SSC Project Recommendation for FY 2021

System-Level Fatigue Reliability Assessment

1.0 OBJECTIVE.

1.1 Develop a system-level method for assessing the degradation of reliability of ship structures by fatigue that considers possible points of fatigue-crack initiation.

2.0 BACKGROUND.

2.1 Most methods in the literature for assessment of the probability of fatigue crack initiation consider only a single structural detail. A ship has thousands of possible locations for fatigue crack initiation, and a proper fatigue analysis should consider the probability that more than one detail could begin to crack in a given time period.

2.2 A method for assessing system-level fatigue was reported by Stambaugh (2020) and by Ayyub et al. (2015). The method asks "How many details will fail in a given time frame given the probability of failure of each detail." The answer is the sum of the products of the probabilities times the number of details within correlated groupings of the same probability of failure. The correlated groupings are used for simplification of the calculation. This is applied in a look at risk analysis for fatigue.

2.3 Soliman et al. (2013) considered independent details that were in different girders and spans of a bridge. This work needs to be expanded to consider the correlation through numerical/probabilistic modeling of the multiple cracks in the same structure.

2.4 Groden (2016) used Dynamic Bayesian Networks and Bayesian Interference to address the problem.

2.5 Zhang (2020) reported on experiments on a simple structure with four possible fatigue crack initiation points. Bayesian networks were established and the uncertainty was propagated through them. The work demonstrated that the Bayesian networks work for this simple problem, but an analysis of an entire ship with thousands of possible crack initiation points is too complex for this method. Zhang stated that a common difficulty of dynamic Bayesian networks in modeling complex structural system is the size of conditional probability tables grows exponentially with an increasing number of states and complex dependence, resulting in a slow inference. A potential approach employing an application programming interface and more computation power could be investigated in terms of speeding up the inference and making a faster real-time prediction.

2.6 Assessment of the probability of fatigue crack initiation is essential to one of the principal focus areas of the Ship Structure Committee, Structural Monitoring, Longevity, and Lifetime Extension.

3.0 REQUIREMENTS.

3.1 Scope.

3.1.1 The Contractor shall conduct an assessment of current methods of through-life fatigue analysis of ship structure.

3.1.2 The Contractor shall identify the ways that these methods can be extended to include system-level fatigue. The contractor shall prepare a summary of the approaches indicating the assumptions, limitations and applicability in the structural fatigue design and lifecycle analysis objectives.

3.1.3 The Contractor shall address the resources needed, changes in data gathering and recording, analysis tools required, and education necessary for application of the research.

3.2 Tasks.

3.2.1 The Contractor shall conduct an assessment of current methods of fatigue analysis of ship structure. A summary of current practices in the various fields will be made, including deficiencies that could be addressed through application of the latest research.

3.2.2 The Contractor shall identify the ways that these methods can be extended to include system-level fatigue. This will include estimating the number of details expected to crack during a given time period, and the probability of that occurring. The contractor shall prepare a summary of the approaches indicating the assumptions, limitations and applicability in the structural fatigue design and lifecycle analysis objectives.

3.2.3 The Contractor shall apply the method to a typical ship, considering all stochastic elements in the estimation of system-level fatigue crack initiation. For that demonstration, a detailed analysis of the ship structure and a hydrodynamic analysis of the loading will not be required. Assumptions can be made as to the lifetime loading spectrum and stress variation at all structural details in the ship structure.

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3.3 Project Timeline. See Enclosure (*x*).

4.0 <u>GOVERNMENT FURNISHED INFORMATION</u>.

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

5.0 <u>DELIVERY REQUIREMENTS</u>.

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 to the Ship Structure Committee and member organizations the computer software developed in this project.

5.3 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 <u>PERIOD OF PERFORMANCE</u>.

6.1 Project Initiation Date: date of award.

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

7.0 <u>GOVERNMENT ESTIMATE</u>. These contractor direct costs are based on previous project participation expenses.

7.1 Project Duration: 12 months.

7.2 Total Estimate: $100,000

7.3 The Independent Government Cost Estimate is attached as enclosure (*x*).

8.0 <u>REFERENCES</u>.

8.1 Ayyub, Bilal, Karl Stambaugh, Timothy McAllister, Gilberto de Sousa, and David Webb (2015), Structural Life Expectancy of Marine Vessels: Ultimate Strength, Corrosion, Fatigue, Fracture, and

Systems, *Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering*, March 2015, Vol. 1, / 011001-1–13.

8.2 Groden, Mark Daniel (2016), A Probabilistic Graphical Framework Fusing Data for Model Updating and Decision Support, dissertation submitted to the University of Michigan, Department of Naval Architecture and Marine Engineering.
8.3 Soliman Mohamed, Dan M. Frangopol, and Sunyong Kim (2013). Probabilistic Optimum Inspection Planning of Steel Bridges with Multiple Fatigue Sensitive Details. *Engineering Structures* Vol. 49 (2013) 996–1006.
8.4 Stambaugh, Karl Allen, (2020) On Ship Structure Risk and Total Ownership Cost Management Assisted by Prognostic Hull Structure Monitoring, dissertation submitted to the Delft University of Technology, 14 July 2020.
8.5 Zhang, Kaihua (2020), Development and Experimental Validation of Dynamic Bayesian Networks for System Reliability Prediction, dissertation submitted to the University of Michigan, Department of Naval Architecture and Marine Engineering.

9.0 SUGGESTED CONTRACTING STRATEGY.

9.1 Contracting strategy. Full and open competition will be employed to ensure that this work could be performed by a variety of organizations, including academia, research laboratories, classification societies, or naval architects. Because this subject is not included in the expertise sought for standing level-of-effort contracts, that contracting strategy is not appropriate for this work.

NOTE:

- Please do not submit any proprietary information in this outline. This will be posted on the SSC Website regardless if the project is selected to be funded.

- All projects will be competed via Government Services Administration (GSA) or Commerce Business Daily (announced)