Revisiting DDGX/DDG-51 Concept Exploration

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Abstract

This study revisits concept exploration for DDG-51 using reconstructed 1978–1979 DDX and 1979–1980 DDGX requirements and options, and 2005 tools. The goal of this study is to assess and highlight the benefits of current tools and processes for concept exploration by comparison with a well-known design that did not use these tools. This case study was completed in a summer and fall ship design project at Virginia Tech. In 1979, the acquisition and design process did not begin with a Mission Need Statement, Analysis of Alternatives or Integrated Capabilities Document as is required today. It began with studies, Tentative Operational Requirements, and Draft Top Level Requirements. In this study, we revisit the 1978–1980 DDG-51 (DDX/DDGX) concept exploration based on the guidance, goals, and constraints of the DDX and DDGX studies, using a notional mission statement, concept of operations, and list of required capabilities. The design space is defined to include many of the same design alternatives that were considered in the DDX and DDGX studies. A multiple-objective genetic optimization (MOGO) based on military effectiveness, cost, and risk is used to search the design space and perform trade-offs. A simple ship synthesis model is used to balance the designs, assess feasibility, and calculate cost, risk, and effectiveness. Alternative designs are ranked by cost, risk, and effectiveness, and presented in a series of non-dominated frontiers. Concepts for further study and development are chosen from this frontier and a comparison with DDG-51 is made based on these results.

Motivation and Introduction

The traditional approach to ship design is largely an "ad hoc" process. Experience, design lanes, rules of thumb, preference, and imagination guide the selection of design concepts for assessment. Often, objective attributes are not adequately synthesized or presented to support efficient and effective decisions. This case study uses a total system approach for the design process, including a structured search of the design space based on the multi-objective consideration of effectiveness, cost, and risk (Brown and Thomas 1998; Brown and Salcedo 2003).

The scope of this study includes only the first phase in the ship design process, concept, and requirements exploration. The concept exploration process followed in this study is shown in **Figure 1**. The first step in this process is to develop a clear and precise mission definition and list of required operational and functional capabilities starting with a Mission Need Statement and Acquisition Decision Memorandum, or an Integrated Capabilities Document. This process should not begin by jumping into specific requirements or design characteristics. These should be products of concept exploration, not initiating constraints. Requirements and design characteristics cannot be rationally specified without a thorough understanding of their impact on total ship cost, risk, and effectiveness. Refinement of the mission definition typically

Nomenclature:

AAW: Anti-air warfare

AHP: Analytical hierarchy process

AOA: Analysis of alternatives

ASN(S&L): Assistant Secretary of the Navy for Systems and Logistics

ASROC: Anti-submarine rocket

ASUW: Anti-surface warfare

ASW: Anti-submarine warfare

BHP: Brake horsepower

CAS: Combined antenna system

CBG: Carrier battle group

CCC: Command, control, communication

CIWS: Close-in weapon system

CODAG: Combined diesel and gas turbine

COGAG: Combined gas turbine and gas turbine (Cruise/Boost)

COGAS: Combined gas turbine and steam

CONOP: Concept of operations

CPP: Controllable pitch propeller

CPS: Collective protection system

DNSARC: Department of the Navy Systems Acquisition Review Council

DV: Design variable

DOE: Design of experiments

ECM: Electronic countermeasures

FCS: Fire control system

FPP: Fixed pitch propeller

GFCS: Gun fire control system

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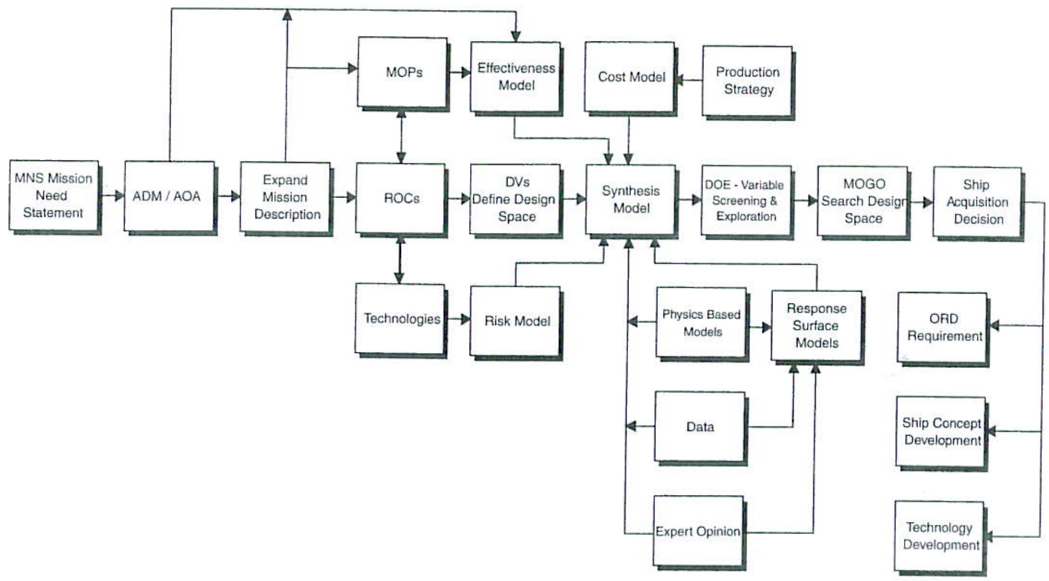

Figure 1: *Concept Exploration Process (Brown 2005)*

GM: Metacentric height above center of gravity

IED: Integrated electric drive

IR: Infrared

KG: Height of center of gravity

LAMPS: Light airborne multipurpose system

MAVT: Multi-attribute value theory

MD: Mechanical drive

MFCS: Missile fire control system

MOGO: Multi-objective genetic optimization

MOP: Measure of performance

NBC: Nuclear, biological, chemical

NCO: Non-combatant operations

NDF: Non-dominated frontier

NSFS: Naval surface fire support

OMOE: Overall measure of effectiveness

OMOR: Overall measure of risk

ORD: Operational requirements document

includes a concept of operations (CONOPs), projected operational environment and threat, specific missions and mission scenarios, and required operational capabilities (ROCs).

Next, the design space is defined using available or developing technology necessary to provide required capabilities. In this case study, this includes most of the design alternatives that were considered in the DDX and DDGX studies. Concept exploration needs to consider only those requirements and design parameters that have a significant impact on ship balance, military effectiveness, cost, and risk. Cost, risk, and effectiveness models must be developed consistent with mission requirements and the alternative technologies. A simple ship synthesis model is used to balance the designs, assess feasibility, and calculate cost, risk, and effectiveness.

Finally, a multiple-objective genetic optimization (MOGO) is used to search the design space for non-dominated feasible designs using the synthesis and objective attribute models (Shahak 1998; Salcedo 1999). Feasible designs are ranked by cost, risk, and effectiveness, and presented as a series of non-dominated frontiers (NDFs). An NDF represents ship designs in the design space that have the highest effectiveness for a given cost and risk. Concepts for further study and development are chosen from this frontier and a comparison with DDG-51 is made based on these results.

This optimization requires mathematically defined objective functions for effectiveness, cost, and risk. Mission effectiveness, cost, and risk have different metrics and cannot logically be combined into a single objective attribute. Multiple objectives associated with a range of designs must be presented separately, but simultaneously, in a manageable format for trade-off and decision making. There is no reason to pay or risk more for the same effectiveness or accept less effectiveness for the same cost or risk. Various combinations of ship features and dimensions yield designs of different effectiveness, cost, and risk. Preferred designs must always be on the NDF. The selection of a particular non-dominated design depends on the decision-maker's preference for cost, effectiveness, and risk. This preference may be affected by the shape of the frontier and cannot be rationally determined a priori. Overall measure of effectiveness (OMOE; Demko 2005; Brown and Demko 2006) and overall measure of risk (OMOR; Mierzwicki 2003; Mierzwicki and Brown 2004) objective functions are developed using the analytical hierarchy process (AHP), multi-attribute value theory (MAVT), and expert opinion (Belton 1986; Saaty 1996). Acquisition and life-cycle cost are calculated using a modified weight-based cost model.

Model Center (MC) software is used for the design and optimization environment (Phoenix Integration 2004). Design variables (DVs) are screened and sensitivity is assessed using a Design of Experiments (DOE) in MC.

DDX and DDGX Concept Design History

The design of a new guided missile destroyer equipped with an AEGIS weapon system, and identified as DG-AEGIS, was initiated in April 1972, continued through 17 months of concept exploration, and started into a scheduled 12-month preliminary design in September 1973. A preliminary design baseline was never established, and all effort for the DG-AEGIS design was terminated in May 1974 due to budget constraints (Naval Sea System Command [NAVSEA] 1985).

In 1978, the Navy recognized that the escalating cost of CG-47 and the retirement of existing ships required the commencement of a new surface combatant program. An OPNAV (CNO) DDX Study Group, under the direction of RADM R. K. Fontaine, USN, was formed in May 1978 to update the operational requirements for surface combatants (Riddick 2003). From May 1978 to February 1979, this group studied future threats facing the Navy in the 1990s and beyond (SEA 00D 1980). The group also investigated combat system capabilities required to meet these threats, and evaluated 11 alternative ship concepts identified as DDX variants to provide this capability within certain size and cost parameters. NAVSEA personnel, led by Capt. D. P. Roane, USN, from the Combat System Directorate and Jim Raber from the Ship Design Directorate, participated in the areas of combat capability assessment and ship design alternatives (NAVSEA 1985).

Chief of Naval Operations (CNO), ADM T. B. Hayward, USN, directed the Naval Material Command in 1979 to conduct Feasibility Studies for a DDX concept armed with guided missiles (DDGX) that could meet selected operational requirements from the Fontaine study (SEA 00D 1981). The general guidance included the following:

- The design or designs should support a lead ship authorization in an FY84–85 shipbuilding program.
- Each alternative ship configuration should include schedules for research and development.
- One alternative should be based on low-risk technology. Other concepts should consider innovations, technology developments, modularity, and cost reduction items that would reduce ship size and cost.
- The design should satisfy top-level requirements developed in the DDX studies.
- The design should emphasize combat capability and survivability to the maximum degree possible within limits of affordability.
- Interaction with other class ship modernization and maintenance plans was to be explored.

NAVSEA concluded the initial DDGX feasibility studies in December 1979 with five baseline configurations and 27 excursions or variants. After the DDGX studies were presented to the CNO, the Chief of Naval Material (CNM) immediately recommended concept design based on ship Variant 3A. This configuration was 469 feet long with a displacement of 7,000 tons and a follow-ship cost of $550 million. CNO tasked CNM to continue the development of the DDGX and provided the following additional direction (NAVSEA 1985):

- The DDGX design must be lower in cost and total capability than CG 47.
- Follow-ship acquisition cost should not exceed $500 million (FY 1980).
- The design must be powerful and survivable and must include significant anti-air warfare (AAW) capability.
- The design should support a lead ship authorization in FY84–FY86.

DDGX Concept Design began in February 1980 with a baseline 1,000 tons lighter and $50 million less than DDGX Variant 3A. Concept design was completed in three steps: major trade-off studies between February 1980 and May 1980, trade-off study evaluations and system-level integration between June 1980 and July 1980, and final concept design baseline development between August 1980 and January 1981. Over 30 major trade-off studies were conducted in the hull, mechanical, and electrical and combat systems areas. The most comprehensive study was in propulsion where over 100 different concepts were identified and 33 of these were studied in detail.

Two final concept design baselines, designated as Alternatives 1 and 2, were conceived by January 1981. These designs reflected final decisions that had been developed for combat system areas, two different propulsion plants, and deckhouse configurations. NAVSEA recommended Alternative 1 in February 1981 and presented it to a CNO Executive Board (CEB) that received it well. After the DDGX CEB, CNM appointed an independent senior review panel to examine both alternatives again. The panel, headed by VADM R. S. Salzer, USN (Ret.), after a brief review, made the following comments and recommendations (NAVSEA 1985):

- A valid requirement for DDGX continued to exist and the design program should continue to support a lead ship authorization in FY85, but neither of the proposed baselines should be used. Instead, concept design should continue with a new configuration. (A number of specific recommendations were made by the Salzer Panel such as to add more missiles and make the propulsion plant more similar to the DD 963, i.e., mechanical drive with four LM-2500s. Initial design studies to incorporate the Salzer Panel recommendations indicated that a feasible ship would displace 8,700 tons.)
- The cost constraint for the DDGX, incorporating attributes selected by the panel, increased from $500 million to between $600 and $650 million.
- New subsystems should be developed independent of the ship program.
- An emphasis for the new DDGX was to be on reliability.
- A more conservative approach to design development should be followed. Designs should accommodate fallback to proven systems, reduced development risk, and systems testing using land-based engineering facilities (LBEF) and "at sea" test and evaluation where possible.

In April 1981, a second concept design began. This design was based on new guidelines to establish a more dependable concept. The Salzer Panel recommendations were studied and most were incorporated into DDGX during the summer of 1981 (NAVSEA 1985).

Throughout the DDGX concept design and at briefings to OPNAV the operator's desire for modifications was expressed. The modifications consisted of increasing the ship's range, adding tactical towed array sonar (TACTAS), selecting a 4 MW transmitter for SPY-1D in lieu of a 2 MW, and incorporating OPNAV's new requirement for separate food preparation facilities for officers and enlisted men. These characteristics increased weight, causing OPNAV to raise the ship's displacement ceiling to 8,500 tons. The Department of the Navy Systems Acquisition Review Council (DNSARC) reviewed the DDGX progress in June 1981 and was satisfied, as was the Secretary of Defense.

In the fall of 1981, to meet all of the operator's requirements including energy conservation, endurance range, and sustained speed requirements, the ship's displacement was increased by 600 tons to 9,100 tons. NAVSEA created three more designs options by November. One ship, 8,500 tons, met all the requirements except the desired speed and range; another ship, 9,100 tons, met all operator requirements; and the last ship was an austere configuration at 8,000 tons. In December 1981 the four alternatives were presented to CNM,