SSC Project Recommendation for FY 2024

Artificial Intelligence-aided Design (AIAD) for Container Ship Structures

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1.0 OBJECTIVE.

1.1 **Clearly state the objectives of this project**.

The objective of this project is to develop an Artificial Intelligence Aided Design (AIAD) framework and the associated tools that streamline the design of cargo container ship hull structures, enabling a digital and intelligent process for achieving optimal design solutions. By integrating parametric modeling techniques, artificial intelligence-based machine learning algorithms, and heuristic optimization techniques, the AIAD framework can enhance the exploration of the entire design space while being adaptable to changing requirements and environmental conditions. By leveraging the capability of the AIAD framework, the project aims to achieve a global optimal container ship cabin structure design, addressing both single-objective and multi-objective optimization targets or scenarios, demonstrating the potential of AIAD as a high-performance, cost-effective, and strong-adaptability design methodology for marine ship structure.

2.0 BACKGROUND.

2.1 **Provide some background on the project**.

As the shipping industry evolves, the imperative to enhance the efficiency of cargo carrying capacity, minimize operational costs, and bolster safety and strength measures is intensifying, spotlighting the critical importance of improving ship structure design. Conventional and even state-of-the-art ship structure design approaches rely heavily on established principles and empirical experience, which, while proven useful over decades, often lack the flexibility to adapt to the various modern maritime requirements and environmental conditions. In principle, the marine ship design is a typical performance-based design. The status-quo iterative design methods are constrained by applicability scope and may not be convergent sometimes, facing the challenge of obtaining the truly optimal design for demanding requirements or constraints albeit their extensive, costly, and time-consuming evaluation. Consequently, there is a pressing need for the adoption of an intrinsically intelligent, dynamic, adaptable, and data-driven design methodology in ship structure design, overcoming the limitations of the conventional CAD design methods by facilitating the exploration of a broader range of design alternatives and significantly reducing the design labor, time, and cost associated with the design cycle.

Recently, the emergence of Artificial Intelligence (AI) and Machine Learning (ML) technology of extraordinary capabilities are transforming traditional design processes and methodologies in the Engineering field. One of the most significant breakthroughs is their ability to perform complex regression analysis with an unprecedented scale and accuracy, enabling engineers to analyze vast datasets, identify patterns, and predict outcomes. Incorporating AI into ship structure design has the potential to enhance the design process by revealing the mapping relationship between structure design and their performances directly, thus sidestepping the costly and time-consuming structural adjustments, and streamlining the design process to achieve optimal results more efficiently (See: [1][2][3][4][5][6]).

2.2 This section usually provides some justification as to why the project was generated and why it should be funded.

Applying AI techniques in ship structure design, while promising, poses several technical challenges that underscore the importance of continued research in this field. The AI-aided structure design approach underscores the necessity for interdisciplinary research and collaboration, emphasizing the integration of diverse fields of expertise to fully harness the potential of artificial intelligence. Funding this project is essential for several reasons:

(1) **Pioneering Innovation**: Given the few existing studies on AI-aided ship structure design, the project represents frontier research in marine science and ship engineering. This project thoroughly will outline the complete workflow of ship structure design assisted by artificial intelligence and develop the specific machine learning neural network architecture, showcasing the step-by-step integration of AI into the design process. *Note that ChatGPT will not be able to design a ship structure, and AI-aided design of ship structures needs its domain-associated technologies.*

(2) **Automatic optimization**: By integrating AI algorithms into structure design, it will significantly reduce both labor and computational costs of ship structure design, as AI can efficiently navigate through countless design permutations to identify optimal solutions faster and with less human intervention, improving the accuracy and reliability of the design process.

(3) **Unlocking Potential**: The limited application of AI in current ship design methodologies indicates that these approaches may have not leveraged the full potential of AI technologies, resulting in limited design variables considered. This project shall present the development of an AIAD approach with more than thousand design parameters tailored for comprehensive cabin structure design, which may gradually replace the existing computer-aided design (CAD) or simulation-based design (SBD).

(4) **Long-term Workload Reduction**: The AIAD framework developed in this project could possess remarkable adaptability across various design conditions and constraints, which simply cannot only be achieved by the current structure design methods but also remain effective as new requirements emerge, facilitating a long-term reduction in workload and design costs.

3.0 REQUIREMENTS.

3.1 **Scope**. (**Container ship structure design**).

3.1.1 The Contractor shall conduct the following assessments of the project.

The contractor is responsible for conducting a thorough assessment that evaluates the feasibility, requirements, and impact of integrating an Artificial Intelligence Assist Design (AIAD) framework into the container ship structural design process. Specifically, the contractor should conduct a systematic assessment of AI-based ML methods' capability to assist structural design, involving assessing the feasibility of forecasting the structural responses of ships under various configurations and performance conditions and analyzing the influence of ML neural network architecture on their predictive accuracy and efficiency. In addition, the project shall be assessed by its practicality and efficacy on the proposed ship structural parametric modeling methods, optimization algorithms, and the overarching integration frameworks, which involve the ability to accurately represent complex ship structures, the ability to find optimization in high-dimensional space, and the effectiveness of utilizing the AIAD framework to achieve structural optimization.

3.1.2 The Contractor shall identify the key technical ingredients of the research.

The Contractor identifies the following elements as the keys to ensuring the success of the AIAD-based design process:

(1) Complying with the ship design codes used by the U.S. Maritime Commission and understanding the specific requirements for the container ship cabin, including space optimization, structural integrity, and safety regulations.

(2) The reliability and accuracy of the data sources used to train the AI model by credibility evaluation.

(3) The ship hull structure knowledge base for ship structure design, including the hull and standard parts member base and the design rule base.

(4) The optimization objectives and constraints in the optimal design process of ship cabin structures.

3.1.3 The Contractor will address the following technical issues:

We shall address several key issues to ensure the success and efficiency of the AIAD-based design process:

(1) The parametric modeling of container cabins, achieving the realization of such modeling with a minimal parameter number, grounded upon the hull structural knowledge base.
(2) The challenges in AI model building and data acquisition for the ship structure strength analysis, including data generation, algorithm selection, feature engineering, training, and interpretability.
(3) The question of how to establish the AIAD framework, which involves building an integrated platform for ship structure optimal design by integrating parametric modeling technology, AI models, and optimization algorithms.

3.2 **Tasks**. (Identify the tasks to carry out the scope of the project).

3.2.1 The Contractor aims to achieve the following technical tasks as milestones:

We shall realize parametric modeling of cabin structure based on knowledge-based engineering. Specifically, Knowledge-Based Engineering (KBE) is used to generate both a configuration base and a rule base for the design of container ship cabin structures. The design configuration base, a comprehensive repository of standardized design elements, components, and configurations specific to container ship cabins, should comply with ship design codes, industry standards, and historical data. The design codes encapsulate essential engineering principles, regulatory requirements, and guidelines that govern the design process. By embedding two bases, the cabin structure can be parametric modeled with lower numbers of parameters, accurately reflecting the geometric and functional relationships between different design variables, reducing data costs for subsequent development of AI models.

3.2.2 The Contractor shall collect data through large-scale simulations.

We shall accurately evaluate the cabin structure performance loads under different wave and sailing conditions. Specifically, under varying wave and sailing conditions, the flow field surrounding the ship will be simulated, which allows the calculation of surface pressure distributions. Based on Finite Element Analysis (FEA), the contractor shall perform a direct strength assessment of the container ship cabin structure, including analyses of both yield strength and buckling strength, providing reliable and accurate data sources that can be used to train the AI model.

3.2.3 The Contractor shall develop a specific ML neural network for structure strength design purposes.

We shall develop an AI-aided ML algorithm and the associated deep neural network architecture dedicated to structural strength prediction. The ML neural network will utilize both design and condition variables as inputs, enabling the precise prediction of structural strength information for the corresponding cabin structure under the corresponding sailing conditions. Through the processes of data generation, algorithm selection, feature engineering, model tuning, training, and testing, the contractor shall realize the fast prediction of cabin structural strength.

3.2.4 The Contractor shall develop AI-based optimization algorithms for ship structure design.

The AIAD framework for ship structure design consists of two main parts: (1) an ML-based neural network model that maps design parameters to design objectives, i.e. resistance and critical strength, and (2) an AI-based optimization process that will lead the initial draft design to a final optimal design of the entire ship hull structure. The contractor shall develop AI-based optimization algorithms and integrate them with the previously delineated ML-based parametric modeling and AI models, and therefore, completely construct the entire AIAD framework. We shall then use the AIAD framework to design the container ship cabin structure across various sailing conditions, guaranteeing that its structural performance aligns with the necessary specifications while concurrently minimizing construction costs.

3.3 **Project Timeline**.

2024.07-2024.09: Parametric modeling of the hull structure.
2024.09-2025.01: Data collection and Dataset construction.
2025.01-2025.03: Tune and Train structural performance prediction AI.
2025.03-2024.05: Develop optimization algorithms and build AIAD framework.
2025.05-2024.07: Summarize the entire project.

4.0 GOVERNMENT FURNISHED INFORMATION.

4.1 Standards for the Preparation and Publication of SSC Technical Reports.

5.0 DELIVERY REQUIREMENTS. (Identify the deliverables of the project).

5.1 The Contractor shall provide quarterly progress reports to the Project Technical Committee, the Ship Structure Committee Executive Director, and the Contract Specialist.
5.2 The Contractor shall provide the container ship cabin structural strength dataset.
5.3 The Contractor shall provide the source program of the AIAD framework.
5.4 The Contractor shall provide at least three container ship cabin design schemes.
5.5 The Contractor shall provide a print-ready master final report and an electronic copy, including the above deliverables, formatted as per the SSC Report Style Manual.

6.0 PERIOD OF PERFORMANCE.

6.1 Project Initiation Date: date of award.
6.2 Project Completion Date: *12* months from the date of award.

7.0 GOVERNMENT ESTIMATE. These contractor direct costs are based on previous project participation expenses.

7.1 Project Duration: *12* months.
7.2 Total Estimate: $100,000 (USD).
7.3 The Independent Government Cost Estimate is attached as enclosure (*x*).

8.0 REFERENCES.

8.1 References

[1] Y. Ao, Y. Li, J. Gong, and S. Li. Artificial intelligence design for ship structures: A variant multiple-input neural network based ship resistance prediction. ASME *Journal of Mechanical Design*, 144(9):091707, 2022.
[2] Y. Ao, Y. Li, J. Gong, and S. Li. An artificial intelligence-aided design (AIAD) of ship hull structures. *Journal of Ocean Engineering and Science*, 8(1):15–32, 2023.
[3] Y. Ao, Y. Li, S. Li, and J. Gong. Construction high precision neural network proxy model for ship hull structure design based on hybrid datasets of hydrodynamic load. *Journal of Marine Science and Application*, Online:https://doi.org/10.1007/s11804–024–00388–4, 2023.
[4] Y. Ao, H. Duan, and S. Li. An integrated-hull design assisted by artificial intelligence-aided design method. *Computers & Structures*, 297:107320, 2024.
[5] Y. Ao, S. Li, Y. Li, and J. Gong. The construction of a neural network proxy model for ship hull design-based on multi-fidelity datasets and the parameter freezing strategy. *Journal of Marine Engineering & Technology*, Online:https://doi.org/10.1080/20464177.2024.2330174, 2024.
[6] Y. Ao, J. Xu, D. Zhang, and S. Li. Artificial intelligence aided design (AIAD) of hull form of unmanned underwater vehicles (UAVs) for minimization of energy consumption. ASME *Journal of Computing and Information Science in Engineering*, 24(1):153–165, 2024.

9.0 SUGGESTED CONTRACTING STRATEGY.

9.1 Contracting strategy. Award the contract to the University of California, Berkeley as an unrestricted gift.

NOTE:

- Please do not submit any proprietary information in this outline. This may be posted on the SSC website regardless of whether the project is selected to be funded or not.
- All projects will be competed via Government Services Administration (GSA) or Commerce Business Daily (announced)