A Short Review of U. S. Naval Ship Concept Design Technology Development Features

Kratki pregled značajki razvojne tehnologije idejnog rješenja za američke ratne brodove

Hao Wang
China Institute of Marine Technology & Economy (CIMTEC), Beijing, China
e-mail: wanghao818489@163.com

Da-ming Pei
China Institute of Marine Technology & Economy (CIMTEC)
Beijing, China

Lin Gan
Wuhan Secondary Ship Design Institute
Wuhan, China

Rong-zhi Chen
Singapore Technologies Marine Ltd (ST Marine), Singapore

Zhan Li
China Institute of Marine Technology & Economy (CIMTEC)
Beijing, China

DOI 10.17818/NM/2017/2.6
UDK 629.56(73):623.8(73)
Professional paper / *Stručni rad*
Paper accepted / *Rukopis primljen:* 14. 2. 2017.

Summary

In present study, a history analysis and review of last 30 years for U.S. naval ship concept design development trend is proposed. Based on the development of naval ship concept design model history, the three features of development process are further summarized. The first is that model-based system engineering (MBSE) becomes the basic of naval ship concept design, while the second one is that the multi-discipline crossing and combination becomes a general innovation model. And the third one is that systematization oriented naval system integration is the developing goal. Some detailed examples are presented to illustrate these three characteristics. Finally, the technology difficulties in naval ship concept design are also presented.

KEY WORDS

Naval Ship
Concept Design
Model-Based System Engineering (MBSE)
Cross-synthesis of Subjects

Sažetak

U radu se predlaže povijesna analiza i pregled posljednjih 30 godina razvoja idejnog rješenja za američke ratne brodove. Na osnovi povijesti razvoja modela idejnog rješenja za ratne brodove opisana su tri obilježja razvojnog procesa. Prvo je to da je MBSE sustav temelj idejnog rješenja za ratne brodove, a drugo je obilježje da multidisciplinarno križanje i kombinacija postaju opći model inovacije. Treće je obilježje da je razvojni cilj sistematizirana integracija pomorskog sustava. Navode se detaljni primjeri koji ilustriraju ta tri obilježja. Na kraju se prikazuju i problemi u tehnologiji.

KLJUČNE RIJEČI

ratni brod
idejno rješenje
inženjering sustava temeljenog na modelu (MBSE)
unakrsna sinteza subjekta

1. INTRODUCTION / *Uvod*

With the development of two new strategic concepts 'Air-Sea Battle' (ASB) [1-2] and 'Joint Concept for Access and Maneuver in the Global Commons (JAM-GC)' [3-4] proposed by the Air-Sea Battle Office (ASBO), to confront the potential threats of Anti-Access/Area Denial (A2/AD) (Figure. 1), the ability of cross domain depth striking goal is particularly emphasized by U. S. Navy, which cover whole Sky-Space-Ocean-Land-Cyber space in the implementation of cross-domain operations. It can provide maximum combat advantage for the joint forces (Figure. 2). The above combat requirements of U. S. Navy have brought many new challenges for naval ship design Research. In order to keeping the forward existing, forward deploying and forward operation, U. S. Navy is in accordance with the principle of weapon system development to meet new combat mission requirements for system integrity. The Naval Sea Systems Command (NAVSEA) has issued a report claimed that 'as the more complex, challenging national security environment, in the future, the integration ship design planning has become necessary'. Thus, U. S. Navy will continue to develop the new concept of ship featured 'model driven, discipline integration, system integration'. And the naval ship system development level is enhanced to obtain the overall combat effectiveness.

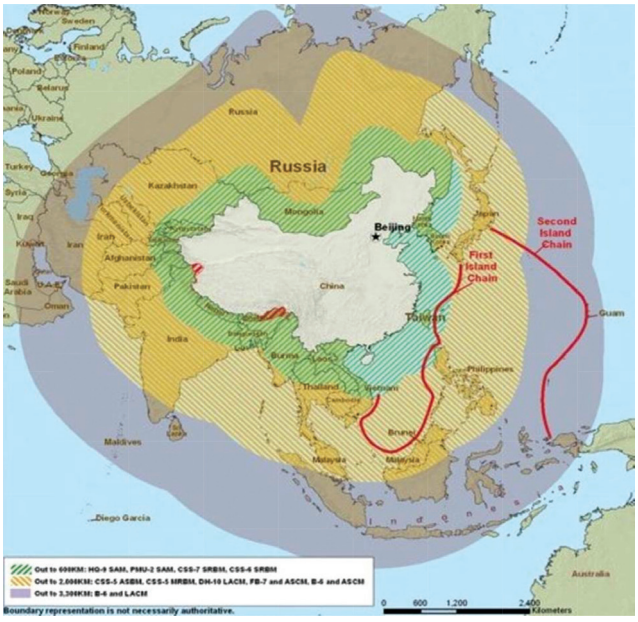

Figure 1 Description of Anti-Access/Area Denial from Russia and China [1]
Slika 1. Opis područja bez pristupa/uskraćenog područja Rusije i Kine [1]

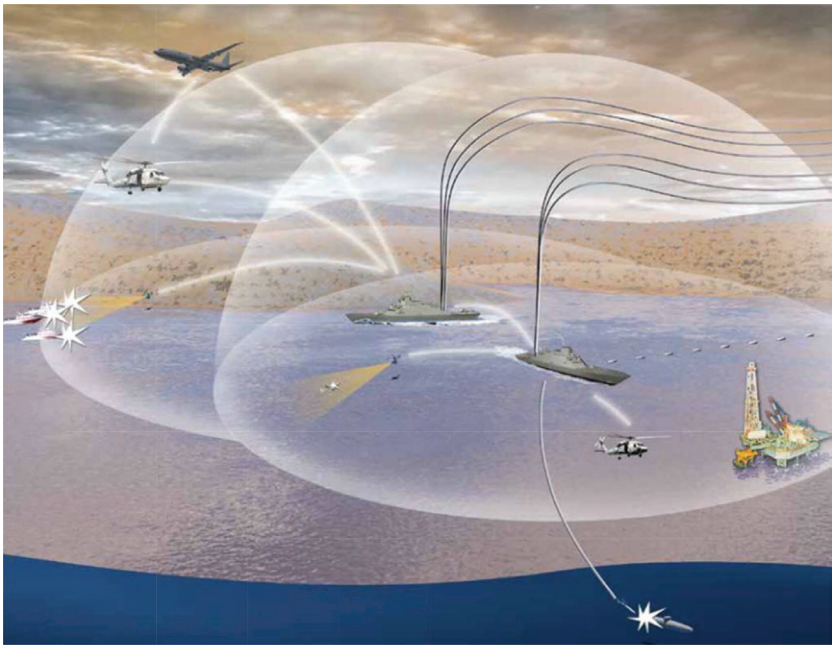

Figure 2 Description of Integration of State-of the-Art for Joint Forces [2]
Slika 2. Opis integracije vrhunske tehnologije za zajedničke snage

In the present review, the analysis and sum up some regular features of the overall concept design of naval ships from the three angles mentioned above are focused.

2. MODEL-BASED DESIGN (MBD): A BASIS OF NAVAL SHIP CONCEPT DESIGN / *MBD Dizajn baziran na modelu: osnova idejnog rješenja za ratne brodove*

2.1. Development of definition for MBD / *Razvoj definicije MBD-a*

The concept of model in U. S. Navy ship design has passed through roughly three development stages, and it is closely agreement with the generation of naval vessels, which can be shortly summarized as 'one generation of design model, one generation of naval ship' [5]. The first stage is before the early 1960s, the naval ship concept design is a series of tedious and time-consuming standard calculation program. And the concept design efficient is very low, which cannot find the global optimization solution in solution space generally. The second stage is between the early 1960s and the middle of 1980s. Along with the development of computer technology and graphics interactive technology, a novel model concept, namely, 'Ship Synthesis Model (SSD)' is suggested by U. S. Navy [6]. This method is on the basis of a series of standard ship design models, which is from measured data of practical ships [7]. Furthermore, this model concept also allows ship designer using practical experience, which can reflect the different design requirements and design input. Thus, the optimization design of the function can observe. Based on SSD, the design program CODESHIP is developed, and it is widely used in the design of Spruance class destroyer [7]. The third stage is between the middle of 1980s and early 21 Century. With the developing demand of Arleigh Burke class destroyer, the concept design of naval ship model consistency and correlation characteristics

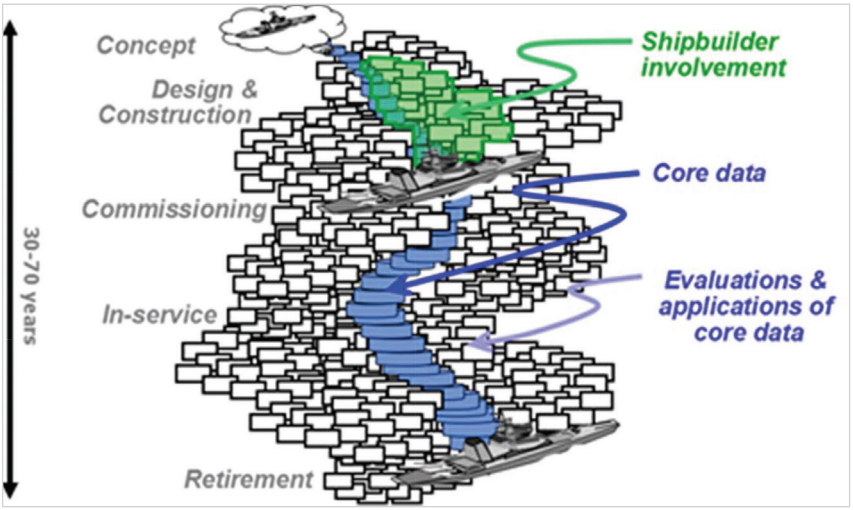

Figure 3 Model and Data Flow of U. S. Naval Ship Design and Production in Full life cycle [5]
Slika 3. Model i tijek podataka u projektiranju i proizvodnji u punom ciklusu [5]

are improved. After that, the Naval Surface Warfare Research Center (NSWC) further expands design space constraints set, to enhance the accuracy of the program [8-10].

In recent years, with the design development of Zumwalt class destroyer (DDG1000), the design of ship is becoming more complex, more miscellaneous, and faster responsive to meet the military needs. Thus, the more problems are exposed in the initial concept design of naval vessels. According to the report of Joint-Design Commit of Society of Naval Architects and Marine Engineers (SNAME) and American Society of Naval Engineers (ASNE), he present design model cannot describe the design and building units probably. Furthermore, the artificial intelligent design platform of ship general arrangement is extreme lacked. And the designer cannot know how and when to use the model probably [11].

By investigating these problems deeply, the famous ship design scholar Robert pointed three personal views including the production model is the basis of naval ship design, the concept design model must be verified in production design and building process, the consistence of product must be emphasized in initial concept design stage [11]. Commonly, in the present ship innovation process, the need of ship production model is derived by external demand. But another internal deriving need is the fast increasing complexity of ship system. Strictly, the definition of Model-Based Design (MBD) firstly introduced by Boeing Corporation [12-15]. Then, the American Society of Mechanical Engineers (ASME) begins the research for the MBSE standard based on that of Boeing Company. Recently, a new standard named 'Y14.41Digital Product Definition Data Practices' is recommended by ASME, *and* its key elements includes three-dimensional (3D) digital definition, from document-based driven to model-based approach, knowledge engineering integration, process virtual simulation et al [16-18].

2.2. Main features of Model-Based Ship System Engineering / *Glavne značajke projektiranja brodskog sustava na osnovi modela*

Unlikely the fast development in aerospace industry, the use of MBSE in ship building seem slower. And some very important investigations of Model-Based System Engineering (MBSE) are proposed by Trent, Pat Hale and Brown [19-30] in their reports such as 'Exploring the use of Model-Based Systems Engineering to develop systems architectures in naval ship design' and 'Naval ship design and synthesis model architecture using a Model-Based Systems Engineering approach'. They pointed out that the traditional design mode A, which is based on the Point Based Design (PBD), is a spiral line (Fig. 4). But with the fast increase of ship system complexity, multi-function and design flexibility, the Set Based Design (SBD) is becoming wildly adopted in the initial ship design. This is because that the design details can be controlled until all effective factors can be solved. Thus, the more work time can be saved and the parallel working mode can be easily proposed. In another word, the each design decision point cannot be easily deleted. If the design space is becoming smaller, the more detailed analysis which will make knowledge becomes a new constraint. Thus, the goal of Set Based Design (SBD) is to get global optimization design point, but not local optimization design point. And the general design chart of Set Based Design (SBD) is given as following Fig. 5. In the practical ship design case, the information such as operation structures, system function and physical characteristics are usually lost when design model is transferred to system engineering model. The naval ship design engineers don't have enough time to define, model and simulate. While in the Set Based Design (SBD) process, in order to obtain the design invariant, it is very important qualifying sensitivity parameters earlier. This change is made by model-based system engineering in industry [31-33].

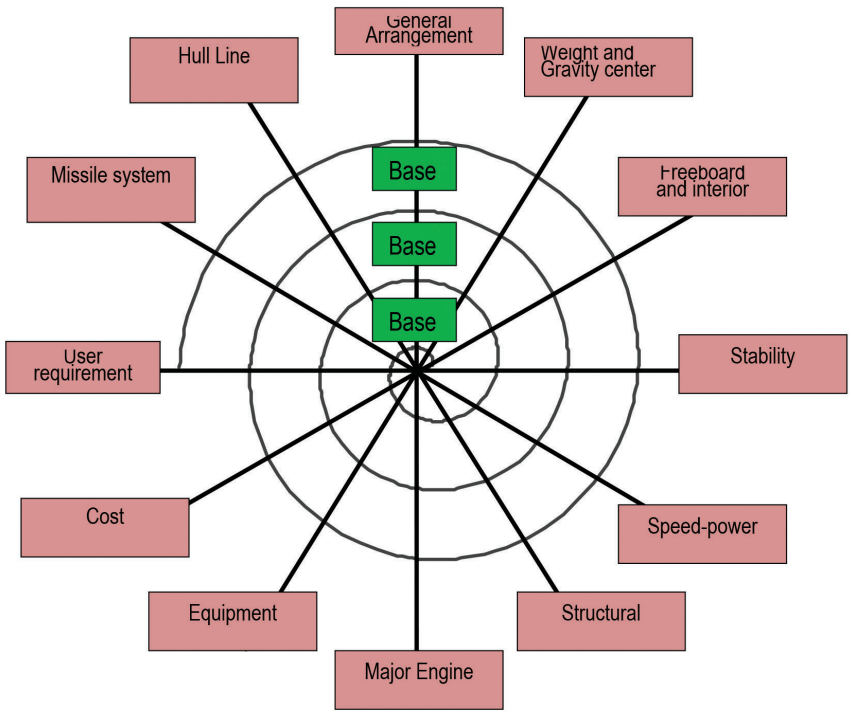

Figure 4 Models and Data Flow of Ship Design (Type A) [8]
Slika 4. Modeli i tijek podataka pri projektiranju broda (Tip A) [8]

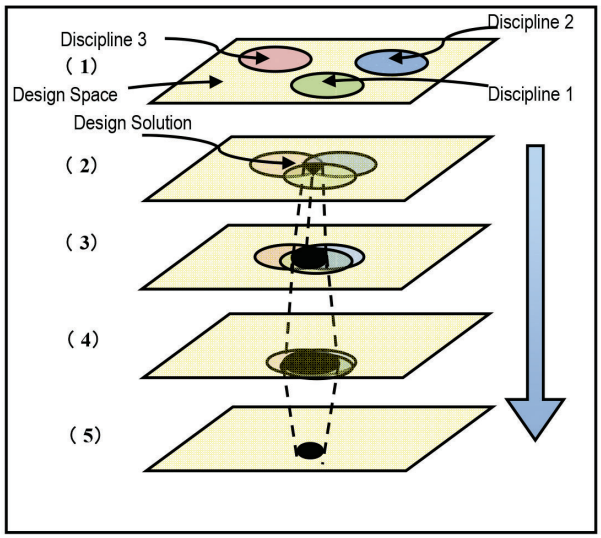

Figure 5 Models and Data Flow of Ship Design (Type B) [8]
Slika 5. Modeli i tijek podataka pri projektiranju broda (Tip B) [8]

Usually, in the initial ship design, the characteristics of MBD can be summarized as two parts. Firstly, the MBD can represent the physical requirements of ship products. Secondly, the MBD can represent the manufacture requirements of ship products. The model can be easily adopted after the design period. It means design-building integration is becoming true. Based on the analysis, it shows that the MBD or MBSE are originally coming from the ship-integration model. During the design and building of Zumwalt-class destroyer (DDG1000), the smart production model is widely used. And the customer, cooperator, the supplier and the subcontractor are connected with the help of gird-based production and process management system [34].

3. FUTURE NAVAL SHIP CONCEPT DESIGN TREND: DISCIPLINE INTEGRATION / *Budući trendovi idejnih rješenja za ratne brodove: integracija discipline*

The naval ship design problem is a typical complex system design problem, and it is far more complex than automobile and aircraft et al. And the basic characteristics of ship design are nonlinear, multi-object, multi-constraint, multi-coupling and parallel. Thus, traditional single design mode cannot easily solve the strong coupling relation between object, constraint and discipline. Although with a high speed development of multi-discipline optimization (MDO) technology, the complex naval ship design system problems cannot be solved perfectly under the discipline integration environment. To solve this problem, a new platform called ASSET-LEAPS is developed by NAVSEA (Fig. 6). The frame-work of ASSET is built by NSWC Cradock division from 1970. Based on artificial model and system engineering, discipline integration characteristics are considered in the ASSET solver. And the data transfer is adopted in LEAPS (Fig. 7). In the design practice, it shows that the ASSET-LEAPS platform can solve discipline integration problem well [35-41].

Another typical example is ship hydrodynamic performance analysis integration platform. In the analysis, the resistance, propulsion and seakeeping are usually considered individual due to the present computational ability. And the integration of these discipline problems is not well solved. Based on the theory model and numerous experimental data, the complex nonlinear interaction problems are solved well. During the progress of development for ship hydrodynamics platform, the CREATE Program or CREATE-SHIPS Project group is established to give a detailed plan. In this plan, the integration platform is divided into following parts including resistance, propulsion, maneuvering, seakeeping, damage stability *et al* plotted in Fig. 8. The core of naval hydrodynamics platform CREATE Program is the interaction algorithm of multi-discipline [42]. For example, the seakeeping code LAMP [43-47], the nonlinear boundary element method (BEM) is adopted to give a relative good prediction of 3D floating dynamics characteristics. Then, a clear road technology map how to develop the naval hydrodynamic before 2020 is built.

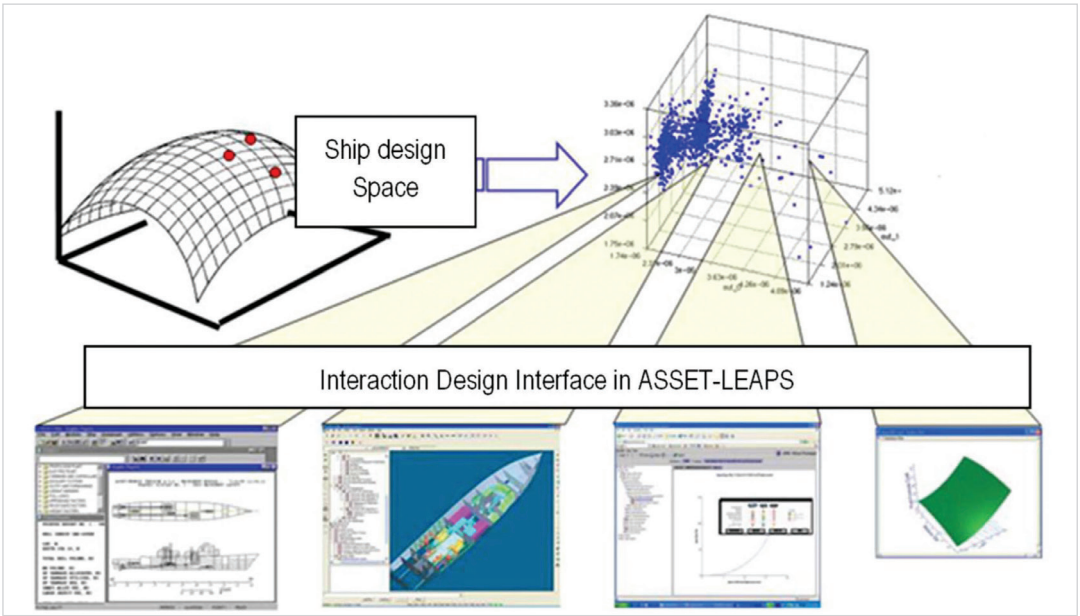

Figure 6 ASSET-LEAPS Ship Design Integration System [21]
Slika 6. Integrirani sustav dizajna brodova [21]

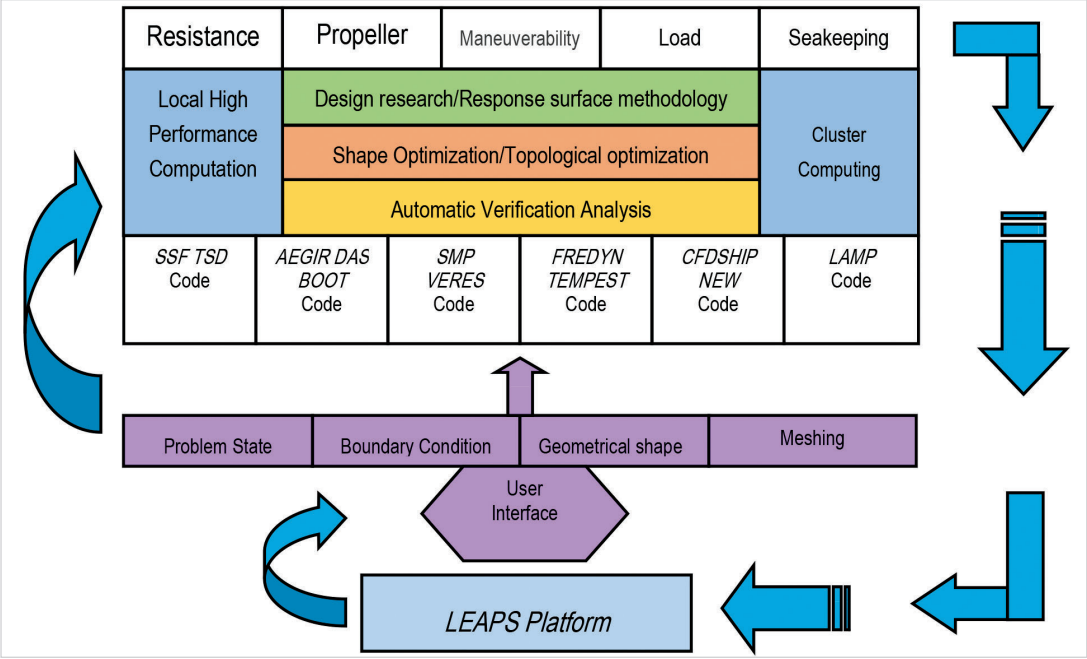

Figure 7 ASSET-LEAPS Ship Design Integration System Framework [42]
Slika 7. ASSET-LEAPS okvir integriranog sustava dizajna brodova [42]

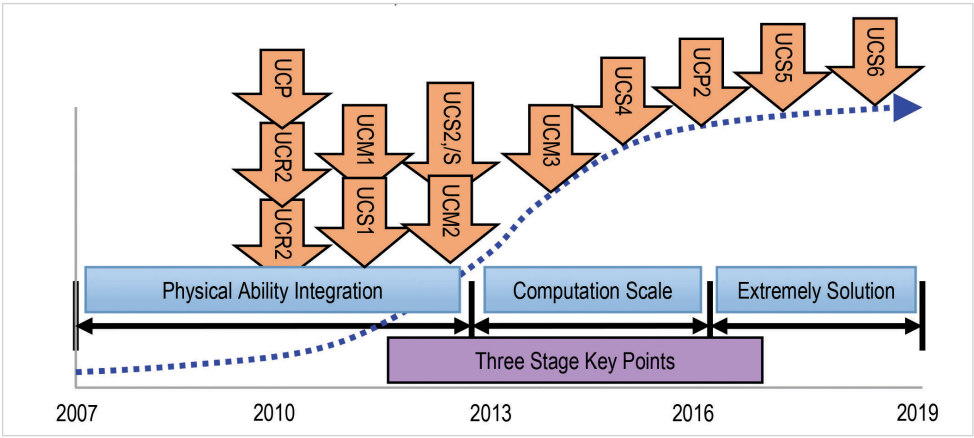

Figure 8 Create Plan Roadmap [44]
Slika 8. Izrada plana [44]

Table 1 The Meanings of Nomenclature for Create Plan Roadmap
Tablica 1. Značenje nomenklature za izradu plana

NO.	Name	Meaning
1	UCR1	Hull with fixed ship sinkage and trim
2	UCR2	Hull with computed sinkage and trim
3	UCP1	Body force model for propulsor
4	UCP2	Full propulsor modeling
5	UCM1	Rotating arm steady turning motion
6	UCM2	Planar Motion Mechanism (PMM)
7	UCM3	Moving appendages and controller
8	UCS1	Prescribed trajectory in regular waves
9	UCS2	Hull responds to regular waves
10	UCS3	Prescribed trajectory in irregular waves
11	UCS4	Predicted motions with moving appendages in waves
12	UCS5	Seaway loads with one way coupling to structures code
13	UCS6	Seaway loads with two way coupling to structures code

4. DESIGN GOAL: COMPLEX SYSTEM INTEGRATION / *Cilj dizajna: integracija kompleksnog sustava*

4.1. Integration between ship platform and equipment / *Integracija brodske platforme i opreme*

With the development of combat environment mode, the integration function of key naval vessel system is more important than the independent equipment performance. Thus, according to the principle that 'equipment to obey the system, the system to obey the overall, overall compliance with the overall', the integration technology such as the information integration, the network integration and software integration technology are both widely applied. And the separate system, information and function are all connected by the ship platform system (Fig .9).

And this total integration design idea is widely adopted in the development of total ship computing environment (TSCE) for DDG-1000. The DDG 1000 Total Ship Computing Environment is a new system architecture that is open which can offers a scalable platform for a new set of cost-efficient mission capabilities. TSCE can provide an efficient shipboard enterprise network allowing seamless integration of all on-board systems. It also gives the Navy to use standardized software and commercial-off-the-shelf hardware based on a fleet-wide basis. TSCE provides computer support for Zumwalt ship control, maintenance, logistics, training and other deployment functions. This level of integration and automation is unprecedented and is a primary driver for the 60% reduction human force implemented on the DDG1000. TSCE integrates security features for authentication, including the access control, network encryption, and the high-assurance are guarded to enable trusted operations. Under the Navy's DDG 1000 Detail Design and Integration contract awarded in 2005, Raytheon IDS serves as the prime mission system equipment integrator for all electronic and combat systems for the Zumwalt-class destroyer program [48-51].

4.2. Integration between ship platform, system environment and users / *Integracija brodske platforme, okruženja sustava i korisnika*

A modern naval ship is a typical, large, complex Person-Environment-Equipment-System integration platform. Due to the military requirement, the naval ship system is becoming more complex, and the Person-Environment-Equipment-System integration of is becoming high. Under ocean environment, performing various tasks may be a problem. The accident still exists, even if the ship design is most abundant (Fig. 10). In 2008, the USS Iwo Jima (LHD-7) which has served 7 years, according to the statistics data, the work efficiency and safety still are affected by three hundred and fifty six types of hazards [41, 51-53].

Early in 60s, the U.S Navy approved the 'Naval Environmental Control Standards (NECS)' and "Human Factor and Facilities Engineering Design Standards (HFFEDS)". And during "Ford" class aircraft carrier (CVN78) development process, the man - machine - environment "integrated design is core of intelligent carrier" concept. To carry out the aircraft operation process optimization, system integration, interactive design, the "Ford" class aircraft carrier combat effectiveness, the operation efficiency and the crew number is improved greatly.

Based on the statistical data of a large number of ships and crew service from U.S. Government Accountability Office (GAO), the proportion of labor costs in the ship crew life cycle costs is the largest part. As the defense budget is becoming less, few staffing is the effective measure to improve the economy of the ship, which must be faced by ship industry and the military responsibility. Thus, to improve the efficiency, reduce the aircraft carrier crew configuration, reduce maintenance costs and other issues of aircraft carrier, Rand Inc. proposed a number of improvement including more efficient use of advanced information and automation system, the optimization of cabin layout, carrier ammunition and supplies transport process [41, 54-57].

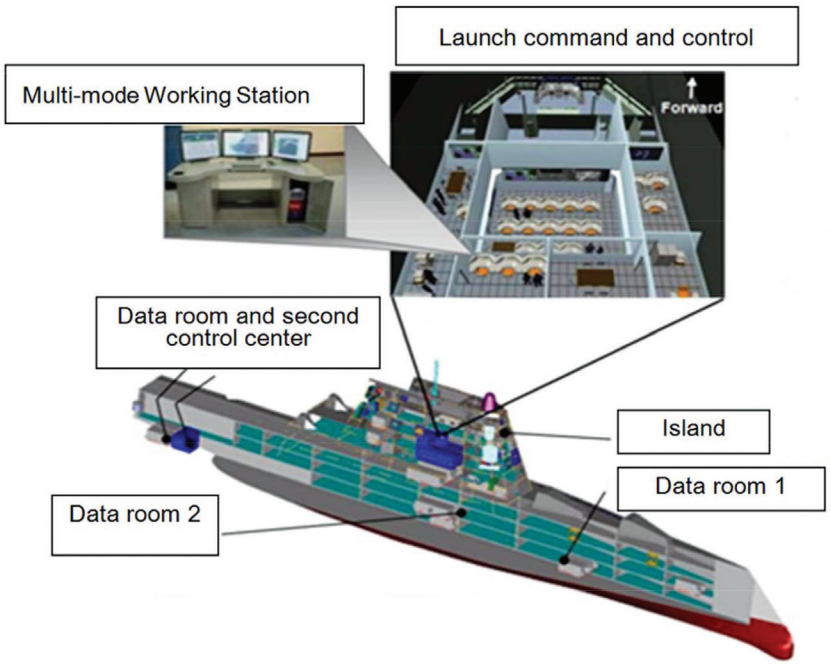

Figure 9 DDG1000 Integration System
Slika 9. DDG1000 sustav integracije

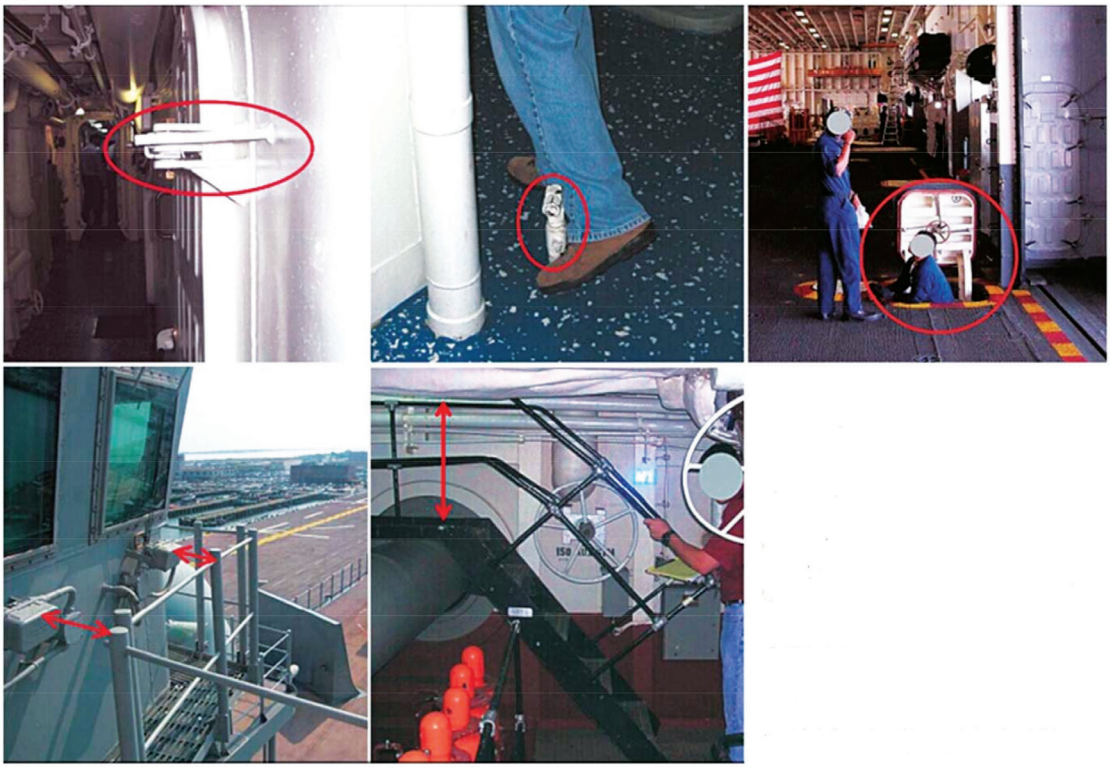

Figure 10 General Errors of ship – human – equipment integration
Slika 10. Greške pri integraciji broad – ljudi – opreme

5. CONCLUSION / *Zaključak*

Based on the above analysis of U.S. naval ship concept design development, the three typical characteristics including model based system engineering (MBSE), multi-discipline crossing and combination and system integration are analyzed. And the naval system combating ability becomes better only if the organic combination of naval ship platform, equipment and naval operators. In the present study, the main conclusion can be summarized as follows,

1. The product Life-cycle from time dimension, the whole system from space dimension and management from person dimension are both considered in the naval ship concept design. It shows that MBSE is a correct way. John Pazik, director of system engineering division of ONR, recently claimed that the MBSE will *be* the design trend in the future in the publication 'Powering the Future Naval Force'.
2. The multi-discipline crossing or combination will be highly emphasized in the development of naval ship design platform. In the practical design, the new, crossing and disruptive method (technology) will be widely studied to build integration design platform.
3. The mission of naval vessel is the core of concept design, which will be reflected in the integration top design. Thus, based on the integration design environment, the ideals including open, common use and artificial intelligence et al. must be considered. Furthermore, to fulfill the information exchange needs between different naval vessels platform, the open and integration service network is also necessary.

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