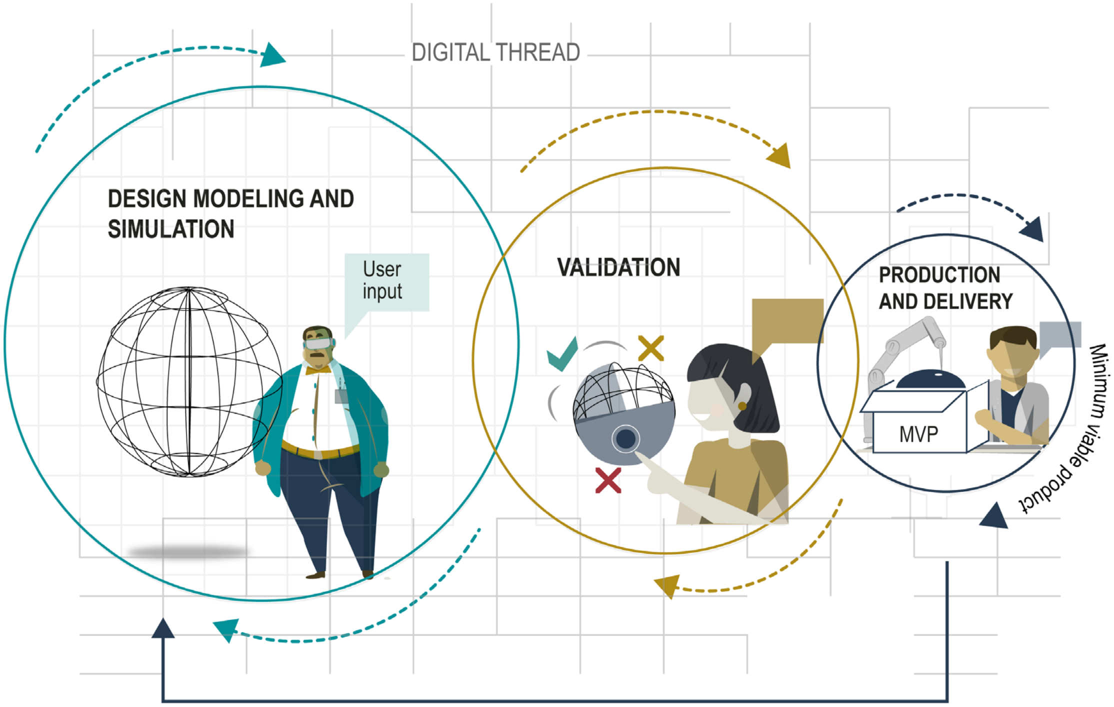
[21] GAO-23-106222 and GAO-22-104513.

[22] GAO-22-104513.

[23] GAO-23-106222.

[24] Minimum viable product refers to a product with the minimum capabilities needed for customers to recognize value and that can be followed by successive updates. A digital thread is a common source of information connecting stakeholders with real-time data across the product life cycle to inform product decisions.

**Figure 4: Iterative Cycles of Design, Validation, and Production Used for Product Development**




Source: GAO analysis of leading company information; GAO (illustration). | GAO-24-105503

# Leading Companies' Design Practices Support Timely and Predictable Ship Delivery

Commercial ship buyers and builders use four primary leading practices, supported by 13 key elements, to enable shorter, predictable cycles for designing and delivering new ships, as discussed in figure 5.

**Figure 5: Summary of Leading Practices GAO Found in Commercial Ship Design**

| Leading practice | | Key elements |
|---|---|---|
|  | **Establish business cases and requirements that support predictable design outcomes** | • Prioritize timeliness of ship design and delivery<br>• Avoid overly prescriptive requirements<br>• Maintains a sound business case through continued reevaluation |
|  | **Use iterative design to accelerate design maturity** | • Prioritize user involvement in the ship design process<br>• Leverage existing ship designs and systems in digital libraries<br>• Prioritize timely vendor decisions and information<br>• Make risk-based decisions to off-ramp design features<br>• Minimize and isolate changes to existing designs<br>• Carefully manage design innovation |
|  | **Use efficient ship design collaboration and decision-making practices** | • Use processes that support timely design decisions<br>• Align decision-making with design maturity measures |
|  | **Employ robust in-house ship design capabilities and tools** | • Maintain strong in-house design workforce capabilities<br>• Use ship design tools to shorten cycle time |

Source: GAO analysis of commercial company information; GAO (illustrations). | GAO-24-105503

# Companies’ Business Cases and Requirements Support Predictable Ship Design Outcomes

## Prioritize Timeliness of Ship Design and Delivery

Leading commercial companies in ship buying and building have strong business cases that prioritize cycle time for ship design and construction over additional capability. These companies prioritize schedule because shorter periods for design and delivery help them preserve their business case and meet strategic business interests. Specifically, ship buyers and builders have an interest in compressing their design and build cycle time to avoid delivering ships with design features that are obsolete or no longer in demand by their customers. Predictability is also a fundamental element of their schedule prioritization. For both parties, delays to designing and delivering a ship as contractually agreed to pose unacceptable financial consequences.

For buyers, delays can prevent them from fulfilling obligations to their customers. Depending on the type of ship, these obligations can include honoring thousands of passenger reservations for a cruise ship vacation. They can also involve transport across oceans of hundreds of cargo containers full of consumer goods or hundreds of thousands of cubic meters of liquid natural gas. Commercial shipbuilders noted that the firm-fixed-price design and construction contracts that they agree to generally include significant financial penalties, such as liquidated damages, for late ship delivery.[25] According to one company, such penalties for delayed ship delivery could involve, for example, liquidated damages to the buyer that exceed $500,000 per day of delay.

For buyers, shorter design and construction cycles also support their interests in being the first to provide the latest innovative technologies and design features at sea for their customers. Further, shorter cycles hasten the start of buyers receiving a return on investment through the revenue received from customers once the ships begin operating. These financial considerations provide incentive for timeliness when considering large, complex ships can cost hundreds of millions of dollars and reach into the billions in some cases, such as with Royal Caribbean Group’s recently delivered *Icon of the Seas,* with a reported cost of $2 billion (see fig. 6).

[25] For nongovernment contracts, a fixed price contract is a type of contract in which the buyer agrees to pay the seller a definite, predetermined price, regardless of costs.

**Figure 6: Royal Caribbean Group's *Icon of the Seas* Cruise Ship**


Source: © 2023 Meyer Turku. | GAO-24-105503

We also found that short, predictable design and build cycles support commercial shipbuilders' interest in optimizing shipyard workflow and maintaining a steady design and construction workforce. In general, leading commercial shipyards have multiple ships under design and construction at any given time. The shipyards also typically have a backlog of new ship builds—for the same or different buyers—waiting to start design and construction. Under these conditions, a delivery delay for one ship can create a cascading negative effect on other ongoing and future builds at the shipyard and the builder's financial bottom line. As a result, builders' design decisions reflect the circumstances of their respective shipyards and their interest in upholding the schedule for designing and delivering new ships.

**Samsung Heavy Industries Prioritizes Schedule When Considering Additional Design Features**

Samsung Heavy Industries builds about 50 vessels per year, including container ships, tankers, and liquid natural gas carriers. They build simultaneously, generally finishing one ship per week and beginning a new one immediately after completion. As a result, the shipyard has roughly 50 ships in some stage of construction in any given week of the year. Representatives from Samsung Heavy Industries noted that the high cost of labor in South Korea drives efforts to ensure steady, efficient workflow at the shipyard. With this pace and demand at the shipyard, delays to an in-progress ship due to the introduction of a new design feature could cause cascading delays to the upcoming vessels, negatively affecting the company's bottom line. To maintain its schedule, Samsung Heavy Industries carefully considers which, if any, new design features can be included on new builds.

Source: GAO analysis of commercial company information. | GAO-24-105503

## Avoid Overly Prescriptive Requirements

The practices commercial ship buyers use to establish requirements help preserve the builders' autonomy for decisions on how to efficiently design and construct ships that meet schedule, cost, and capability requirements. The requirements can include functional specifications, preliminary general arrangements, and ship renderings. Collectively, these requirements serve as the foundation for buyer and builder collaboration. This helps them to reach early agreement on key attributes of the ship design concept and to progressively define the final ship design. Buyers typically share requirements that capture high-level operational needs with prospective shipbuilders and collaboratively develop detailed requirements during iterative planning.

Buyers and builders use feedback from ship engineers and operators—as well as passengers in the case of cruise ships—to inform ship requirements for new designs. Before contract award, they also ensure both parties have a clear understanding of the relationship between requirements, cost, and schedule for each new ship design. This ship design practice is consistent with what we previously found leading companies across different industries do to successfully develop and deliver products to users with speed.[26]

[26] GAO-23-106222.

**Chevron and Carnival Corporation Collaborate with Shipbuilders to Define Requirements**

Chevron develops and provides a functional requirements document—typically 5-10 pages in length—to engage prospective shipbuilders in new ship design and construction projects. This document serves as the launching point for determining design work and the cost and schedule estimates needed to design and deliver a ship that meets Chevron's requirements. As design activities progress, the shipbuilder typically responds with 50-100 pages of more detailed design requirements. After Chevron reviews this information from the builder, the company assesses costs and provides further detail to the builder. The builder subsequently develops more extensive contract specifications—typically between 500-1000 pages—that support contract award for design and construction of new ships.

Carnival Corporation representatives told us they may have preferences for a ship design to include certain systems, but the company generally does not dictate that builders must include those systems in their designs. Instead, Carnival Corporation will define requirements like the type of propulsion and ship operational speeds, with the builder responsible for designing a ship and selecting the material solutions to meet Carnival Corporation's requirements.

Source: GAO analysis of commercial company information. | GAO-24-105503

## Maintain a Sound Business Case

As the pursuit of new ship designs and builds progresses, leading commercial ship buyers and builders regularly reassess their respective business cases. For example, a cruise ship buyer may determine that feedback collected from cruise ship passengers warrants a change in design to either add high-demand design features or remove less-valued features. Further, a cargo ship buyer may identify a changing business case based on feedback from ship operators, indicating opportunities to gain efficiencies in operations or maintenance from incorporating different equipment into ship designs. For any design decisions that may affect the delivery date, buyers and builders reach agreement on a way forward that aligns with their respective interests.

Prior to contract award, if a builder believes that a ship cannot be designed and constructed to meet the buyer's operational requirements and schedule and cost objectives, trade-offs must be made for the project to proceed. Such trade-offs can include removing or revising ship capability requirements, including innovative features that may carry outsized schedule or cost risk. They can also involve the buyer agreeing to take responsibility for all or portions of the development, testing, procurement, and installation of a ship's design features. In such cases, the buyer may also accept responsibility for any financial consequences or delays to the ship's delivery associated with those buyer-supplied design features.

**Meyer Werft Uses Buyer-Supplied Materials to Integrate Novel Design Elements**

Meyer Werft worked with the buyer, Norwegian Cruise Line, to design a cruise ship with a go-kart racing track on the top deck—the longest track at the time of the ship's delivery on the high seas. Meyer Werft determined that a go-kart track was not something it had the expertise to design; however, it assessed that it would be able to help to develop a feasible solution and integrate the track if the buyer provided it. According to Meyer Werft, Norwegian Cruise Line accepted financial and schedule-based risk for including this feature in the design and provided the track as buyer-responsible equipment, with Meyer Werft serving as the integrator.

Source: GAO analysis of commercial company information. (c) 2017 Meyer Werft (image). | GAO-24-105503

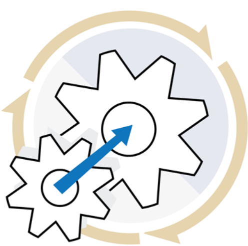
Commercial ship buyers and builders retain a general willingness to update requirements post-contract award in response to design and construction challenges, business case changes, and prioritization of delivery schedules. Commercial builders told us that they often can accommodate unexpected design changes after contract award if they are introduced relatively early in the overall design and construction. For example, Fincantieri and Meyer Werft noted that they consider their design flexibility as a key factor in maintaining strong relationships with cruise ship buyers. Meyer Werft added that it maintains this flexibility, in part, by offering proven design modifications. Additionally, the builders generally remain willing to modify design features later in the design and construction cycle if they determine that the modifications can be completed within the delivery schedule and without notable cost to the builder.

Buyers also commonly agree to buyer-supplied design changes post-contract award when a change in their business case supports a design change that is outside the contract requirements agreed to by the builder. Buyers told us that the builders' push for design changes to be buyer-supplied increases as the ship's design matures and is especially likely if a change is desired once construction is well underway. This increase later in the build cycle stems from shipbuilders wanting to avoid accepting responsibility for changes that could impede their ability to meet the delivery schedule.

**Changing Business Case Leads Royal Caribbean to Make Significant Design Change**

About 6 months before the builder was scheduled to deliver the *Wonder of the Seas* cruise ship, Royal Caribbean reevaluated its business case for the ship and changed the geographic market where the ship would operate once delivered. Based on this change, Royal Caribbean determined that the revised business case supported a redesign for a themed restaurant that had already been built and installed on the ship. Before finalizing its decision to implement the change, Royal Caribbean worked with the builder to determine that the change could be done without undermining the ship delivery schedule. Royal Caribbean accepted responsibility for deconstructing the existing restaurant and designing and constructing the new one, which took about 3 months. The company also accepted financial responsibility for the change, which company representatives noted cost roughly three times more than it would have if included in the original design. Despite the significant additional investment, Royal Caribbean representatives noted that—consistent with its business case—the company achieved a full return on its investment shortly after the ship went into cruise operation.

Source: GAO analysis of commercial company information. | GAO-24-105503



## Companies Use Iterative Design to Accelerate Ship Design Maturity

Leading commercial ship buyers and builders use iterative processes to efficiently establish requirements and designs focused on timely delivery of ships with capabilities desired by customers. Knowledge about the ship's design is progressively refined and documented through ship specifications, contract requirements, and design products supporting construction. As they proceed, the buyer and builder make design trade-offs as needed to support timely delivery of affordable ships that commonly operate at sea for decades delivering required capabilities. This approach incentivizes buyers to identify the capabilities needed for customers to recognize value in a ship's design and avoid chasing immature or expansive innovations to the detriment of timely ship delivery. These commercial ship design practices are consistent with broader leading practices for product development across different commercial industries.[27] Specifically, these practices being used for commercial ship design reflect a cyclical process to determine what capabilities are achievable within a fixed period, design and deliver one or more ships with those capabilities, and repeat this process for successive ship designs.

### Prioritize User Involvement in Design Process

Commercial ship buyers and builders prioritize user involvement in iterative design processes by obtaining and applying design input from their ship operators and the broader user community. This includes direct ship operators' and engineers' involvement in the review of design models and drawings during design maturation. Additionally,

[27] GAO-23-106222 and GAO-22-104513.

commercial buyers and builders receive feedback post-ship delivery to inform designs for subsequent ships and modifications to operational ships. For cruise ships, buyers told us that they use their extensive market research—including passenger feedback from operational ships—to inform ship design decisions from the concept stage of the design process through to relatively late-cycle construction. This market research helps them make design decisions that align with user needs and expectations and helps ensure that cruise operators receive a return on their investment.

**Commercial Ship Operators and Engineers Contribute to Design Reviews and Decisions**

Chevron uses its officer development program to involve first mates and engineers directly in the review of ship designs. The company sometimes also includes ex-chief engineers in its design teams to ensure operational perspectives are accounted for in designs. The operators and engineers review design drawings and contribute to the overall comments that Chevron provides to the shipbuilder. Chevron also performs "lookback" reviews, through which comments can be added to and preserved for design drawings as a form of lessons learned for use in future designs. Once ships are delivered, Chevron uses operational feedback, which includes lessons learned from incidents or near misses, to inform future designs.

Maersk similarly includes senior personnel from ship operations in the design review and approval process. Specifically, the company has "sea-to-shore" contracts with its captains and chief engineers, who are experienced ship operators, and assigns one of each position to the design review and approval team for new ship designs. These same individuals will typically move with the approved design to the shipyard to serve as oversight during construction and then sail on the lead ship (or a retrofitted ship for smaller-scale design efforts) when it is delivered. This approach enables the personnel to experience the ship from the design stage to operations.

Source: GAO analysis of commercial company information. | GAO-24-105503

### Leverage Existing Ship Designs and Systems

We found that commercial shipbuilders draw heavily from their respective digital libraries of existing ship designs and ship systems to speed design maturity and reduce risk. Use of proven ship designs and makers lists—which identify buyer-approved vendors for major equipment, such as main engines and propellers—minimizes design, cost, and schedule uncertainties for buyers and builders. Use of existing ship designs and systems also supports earlier technical maturity for new designs and reduces the need to validate that designs or equipment meet vessel standards.[28] Further, use of existing ship design information helps companies incorporate maintenance and operations considerations in their new designs. Maintenance and operations contribute significantly to a ship's total cost for its buyer, with much of the cost to maintain and operate it fixed at the time when

[28]The International Maritime Organization requires a ship's design and construction to be approved by ship classification societies, such as the American Bureau of Shipping, Det Norske Veritas, or Lloyd's Register. These societies (1) establish and maintain standards for the construction and classification of ships and offshore structures, (2) supervise construction in accordance with these standards, and (3) carry out regular surveys of ships in service to ensure the compliance with these standards.

requirements are set and the ship is designed. As a result, efforts to account for these factors in new ship designs support improvements to life-cycle costs for the ships.

**Commercial Ship Buyers Use Existing Design Knowledge to Improve Maintenance and Operations in New Designs**

Because of its extensive use of existing designs for new ships, Chevron engages its operations teams early in the design process to obtain feedback that can be used to mitigate maintenance and operations issues through design changes. For example, operator feedback on equipment accessibility and maintenance on an existing ship sometimes leads to decisions to include specific equipment in Chevron's new ship designs.

Maersk noted that the evaluation of proposals for new ships is extremely time-intensive because proposed designs can include hidden costs—such as longer-term quality and maintenance costs—that the company seeks to understand before entering into a contract for new ships. The company puts significant effort into using its existing ship design and performance knowledge to evaluate the most-valued components for any ship design because those components have the greatest influence on whether the ship meets Maersk's expectations when delivered and put into operation.

Source: GAO analysis of commercial company information. | GAO-24-105503

Leveraging existing designs and mature equipment also creates opportunities for shipyards to use their prior experiences building to those designs and incorporating that equipment to create efficiencies in new ship construction. For example, Meyer Werft used its library of design data to create a high number of design iterations to determine how to optimize a new design for a recent Carnival cruise ship from a vast array of options. The company's use of design iterations created flexibility that better enabled it to adapt the design if Carnival Corporation wanted to make changes during the design and construction cycle.

Commercial shipbuilders told us that using existing design and system knowledge enables them to start new ship designs with greater baseline design maturity. As an example, Samsung Heavy Industries uses its existing ship design library to identify a baseline design, or "mother ship." This practice provides an optimal design with significant design maturity from the outset. Samsung Heavy Industries then works with the buyer to incorporate new design features that address the buyer's specific needs not already addressed by the mother ship design. For Damen Shipyards Group, the company uses a stable, "Damen Standard" design to build some of its most highly in-demand ship classes without having a specific buyer. Damen stated that the company understands how to efficiently build a baseline ship and will tailor it to meet specific capability interests once the buyer is confirmed (see fig. 7).

Figure 7: Damen Double-Ended Road Ferry


Source: Damen Shipyards. | GAO-24-105503

## Prioritize Timely Vendor Decisions and Information

Commercial builders facilitate a shorter design and construction cycle by rapidly selecting vendors (i.e., equipment suppliers) and managing the timely receipt of associated vendor-furnished information (VFI). Builders noted that rapid selection can include reaching vendor agreements before contract awards or shortly thereafter, such as within 2 months. Commercial builders are incentivized to finalize agreements with vendors for equipment as early as possible to avoid design uncertainty or instability from having incomplete or unreliable VFI in ship designs. For example, Seatrium typically engages in the identification and selection of equipment and vendors prior to finalizing the shipbuilding contract. The company noted that this strategic approach holds particular significance for more complex ship designs, especially for those incorporating unique mission equipment—such as pedestal cranes for heavy lift vessels—where vendor options are inherently limited (see fig. 8).

Figure 8: Seatrium Dual-Fuel Dredger Vessel


Source: Seatrium, all rights reserved. | GAO-24-105503

Prompt vendor selection also helps commercial ship buyers or builders expedite any additional development and testing equipment vendors need to complete to meet the needs of the new ship design and establish reliable VFI. An example of reliable VFI would be having finalized specifications for a piece of equipment but awaiting the results of factory acceptance testing to validate those specifications through manufacturing. Shipbuilders told us that, until vendor agreements are reached, the best available VFI could involve basic specification sheets that provide limited details on the characteristics for previous models of equipment. Builders noted that, whether unavailable or incomplete, delays in obtaining reliable VFI constrain ship design progress and can negatively affect the builder's readiness for construction and ship delivery schedule.

### Make Risk-Based Decisions to Off-Ramp Design Features

Commercial ship buyers and builders told us they use off-ramping practices to support decisions that remove or amend design features or specifications from new ship designs. This includes decisions to exclude design features through collaborative efforts between ship buyers and builders prior to contract awards as well as changes after contract awards. Use of off-ramping can occur when the design feature presents significant risk to achieving the ship delivery date. It can also occur when risk identified from a business case change supports removing design features from the ship's design, such as with the previously discussed cruise ship restaurant example.

In cases where a design feature is removed or significantly changed, that feature can be deferred to future commercial ship designs. Companies perform risk assessments in these instances and may decide to defer the feature because they determine that including it in the design poses an unacceptable risk to meeting the objectives of the existing build. For example, cruise ship buyers and builders noted cases where the buyer may desire an innovative design feature not explicitly defined in contractual requirements that cannot be achieved within the agreed to ship delivery schedule. In such cases, the builder typically works with the buyer to find a solution that aligns with the existing schedule. The builder and buyer will also discuss including the desired design feature in future ships when the longer lead time required to incorporate that feature in design and construction can be accounted for in up-front decision-making.

### Minimize and Isolate Changes to Existing Designs

Commercial shipbuilders isolate changes within the total ship design to maximize the value of using an existing design as their foundation for new ship designs. This approach helps preserve design maturity and reduces total work required for new ship designs. For example, Fincantieri officials told us that the company reduces time and labor hours for functional design by 90 percent or more for "sister" ships—a second ship on the same contract—by carrying over most of the previously validated design of the first ship to the sister ship design. By managing design changes in a manner that minimizes the amount of ship spaces affected, commercial builders and buyers limit total risk to the ship design and maximize the shipyard's experience in building to the prior ship design. This practice supports shorter design and construction cycles as well as more predictable cost and construction performance.

**Maersk Isolates Design Changes When Introducing Innovations**

As part of the company's efforts to become carbon neutral, Maersk explored existing green technology options for its container vessels. As part of these efforts, the company identified an opportunity to use methanol-based technology to power a new class of ships. To develop a ship design that included methanol-fueled technology, Maersk worked with Hyundai Heavy Industries—which had used similar technology in previously built methanol tanker vessels—to use a more standard container vessel design. The resulting design for dual-fuel methanol- and conventional-fueled systems limited total ship design changes to those areas of the ship where the new methanol-fuel system is integrated. The lead ship, *Laura Maersk*, was delivered roughly 2 years after contract award and began operations in 2023.


Source: GAO analysis of commercial company information. A.P. Moller Maersk (image) | GAO-24-105503

## Carefully Manage Design Innovation

In general, significant innovation—which can include novel design features and advanced technologies—must be technically mature for a commercial shipbuilder to agree to include it in the design. This means that the innovation must be well understood and proven—which can be accomplished through its use on other ships or formal testing, such as physical or digital prototyping.

**Maersk Pilots Novel Technologies to Minimize Risk to New Ship Designs**

To minimize risk to new ship design and construction, Maersk generally pilots novel technologies by installing them on existing ships. This can include piloting similar technologies across different ships for comparison. Using sensors-based onboard monitoring systems, Maersk collects data that enable the company to assess the performance of the novel technologies. Maersk also uses fleet-wide performance data to evaluate whether the innovations improve ship performance beyond what is provided by existing systems. Collectively, these data support decisions on whether to include the technologies in future designs. Maersk's piloting practice also supports iterative design principles by validating new design elements on existing ships that can be used in new ship design and construction.

Source: GAO analysis of commercial company information. | GAO-24-105503

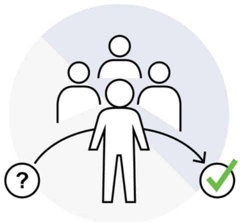
Commercial buyers and builders also told us that they limit the amount or scale of novel design features they are willing to include in a ship design as part of their risk management. Royal Caribbean noted that financial factors play a role in bounding the amount of new features that can go into a ship, with a finite amount of money available for such features given all the baseline costs involved with any new cruise ship. Maersk and Chevron noted a clear link between introducing innovations and maintaining shorter cycles for design and construction. Maersk added that its responsibility as the buyer is to ensure the timing of its orders support delivery of the ships by a certain date, so if the company wants ships sooner, it can consider a more standard ship design. Chevron also noted that too many innovations in a ship design can undermine the builder's ability to maximize its business model and more rapidly design and build ships.

We found that buyers—particularly of cruise ships—will sometimes pursue design innovations through an iterative design process that informs final requirements for reserved areas, or "white spaces," in designs. For these undefined design elements—determined prior to contract award—the buyer will work with the builder and vendors, as well as a classification society when needed, to validate compliance with technical standards and finalize detailed design requirements.

**Carnival Corporation Uses Iterative Design Process to Support Innovative Features**

Carnival Corporation began the ship design concept for its *Carnival Mardi Gras* cruise ship—delivered in December 2020—with the desire to add a yet-to-be-determined innovation. About 6 months after the contract was signed for the new ship, Carnival Corporation determined that the innovation would be the first at-sea roller coaster. This initiated an iterative process where the builder—Meyer Turku—planned for the eventual installation of a roller coaster in the ship design, and Carnival Corporation accepted responsibility for working with a roller coaster vendor to iteratively design and test the system before delivering it to the builder. Carnival Corporation also accepted responsibility for the roller coaster's cost and timely delivery to preserve the builder's ship delivery schedule. Land-based testing of the roller coaster helped refine and validate the design. Onboard testing helped identify additional design requirements for associated spaces, such as vibration and acoustic dampening. Since *Mardi Gras'* delivery, Carnival Corporation included the roller coaster system in the design of its newest ship in the *XL* class, *Carnival Celebration*.

Source: GAO analysis of commercial company information. Carnival Corporation (image) | GAO-24-105503



# Companies Use Efficient Ship Design Collaboration and Decision-Making Practices

### Use Processes That Support Timely Design Decisions

We found that commercial ship buyers and builders use consistent, effective collaboration to support timely decision-making practices from design concept to ship delivery. Their use of extensive up-front communication establishes a common understanding of ship requirements, schedule, and cost before contract award, which hastens design maturity. This collaboration includes candid conversations between ship buyers and builders at the concept stage regarding what can and cannot be reasonably incorporated into a design based on technical, cost, and schedule parameters. Seatrium stated that it proactively engages buyers early to ensure a comprehensive understanding of the buyer's requirements. Seatrium added that this approach allows the company to identify crucial factors influencing the ship's design—such as speed specifications—early in the process, which minimizes potential issues in the later stages of the design and construction cycle.

The decision-making processes employed by commercial ship buyers and builders are also designed for efficiency. For example, Royal Caribbean told us that it uses measurements of risk to determine responsibility for decision-making. For higher risk design elements, the program manager for the new ship is the primary decision-maker. For lower-risk design decisions, the company supports timeliness by delegating authority to lower working levels, such as an assistant project manager for a specific design element of the ship.

Commercial ship buyers and builders also told us that their design and construction contracts—which include firm-fixed prices and fixed ship delivery schedules—include a period typically ranging from 10 to 21 days for buyers to review and comment on design products. They added that design products requiring buyer approval, such as drawings or other design deliverables, may be considered approved by default if the ship buyer does not respond within the period agreed to in the contract. These typical expectations for design review support a timely process for maturing designs to support construction. As ship design updates are requested and accepted, commercial buyers and builders stated that they maintain steady communication with each other, enabled by access to a shared electronic communication platform. The platform provides a real-time means for conveying design decisions among stakeholders and access to information related to the ship design. The overall collaboration and decision-making practices used by these companies allow them to efficiently decide how, if at all, to incorporate design updates without significantly disrupting the overall design and ship delivery schedule.

### Align Decision-Making with Design Maturity Measures

Commercial ship buyers and builders ensure key decisions are closely linked to consistent measures of design maturity and associated effects on construction readiness. Although we found some variation among companies in how much of the total ship design must be completed before they will begin construction, they consistently expect a high degree of design maturity to proceed with construction. For example, Damen told us the company completes the full detail design before starting construction for the first ship in a new class. Samsung Heavy Industries expects at least 90 percent of production design drawings to be completed at the time of its ship model gate review that supports a decision to begin construction—only smaller design elements can remain unfinished.

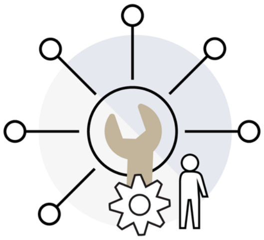
Overall, we found that commercial ship buyers and builders only begin construction when design maturity and related measures demonstrate their readiness to do so. To ensure such readiness, companies set and uphold expectations that (1) basic and functional design will be fully 3D modeled with reliable VFI included to achieve design stability before construction begins, and (2) at a minimum, detail design for any given block of the ship will be completed prior to beginning construction of that block. For more details on the tasks commercial ship buyers and builders use in different design phases to support the leading ship design practices, see appendix II.

**Fincantieri and Meyer Werft Use Design Maturity Measures to Inform Construction Decisions for Cruise Ships**

Fincantieri's internal standard requires an approved functional design and verification that both the hull 3D model and the outfitting 3D model (model of ship spaces and equipment) are mature before beginning construction of any block for its cruise ships. This includes mature modeling of the design and routing of all pipes, ducts, and cable runs for systems expected to be in that block. It also includes verifying that no physical interferences exist between the systems and the hull and completion of other design quality checks.

When incorporating new technologies in ship designs, Meyer Werft uses its technology assurance process to assess risk. This process helps the company keep the addition of new technologies manageable and avoid overcommitting to including innovations in design and construction. The process uses a color-coded scoring system to measure and communicate risk levels, allowing stakeholders to easily review top risks, risk assessment methods, and progress in risk mitigation. Meyer Werft representatives stated that—whether dealing with innovation or new design in general—the company must possess clear details and approval of the ship design's functional systems to begin construction.

Source: GAO analysis of commercial company information. | GAO-24-105503



# Companies Employ Robust In-House Ship Design Capabilities and Tools

**Maintain Strong In-House Design Workforce Capabilities**

Commercial ship buyers and builders maintain strong in-house ship design capabilities. Doing so ensures both sides have a firm and common understanding of the ship design concept and required performance before agreeing to contracts that lock in ship prices and delivery dates. In general, commercial shipbuilders in our review employ an extensive amount of personnel to support ship design efforts. For example, Damen has the equivalent of over 1,100 personnel involved in its design and engineering for first-in-class and single-ship designs. Commercial shipbuilders use their own personnel to perform most of the design work for the ships they build. For detail design, builders noted that their in-house expertise supports decisions that align the ship's design with the shipyard's characteristics to create an efficient build strategy.

Commercial ship buyers use in-house resources to develop design concepts and evaluate the builders' design proposals, development, and execution during construction. For example, Royal Caribbean personnel complete engineering feasibility and packaging assessments and architectural design work—including for buyer-supplied equipment—before finalizing contract awards. Royal Caribbean's department for new ship builds creates a specific team for each project that typically includes a project manager, outfitting manger, technical engineering manager, and area managers for different portions of the ship design. Royal Caribbean noted that having robust in-house resources to advance a design through functional design provides the company—as a buyer—with a firm understanding of how design affects cost, which helps set achievable expectations and supports better decisions. As another example, Maersk has a team of about 100 engineers to support its ship design activities at its offices and on-site at builder shipyards. Within this engineering team, 10 percent of personnel specifically focus on new concept development for ship design and innovation. These personnel regularly leverage subject matter expertise within Maersk's overall engineering team for specific functional design aspects to support design development and oversight.

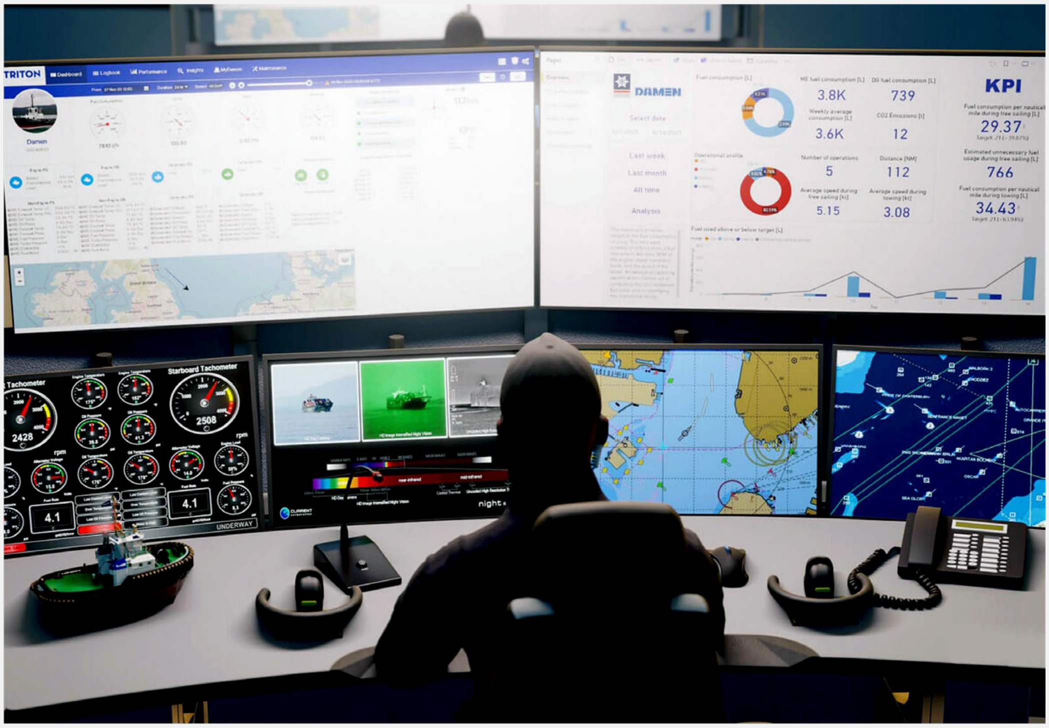
**Use Ship Design Tools to Shorten Cycle Time**

We found that commercial ship buyers and builders use advanced 3D modeling and—to varying degrees—other modern ship design tools to accelerate design maturity and support efficiencies in design and construction. Overall, they noted that their use of modern digital design tools creates efficiencies for design validation, optimization, and completion, among other benefits.

**Samsung Heavy Industries and Damen Use Digital Tools to Achieve Efficiencies with Ship Design, Construction, and Operations**

Samsung Heavy Industries uses a paperless system to manage ship design and construction. The system combines 3D modeling and scheduling information to produce what Samsung refers to as a “4D concept.” The system is available on mobile devices throughout the shipyard to enable digital access to design drawings and models for use in construction. Samsung also uses augmented reality tools that enable personnel to overlay 3D modeling on actual construction work to evaluate results against design.

Damen uses its Triton “internet of things” platform to enable access by the company and others, such as suppliers or ship owners, to specific data on system performance. The Triton platform provides a dashboard where data from onboard ship sensors can be leveraged for real-time or point-in-time data extraction and analysis. As an example of Triton’s capabilities, digital twin data for Damen’s all-electric tugboat can be used to evaluate how much electric power capability is needed for the ship and refine the design to reflect learning. Analytics can take the data and diagnose what has happened, what will happen, and be prescriptive about what to do in the future. This information can be used to optimize ship designs.




Source: GAO analysis of commercial company information. Damen Shipyards (image). | GAO-24-105503

Commercial companies have used advances in 3D modeling capabilities since our 2009 work on shipbuilding practices to increase the amount of design knowledge in modeling and its availability to stakeholders. The 3D modeling systems can increase design efficiency by, for example, customizing the systems to automatically route pipes and electrical cable trays in accordance with preconfigured rules for the ship design. Modern digital engineering, product life-cycle management, and enterprise resource planning systems have also contributed to improved design processes. For example, Fincantieri noted that the company adopted technology within its engineering tools that performs automatic checks between piping technical specifications and materials used for modeling. Further, these checks identify any inconsistences between 2D schemes and 3D modeling, which allows the company to perform updates and maintain alignment of 2D and 3D design information. Commercial ship buyers and builders use their respective systems to refine, store, and communicate design and requirements information that helps stakeholders make decisions throughout the life cycle for a ship's design and construction.

The advances in tools supporting commercial ship design enable builders to mature basic, functional, and detail design earlier in the overall project cycle than was previously achieved with less capable tools. These advances help builders achieve the leading ship design practice of complete 3D modeling of all basic and functional design before starting ship construction. When combined with reliable VFI, the 3D modeling capabilities that commercial builders employ help reduce design uncertainty prior to construction and improve cost and schedule predictability.

Commercial ship buyers and builders varied in their use of other modern design tools that provide virtual representations of physical products—referred to as digital twins—and virtual or augmented reality that immerses users in a virtual environment using head-mounted displays or other technology, to support ship design and construction. Some builders were using virtual or augmented reality tools for activities like testing ship design ideas and virtual walk-throughs of the ship design. For example, Meyer Werft tests the company's design ideas in a virtual environment—using virtual reality in certain cases—from the initial ship design to the production of the final vessel. The company noted that this approach saves time and money as well as enables constant delivery of new innovations to the ships it designs and builds.

**Seatrium's Immersive Virtual Reality Tools Help Validate Soundness of Ship Designs**

Seatrium harnesses the power of its Cave Automatic Virtual Environments (CAVE)—immersive virtual reality systems—for a multifaceted array of applications involving design visualization, simulation, and training. The company stated that these state-of-the-art virtual reality tools offer a lifelike and interactive environment and empower designers and engineers to delve deeply into ship designs. The immersive experiences aid in the early identification of design issues or gaps, while also serving as a robust validation tool for design integrity. For example, CAVE can enable a designer to seamlessly detect potential structural penetrations or foresee collisions in the piping layout of a ship's general arrangement, ensuring a meticulous and error-free design process.

Source: GAO analysis of commercial company information. Seatrium (image). | GAO-24-105503

We found commercial ship buyers and builders view digital twinning as an area of opportunity for future ship design, with present use limited to twinning of ship systems or shipyards rather than entire ships. Our work on leading practices in product development highlights the use of digital twins as a tool to support testing and validation of a product's integrated functionality in its operating environment.[29] For example, Chevron is using digital twinning models to analyze the effects of different loading and damage scenarios and the impact of grounding, flooding, and collision on the ship. Damen has also used digital twinning for virtual commissioning, verification, and validation for new designs.

In addition to modern digital design tools, we found regular use of physical prototyping to support testing and validation of commercial ship designs. For example, Meyer Werft creates scale models of the hull and superstructure for its cruise ship designs to support hydrodynamic tank tests that provide feedback on resistance and speed, maneuverability, and propeller design and optimization. The company also creates full-scale architectural mock-ups of ship spaces to verify the material quality, design appearance, and integration of different components, such as electrical systems.

[29] GAO-23-106222.

# Cumbersome Practices and Ship Design Capability Limitations Challenge the Navy's Ability to Improve Timeliness

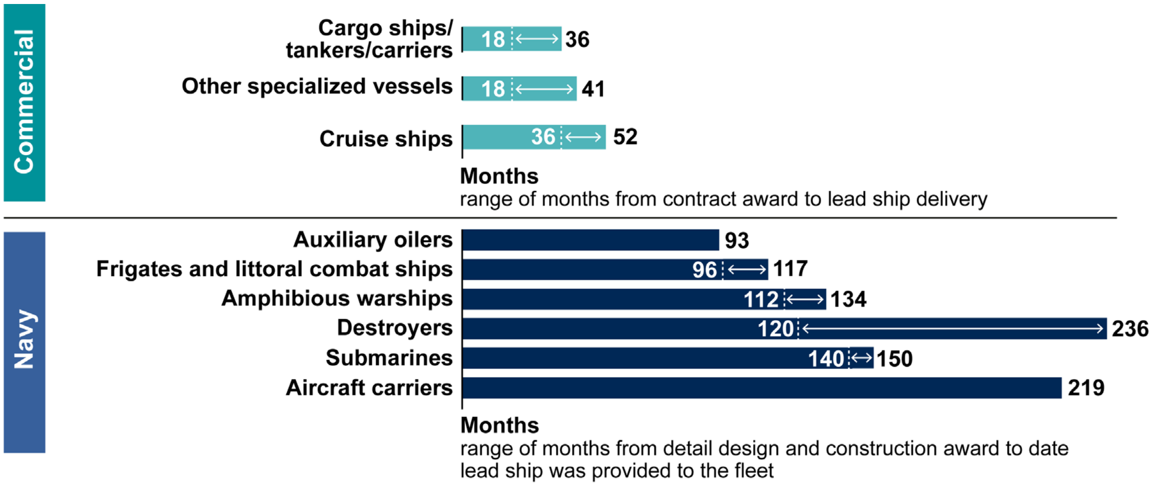
Navy shipbuilding programs often take significantly longer to design and deliver new ships compared to the typical timelines for commercial ships. We found that several factors contribute to the differences in the pace of ship design and delivery, including:

- The Navy's practices for setting requirements and designing new ships lack the streamlined and iterative practices that support shorter cycle times for commercial ships.
- The Navy's linear acquisition practices set key program requirements before designs are stable and lack the type of user involvement, timely VFI, and robust design library used by commercial ship buyers and builders to support design maturation.
- The Navy's layered review practices extend the time needed to make design decisions, and key program decisions lack the clear connection with design maturity measures that exists within the commercial ship industry.
- The Navy's shortfalls in its in-house design capabilities and tools create challenges for achieving the shorter cycle times achieved for commercial ships.

## Long Cycle Times Increase Program Risks for New Ship Designs

We found notable contrast in the design and construction cycle times that are typical for selected types of commercial ships compared to the lead ships for Navy shipbuilding programs (see fig. 9).

Figure 9: Comparison of Design and Construction Cycle Times for Selected Commercial and Navy Ships

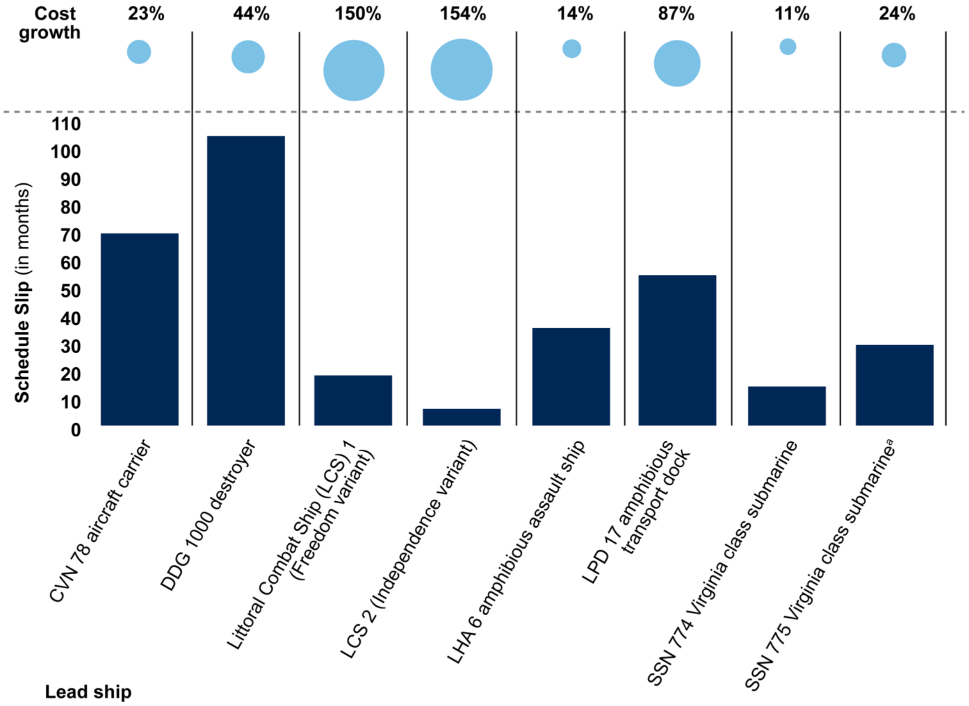



Source: GAO analysis of commercial company and Navy information. | GAO-24-105503

Notes: For commercial ships, the number of months reflected in the ranges indicate the shortest and longest periods for companies to deliver a lead ship after contract award. "Commercial other specialized vessels" includes ship types such as offshore support vessels, ferries, icebreakers, tugboats, and research and science vessels. For Navy ships, the number of months reflected in the ranges indicate the shortest and longest periods for the Navy to provide selected lead ships to the fleet since 2007. We measured Navy cycle times based on the actual obligation work limiting date (OWLD) or planned date for lead ships that have yet to reach OWLD. OWLD generally coincides with when a Navy ship is provided to the operational fleet. While the fleet has some responsibilities for operating and maintaining the ship prior to OWLD, the acquisition program office is still managing construction-related work on the ship until this date. Since we found that commercial ships typically enter operation soon after delivery, Navy OWLD provides the best proxy for comparison to commercial delivery dates. For Navy programs that had a contract prior to the detail design and construction award, we used that contract award date as the start of the cycle.

A lengthy cycle time creates business case challenges as threats and mission needs can change. For example, 11 years elapsed between the start of the DDG 1000 program and construction beginning on the lead ship. During that time, the Navy shifted from a focus on capability needs for operations in nearshore waters to deeper water operations. With this shift, the Navy determined that the DDG 51 class of destroyers would be a more effective option to meet operational needs and reduced the total number of DDG 1000 class ships from 32 to three ships. Figure 10 shows the challenges the Navy has encountered in upholding the original delivery schedules and costs supporting the business cases for its shipbuilding programs.

**Figure 10: Selected Navy Shipbuilding Programs' Lead Ship Cost Growth and Delays in Providing Ships to the Fleet**




Source: GAO analysis of Navy information. | GAO-24-105503

[a]SSN 774 is the lead ship of the *Virginia* class submarines; however, the second submarine of the class, SSN 775, was delivered by Newport News Shipbuilding prior to the delivery of SSN 774 by General Dynamics Electric Boat.

Notes: Cost growth is measured as the difference between the initial cost estimate reflected in the Navy's budget request documents prior to ship construction (year in which the Navy requested authorization for the ship from Congress) and the actual cost. We measured schedule change from the originally planned to the actual obligation work limiting date (OWLD) for Navy programs. Since we found that commercial ships typically enter operation soon after delivery, Navy OWLD—which generally coincides with when a Navy ship is provided to the operational fleet—provides the best proxy for comparison to commercial delivery dates. It is possible for a Navy program to maintain its ship delivery date but have a schedule delay to OWLD.

# Requirements Practices Hinder Business Cases and Ship Design Maturity

The extensive process used by the Navy to establish capability requirements for new ships contrasts significantly with the typical commercial process used to efficiently move from basic requirements to specifications that support a contract award for ship design and construction. Specifically, Navy shipbuilding programs progress through a protracted process to solidify requirements in the capability development document (CDD) prior to contract award for detail design and lead ship construction. The CDD outlines the operational requirements that will deliver the capability to meet operational performance expectations for the ship. Figure 11 shows the general process for the Navy and DOD's Joint Staff to develop and review capability requirements for new shipbuilding programs in response to identified capability gaps. This process applies to initial CDDs submitted by the Navy to the Joint Staff for review as well as to CDD updates later in the acquisition cycle.

**Figure 11: Capability Development Document Review and Validation Process**

| Navy requirements setting process | | | Joint Capabilities Integration and Development System (JCIDS) approval process | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Navy** | | | **Joint Staff Gatekeeper** | **Department of Defense (DOD) stakeholders** | **Navy** | **Functional Capabilities Boards** | **Joint Capabilities Board (JCB)** | **Joint Requirements Oversight Council (JROC)** |
| Endorse initial requirements | Set guidance and authorize development of capability documents | Endorse capability documents | Recieves documents, assigns Joint Staffing Designators (JSD), and submits documents for staffing in the JCIDS process | Have the opportunity to review documents and provide feedback through comments | Adjudicate comments provided by DOD stakeholders | Review and approve documents based on the adjudication of comments | Validates documents with a JSD of JCB interest or reviews and forwards documents to the JROC | Final review and validation of documents with a JSD of JROC interest |

Source: GAO analysis of Navy and DOD information. | GAO-24-105503

Along with the overall DOD requirements review process shown in the figure above, the Navy's acquisition guidance includes gated reviews intended to ensure that requirements align with acquisition plans.[30] These reviews support the Navy's efforts to develop and endorse capability requirements before submitting them for Joint Staff review.

The overall requirements setting process leads to significant time elapsing before Navy shipbuilding programs can move forward with contract awards for detail design and construction. For example, it took over 4 years from when the Navy initiated its pursuit of DDG 51 Flight III to validate the program's CDD. This included 2 years between the Navy's CDD approval at the program's third gate review and the Joint Requirements Oversight Council's CDD validation. DOD's guidance for the Joint Capabilities Integration and Development System portion of the overall CDD review and validation process indicates that it should be accomplished in no more than 103 calendar days.

[30]Department of Defense, Secretary of the Navy, SECNAV Instruction 5000.2G, *Department of the Navy Implementation of the Defense Acquisition System and the Adaptive Acquisition Framework* (Apr. 8, 2022). This instruction includes a gate review process specific to Department of the Navy weapon system programs.

However, our prior work reviewing this process found that none of the DOD programs we reviewed completed the process within this time.[31] That work also found a variety of issues that could affect the length of elapsed time, with the comment adjudication period cited by Joint Staff officials as the biggest contributor to the length of reviews.

In addition to timeliness issues, we found that the Navy's processes do not require confirmation of the continued relevance of its business case—a leading practice—through formal reevaluation of CDDs during ship construction or prior to the start of construction for each ship. Specifically, the Navy's acquisition guidance includes a gate review after detail design and construction contract award to endorse any CDD updates. However, the guidance does not require that the Navy proactively continue to assess its business case supporting approved capability requirements as a shipbuilding program progresses. The lack of such a requirement limits formal opportunities to identify changes that could improve the capability delivered to the fleet. It also increases the risk of the Navy investing resources in ship designs with capabilities that are no longer needed.

A recent law requires DOD to develop and implement a streamlined requirements development process, and we plan to evaluate DOD's requirements process in greater depth as part of other planned work.[32] However, we identified some steps that the Navy has already taken for its recent shipbuilding programs to improve the requirements process, which are also consistent with leading practices. Specifically, Navy officials said that they have focused on increasing communication with prospective shipbuilders during requirements setting and conceptual design activities. They have also held requirements open later into the acquisition cycle for more recent shipbuilding programs. This helps the Navy and the builder increase their understanding of the requirements' effect on design, schedule, cost, or other factors before finalizing the CDD. Navy officials told us that communication with shipbuilders can help shape requirements and design to get a ship with desired capability at a reduced cost by leveraging the builders' knowledge of available innovations and current shipyard capabilities. These efforts support improvements to requirements setting and early design that could contribute to more predictable program outcomes for future ship classes.

In addition to the lengthier process for setting requirements, we identified some other requirements challenges that impair the Navy's ship design efforts. For example, we found that the requirements setting process can lead to prematurely creating parameters that have outsized ramifications on cost and schedule. Further, these parameters contribute to inefficient or ineffective design decisions that can result in ship delivery

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[31]GAO, *Weapon System Requirements: Joint Staff Lacks Reliable Data on the Effectiveness of Its Revised Joint Approval Process,* GAO-22-104432 (Washington, D.C.: Oct. 21, 2021).

[32]House Report 118-125, accompanying the National Defense Authorization Act for Fiscal Year 2024, directed GAO to provide a briefing and subsequent report to the congressional defense committees on options to reform DOD's requirements processes.

Section 811 of the National Defense Authorization Act for Fiscal Year 2024 requires that, by October 1, 2025, the Secretary of Defense develop and implement a streamlined requirements development process for DOD to improve alignment between modern warfare concepts, technologies, and system development and reduce the time to deliver needed capabilities to warfighters.

delays, cost growth, and additional work to fully meet operational requirements or unfulfilled requirements.

**Early Restrictive Requirements Contribute to Challenges for Navy's Littoral Combat Ship**

For the Littoral Combat Ship program, achieving the sprint speed and cruising range set in the requirements necessitated the use of diesel and gas turbine engines with a combining gear that allowed the ship to run on a combination of the two engine types to attain its maximum speed. Neither of the program's two ship variants met the combined original speed and range expectations, and Navy officials later determined that the top speed was not essential to mission performance. Further, this propulsion system resulted in major challenges, including engine failures and mechanical problems stemming from problems with the combining gear. In this example, the lack of flexibility to modify requirements resulted in significant challenges and ships that were unable to meet those same requirements.

Source: GAO analysis of Navy information. U.S. Navy, Christopher Thomas, Mass Communication Specialist, 2nd Class (image). | GAO-24-105503

## Linear Acquisition Approach Increases Cycle Times for New Ships

The Navy generally uses a longer, more linear approach to design and deliver new ships that contrasts to the iterative design practices that we found in use for commercial ship designs. This linear approach defines and locks down requirements relatively early, and development focuses on compliance with original requirements. The Navy's approach also focuses on designing and delivering extensive, and often novel, capability with the lead ship, with reduced emphasis on the length of time needed to deliver the ship compared to commercial practices.

For instances of major design changes to existing ship classes—such as those included in DDG 51 Flight III and LPD 17 Flight II—the Navy treats them much like new shipbuilding programs, with linear requirements setting and design maturation processes. This leads to a considerable amount of time elapsing before a lead ship is delivered to the fleet. For example, about 14 years elapsed between the Navy's decision to pursue DDG 51 Flight III and its June 2023 acceptance of lead ship delivery.

As part of the linear approach used for its shipbuilding programs, the Navy measures results against an acquisition cost, schedule, and performance baseline. We found challenges with the Navy setting these baselines for programs before achieving a stable design for the new ships. Specifically, DOD policy requires that Navy shipbuilding programs receive approval for their acquisition program baseline—which outlines capability, cost, and schedule requirements—before awarding a detail design and construction contract for the lead ship.[33] However, the Navy generally does not work with builders to achieve design stability before setting these baseline requirements and awarding these contracts. Instead, the Navy commonly defers significant amounts of basic and functional design work—which provides such stability—until after the detail design and construction contract awards. For example, shortly after the detail design and construction contract award for FFG 62, the program office stated that most of the ship's design drawings for basic and functional design remained incomplete.

As a result of setting baseline requirements without a stable ship design, key decisions for Navy shipbuilding programs are informed by less design knowledge than what commercial ship buyers and builders expect to have before entering into contracts. Further, the Navy's approach poses greater risk that the business case for its new ships will erode because cost, schedule, and capability requirements are set before the design has sufficiently matured to support more predictable outcomes.

## Limited User Involvement

We found less consistent and direct involvement of ship operators and engineers in the Navy's ship design activities compared to commercial practices. The Navy has extensive guidance to support its ship design management and ensure the human component—operators, maintainers, and support personnel—is reflected in design.[34] This guidance supports the Navy's establishment of ship design teams with extensive subject matter expertise in the design and engineering of ships. However, we found that this guidance does not explicitly include the type of consistent user involvement employed in commercial ship design—such as the inclusion of ship operators on design teams and in direct design reviews—to incorporate user input in design decisions.

Further, Navy shipbuilders indicated direct user involvement in the design process varied. For example, one builder stated that the Navy's end users for new ships have little or no involvement in the design process unless such involvement is explicitly included in the contract requirements. In contrast, another Navy shipbuilder told us that ship operators and maintainers are consistently involved in the 3D model review process

[33]Department of Defense Instruction 5000.85, *Major Capability Acquisition* (Nov. 4, 2021).

[34]Naval Sea Systems Command Technical Publication S9800-AC-MAN-010, *Ship Design Manager (SDM) and Systems Integration Manager (SIM) Manual* (Feb. 13, 2012); and NAVSEA Instruction 3900.8A, *Human Systems Integration (HSI) Policy in Acquisition and Modernization* (May 20, 2005).

for ship designs, providing lessons learned for consideration. Without consistent practices to ensure direct user involvement in design efforts across Navy shipbuilding programs, the Navy falls short of leading practices and increases its risk of design decisions that do not fully account for the needs of its sailors.

### Inconsistent Off-Ramping Practices

In another contrast to commercial practices, the Navy has a history of remaining committed to its pursuit of originally approved capability requirements on the lead ship when technical, cost, schedule, or other business case issues arise, rather than deferring desired capability to future designs.[35] As we previously found, the Navy's lack of adaptability has proven particularly challenging when pursuing ambitious requirements for ships that require innovations that have yet to be proven out.[36]

Further, we found that when the Navy has decided to off-ramp design innovations, it has been after it made significant investments. For example, the Navy invested hundreds of millions of dollars to develop the remote multi-mission vehicle systems for the Littoral Combat Ships before replacing them with a different system due to performance shortfalls.

### Limited Design Library

The Navy makes some use of existing designs but lacks a digital design library like those used by commercial industry to support iterative design and shorten the time needed to mature new designs. The limitations of the Navy's library reduce the range of existing ship designs that the Navy can leverage to evaluate and optimize baseline designs for its new ships. They also hamper the Navy's ability to expedite design and construction by increasing initial design maturity for new ships. A senior Navy official noted that, while the Navy has a solid digital library for ship systems and components, its library is more limited for ship designs. The official also said the Navy would benefit from a more expansive library of ship designs but noted that developing one would likely require a collaborative effort with Navy shipbuilders. He cited the builders' intellectual property interests for their respective ship designs as a reason for needing collaboration.

### Challenges with Timely Vendor-Furnished Information

In addition to design library limitations, we found that the Navy generally incorporates reliable VFI in its ship designs later than commercial ship buyers and builders. The companies' speed compared to the Navy stems from efficient processes for finalizing vendor agreements, regular adoption of equipment in use on existing commercial ships, and intolerance for including immature technologies in commercial ship designs. Navy shipbuilders commonly make vendor decisions after the award of detail design and lead ship construction contracts, with extended time elapsing in some cases before vendor finalization. Causes of delay include, for example, the lack of an existing relationship between the shipbuilder and vendors requiring more time to reach agreement. The practices employed for Navy shipbuilding add time to the design cycle by delaying the start of any development efforts needed for equipment to meet Navy requirements. They also delay the receipt of reliable VFI needed to mature the ship design. Without timely receipt of reliable VFI, design maturity is limited by inaccurate or incomplete design

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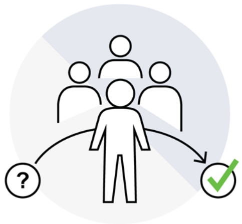
[35]We previously found that DOD's policies do not require all programs to consider off-ramping non-critical capabilities to achieve schedule. GAO-22-104513.

[36]GAO-18-238SP.

information, which could result in design and construction rework if the actual specifications vary significantly from estimates.



## Decision-Making Practices and Inconsistent Design Maturity Measures Affect Timeliness and Risk

We found that the Navy and its shipbuilders generally have less direct communication prior to contract award than commercial ship buyers and builders. Our prior work found that shipbuilders may communicate less openly to preserve their competitive interests when the request for proposals process is the primary means for communication with the Navy because their inquiries would be available to the public.[37] Reduced early communication increases the risk of shipbuilders and the Navy experiencing challenges post-award due to a lack of common understanding about requirements. The Navy has worked to increase early communication in recent programs, such as with the FFG 62 frigate and DDG(X) destroyer. This includes awarding multiple contracts to prospective builders for the early design phase. This approach is intended to enable greater communication and collaboration before decisions are made on contract awards for detail design and lead ship construction.

### Extended Stakeholder Involvement in Decision-Making

The Navy's decision processes for new ship designs lack the streamlined and more time-constrained processes we found commercial ship buyers and builders use to reduce cycle times for ship design. Instead, Navy shipbuilding programs have many stakeholders with the authority to affect design decisions. This can prolong timelines for design decisions. Interoperability requirements for ships across the Navy's fleet can create design demands not present for commercial fleets that necessitate additional stakeholder involvement in design decisions. Still, timely decision-making for commercial ship design is supported by empowering project leaders to make most decisions without layers of stakeholders needing to weigh in. This approach is consistent with leading ship design practices as well as broader leading practices for product development identified in prior work.[38]

As an illustration of the extended Navy timelines, we found through an assessment of selected Navy ship design and construction contracts that they generally allotted anywhere from 21 to 60 days for the Navy to review and respond to ship design documentation submitted by shipbuilders. In contrast, the longest typical timeline any commercial ship buyer and builder in our review identified for these activities was 21 days. Additionally, Navy officials noted that there are instances where the Navy and builder agree to extend their design review periods when additional time is needed. With these review timelines potentially applying to hundreds of contractually defined design products for a shipbuilding program, timeliness of design approval can weigh on the pace of design progress and contribute to a longer design cycle for Navy programs.

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[37] GAO-19-512.

[38] GAO-23-106222 and GAO-22-104513.

Navy officials noted that design decision-making is challenging because the Navy often manages key technologies as unique programs. As a result, shipbuilding programs do not have control of all the systems on the ships. Coordinating with these different programs to reach a decision for a ship's design can be time-consuming. Navy officials also told us that the number of stakeholders has grown over time due to risk aversion—principally the risk of overlooking key factors when making program decisions—and challenges with ensuring a single stakeholder has sufficient knowledge of all systems to support decision-making and accountability. Navy shipbuilders agreed that many design decisions require layers of Navy review or consensus of many stakeholders for approval, which results in an administratively burdensome and time-consuming process. For example, one shipbuilder noted that design changes can sometimes take weeks or months to finalize because of the Navy's layers of technical review that support decision-making, and the associated internal coordination required to make such decisions.

The Navy's recently acknowledged shortfalls with its in-house ship design capability further contribute to its timeliness challenges for design decision-making. Specifically, in May 2023, the Acting Assistant Secretary of the Navy for Research, Development, and Acquisition stated that the department did not have the ability to fully execute a Navy-led ship design due to, among other factors, workforce deficiencies.[39] Navy officials told us that significant reductions to their design-related workforce over time affected the Navy's timelines for evaluating design products and resolving design issues. For example, a senior Navy official told us that, instead of the 10 technical experts and 10 supporting staff that the Navy had in the past to review hydrodynamics for all surface ship designs, the Navy currently relies on one technical expert for these reviews. The official stated that similar circumstances exist for reviewing general arrangements for ship designs. Beyond the workforce capacity considerations, Navy officials noted that a significant loss of experience and institutional knowledge within the Naval Sea Systems Command negatively affects the command's in-house ship design capability.

### Inconsistent Connection between Design Maturity Measures and Decisions

The Navy's ship design practices have a less consistent and clear connection between design maturity data and decision-making compared with the practices used by commercial ship buyers and builders. When evaluating design maturity and making decisions on construction readiness, commercial companies generally focus on key ship design knowledge attained—including design product approvals, VFI completeness, and material availability for construction—rather than calculations of design completion. Use of this information at key decision points in the design cycle helps the buyer and builder ensure a clear understanding of existing maturity and remaining risks.

The Navy's design maturity expectations and results vary across shipbuilding programs. For example, we found that programs were mixed as to whether they set an expectation that basic and functional design would be completed before starting ship construction. We similarly found variation in whether the programs achieved 100 percent completion for basic and functional design before beginning ship construction. Additionally, we found that Navy shipbuilding programs generally do not expect complete 3D modeling of

[39]Department of the Navy, Assistant Secretary of the Navy for Research, Development, and Acquisition Memorandum for Commander, Naval Sea Systems Command, *World-Class Ship Design Capabilities* (May 10, 2023).

basic and functional design before ship construction begins, which is inconsistent with leading practices we found in commercial ship design.

The Navy has taken some actions in recent shipbuilding programs to formalize design maturity measures. For example, we found that several Navy shipbuilding programs set thresholds for the degree of design maturity they require before deciding to begin ship construction. How programs measured their achievement of these thresholds varied but typically reflected percentages of design drawings or design-specific contract deliverables expected to be submitted at key milestones before construction. Navy shipbuilders noted that using this type of metric does not necessarily provide a clear understanding of overall design maturity. For example, the metrics may overstate design completeness by giving builders credit for submitting design-related documentation without fully accounting for the quality or completeness of associated design. Drawings that appear complete could include design placeholders that lack necessary VFI for key equipment and, consequently, mask design uncertainties and remaining design work. Further, Navy officials noted cases where builders submitted blank design products, which met the submittal deadline to the Navy but did not contribute to advancing design maturity.

Because of challenges tracking deliverables across different design processes, Navy program officials for the T-AO 205 *John Lewis* class oiler ship told us that they required the shipbuilder to submit a design maturity assessment report prior to the program's critical design review. The program officials added that the requirement forced the shipbuilder and the program office to align their design efforts and prompted discussions that led to a better understanding of design maturity.

A recent law emphasizes the role design maturity should play in Navy decision-making and could help better align its shipbuilding program activities with the leading practices we found in commercial ship design. Specifically, the National Defense Authorization Act for Fiscal Year 2022 required the Secretary of the Navy to certify to congressional defense committees the completion of basic and functional ship design before approving the start of construction for the first ship. The Act also required the Secretary of the Navy to provide these committees certain design maturity information as part of its production readiness review reporting and certification.[40]

[40]National Defense Authorization Act for Fiscal Year 2022, Pub. L. No. 117–81 (2021), § 1013 (codified at 10 U.S.C. § 8669c). Section 8669c(a) of title 10, United States Code, requires the Secretary of the Navy to submit a report to the congressional defense committees on the results of any production readiness review before approving the start of construction for the first ship for any major shipbuilding program. The report is required to include, among other things, an assessment of (1) the maturity of the ship's design, as measured by stability of the ship contract specifications and the degree of completion of detail design and production design drawings; and (2) the extent to which adequate processes and metrics are in place to measure and manage program risks. 10 U.S.C. § 8669c(b). Section 8669c(a) also requires the Secretary of the Navy to certify to the congressional defense committees that basic and functional design of the vessel, as defined by the statute, is complete before the Secretary of the Navy approves the start of construction for the first ship for any major shipbuilding program.

The statutory requirements reflect some elements of the leading practices we found for commercial ship design. However, the statutory definition for basic and functional design differs from leading practices in two notable ways.[41]

1. The statute does not explicitly require actions to ensure Navy shipbuilding programs model basic and functional design in 3D to demonstrate completion prior to starting construction of the first ship.

2. The statute does not require actions to ensure positioning and routing of all major distributive systems of the first ship to demonstrate basic and functional design completion.

Additionally, the statute does not include requirements supporting two other key leading practices we found supporting commercial ship design. Specifically, the statute does not require Navy reporting and certification on the results of the production readiness review to include:

1. Confirmation that a program requires detail design to be complete for each ship block prior to construction of that block.[42]

2. Information on the completeness of VFI to support stakeholders' understanding of remaining design uncertainty prior to beginning construction.

The absence of these key design maturity elements from leading ship design practices in the statutory requirements for Navy certification and production readiness review reporting increases risk for Navy shipbuilding programs. Specifically, their absence increases the risk that the design maturity information used by the Navy to support its construction readiness decisions lacks the completeness or reliability expected by leading ship design practices. As we previously found, starting construction before achieving sufficient ship design maturity has contributed to construction inefficiencies and significant schedule, cost, and performance issues for Navy shipbuilding programs.[43]

In addition, the Navy stated that it has not issued any guidance on its approach to evaluating design maturity for programs to support these statutory design certification and reporting requirements. Navy officials also told us that they have no plans to issue such guidance. Instead, they said that they use engineering judgement to establish working definitions for what a major shipbuilding program must achieve to meet the

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[41]Section 8669c(c) of title 10, United States Code, defines the term 'basic and functional design', when used with respect to a vessel, to mean design through computer aided models, that—''(A) fixes the major hull structure of the vessel; ''(B) sets the hydrodynamics of the vessel; and ''(C) routes major portions of all distributive systems of the vessel, including electricity, water, and other utilities."

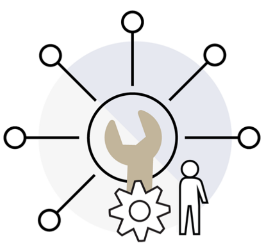
[42]For submarines, the Navy refers to the completion of "design disclosures" as signifying detail design work at all levels for a given area or system has been accomplished to establish component dimensions and materials needed for construction. For purposes of this report, we are equating this to the completion of a "block" for surface ships.

[43]GAO-18-238SP and GAO-09-322.

statutory requirement to certify completion of a ship's basic and functional design. They added that shipbuilding programs can choose how to define detail design.

The lack of Navy guidance to support the statutorily required certification and production readiness review reporting on design maturity increases the potential for confusion and inconsistencies in the Navy's approach to fulfilling these statutory requirements across its shipbuilding programs. For example, the Secretary of Navy certified, in August 2022, that the FFG 62 frigate program had completed basic and functional design, as defined by the statute. The Navy's certification included technical data showing 90 percent of the frigate's functional design was completed before beginning construction, which is counter to leading ship design practices. Navy officials told us that the statutory definition of basic and functional design includes a subset of the overall design characteristics that the Navy reviews and considers when determining readiness for ship construction. They also stated that the Navy requires a more rigorous level of design maturity than what is required by the statute's basic and functional design definition. Navy officials said that these factors and other metrics tracked by the FFG 62 program supported certification that basic and functional design—as defined by statute—was complete.

While the Navy's approach meets the statutory requirement to certify completion of basic and functional design, the FFG 62 certification and production readiness review reporting did not demonstrate the type of clear connection between design maturity data and decision-making expected by leading practices to support construction readiness. Further, subsequent functional design problems encountered by the FFG 62 program, which have contributed to cost and schedule issues for the lead ship, raise concerns about the Navy's approach to measuring functional design maturity.[44]



## Limitations in In-House Ship Design Capabilities and Tools Hinder Timeliness

As previously discussed, the Navy has acknowledged shortfalls in its design workforce, which contrasts to the significant in-house design capabilities that we found typical of commercial ship buyers and builders. The Navy's workforce shortfalls present challenges to minimizing the overall cycle times for ship design and effectively managing design risk for design and construction. In recognition of the challenges, the Acting Assistant Secretary of the Navy for Research, Development, and Acquisition initiated activities in May 2023 to improve the Navy's in-house ship design capabilities and enable the Navy to effectively lead ship design efforts.

In December 2023, the Navy confirmed to us that it had developed a draft strategic plan focused on reinvigorating the Navy's in-house ship design capabilities. The draft plan's high-level objectives include strengthening the Navy's technical community to support in-house design capabilities; better aligning Naval Sea Systems Command and other Navy organizations to support efficient and effective design efforts; and establishing new ship design team facilities at certain Navy locations. Navy leadership stated that, without a

[44]We intend to discuss these and other issues related to the FFG 62 program in greater detail as part of a planned report focused on the Navy's *Constellation* class guided missile frigate acquisition program.

reinvigorated Navy ship design capability, the department risks overreliance on shipbuilders for design work. Further, the Navy will remain challenged in its ability to reduce the cycle time for design and construction and effectively manage design risk. We plan to monitor the Navy's progress in finalizing a strategic plan to address the identified design shortfalls and as the Navy works toward implementing that plan.

For design tools, we found commercial ship buyers and builders and the Navy and its builders using a range of digital 3D modeling applications to mature ship designs. Similar to commercial companies in our review, Navy shipbuilders we spoke with noted significant advancements in recent years with 3D modeling capabilities and the integration of design data from other systems in the models. However, Navy shipbuilding programs generally encounter more challenges in integrating 3D modeling with other information systems to enhance the depth of knowledge available to stakeholders. The challenges include incompatible systems and continuing use of 2D design information for legacy ship classes, such as *Arleigh Burke* destroyers and *Virginia* class submarines. These programs used less sophisticated digital design technologies or methods to document their ship design before the rise of 3D modeling capabilities.

By using 2D design information instead of 3D information, Navy shipbuilding programs face increased risk that 2D designs obscure issues—such as multiple design components occupying the same space. Such issues are more easily identifiable when visualizing a space using 3D modeling. Further, shipbuilders noted that 2D design is limited, compared to 3D design capabilities, in its ability to provide for simultaneous access of designs by multiple users, rapid assessment of many design options, and effective modeling of designs earlier in the design cycle to inform decision-making.

Navy shipbuilders cited the timeliness of VFI receipt as an additional challenge for 3D modeling completion. Specifically, Navy shipbuilders told us that their ability to capitalize on the opportunities that design tools offer to expedite ship design maturity is predicated on the timely receipt of reliable VFI, which regularly is not achieved. Without it, the 3D modeling is held back by the risk of design changes from unstable information on ship equipment.

Beyond 3D modeling, the previously discussed May 2023 design shortfalls acknowledged by Navy leadership also included capability gaps with in-house design tools. As with the design workforce issues, the Navy expects its ongoing work related to a strategic plan for design capabilities to set a course to replenish its in-house design tool set. In addition, Navy shipbuilders told us they are adopting other modern design tools to varying degrees, noting limited use of digital twinning and early-stage employment of virtual or augmented reality to support ship design and construction. For example, one Navy shipbuilder told us that its increased capability in 3D modeling and recently introduced virtual reality allows for design testing using the ship model as a digital prototype. The company is also creating a digital twin of its shipyard to support production efficiencies. However, Navy shipbuilders' use of these tools remains more limited overall than what we found for commercial builders.

Navy shipbuilders told us that the use of modern design tools can advance design maturity and inform design decision-making. Specifically, the tools can help validate the physical integration of the ship, which ensures that multiple systems or features are designed into the ship without creating design conflicts, such as two systems occupying the same space. In the absence of a requirement by the Navy to use these design tools, Navy shipbuilders indicated that one challenge to expanding their design tools is building the business case to support the investment required to acquire and implement them. Still, without assessing potential opportunities to expand the use of modern design tools—within the Navy and across its shipbuilders—the Navy will not have a solid understanding of the types of investments required to ensure modern design tools are consistently used across its shipbuilding programs. The Navy could miss opportunities to gain efficiencies that support shorter, more predictable cycle times for ship design.

# Conclusions

The demands pushing the Navy to increase the pace of design and construction for new ships will likely go unfulfilled without reforms to its ship design approach that provide greater flexibility and enhanced timeliness. Since our initial shipbuilding leading practices work in 2009, the Navy and its shipbuilders have taken steps to improve design practices, which include implementing many of our recommendations directed at increasing design maturity before the start of construction. Our analysis of the practices used by commercial ship buyers and builders indicates that the Navy has additional opportunities to embrace leading ship design practices to support timely, predictable outcomes for its shipbuilding programs. These opportunities involve:

- Improving consistency and communication of ship design maturity measures that support decisions to begin construction.
- Ensuring validated requirements continue to reflect operational needs before making decisions to proceed with the construction of each ship.
- Increasing the level of design maturity achieved before making decisions on detail design and construction contract awards and cost and schedule expectations for shipbuilding programs.
- Ensuring consistent, direct user involvement throughout the ship design process to inform decision-making.
- Improving processes and resources to streamline decision-making by ensuring that the amount of stakeholder involvement matches the significance of decisions and decision-makers have the support needed to efficiently make them.
- Improving the Navy's digital ship design resources to increase its inventory of existing design knowledge and its efficiency in maturing and validating new ship designs.

Without additional action to better align its ship design efforts with leading practices, the Navy will be significantly challenged in its ability to rapidly confront evolving maritime threats with new ships that have the capabilities to combat those threats. These challenges affect current programs' timelines for delivery of new ships. They also create headwinds from the outset for the Navy's major future programs planned for the coming decades to deliver the next generation of destroyers, attack submarines, and amphibious assault ships, among other new additions to its fleet. In addition, without increased use of leading ship design practices, Navy shipbuilding programs will likely continue to regularly take a decade or more to move from concept to ship delivery. This increases the risk that capabilities approved in the earlier stages of a program lose their relevance and puts the Navy perpetually on the defensive because it cannot deliver timely, new capability to match the pace of new threats.

In addition, our analysis of the practices used by commercial ship buyers and builders indicates opportunities for Congress to revise the design maturity reporting and certification requirements. Specifically, Congress could better ensure that the Navy's practices align with leading ship design practices by requiring that Navy reporting (1) ensure 3D modeling of basic and functional design before construction starts, (2) confirm that detail design will be completed for each block of the ship before constructing that block, and (3) report on VFI completeness prior to the start of construction.

# Matters for Congressional Consideration

We are making the following three matters for congressional consideration:

Congress should consider updating statutory certification and production readiness review reporting requirements for Navy shipbuilding programs under section 8669c of title 10 United States Code, to require certification of the completion of basic and functional design in 3D modeling and the positioning and routing of all major distributive systems prior to the start of construction (consistent with leading industry practices in ship design). (Matter for Consideration 1)

Congress should consider requiring, as part of section 8669c of title 10, United States Code, that the Navy certify that detail design will be completed for each block of a ship's construction before beginning construction of that block. (Matter for Consideration 2)

Congress should consider requiring, as part of section 8669c of title 10, United States Code, that the Navy report on the degree of vendor-furnished information completeness supporting the overall maturity and stability of a ship's design before beginning construction. (Matter for Consideration 3)

# Recommendations for Executive Action

We are making eight recommendations to the Navy:

The Secretary of the Navy should ensure that each shipbuilding program reevaluates validated requirements in capability development documents before the start of construction for individual ships and periodically during ship construction to confirm their continued relevance and identify any appropriate changes. (Recommendation 1)

The Secretary of the Navy should ensure that shipbuilding programs complete functional design for new ships before awarding detail design and construction contracts. (Recommendation 2)

The Secretary of the Navy should ensure that the design teams for new ship designs include user representation, such as current or recent operators and engineers from the Navy's fleet, to provide consistent, direct user input in the design review process and inform decision-making. (Recommendation 3)

The Secretary of the Navy should develop a robust digital ship design library to enhance the Navy's ability to leverage existing designs and expedite design and construction. (Recommendation 4)

The Secretary of the Navy should—in coordination with Navy shipbuilders—evaluate opportunities to accelerate the receipt of reliable vendor-furnished information to support earlier design maturity for new ships. (Recommendation 5)

The Secretary of the Navy should evaluate the response timelines for reviewing and approving design products and the sufficiency of the Navy's resources supporting design review and decision-making processes to identify any opportunities to shorten design review timelines. (Recommendation 6)

The Secretary of the Navy should establish—and regularly update, as needed—guidance outlining the information and evaluation methodology used to certify the completion of basic and functional design prior to a ship's construction start for any major shipbuilding program, to include the Navy's explanation of what design activities and outputs must be accomplished to meet the statutory requirement for completion of a ship's basic and functional design. (Recommendation 7)

The Secretary of the Navy should evaluate opportunities to increase the use of modern design tools, including digital twinning and virtual or augmented reality. (Recommendation 8)

# Agency Comments and Our Evaluation

We provided a draft of this report to the Navy in January 2024 for review and comment. In April 2024, the Navy provided written comments in response to the recommendations, which are reproduced in appendix III. The Navy also provided technical comments, which we incorporated as appropriate. In its written comments, the Navy concurred with seven of our eight recommendations (our first recommendation and third through eighth recommendations), noting in some cases that the Navy's current actions already address our recommendations. We disagree and clarify the necessary actions for those recommendations below. The Navy partially concurred with our second recommendation.

In response to the first recommendation, the Navy stated that it will continue to evaluate the capability requirements for shipbuilding programs in accordance with DOD and Navy instructions. As discussed in the report, the guidance in these instructions focuses on endorsing updates to capability development documents without providing a clear requirement for the Navy to evaluate whether updates are needed. To ensure the continued relevance of capability requirements, we recommended that Navy shipbuilding programs regularly revisit the need for those operational capabilities.

In response to the third recommendation, the Navy stated that it will continue to include fleet representation in the Navy's ship design review process. As discussed in the report, the fleet representation in the Navy's design efforts is not consistent across shipbuilding programs. Further, this representation is not required to include recent or active ship operators or engineers. To align with the leading practices discussed in the report and meet the intent of the recommendation, Navy guidance and actions need to be refined and expanded for its shipbuilding programs to demonstrate consistent, direct user involvement throughout the ship design process.

In response to the fifth recommendation, the Navy stated that it will continue to use relevant contract requirements to support VFI receipt and considers timely and accurate VFI to be a Navy best practice. As we discussed in the report, timely receipt of reliable VFI is a leading ship design practice, but one that proves challenging for the Navy to consistently achieve. Specifically, Navy shipbuilders told us they regularly experience delays in receiving reliable VFI, with the delays being extensive at times. The shipbuilders also noted that VFI delays undermine opportunities to expedite ship design maturity. The disruptions caused by late delivery of VFI warrant Navy evaluation of new opportunities to accelerate the receipt of reliable VFI. Through a dedicated evaluation of options for shortening the time needed to obtain reliable VFI, the Navy could contribute to earlier design stability and shorter overall cycle times for designing and delivering new ships.

The Navy partially concurred with our second recommendation to ensure that shipbuilding programs complete functional design for new ships before awarding detail design and construction contracts. In its comments, the Navy stated that it was moving toward increasing early functional design work and requiring functional design completion before the start of ship construction. The Navy, however, stated that it is not always realistic or necessary to do so before awarding a detail design contract. Instead, the Navy suggested that we align our recommendation with the statutorily required certification for basic and functional design completion prior to the approval of construction start for lead ships.

We stand by our recommendation. We understand that completing functional design before awarding detail design and construction contacts represents a significant change to the Navy's traditional acquisition approach for its shipbuilding programs. However, as we discussed in the report, the statutory design certification did not prevent the Navy from proceeding with construction of its new FFG 62 class frigate when the program's design maturity data indicated that functional design was not 100 percent completed, which is counter to leading ship design practices. Further, the FFG 62 program's functional design problems since that certification—and the associated cost and schedule issues—support our position that the Navy should stabilize its new ship designs before awarding contracts for detail design and construction of the lead ship. This may require that the Navy rethink its contracting approach for some of its shipbuilding programs, which could involve separate contracts for basic and functional design, detail design, and ship construction. Such action would increase the Navy's design knowledge available before setting acquisition program baselines, which supports more predictable cost and schedule estimates. Completing basic and functional design before awarding contracts for detail design and lead ship construction would also increase design maturity from the outset and reduce risk. Such an approach is consistent with the leading practices we found used in commercial ship design to enable shorter, more predictable timelines for design.

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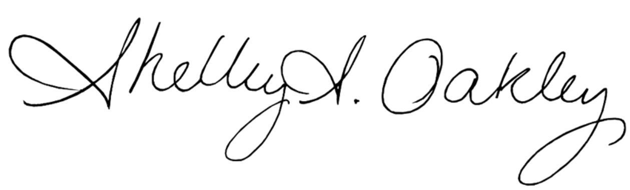
We are sending copies of this report to the appropriate congressional committees and other interested parties, including the Secretary of Defense and the Secretary of the Navy. In addition, the report is available at no charge on the GAO website at https://www.gao.gov.

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



Shelby S. Oakley
Director, Contracting and National Security Acquisitions

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# Appendix I: Objectives, Scope, and Methodology

This report examines (1) the leading design practices used by commercial ship buyers and builders to inform their understanding of design maturity and readiness for construction; and (2) how the Navy's ship design practices compare with the leading practices in commercial ship design.

To identify leading design practices used by commercial ship buyers and builders, we reviewed documentation and interviewed representatives from selected leading companies and organizations involved with designing, building, or buying of large, complex, and specialized commercial ships to identify leading practices. To select the companies to include in our review, we established criteria using a range of factors, including:

- Construction of commercial ships or platforms at a relatable size and complexity to U.S. Navy ships
- Established financial success (i.e., a yearly revenue exceeding $1 billion for builders)
- Number of ships in a buyer's fleet

We used the selection factors to establish a list of prospective ship buyers and builders for inclusion in our review. We also included companies that were specifically recommended to us by one or more of the companies included in our review. From the list, we selected ship buyers and builders that represent a broad range of ship types. We then engaged in outreach with the companies, conducting site visits or meetings and obtaining documentation from the companies that agreed to participate in our review of ship design practices.

Based on feedback received from companies through our outreach, we determined that major shipbuilders predominately perform ship design work in-house, particularly for more advanced designs that serve as the basis for ship construction. As a result, the commercial shipbuilders included in our review also reflected leading ship designers, with in-house design capabilities that supported the completion of design work spanning from concept design to detail design. We, therefore, do not have a standalone ship designer category in this analysis. For the purposes of this report, we also talked with a ship design company—Gibbs and Cox—which performs work for the government and commercial sectors, and a ship classification society—American Bureau of Shipping—which does the same.

Table 2 provides the commercial ship buyers and builders participating in our review.

**Table 2: Commercial Ship Buyers and Builders Included in GAO's Ship Design Practices Review**

| Company | Location | Buyer or builder | Types of ship(s) built or bought |
|---|---|---|---|
| A.P. Moller-Maersk | Copenhagen, Denmark | Buyer | Container ships |
| Carnival Corporation | Florida, United States | Buyer | Cruise ships |
| Chevron Shipping LTD | California, United States | Buyer | Liquid natural gas carriers and very large crude carriers |
| Damen Shipyards Group | South Holland, Netherlands | Builder | Container ships, freighters, tankers, cargo ships, heavy lift vessels, ferries, tugs, workboats, pilot and tender vessels, offshore support and dredging vessels, pontoons and barges, and fishing vessels |
| Fincantieri | Trieste, Italy | Builder | Cruise ships, offshore units, and ferries |
| Meyer Werft | Papenburg, Germany | Builder | Cruise ships, ferries, river cruise ships, and special purpose vessels |
| Royal Caribbean Group | Florida, United States | Buyer | Cruise ships |
| Samsung Heavy Industries | Geoje-si, South Korea | Builder | Container ships, crude oil tankers, chemical tankers, product carriers, shuttle tankers, liquid natural gas carriers, drillships, semi-submersible rigs, jack-up rigs, and offshore support vessels |
| Seatrium | Singapore | Builder | Multi-purpose offshore support vessels, anchor handling tug/supply vessels, dredgers, tugboats, icebreakers and ice-class support vessels, jack-up rigs, drilling rigs, semi-submersibles, floating production storage & offloading vessels, floating storage and regasification units, floating liquid natural gas production platforms and bunkering vessels, pipelay and cable laying vessels, wind turbine installation vessels, and high voltage direct or alternating current offshore platforms |

Source: GAO analysis of commercial company information. | GAO-24-105503

We conducted semi-structured interviews with company representatives knowledgeable about the ship design process. We also engaged in site visits to meet with representatives from four commercial companies (Damen, Fincantieri, Maersk, and Meyer Werft) and to receive shipyard tours. During these interviews and site visits, we collected information about (1) their role in the ship design process and general approach to design, including the role of contracts on their approach; (2) the manner in which design stability is assessed and determined; (3) how design-related risk is monitored and mitigated to achieve successful outcomes from concept design to delivery; (4) the extent to which ship buyers and builders have relied on metrics and indicators to inform their understanding of design stability; (5) the basis for establishing these indicators and metrics and their evolution over time; and (6) the extent to which their approaches incorporate leading practices, such as those related to iterative design and obtaining user feedback. This work allowed us to identify leading practices that commercial companies use to successfully construct ships within cost and schedule targets.

To validate our analysis, we developed and shared summaries with each company about the key information they provided through interviews or other documentation. We used the input received on these summaries to address any need for technical corrections or exclusion of company proprietary information. The summary information included quantitative data related to design and construction cycle times for different commercial ship types and response timelines when reviewing ship design products. We determined these data were sufficiently reliable for the purposes of our reporting.

Once we conducted our initial assessment of commercial company leading practices, we conducted a roundtable discussion with Navy officials from Naval Sea Systems Command; Program Executive Offices; Office of the Assistant Secretary of the Navy for Research, Development, and Acquisition; and the Office of the Chief of Naval Operations to share our assessment and provide the opportunity for them to provide feedback. We also used this session to obtain the participants' perspectives on the leading practices we identified, including potential benefits and challenges to the Navy incorporating these practices into its ship design processes.

To identify the ship design practices used by the Navy and compare them with the leading practices we found in commercial ship design, we reviewed our prior work on leading practices for shipbuilding and commercial product development to evaluate the extent to which those leading practices are relevant to current ship design practices.[1] This included examining our past findings and recommendations to assess the Navy's ship design practices and results across its shipbuilding programs. We used this information to support our analysis of how the Navy's practices compare with commercial practices for ship design.

Additionally, we reviewed documentation and interviewed representatives from the U.S. Navy and Navy ship design and building companies about their design practices. This included six Navy programs:

- DDG 51 Flight III *Arleigh Burke* class destroyers
- DDG(X) destroyers
- FFG 62 *Constellation* class frigates

[1] GAO-23-106222, GAO-22-104513, GAO-18-238SP, and GAO-09-322.

- LPD 17 Flight II *San Antonio* class amphibious transport docks
- SSBN 826 *Columbia* class nuclear-powered ballistic missile submarines
- T-AO 205 *John Lewis* class fleet replenishment oilers

We selected these programs because they have undertaken significant design activities since we assessed leading practices in shipbuilding—including ship design—in 2009.[2]

Our work also included six U.S. Navy shipbuilders representing all six Navy programs contained in our scope as well as other programs. Table 3 provides the Navy shipbuilders participating in our review.

**Table 3: U.S. Navy Shipbuilders Included in GAO's Ship Design Practices Review**

| U.S. Navy shipbuilder | Location | Navy ships built or planned |
|---|---|---|
| Austal USA | Mobile, Alabama | Auxiliary Floating Dry Dock Medium<br>EPF 1 *Spearhead* class expeditionary fast transport<br>Expeditionary Medical Ship<br>Landing Craft Utility vessel<br>Littoral Combat Ship *Independence* variant<br>T-AGOS 25 ocean surveillance ship<br>T-ATS *Navajo* class towing, salvage, and rescue ship |
| General Dynamics Bath Iron Works | Bath, Maine | DDG 51 Flight III *Arleigh Burke* class destroyer<br>DDG 1000 *Zumwalt* class destroyer<br>DDG(X) destroyer |
| General Dynamics Electric Boat | Groton, Connecticut | SSBN 826 *Columbia* class nuclear-powered ballistic missile submarine<br>SSN 774 *Virginia* class attack submarine |
| Fincantieri Marinette Marine | Marinette, Wisconsin | FFG 62 *Constellation* class frigate<br>Littoral Combat Ship *Freedom* variant |
| Huntington Ingalls Industries, Ingalls Shipbuilding | Pascagoula, Mississippi | DDG 51 Flight III *Arleigh Burke* class destroyer<br>DDG 1000 *Zumwalt* class destroyer<br>DDG(X) destroyer<br>LHA 6 *America* class amphibious assault ship<br>LPD 17 *San Antonio* class amphibious transport dock |

[2] GAO-09-322.

| U.S. Navy shipbuilder | Location | Navy ships built or planned |
|---|---|---|
| General Dynamics National Steel and Shipbuilding Company | San Diego, California | ESB 3 *Lewis B. Puller class* expeditionary sea base<br>T-AKE 1 *Lewis and Clark* class dry cargo/ammunition ship<br>T-AO 205 *John Lewis* class fleet replenishment oiler |

Source: GAO analysis of company and Navy information. | GAO-24-105503

For the Navy programs and the shipbuilders, we engaged in semi-structured interviews to assess the practices that they employ or plan to employ when designing ships and, to the extent possible, how effective the Navy has been in meeting its design objectives. We also traveled to meet with certain shipbuilders—Bath Iron Works and Fincantieri Marinette Marine—and with Navy officials in person and to receive shipyard tours. We also coordinated with other ongoing reviews, such as our annual assessment of major weapon system programs and reviews of the *Columbia* class submarine and *Constellation* class frigate programs, to obtain relevant ship design information.

To gain pertinent background information, we communicated with officials from several allied countries' navies and audit institutions, the ship software company Cadmatic, and Spain's state-owned naval builder Navantia. Our meetings with these entities were not specifically a part of the scope of our work, but they did provide relevant context regarding the current shipbuilding and buying landscape. Additionally, for cases where the leading commercial shipbuilders included in our review had experience designing and building ships for government or military buyers, we similarly collected information to gain context on their overall ship design practices.

We conducted this performance audit from October 2021 to May 2024 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: Key Tasks Supporting Leading Ship Design Practices

Table 4 shows key tasks in different design phases that support the leading ship design practices we found being used by commercial ship buyers and builders.

**Table 4: Leading Practices for Commercial Ship Design**

| Design phase | Key tasks involved |
| --- | --- |
| Basic and functional design | • Fix ship steel structure and set hydrodynamics<br>• Design safety systems and get approvals from applicable authorities<br>• Route all major distributive systems, including electricity, water, and other utilities<br>• Provide information on position of piping, ventilation, equipment, and other outfitting in each block<br>• 3D model the ship structure and major systems, with reliable vendor-furnished information (VFI) incorporated to support understanding of final system design. Reliable VFI reflects a firm understanding of the characteristics for ship equipment and components, including requirements for space, weight, power, water, and other utilities. An example of reliable VFI is having finalized specifications for a piece of equipment but awaiting the results of factory acceptance testing to validate those specifications through manufacturing |
| *Design stability achieved upon completion of basic and functional design* | |
| Detail design | • Use 3D modeling information to generate work instructions for each block—basic unit of ship construction—that show detailed system information and support construction; includes guidance for subcontractors and suppliers, installation drawings, schedules, material lists, and lists of prefabricated materials and parts<br>• At a minimum, complete detail design for any given block of the ship prior to beginning construction of that block |

Source: GAO analysis of commercial ship design information. | GAO-24-105503

Note: Ship buyers and builders may use different terms to denote the design phases. However, the tasks completed are the same regardless of terminology.

# Appendix III: Comments from the Department of the Navy

**THE ASSISTANT SECRETARY OF THE NAVY**
(RESEARCH, DEVELOPMENT AND ACQUISITION)
1000 NAVY PENTAGON
WASHINGTON DC 20350-1000

APR 11 2024

Ms. Shelby Oakley
Director, Acquisition and Sourcing Management
U.S. Government Accountability Office
441 G Street, NW
Washington DC 20548

Dear Ms. Oakley,

This is the Department of Defense (DoD) response to the GAO Draft Report GAO-24-105503, “NAVY SHIPBUILDING: Increased Use of Leading Design Practices Could Improve Timeliness of Ship Deliveries,” dated January 25, 2024 (GAO Code 105503).

The Department appreciates the opportunity to comment on the draft report. The Department concurs with recommendations 1, 3, 4, 5, 6, 7, and 8. The Department partially concurs with recommendation 2 and recommends alignment to 10 U.S. Code § 8669c Assessments required prior to start of construction on the first ship of a shipbuilding program. Technical comments are enclosed. No sensitivity items were noted.

For further questions regarding this report, please contact Ms. Katie Powers who can be reached at katherine.e.powers11.civ@us.navy.mil and phone 703-697-3781.

Sincerely,

Nickolas H. Guertin

Enclosure:
As stated

**GAO DRAFT REPORT DATED JANUARY 25, 2024**
**GAO-24-105503 (GAO CODE 105503)**

**"NAVY SHIPBUILDING: INCREASED USE OF LEADING DESIGN PRACTICES COULD IMPROVE TIMELINESS OF SHIP DELIVERIES"**

**DEPARTMENT OF DEFENSE COMMENTS TO THE GAO RECOMMENDATIONS**

**RECOMMENDATION 1:** The GAO recommends that the Secretary of the Navy should ensure that each shipbuilding program reevaluates validated requirements in capability development documents before the start of construction for individual ships and periodically during ship construction to confirm their continued relevance and identify any appropriate changes.
**DoD RESPONSE:** Concur. The Navy will continue to evaluate validated requirements at annual Navy Gate Reviews/Configuration Steering Boards, as well as milestone decision reviews, in accordance with SECNAVINST 5000.2G and DoDI 5000.02 series instructions.

**RECOMMENDATION 2:** The GAO recommends that the Secretary of the Navy should ensure that shipbuilding programs complete functional design for new ships before awarding detail design and construction contracts.
**DoD RESPONSE:** Partially Concur. The Navy is moving towards doing more functional design work before Milestone B and requiring functional design completion before start of construction. However, it is not always realistic or necessary for functional design efforts to be complete before awarding a detail design contract. The Navy requests that GAO consider rewording the recommendation to align with 10 U.S.C. 8669c. Section 8669c requires certification to Congress that basic and functional design is complete 30-days prior to the approval of the start of construction for the first ship of a major shipbuilding program.

**RECOMMENDATION 3:** The GAO recommends that the Secretary of the Navy should ensure that the design teams for new ship designs include user representation, such as current or recent operators and engineers from the Navy's fleet, to provide consistent, direct user input in the design review process and inform decision-making.
**DoD RESPONSE:** Concur. The Navy will continue to include fleet/user representation on teams responsible for execution of vessel design. User engagement early in the shipbuilding process is considered a Navy best practice.

**RECOMMENDATION 4:** The GAO recommends that the Secretary of the Navy should develop a robust digital ship design library to enhance the Navy's ability to leverage existing designs and expedite design and construction.
**DoD RESPONSE:** Concur.

**RECOMMENDATION 5:** The GAO recommends the Secretary of the Navy should ensure that Naval Sea Systems Command - in coordination with Navy ship builders - evaluates

opportunities to accelerate the receipt of reliable vendor-furnished information to support earlier design maturity for new ships.
**DoD RESPONSE:** Concur. The Navy will continue to leverage appropriate contract requirements to receive quality vendor-furnished information in a timely manner. Timely and accurate vendor-furnished information is considered a Navy best practice.

**RECOMMENDATION 6:** The GAO recommends that the Secretary of the Navy should evaluate the response timelines for reviewing and approving design products and the sufficiency of the Navy's resources supporting design review and decision-making processes to identify any opportunities to shorten design review timelines.
**DoD RESPONSE:** Concur. The Navy is currently assessing organic ship design capabilities to determine the sufficiency of workforce resources in supporting the shipbuilding design, review and decision-making process.

**RECOMMENDATION 7:** The GAO recommends that the Secretary of the Navy should establish - and regularly update, as needed - guidance outlining the information and evaluation methodology used to certify the completion of basic and functional design prior to a ship's construction start for any major shipbuilding program, to include the Navy's explanation of what design activities and outputs must be accomplished to meet the statutory requirement for completion of a ship's basic and functional design.
**DoD RESPONSE:** Concur.

**RECOMMENDATION 8:** The GAO recommends that the Secretary of the Navy should evaluate opportunities to increase the use of modern design tools, including digital twinning and virtual or augmented reality.
**DoD RESPONSE:** Concur. The Navy will continue to evaluate opportunities to leverage modern design tools in shipbuilding and ship design.

# Appendix IV: GAO Contact and Staff Acknowledgments

## GAO Contact

Shelby S. Oakley, (202) 512-4841 or oakleys@gao.gov

## Staff Acknowledgments

Principal contributors to this report were Diana Moldafsky (Assistant Director), Sean Merrill, (Analyst-in-Charge), Adriana Aldgate, Rose Brister, Laura Durbin, Lori Fields, Kathryn C. Long, Anne McDonough, Jean McSween, Kya Palomaki, Jodie Sandel, Sylvia Schatz, and Alyssa Weir.

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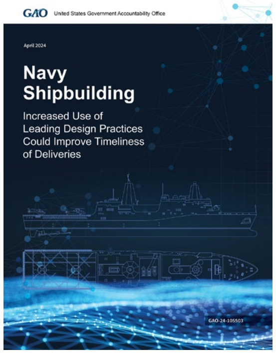


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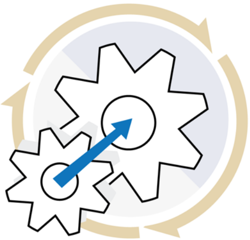

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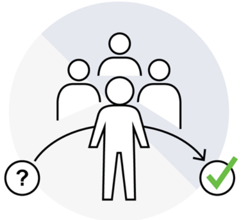



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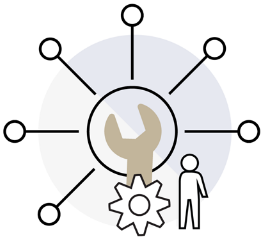

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