SSC Project Recommendation for FY 2024

Digital Twin Framework for Slamming Fatigue Life-Cycle Management

Submitted by:

Jose D. Mesa, Ph.D.,	Design Research Engineering, L.L.C.	(jmesa@dreng.com)
Matthew L. Schirmann, Ph.D.,	Design Research Engineering, L.L.C.	(schirmannm@dreng.com)

1.0 OBJECTIVE.

1.1 The project aims to enhance maritime safety and efficiency through the development of a digital twin-driven system, enabling real-time monitoring and management of vessel slamming fatigue using sensor data and machine learning for proactive decision-making and maintenance.

2.0 BACKGROUND.

2.1 The maritime industry is currently facing a complex challenge in accurately predicting and managing the structural integrity and operational efficiency of vessels subjected to slamming events. The complexity of fluid-structure interactions (FSI) during such events poses a significant challenge for existing modeling tools, which often fall short in their ability to provide accurate, real-time insights into vessel fatigue and structural health. This gap leaves vessels at risk of unforeseen operational issues and potential safety hazards.

2.2 Traditional methods and tools available for assessing vessel slamming and the resulting fatigue damage lack the sophistication needed to model the problem accurately. They are often unable to capture the complex, nonlinear dynamics of FSI, resulting in a reactive approach to vessel maintenance and safety management. The absence of comprehensive, real-time monitoring solutions hampers the maritime industry's ability to proactively address these challenges.

2.3 Recognizing this gap, our project aims to develop an integrated solution that combines the latest advancements in digital twin technology, Computational Fluid Dynamics (CFD), and the Finite Element Method (FEM). By integrating low-fidelity and high-fidelity simulation tools with real-time operational data, the proposed system will accurately estimate the impact of slamming events on vessel fatigue. This innovative approach leverages both academic research and industry knowledge, ensuring that the solution is grounded in state-of-the-art scientific understanding while being highly applicable to real-world operational environments.

2.4 The project stands at the intersection of academic innovation and practical industry application, aiming to deliver a solution that not only advances the theoretical understanding of slamming-induced fatigue, but also provides a tangible, field-deployable tool for maritime operators. This blend of academic research and understanding of industry challenges enhances the development of a state-of-the-art framework that will promote maritime safety, operational efficiency, and vessel lifecycle management.

2.5 By doing so, the project addresses a critical need within the maritime industry for a proactive, accurate, and comprehensive monitoring solution, justifying its development as a pioneering initiative in maritime operations.

3.0 REQUIREMENTS.

3.1 Scope:

3.1.1 The project encompasses the development and implementation of a "Digital Twin Framework for Slamming Fatigue Life-cycle Management" system. This entails the creation of a digital twin model, integration of operational sensor data, dashboard development for real-time monitoring, and comprehensive system validation to ensure accuracy and reliability.

3.2 Tasks:

3.2.1 **Digital Twin Framework Development**: Develop a digital twin of the target vessel panel, integrating low-fidelity and high-fidelity simulations (CFD and FEM) to model complex FSI phenomena accurately.

3.2.2 **Identification of Onboard Data Collection**: Identify essential field parameter data for collection by the onboard monitoring system to be utilized by the digital twin slamming framework for estimating fatigue damage under varying operating conditions (e.g., vertical/horizontal velocities, wave height, period, pitch angle). If no vessel operational data is available, prediction will be performed using mock data based on typical vessel operation conditions to simulate vessel slamming events.

3.2.3 **Dashboard Development**: Create an intuitive, real-time monitoring dashboard to display critical data and analytics for operators, providing immediate insights into vessel conditions and fatigue levels.

3.2.4 **Digital Framework Validation**: Perform rigorous testing and validation of the digital twin model and monitoring system with experimental data and canonical test results to confirm the system's accuracy and reliability.

4.0 GOVERNMENT FURNISHED INFORMATION.

To facilitate the development and implementation of the "Digital Twin Framework for Slamming Fatigue Life-cycle Management" system, the following information and resources will be provided by the government:

4.1 **SSC Technical Report Standards**: Comprehensive guidelines and standards for the preparation and publication of SSC Technical Reports (Standards for the Preparation and Publication of SSC Technical Reports). These standards cover the required format, content, and quality criteria for technical documentation and reporting related to the project. Adherence to these standards is crucial for ensuring consistency, accuracy, and reliability of project outcomes and their communication.

4.2 Vessel Specifications and Data: If available, detailed specifications, blueprints, and historical operational data for the selected vessel(s) by SSC. This may include structural designs, material properties, previous maintenance records, and sensor data logs. If specific vessel data are not provided, a combination of simulated and publicly available data from research vessels will be used to deliver the project's minimum value product (MVP).

5.0 DELIVERY REQUIREMENTS.

The successful completion of the "Digital Twin Framework for Slamming Fatigue Life-cycle Management" project will result in the delivery of the following items:

5.1 **Digital Twin Framework**: A fully developed and operational digital twin framework of the target vessel, incorporating advanced simulation techniques for accurate fluid-structure interaction analysis. The model will integrate both low-fidelity and high-fidelity tools, including Computational Fluid Dynamics (CFD) and the Finite Element Method (FEM).

5.2 **Monitoring Dashboard**: An intuitive, user-friendly dashboard designed for the real-time monitoring of vessel slamming events and cumulative fatigue damage. The dashboard will display critical data and analytics derived from onboard sensor data, enabling immediate operational insights and decision-making support.

5.3 **System Documentation**: Comprehensive documentation detailing the system architecture, components, and operation. This will include a user manual with step-by-step guides for utilizing the monitoring dashboard and interpreting data.

5.4 **Project Final Report**: A comprehensive final report summarizing the project's objectives, methodology, key findings, and recommendations for future work. The report will adhere to the "4.1 Standards for the Preparation and Publication of SSC Technical Reports" to ensure compliance with SSC documentation standards.

6.0 PERIOD OF PERFORMANCE.

The "Digital Twin Framework for Slamming Fatigue Life-cycle Management" project, upon receiving funding, is scheduled to commence in June 2024. The timeline for the project is outlined as follows to ensure a structured and efficient approach to achieving the project's objectives:

6.1 Development Phase (June 2024 – May 2025):

- June 2024: Project kickoff and initial setup. Finalization of the project plan and detailed schedule.
- July 2024 - November 2024: Development of the digital twin model, incorporating low-fidelity and high-fidelity simulation tools. Integration of Finite Element Method (FEM) for enhanced fluid-structure interaction accuracy.
- November 2024 - February 2025: Integration of real-time sensor data analysis with the digital twin model. Development and testing of the real-time monitoring dashboard.
- February 2025 - May 2025: Final system integration and testing. Validation of the digital twin model and monitoring system using experimental data and canonical test results.

6.2 Reporting Phase (May 2025):

- May 2025- June 2025: Preparation of the final project report, detailing the methodology, development process, system testing and validation results, and recommendations for future implementations. The report will adhere to the "4.1 Standards for the Preparation and Publication of SSC Technical Reports" to ensure compliance with SSC guidelines.

7.0 GOVERNMENT ESTIMATE.

Design Research Engineering, L.L.C. requests the full funding amount of $100,000 for the "Digital Twin Framework for Slamming Fatigue Life-cycle Management" project. This budget is essential to develop, implement, and deliver the innovative system within the proposed timeline, covering all project phases from digital twin modeling and real-time monitoring to system validation and final reporting. The investment will enable us to address the complex challenges of vessel slamming and lifecycle management effectively, ensuring significant advancements in maritime safety and efficiency. We are committed to realizing this solution's full potential with the support of the requested funding.

7.1 Project Duration: 12 months.

7.2 Total Estimate: $100,000.00

8.0 REFERENCES.

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8.2 Matthew L. Schirmann, James W. Gose, and Matthew D. Collette (2023) "A comparison of physics-informed data-driven modeling architectures for ship motion predictions." Ocean Engineering 286: 115608.

8.3 Jose D. Mesa, Kevin J. Maki, Matthew T. Graham (2022) “Numerical Analysis of the Impact of an Inclined Plate with Water at High Horizontal Velocity". Journal of Fluid and Structures, 114:103684.

8.4 Matthew L. Schirmann, Matthew D. Collette, and James W. Gose (2022) "Data-driven models for vessel motion prediction and the benefits of physics-based information." Applied Ocean Research 120: 102916.

8.5 Matthew L. Schirmann (2021) “Physics-Informed Data-Driven Models for Ship Response Prediction using Global Wave Data” (Doctoral dissertation).

8.6 Matthew L. Schirmann, Matthew D. Collette, and James W. Gose (2020) "Improved vessel motion predictions using full-scale measurements and data-driven models." In Proceedings of the 33rd Symposium on Naval Hydrodynamics.

8.7 Matthew L. Schirmann, Tomer Chen, Matthew Collette, and James W. Gose (2019) "Linking seakeeping performance predictions with onboard measurements for surface platform digital twins." In Practical Design of Ships and Other Floating Structures: Proceedings of the 14th International Symposium, PRADS 2019, September 22-26, 2019, Yokohama, Japan. Volume I 14, pp. 790-804. Springer Singapore, 2021.

8.8 Jose D. Mesa (2018) “Hydroelastic Analysis of Aluminum and Composite High-Speed Planing Craft Structures During Slamming” (Doctoral dissertation).

8.9 Jose D. Mesa, Kevin J. Maki (2018) “Hydroelastic Assessment of Different High-Speed-Vessel Stiffened Panel Designs". Naval Engineers Journal, September 2018, No 130-3, pp 33-42.

8.10 Matthew L. Schirmann, Matthew D. Collette, and James W. Gose (2018) "Ship motion and fatigue damage estimation via a digital twin." In Life Cycle Analysis and Assessment in Civil Engineering: Towards an Integrated Vision, pp. 2075-2082. CRC Press, 2018.

8.11 Jose D. Mesa, Kevin J. Maki (2017) “Numerical hydroelastic analysis of slamming for high-speed vessels”. In Proceedings of the 14th International Conference on Fast Sea Transportation, Nantes, France, September 27th-29th.

8.12 Margaret Craig, Dominic Piro, Lauren Schambach, Jose Mesa, Dave Kring, Kevin Maki (2015) “A Comparison of Fully-Coupled Hydroelastic Simulation Methods to Predict Slam-Induced Whipping”. In the Proceedings of the 7th International Conference on Hydroelasticity in Marine Technology Split, Croatia, September 16th-19th.

9.0 SUGGESTED CONTRACTING STRATEGY.

To ensure the successful execution of the " Digital Twin Framework for Slamming Fatigue Life-cycle Management " project within the allocated budget and timeframe, Design Research Engineering proposes the following contracting strategy:

1.1 **Phased Contract Approach**: Implement a phased contract approach that aligns with the project milestones. This strategy allows for iterative review and adjustments, ensuring that each phase of the project, from development to deployment, meets the predefined objectives and standards before proceeding to the next phase.