<u>SSC Project Recommendation for FY 2016</u>

Structural Life Sustainment: Tradeoffs among Initial Design Safety Margins, Inspection Practices and Maintenance Strategies

1.0 OBJECTIVE.

1.1 The objective of this project is to develop an in-depth understanding of and provide guidance on structural life sustainment through tradeoffs among (1) initial design safety margins, (2) inspection practices, and (3) maintenance strategies using probabilistic methods, fatigue cumulative damage models, fracture mechanics methods, and reliabilities of non-destructive techniques.

2.0 BACKGROUND.

2.1 Reliability and life expectancy analysis are typically based on particular failure modes at the component and system levels. The following primary failure modes with corrosion effects are typically considered: (1) failure of a hull girder as a stiffened thin-walled structure by reaching its ultimate strength; (2) failure of a stiffened panel by material yielding or instability of one or a group of its components; (3) fatigue of structural details due to cyclic loading; and (4) fracture of a member. Numerical and simulation methods are typically used for assessing the time-dependent reliabilities for these failure modes.

2.2 The first and second failure modes above are based on ultimate strength and extreme loading conditions with corrosion consideration that degrade strengths of the hulls and members. These two failure modes require the use of extreme value analysis and first-crossing time-dependent reliability analysis. These modes were investigated extensively for marine vessels, bridge girders and other similar structures.

2.3 As for the latter two, fatigue damage is one of the most import failure modes of ship structures. Extensive works have been done to investigate the fatigue behavior of ship structures. The Palmgren-Miner, i.e., stress cycles to failure, called S-N cumulative damage fatigue analysis or fracture mechanics approach is normally adopted. The Palmgren-Miner approach is a more oriented design formulation that predicts the operational life as a function of the number of cycles at various stress levels. The S-N formulation provides a prediction of fatigue life based defining failure by crack initiation. The fracture mechanics approach is oriented to predict the behavior of cracked structural details aiming at defining the number of load cycles necessary to make an initial crack grow to a critical size that will cause structural failure. Fracture mechanics methods assess life based on crack propagation from an initial crack size to full penetration in a structural member. A combination of fracture mechanics and stochastic modeling of loads provides the necessary tools for these reliability calculations. A limit state function can be formulated by applying linear elastic fracture mechanics. The uncertainties of key influencing parameters can be taken into account by treating them as basic random variables. Such methods should account for corrosion effects on member thicknesses and geometry. Additionally, a fracture mechanics approach produces crack size distribution associated with a vessel's operational life and use.

2.4 Reliability and life expectancy analysis of marine vessels for structural life sustainment requires the management of voluminous and potentially dispersed information. The management in this case can be facilitated by the use of analytical tools. Such methods require specification of the basic random variables for the corresponding performance functions representing a structural failure mode. Such tools can be used to manage ships analyzed and associated stations, components, details and results, and users. The methods are illustrated using examples with insightful observations in this tool.

2.5 Structural reliability and statistics-based assessment methods require analyzing uncertainties in terms of sources and types, and the quantification of these uncertainties in terms of biases relating to values of parameters and prediction models, their coefficients of variation, and their probability distribution types.

2.6 There is a need to investigate the effectiveness of inspection practices in assessing weld quality. For this purpose, fatigue life of marine vessels is investigated using the stress cycles to failure (i.e., S-N) cumulative damage fatigue analysis, and the fracture mechanics methods based on crack propagation from an initial crack size to full penetration in a structural member. The S-N cumulative damage fatigue analysis is used in designing such vessels for a particular design life, say 30 years. Analysis using fracture mechanics follows to back calculate the initial crack size distribution necessary to obtain the end of life condition as defined by the S-N design method, i.e., initial crack size distribution necessary to obtain full penetration cracks in structural members. The paper explores quantified weld quality requirements during construction based on fatigue response for specific weld types, e.g., longitudinal butt and transverse fillet, and recommendations of related inspection techniques appropriate for weld quality criteria. The outcome of such an analysis can inform assurance related decisions of welding associated with construction, repairs or modifications in terms of the fatigue strength of hull structures.

3.0 REQUIREMENTS.

3.1 Scope.

3.1.1 The Contractor shall develop an in-depth understanding of and provide guidance on structural life sustainment through tradeoffs among (1) initial design safety margins, (2) inspection practices, and (3) maintenance strategies.

3.1.2 The Contractor shall assess the lifetime effects of initial construction quality on fatigue failure. The contractor shall review existing construction quality standards and provide guidance and computational procedures to account for lifetime effects based on fatigue failure predictions using S-N and fracture mechanics predictions models for the purpose of structural reliability and statistical analysis. The contractor shall develop an approach for estimation of the effects of weld and inspection quality on crack growth rates in fracture mechanics terms and statistical properties of imperfections and inspections in a life assessment methodology.

3.1.3 The Contractor shall illustrate the proposed methods using practical examples, and demonstrate its effectiveness in informing decisions. The contractor shall summarize any insights gained and provide guidance accordingly for the use of practitioners.

3.1.4 The Contractor shall document the results in a final report. The report shall include the methodology and uncertainty quantification results presented in a format that is compatible with the SSC format for reports. The contractor shall present the findings from the project to a project monitoring committee at a location in the Washington Metropolitan area.

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

3.2.1 Assess the lifetime effects of initial construction quality on fatigue failure

3.2.2 Develop an in-depth understanding of and provide guidance on structural life sustainment through tradeoffs among (1) initial design safety margins, (2) inspection practices, and (3) maintenance strategies

3.2.3 Illustrate the proposed methods

3.2.4 Document the methods and results in a final report

3.3 Project Timeline. (in months)

Task	1	2	3	4	5	6	7	8	9	10	11	12
Assess the lifetime effects of initial construction quality on fatigue failure	X	X	X	X	X	X	X	X				
Develop an in-depth understanding of and provide guidance on structural life sustainment				X	X	X	X	X	X	X		
Illustrate the proposed methods						X	X	X	X	X	X	
Document the methods and results in a final report	X	X	X	X	X	X	X	X	X	X	X	X

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 update presentations as needed on the progress of the project, not to exceed three meetings.

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 as posted on the website http://www.shipstructure.org.

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

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

8.0 REFERENCES.

8.1 Reference.

de Souza, G. F. M., and Ayyub, B. M., “Probabilistic Fatigue Life Prediction for Ship Structures Using Fracture Mechanics,” NEJ, ASNE, 112(4), July 2000, 375-397.

Ayyub, B. M., Stambaugh, K. A., McAllister, T. A., de Souza, G. F., and Webb, D., 2015 “Structural Life Expectancy of Marine Vessels: Ultimate Strength, Corrosion, Fatigue, Fracture and Systems,” ASCE-ASME J. Risk Uncertainty Eng. Syst., Part B: Mechanical Eng., Vol 1, DOI: 10.1115/1.4026396.

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.