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Navy Shipbuilding: Increased Use of Leading Design Practices Could Improve Timeliness of Deliveries

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Navy Shipbuilding: Increased Use of Leading Design Practices Could Improve Timeliness of Deliveries

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Abstract

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. In response to the Navy's shipbuilding issues and interest in identifying how modern design practices support timely delivery of new ships, GAO completed a review to assess (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.

Leading Companies' Design Practices Support Timely and Predictable Ship Delivery

Commercial ship buyers and builders use four primary leading practices to enable shorter, predictable cycles for designing and delivering new ships (see Figure 1).

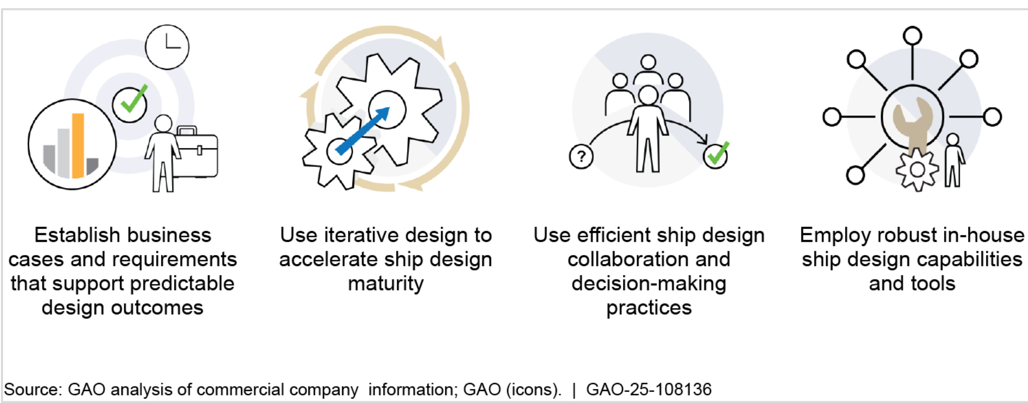


Figure 1. Primary Leading Practices GAO Found in Commercial Ship Design

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.[1] 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.

GAO 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.

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 GAO previously found leading companies across different industries do to successfully develop and deliver products to users with speed.

[1]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.

Maintain a Sound Business Case

As the pursuit of new ship designs and builds progresses, 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.

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. 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 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, 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 GAO 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.

Chevron and Maersk provided other examples of how 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 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 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.

Leverage Existing Ship Designs and Systems

GAO found that commercial shipbuilders draw heavily from their respective 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.[2] 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 associated cost fixed at the time when 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.

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 GAO 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.

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

[2]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.

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 commonly identifies and selects equipment and vendors before the shipbuilding contract is finalized, noting this practice is especially important for complex ship designs that include unique mission equipment—such as pedestal cranes for heavy lift vessels—for which vendor options are limited.

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 GAO 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 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 GAO 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 using the desired design feature in future ships when the longer lead time required to incorporate that feature 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 GAO that the company reduces design time and design labor hours by 90% 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.

For example, as part of the company's efforts to become carbon neutral, Maersk explored existing green technology options for its shipping 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 tanker vessels—to use an existing container ship design already operating in Maersk's fleet. The resulting design—which includes 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.

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.

Commercial buyers and builders also told GAO 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 number 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. Two other buyers noted a clear link between introducing innovations and maintaining shorter cycles for design and construction. One of those companies 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. One company 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.

GAO 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 works with the builder and vendors, as well as a classification society when needed, to validate compliance with technical standards and finalize detailed design requirements.

Companies Use Efficient Ship Design Collaboration and Decision-Making Practices

Use Processes That Support Timely Design Decisions

GAO 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, as the ship designer and builder, it uses early engagement with buyers to ensure the company's understanding of the buyer's requirements. Seatrium also uses this early engagement with buyers to identify key factors that will affect the ship's design, such as requirements for a vessel to achieve a certain speed, as early as possible, which minimizes potential issues in 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 GAO 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 GAO 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 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 GAO 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 GAO 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% 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, GAO 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.

Table 1 provides more details on key tasks in different design phases that support the leading ship design practices GAO found being used by commercial ship buyers and builders.

Table 1. Leading Practices for Commercial Ship Design

Design phase	Key tasks involved
Basic and functional design	• Fix ship steel structure and set hydrodynamics • Design safety systems and get approvals from applicable authorities • Route all major distributive systems, including electricity, water, and other utilities • Provide information on position of piping, ventilation, equipment, and other outfitting in each block • 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 a piece of equipment with finalized specifications 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 • 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.)

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 GAO's 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 designer. One buyer noted that having robust in-house resources to advance a design through functional design provides the company 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% 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

GAO 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. For example, 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 "4D" modeling. 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. This information can be used to optimize ship designs.

Commercial companies have used advances in 3D modeling capabilities since GAO's 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's engineering tools perform automatic checks between technical specifications and materials used for modeling. The checks identify any inconsistences and focus on data and 3D model updates to support design changes as opposed to updating 2D drawings. Collectively, these systems enable commercial builders and buyers 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 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, one builder 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.

GAO 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. GAO's 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. 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. One builder has also used digital twinning for virtual commissioning, verification, and validation for new designs.

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. GAO found that several factors contribute to the differences in the pace of ship design and delivery, as shown in Figure 2.

Establish business cases and requirements that support predictable design outcomes

Commercial	Navy
• Prioritizes timeliness of ship design and delivery • Avoids overly prescriptive requirements • Maintains a sound business case through continued reevaluation	• 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	Navy
• 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	• 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	Navy
• Uses processes that support timely design decisions • Aligns decision-making with design maturity measures	• 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

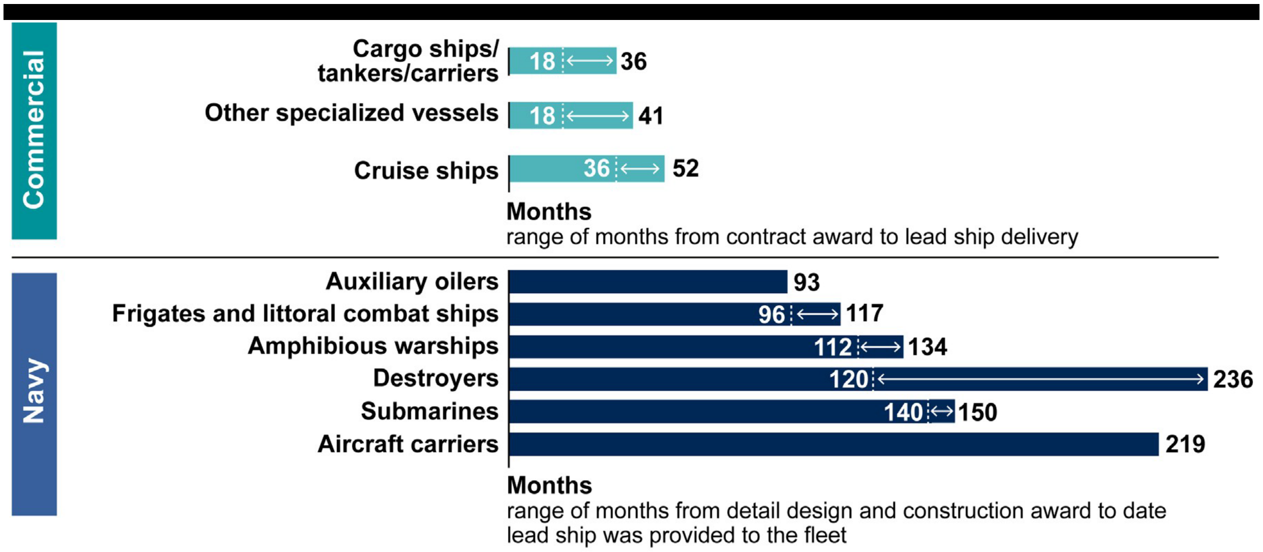
Commercial	Navy
• Maintains strong in-house design workforce capabilities • Uses ship design tools to shorten cycle time	• Evaluating ways to address acknowledged shortfalls in its in-house design workforce and tools • Adopting modern design tools to varying degrees, with the potential for expanded, 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-25-108136

Figure 2.GAO Comparison of Leading Ship Design Practices for Commercial Companies and U.S. Navy

Long Cycle Times Increase Program Risks for New Ship Designs

GAO found notable contrast in the design and construction cycle times that is typical for selected types of commercial ships compared to the lead ships for Navy shipbuilding programs, as shown in Figure 3.



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

Figure 3. Comparison of Design and Construction Cycle Times for Selected Commercial and Navy Ships

Notes: "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 indicate the shortest and longest periods for the Navy to provide selected lead ships to the fleet since 2007. GAO measured Navy cycle times based on the actual obligation work limiting date (OWLD), or planned date for lead ships that had yet to reach OWLD. OWLD generally coincides with when a Navy ship is provided to the operational fleet. Since GAO 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, GAO 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 DDG 1000 class from 32 to three ships.

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. The Navy's acquisition guidance also includes gated reviews intended to ensure that requirements align with acquisition plans. 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 its 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 CDD review and validation process indicates that it should be accomplished in no more than

103 calendar days. However, GAO's prior work reviewing this process found that none of the DoD programs GAO reviewed completed the process within this time. 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, GAO 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.[3] However, GAO 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 builder increase their understanding of the requirements' effect on design, schedule, cost, or other factors before finalizing the CDD. Navy officials told GAO 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.

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 GAO 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. GAO found challenges with the Navy setting these baselines for programs before achieving a stable design for the new

[3]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.

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. 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

GAO 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. This guidance supports the Navy's establishment of ship design teams with extensive subject matter expertise in the design and engineering of ships. However, GAO 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 GAO that ship operators and maintainers are consistently involved in the 3D model review process 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. As GAO 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.

Further, GAO 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 Ship 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. It also hampers 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 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, GAO 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 the lack of an existing relationship between the shipbuilder and vendors requiring more time to reach agreement. Navy practices 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 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

GAO found that the Navy and its shipbuilders generally have less direct communication prior to contract award than commercial ship buyers and builders. GAO's prior work found that shipbuilders may communicate less openly when the request for proposals process is the primary means for communication with the Navy in order to preserve their competitive interests. 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 GAO 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.

As an illustration of the extended Navy timelines, GAO 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 GAO's review identified for these activities was 21 days. Additionally, Navy officials noted instances where the Navy and builder agreed to extend 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.

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 GAO 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. Navy officials told GAO 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 GAO 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 commercial practices. 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, GAO found that programs were mixed as to whether they set an expectation that basic and functional design would be completed before starting ship construction. GAO similarly found variation in whether the programs achieved 100% completion for basic and functional design before beginning ship construction. GAO also found that Navy shipbuilding programs generally do not expect complete 3D modeling of basic and functional design before ship construction begins, which is inconsistent with leading ship design practices.

The Navy has taken some actions in recent shipbuilding programs to formalize design maturity measures. For example, GAO 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. 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.

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 ship design practices. 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.[4]

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 GAO that they have no plans to issue such guidance. Instead, they said that they use engineering judgment to establish working definitions for what a major shipbuilding program must achieve to meet the 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 requirements across its shipbuilding programs. For example, the secretary of the Navy certified in August 2022 that the FFG 62 frigate program had completed basic and functional design, as defined by the statute. The certification included technical data showing 90% of the frigate's functional design was completed before beginning construction, which is counter to leading ship design practices. Navy officials told GAO 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

[4] 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.

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.

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 GAO 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 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 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. GAO plans to monitor the Navy's progress in finalizing a strategic plan to address the identified design shortfalls and the Navy works toward implementing that plan.

For design tools, GAO 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, Navy shipbuilders GAO 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.

Additional challenges cited by Navy shipbuilders include the Navy's continued use of 2D design products for reviews and the timeliness of VFI receipt. For example, one Navy shipbuilder noted that programs continue to rely more on 2D drawings to support design review despite the availability of 3D design products to support these reviews. Further, Navy shipbuilders told GAO 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. 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 GAO 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 GAO that its increased capability in 3D modeling and recently introduced virtual reality allow 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 GAO found for commercial builders.

Navy shipbuilders told GAO that 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 Navy requirement 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 GAO's initial shipbuilding leading practices work in 2009, the Navy and its shipbuilders have taken steps to improve design practices, which include implementing many of GAO's recommendations directed at increasing design maturity before the start of construction. GAO's 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.

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