3
PROJECT RECOMMENDATIONS FOR FISCAL YEAR 2011

Table 3-1 lists the projects proposed for the 2011 program. Detailed descriptions of each project follow below. Every project recommended by the SSC is considered to be of significant potential value to the marine industry.

TABLE 3-1 Project Recommendations for Fiscal Year 2011

11-01 Development of Crack Arrestors for Aluminum Ship Structures

Submitted by: Robert A. Sielski

1.0 **OBJECTIVE**.

1.1 This project will develop practical methods for incorporating crack arrestors into aluminum ship structures to stop or significantly slow the growth of fatigue cracks.

2.0 **BACKGROUND**.

2.1 Fatigue crack propagation cannot be significantly reduced by the welded crack arrestor strakes of tougher material at the gunwale and bilge that are currently incorporated in steel hulls, and aluminum hulls have no such crack arrestors. Incorporating fatigue analysis in ship design procedures can significantly reduce the probability of crack initiation in aluminum hulls, but if cracks do initiate, they will be subject to rather fast fatigue propagation that can lead to hull failure. Means are needed to prevent failure by fatigue crack propagation of aluminum hulls by the introduction of either riveted or effectively designed welded crack arrestors [Sielski, 2009].

2.2 Past SSC reports, including SSC-413, Effect of Welded Stiffeners on Fatigue Crack Growth Rate, and SSC-435, Predicting Stable Fatigue Crack Propagation in Stiffened Panels, investigated means of slowing fatigue crack propagation in steel hulls, particularly through welded stiffeners. Those studies showed that welded stiffeners did not always slow the rate of fatigue crack growth, especially in way of a transverse butt in the hull.

2.3 The rate of fatigue crack growth in aluminum is about 30 times greater than in steel when subjected to the same stress range and with the same size crack. In ship structures designed to resist fatigue crack initiation, the rate of fatigue crack propagation can still be as much as four times greater in aluminum than in steel hulls. Effective means of crack arrest are needed in aluminum hulls.

2.4 One method that was found effective in the past for steel hulls was to provide mechanically fastened seams at critical locations, such as the bilge and gunwale. When a propagating fatigue crack reaches such a seam, the crack must reinitiate in the adjacent plate before it can continue to grow. Mechanically fastened seams require more labor during fabrication than welding, and can be a source of leakage and of corrosion. Other means of reducing crack growth rates may be possible, such as providing inserts in the plating that will reduce the stress intensity factor at the crack tip.

2.5 If a means of crack arrest is not built into an aluminum ship, effective means of temporary repair for slowing fatigue crack growth are needed to prevent failure of the hull of a ship in which a crack is growing.

2.6 This project was developed in recognition of the criticality of cracks in aluminum hulls. An effective means of crack arrest is needed to prevent catastrophic failures.

3.0 **REQUIREMENTS**.

3.1 Scope.

3.1.1 The Contractor shall conduct an assessment of methods for slowing the rate of crack growth in aluminum structures.

3.1.2 The Contractor shall develop an experimental procedure for assessing the effectiveness of various types of crack arrestors in aluminum structures.

3.1.3 The Contractor shall identify the most likely types of crack arrestors to be used in aluminum hulls.

3.1.4 The contractor shall carry out an experimental program to determine the effectiveness of various types of crack arrestors in aluminum structures.

3.1.5 The Contractor shall prepare a report on the results of the project.

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

3.2.1 The Contractor shall conduct a literature search for methods of crack arrest in ship structures, particularly aluminum hulls.

3.2.2 The Contractor shall develop various structural configurations that could be effective as crack arrestors in aluminum hulls.

3.2.3 The Contractor shall develop an experimental program for assessing the effectiveness of various crack arrestors. Prior to the commencement of the test program, the concurrence of the SSC Project Technical Committee will be obtained.

3.2.4 The Contractor shall carry out an experimental program that will evaluate the effectiveness of the different types of crack arrestors.

3.2.5 The contractor shall prepare a final report on the project using the SSC reporting standards as a guideline.

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>. (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 information for approval to the Project Technical Committee and the Ship Structure Committee Executive Director concerning the test materials, test specimen geometry, load fixtures, and intended load levels prior to the beginning of testing.

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 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: $150,000.00

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

8.0 REFERENCES.

8.1 Sielski, Robert A. The Need for Crack Arrestors in Ship Structure, to be presented at the twelfth International conference on Fracture, to be held July 12–17, 2009 in Ottawa, Ontario.

9.0 SUGGESTED CONTRACTING STRATEGY.

9.1 Full and open contracting beyond existing government level of effort contracts should be used for this project to ensure the participation of fracture experts that are not part of the usual teams bidding of government level of effort contracts.

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)

11-02 The Fatigue Strength of Mechanically Fastened Seams in Aluminum Structure

Submitted by: Robert A. Sielski

1.0 OBJECTIVE.

1.1 This project will develop data for the fatigue strength of mechanically fastened seams in aluminum structure to enable fatigue calculations to be performed during the design of such seams as crack arrestors in aluminum hulls.

2.0 BACKGROUND.

2.1 Aluminum structures have crack propagation rates that are up to 30 times faster than in steel if cracks of the same size are tested at the same stress. Even in comparable designs, where the scantlings of the aluminum ship or craft tend to be greater than in a steel vessel, crack propagations rates can be three times faster in aluminum (Sielski, 2008). No provision is generally made in the design of aluminum ships and craft for any method of arresting a propagating fatigue crack.

2.2 One means of stopping, or at least significantly slowing down, a propagating crack in ship structure is to place a mechanically fastened seam in the path of anticipated fatigue cracks. Historically, this was done in steel ships by providing riveted seams at the gunwale and turn of bilge. These seams were intended primarily to arrest fast fracture in low-toughness hull steel. Beginning in the 1960s these riveted seams were replaced by strakes of tougher steel, and by then, hull steel had become tougher. No corresponding crack arrestors have been incorporated into aluminum hulls as they evolved from small craft to larger ocean-going vessels.

2.3 Due to the greater labor required and the lack of skilled riveters for ship structure, a mechanically fastened seam would use fasteners such as swaged fasteners (lockpins) to close the joint. These were shown to be effective in steel structures when they were used in place of rivets, and were also effective for the joint between steel hulls and aluminum deckhouses before the welded bimetallic joint was developed.

2.4 Mechanically fastened joints are the primary means of joining aluminum aircraft structure and a good deal of data exists on the fatigue strength of joints for the alloys used and in the sheet thickness typical of such structures. However, no comparable data exists for marine alloys in the thickness of typical ship structures. The only available data from standard sources such as Eurocode 9 or the Aluminum Design Manual of the Aluminum Association is for butts perpendicular to the direction of stress, and not for seams parallel to the direction of stress.

2.5 To safely design a mechanically fastened seam in the current design environment requires information on the fatigue strength of such a joint. In addition, the design of such a seam as a crack arrestor requires data on the fatigue cycles required to reinitiate a crack on the other side of the riveted seam.

3.0 REQUIREMENTS.

3.1 Scope. (Identify the phases of the project).

3.1.1 The Contractor shall conduct an assessment of current literature and other data available on the fatigue strength of riveted or otherwise mechanically fastened seams in aluminum structure parallel to the direction of loading. The plates joined will be either intact or with a simulated crack across one of the plates that are joined at the seam.

3.1.2 The Contractor shall identify the test specimen sizes and configurations appropriate for the conduct of testing. Identification will also be made of the fixturing required for such testing.

3.1.3 The Contractor shall address the number of test specimens required to adequately define the fatigue strength of the seams with and with a crack in one of the plates that are joined by the seam.

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

3.2.1 The Contractor shall conduct a literature review of the testing for the fatigue strength of riveted or otherwise mechanically fastened seams in aluminum structure parallel to the direction of loading. The plates joined will be either intact or with a simulated crack across one of the plates that are joined at the seam.

3.2.2 The Contractor shall design test specimens for testing the fatigue crack initiation strength of a mechanically fastened seam parallel to the direction of loading in aluminum plates. The design alloys used, joining methods, and number of specimens shall be agreed to prior to testing.

3.2.3 The Contractor shall design the fixturing required for the testing of the specimens.

3.2.4 The Contractor shall procure or manufacture the test specimens and fixtures.

3.2.5 The Contractor shall conduct fatigue testing on the specimens. The goal will have data for at least 1,000,000 cycles, and preferably 10,000,000 cycles for some of the specimens. Testing will be with full reversal of tension and compression. Sufficient tests shall be performed to develop the statistics of the fatigue strength of the seams.

3.2.6 The Contractor shall summarize the test data in appropriate charts and tables and in a manner consistent with the fatigue data of Eurocode 9.

3.2.7 The Contractor shall prepare a final report of the project.

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>. (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 information for approval to the Project Technical Committee and the Ship Structure Committee Executive Director concerning the test materials, test specimen geometry, load fixtures, and intended load levels prior to the beginning of testing.

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 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: $150,000.00

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

8.0 REFERENCES.

8.1 Reference.

9.0 SUGGESTED CONTRACTING STRATEGY.

9.1 Full and open contracting beyond existing government level of effort contracts should be used for this project to ensure the participation of fracture experts that are not part of the usual teams bidding of government level of effort contracts.

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)

11-03 Challenges to be faced by the Arctic ships

Submitted by: Dr. Sreekanta (**Sree**) Das [The University of Windsor, Canada]

1.0 OBJECTIVE.

1.1 The proposed project is a scoping study, aimed at identifying questions concerning the challenges with regard to the structural safety and integrity of ships navigating in the Arctic Ocean. A detailed literature review will be undertaken in this work to recommend future research required to ensure structural safety and integrity of ships operating in the Arctic.

2.0 BACKGROUND.

2.1 The economy of Canada and the USA largely depends on their imports and exports; the majority of which is transported by ships. Hence, the performance and safety of ships are important for their overall economy. These ships are subjected to various structural loads including fatigue loads due to the wave actions and may also experience impact loads due to collision with ice and other objects in addition to service loads that come from self weight of the ship and the weight of personnel and goods that they carry. In addition, these ships may endure cold weather if they travel in the northern Atlantic and Pacific Oceans and in the Arctic Ocean. Climate change is making the parts of the Arctic Ocean navigable for longer shipping seasons. Therefore, now-a-days, more commercial cargo ships navigate Arctic waters and also, a small number of pleasure craft voyages in the summer. It is expected that more commercial ships, pleasure craft, and coastal patrol vessels will be navigating through the Northwest Passage and for much longer periods in near future. As a result, an obvious question comes in our mind "what are the challenges that will be faced by the ships which will be sailing through the Northwest Passage of the Arctic Ocean?" For example, one of the many dangers faced by Arctic ships in the Northwest Passage will be drifting heavy ice released by the breakup among the Arctic islands. There could be many other unknown and known threats and challenges that the Arctic ships need to face. Therefore, this project is proposed for a scoping study, aimed at identifying various challenges and issues with regard to structural behavior that need to be faced by the ships while navigating in the Arctic Ocean.

2.2 The ice in the Arctic region is melting at an alarming rate due to the global warming. As a result, the Northwest Passage in the Arctic Ocean, which connects the Atlantic and Pacific Oceans through the Canadian Arctic Archipelago, provides a shorter shipping route between Europe and Asia and is becoming more viable and imminent for the shipping industry. The Arctic pack ice prevents regular marine shipping throughout the year, but recent climate change is reducing the pack ice and this Arctic shrinkage is making the waterways more navigable for a much longer season. Some studies show, if ice melting continues at the current speed, by the end of the century, there could be no more summer ice in the Arctic Northwest Passage.

It is anticipated that the ships being exposed to the Arctic cold weather and impact with the ice packs may not behave like the ships that usually travel through much warmer water and in much warmer climates. This project therefore, focuses on identifying critical effects of cold weather and other critical structural issues for a ship exposed to Arctic water and climate.

3.0 REQUIREMENTS.

3.1 Scope.

3.1.1 The Contractor shall conduct an extensive review of literature and current standards relevant to the objective of the study, and

3.1.2 The Contractor shall submit the written report on the literature review and identify the critical areas of concern for the ships navigating through the Arctic Ocean.

3.2 Tasks.

3.2.1 The Contractor shall conduct a literature review as mentioned in the Scope, and

3.2.2 The Contractor shall indentify the critical researches that need to be undertaken to ensure safe performance and structural integrity of the Arctic ships.

3.3 Project Timeline. The study will take 12 months from date of award of the work.

4.0 GOVERNMENT FURNISHED INFORMATION.

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

5.0 DELIVERY REQUIREMENTS.

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 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. Cost includes salary of one Graduate (Master's) student for 12 months, expenses for consumables, and computing aids. The University of Windsor will provide faculty and other support as in-kind contribution. The cost estimate includes the overhead costs charged by the University of Windsor.

7.1 Project Duration: 12 months.

7.2 Total Estimate: $ 25,000 (Canadian)

7.3 Cost Estimate Breakup:

1. Salary of on graduate student for 12 months = $15,000
2. Consumables such as papers, literature loans/purchases etc. = $3,000
3. Computer, Software, and Documentation = $5,000
4. University of Windsor overhead cost = $2,000

Total = Can $25,000

8.0 REFERENCES.

8.1 CBC News in Depth (2006). In Depth Northwest Passages: The Arctic Grail. Web: http://www.cbc.ca/news/background/northwest-passage/ . Updated on 27 October 2006. Viewed on 10 December 2008.

8.2 Wikipedia (2008). Northwest Passage. Web: http://en.wikipedia.org/wiki/Northwest_Passage. Viewed on 9 December 2008.

8.3 CBC News in Depth (2008). 1st Commercial Ship Sails through Northwest Passage. Web: http://www.cbc.ca/canada/north/story/2008/11/28/nwest-vessel.html?ref=rss. Updated on 1 December 2008. Viewed on 8 December 2008.

8.4 Canwest News Service (2008). Northwest Passage Navigable, says Federal Ice Authority. Web: http://www.canada.com/topics/news/national/story.html?id=66e11c80-9593-4ea2-a1e5-10afcbc87d7d. Updated on 13 August 2008. Viewed on 10 December 2008.

9.0 SUGGESTED CONTRACTING STRATEGY.

9.1 The project will be executed by a Graduate (Master’s) student under the supervision of the applicant. The graduate student will work on this project as the student’s master’s thesis. Thus, the SSC funding will be the major source of support for the proposed work.

11-04 Effect of Cold Temperature and Fatigue Load Cycles on Ship Hull Steel

Submitted by: Dr. Sreekanta (**Sree**) Das [The University of Windsor, Canada]

1.0 OBJECTIVE.

1.1 Numerous studies were undertaken to evaluate the integrity of aged ship structures considering fatigue as one failure criterion and strength (ultimate load carrying capacity) as the other failure criterion. However, ship hull experiences both fatigue and ultimate loads during its service. Several researchers have expressed serious concerns on the detrimental effect of the fatigue load cycles on the mechanical properties such as yield and ultimate strength, modulus of elasticity, and ductility of ship hull steel. The presence of very cold temperature may even worsen this effect. Therefore, this study will be undertaken to understand the combined effect of fatigue load cycles and cold temperature on the mechanical properties of ship hull steel.

2.0 BACKGROUND.

2.1 A ship in service, experiences continuous fatigue load cycles in addition to service loads and residual and other locked-in stresses. Thus, fatigue damages accumulate over the service life of the ship and the ship hull is expected to loose its structural integrity and fail in fracture when the fatigue life of the ship hull is reached. Thus, the fatigue life and fatigue failure is one of the major design considerations for the ship structures.

Ship structure is also designed for its ultimate strengths to ensure that the failure of ship hull does not occur due to application of ultimate loads such as one from slamming effect or impact with an iceberg, rock, and landing dock. However, the strength design is undertaken assuming the ship hull material is virgin and thus, no consideration is made to account the damages due to fatigue that can accumulate during its service. In reality, a ship hull in service for a considerable period of time will have accumulated damage due to fatigue load cycles and this damage is expected to alter the mechanical properties of ship hull material. The change in mechanical properties due to accumulated fatigue damage may be detrimental and if that is proven to be true then the current design practice of ship hull structure assuming the material is virgin will be subjected to review.

The ice in the Arctic region is melting at a rate much faster than ever due to the global warming. As a result, the Northwest Passages in the Arctic Ocean which connects the Atlantic and Pacific Oceans through the Canadian Arctic Archipelago and provides a shorter shipping route between Europe and Asia is becoming more viable and imminent for the shipping industry. It is expected that more commercial ships, pleasure crafts, and coastal patrolling vessels will be navigating through the Northwest Passages and for much longer period in the near future. As a result, these vessels will also experience Arctic cold weather for much longer period of time. It is anticipated that the Arctic cold temperature will only act as a catalyst for the speculated damaging interaction between fatigue damage and mechanical properties of ship hull steel. Therefore, this project is proposed for a detailed experimental and possibly numerical study to determine the combined effect of Arctic cold temperature and fatigue damage on the mechanical properties of ship hull steel material.

2.2 The project idea has arisen from a number of recent developments and activities. The area of aging processes in ships is a complex subject that deserves increased attentions. The Northwest Passages are becoming more viable and imminent for the shipping industry. The coming area of challenge and scientific development will be the area of interacting among various loads, extreme weather, and response effects. Aging involves several of these interacting effects such as corrosion, fatigue, and plastic deformations. Navigation of vessels through the Northwest Passages requires interactions of these effects in Arctic cold temperature. In coming years, we will need to tackle these combined effects if we are to come to grips with aging processes in ships especially those will be voyaging in the Arctic Northwest Passages and get a true assessment of safety of these vessels. This project focuses on one of these issues and aims to provide us a key tool for such work. Without the ability to determine the effect of fatigue damages and cold temperature, we will be left with an inaccurate understanding of the behavior of hulls of aged ships which will be navigating through the Northwest Passages.

3.0 REQUIREMENTS.

3.1 Scope.

3.1.1 The Contractor shall conduct an extensive literature review on various fatigue damage models applicable to ship hull structures.

3.1.2 The Contractor shall undertake a detailed test program to determine the effect of fatigue damage and cold temperature on the mechanical properties ship hull steel.

3.1.3 The Contractor shall investigate if a numerical model can be developed to simulate the test behaviors.

3.1.4 The Contractor shall provide recommendations on how to evaluate the effect of fatigue damage and cold temperature on various mechanical properties based on the test data obtained from this study.

3.2 Tasks.

3.2.1 Task 1 - The Contractor shall conduct a literature review of the various damage prediction models that may be applied to ship hull steel subjected to fatigue load cycles and Arctic cold temperature.

3.2.2 Task 2 - The Contractor shall conduct necessary laboratory tests to validate if any available model can be used to predict the effect of cold temperature and fatigue cycles on the mechanical properties of ship hull steel.

3.2.3 Task 3 – The Contractor shall conduct laboratory tests to determine the effect of fatigue damages and cold temperature on mechanical properties of ship hull steel.

3.2.4 Task 4 - The Contractor shall investigate if a numerical model for predicting the test behavior can be developed for future study.

3.2.5 Task 5 - The Contractor shall then provide recommendations on how to evaluate the effect of fatigue damage and cold temperature on various mechanical properties of ship hull steel.

3.3 Project Timeline. The study will take 24 months.

4.0 GOVERNMENT FURNISHED INFORMATION.

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

5.0 DELIVERY REQUIREMENTS.

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 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: 24 months from the date of award.

7.0 **GOVERNMENT ESTIMATE.** These contractor direct costs are based on previous project participation expenses. Estimated costs include salary of one Doctoral Student for 24 months, expenses for consumables, and computing aids. The University of Windsor will provide faculty and laboratory technician support as in-kind contribution. The cost estimate includes the overhead costs, charged by the University of Windsor.

7.1 Project Duration: 24 months.

7.2 Total Estimate: $ 100,000 (Canadian Dollars)

7.3 Cost Estimate Breakup:

5. Salary of a doctoral student for 24 months = $40,000
6. Consumables such as materials, gauges, hydraulic oil = $20,000
7. Equipment such as servo-valve and extensometer = $15,000
8. Computer, upgrade in data acquisition system, and documentation etc. = $15,000
9. Rental cost for an environmental chamber = $5,000
10. University of Windsor overhead cost = $5,000

Total = Can $100,000

8.0 REFERENCES.

8.1 XueKang, G and Torgeir M (2002). Long-term Fatigue Damage of Ship Structures under Nonlinear Wave Loads. Marine Technology, Vol. 39, No. 2, pp. 85-104

8.2 Bily, M. (1993). Cyclic Deformation and Fatigue of Metals. Elsevier, Amsterdam, Germany
8.3 DNV Classification Note 30.7 (2003). Fatigue Assessment of Ship Structures. Det Norske Veritas, Høvik, Norway
8.4 IACS (2006). Common Structural Rules for Bulk Carriers. IACS Limited, London, UK.
8.5 ABS (2008). Rules for Building and Classing Steel Vessels. ABS Publications, Huston, USA
8.6 Petinov, SV (2003). Fatigue Analysis of Ship Structures, Backbone Books, NJ, USA
8.7 Ellyin, F (1997). Fatigue Damage, Crack Growth and Life Prediction. Chapman & Hall, London, UK

9.0 SUGGESTED CONTRACTING STRATEGY.

9.1 The project will be executed by a graduate (doctoral) student under the supervision of the applicant. The graduate student work on this project as the student's doctoral dissertation. Thus, the SSC funding will be the major source of support for the proposed work.

11-05 Changeable-Die System for Cold-Forming of Three Dimensionally-Curved Metal Plates

Submitted by: Prof. J.K. Paik, Pusan National University, Korea

1.0 OBJECTIVE.

1.1 To develop the overall procedure of changeable-die system technology for cold forming of three dimensionally-curved metal plates, consisting of several sub-systems for computer-aided analysis (CAA) and computer-aided manufacturing (CAM)/pressing.

1.2 To develop the CAA sub-system for predicting spring-back characteristics associated with cold forming of target metal plates using elastic-plastic large deflection finite element method analysis.

1.3 To develop the CAM/pressing sub-system which is a changeable forming-die consisting of a set of cylindrical pins at both upper and lower sides together with a pressing frame.

1.4 To make a proto-type forming machine based on the technology noted above, which will be used for validating the applicability of the forming technology to shipyard practices of ship hull plate forming.

2.0 BACKGROUND.

2.1 Hull plates of ships and ship-shaped offshore structures like in thin-walled surfaces of other system structures such as high speed trains and automobiles take geometrically complex and three dimensionally curved forms. Because of geometric complexity of target plate surface together with small quantity, it is not relevant to apply the pressing-die based cold-forming technology for curved plate forming. In this regard, the line heating technology has been typically employed for forming curved steel hull plates in shipyards.

2.2 However, the line heating technology is primarily based on past experience of workmen in terms of expansion and shrinkage of metal plates during heating and cooling, which causes a lot of uncertainties and makes the forming quality control difficult. Also, the line heating process essentially brings dangerous, difficult and dirty environment due to heat, flame and light.

2.3 The changeable-die system has been invented as an innovative technology for cold-forming of geometrically complex plates. Spring-back characteristics of target plates due to three dimensional surface forming are predicted at a number of individual pressing-pin positions by nonlinear finite element method analysis in advance. The cold-forming die consisting of a set of pressing pins is then rearranged for fitting with the target surface of curved plate but taking account of the spring-back characteristics.

2.4 The changeable-die based cold-forming technology shall provide a quality-controllable and cost-effective system together with safer and cleaner work environment.

3.0 REQUIREMENTS.

3.1 Scope. (Identify the phases of the project).

3.1.1 The Contractor shall establish the procedure of changeable-die based cold-forming system for forming three dimensionally curved metal plates. This system shall be applicable for cold-forming of steel and aluminum alloy curved plates

3.1.2 The Contractor shall develop the computer-aided analysis (CAA) system for predicting the spring-back characteristics of target metal plates associated with cold-forming/pressing.

3.1.3 The Contractor shall develop the computer-aided manufacturing (CAM) system which is composed of a set of pressing pins together with pressing frame.

3.1.4 The Contractor shall make a proto-type machine based on the cold-forming technology noted above to validate the applicability of the technology.

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

3.2.1 The Contractor shall establish the forming procedure and its sub-systems which will include computer-aided analysis of spring-back characteristics and pressing pin control of changeable-die.

3.2.2 The Contractor shall develop the computer-aide analysis system for predicting spring-back characteristics at various pressing pin positions of target plate surface, using elastic-plastic large deflection finite element method.

3.2.3 The Contractor shall develop the pressing pin system which can rearrange the die surface by controlling the positions of individual pressing pins.

3.2.4 The Contractor shall make a proto-type machine of the changeable-die based cold forming system for validating the applicability to shipyard practices.

3.3 Project Timeline. See Enclosure A.

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 details of the system design drawing including pressing pins and pressing frame.

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 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: US$ 100,000

8.0 REFERENCES.

8.1 Curved surface forming method of a metal plate, Invented by J.K. Paik, Patent Application No. PCT/KR2007/006350.

8.2 Curved surface forming method of s steel plate for a ship using a multi-point press, Invented by J.K. Paik, Certificate No. of Patent 10-0783417, Korea.

8.3 Curved surface forming method of a metal plate, Invented by J.K. Paik, Patent Application No. 10-2007-0122224, Korea.

Enclosure A Project Timeline

Task	1	2	3	4	5	6	7	8	9	10	11	12
3.2.1	■	■										
3.2.2			■	■								
3.2.3					■	■	■					
3.2.4								■	■	■	■	
Report			■			■			■			■

11-06 Thin/Light Planar Steel Structures Design And Construction Techniques

Submitted by:
GD/NASSCO
2798 East Harbor Drive,
San Diego, CA 92113

1.0 OBJECTIVE.

1.1 The objective of the study is to develop better design and production techniques for accurately and efficiently fabricating thin plate planar steel structures (TPPSS).

2.0 BACKGROUND.

2.1

Accurate and efficient construction of TPPSS is often a challenge for traditional large-ship shipyards. TPPSS are commonly found on ship's bridges, deckhouses, garages, light vehicle decks, small platforms, and equipment foundations; but are often plagued with construction inaccuracies and large deformations that are very difficult and costly to repair. When the same design philosophy, worker skill set, and equipment used to assemble heavy plates are applied to the fabrication of much lighter structures, results are often poor and inconsistent. In order to take control of the TPPSS construction process, new design and construction techniques must be developed.

It is widely assumed that most deformation in TPPSS assemblies is due to welding. Other possible sources include, but are not limited to, the stresses developed in the plates during initial cooling at the steel mill, shop surface preparation and priming (Wheelabrador), and the forceful fitting together of relatively flexible assembly components.

This study will define TPPSS used in shipbuilding based upon the main parameters influencing the accuracy and fairness of the fabricated structure: material properties, material preparation, plate thickness, panel size and aspect ratio, stiffener shape and size, weld size, fitting and welding process. The study will also identify industry trends to expand the use of light gage structures in response to high energy, material and labor costs as well as the potential life cycle savings for the ship owner due to the overall vessel weight reduction. In addition the study will address the negative impact on corrosion as a consequence of thickness reduction, and suggest possible changes in structural design aimed at improving the corrosion resistance of light structures.

2.2 Government and classification societies have developed construction fairness standards based upon material properties and geometry parameters. Unfortunately these standards are often inconsistent to one another; and in the case of thin plates they are very difficult to attain in a typical shipyard environment where designers, fitters, and welders are use to working with much heavier material, less prone to deform during fabrication and welding.

This study will clarify the major parameters influencing the fairness and fabrication deformation of TPPSS, identify the structural requirements of

TPPSS based upon their use, location and connection with the rest of the ship's structure, and will provide guidelines aimed at improving the design and construction of TPPSS.

3.0 <u>REQUIREMENTS</u>.

3.1 **The project will be divided in 5 phases**:

3.1.1 **Discovery:** During this phase the current industry and Class acceptance standards for fairness in TPPSS are compared against the average fairness level currently attainable in the shipyard production environment.

3.1.2 **Analysis:** During this phase TPPSS a typical configuration is analyzed to understand how different parameters can influence strength and deformation resistance. This phase will also identify the strength requirements of thin plate structures as they are commonly used in the construction of large vessels

3.1.3 **Benchmarking**: During this phase the project will identify design and production techniques as well as state of the art equipment used by the industry to improve the accuracy and fairness of TPPSS.

3.1.4 **Prototyping and testing:** During this phase one TPPSS of a configuration optimized for low distortion and producibility based on the analysis will be fabricated and welded. Strength and accuracy of finished products is measured and compared against the FEA.

3.1.5 **Conclusion and recommendations:** During this phase the results of the study, together with study conclusion and recommendations are compiled in a final report

3.2 **Tasks**:

3.2.1 NASSCO will review Class regulations, government standards, and industry standards as well as academia and commercial literature pertaining to fairness and fabrication distortion avoidance of TPPSS. NASSCO will consult with Regulatory Body inspectors and shipyard production personnel to assess the qualitative and quantitative discrepancy between expected accuracy levels of TPPSS.

3.2.2 NASSCO will develop a baseline electronic model of TPPSS then perform FEA to assess strength and deflection characteristics of the un-deformed structure under load. The models will be modified to mimic typical weld distortion and assess the relative strength. Panel geometry will be iteratively optimized to reduce weight and load carrying/deflection resistance characteristics.

3.2.3 NASSCO will review design and construction techniques successfully used in the steel fabrication industry worldwide to fabricate TPPSS. Examples include, but are not limited to, shipyards specialized in the construction of cruise ships, car carriers, and mega yachts, as well as large metal building fabricators. At least three shipyards will be benchmarked plus other metal construction facilities.

3.2.4 NASSCO will develop and fabricate a prototype TPPSS, about 3000 mm x 4000 mm in size based on the enhancement result from 3.2.2 and 3.2.3. The prototype will include one or more plate joints. Construction deformation of the un-loaded prototype will be measured and recorded. NASSCO will then perform load carrying capacity tests on the prototype, measuring and recording the deformation under distributed load and point loads in different (worst case) locations. Loads will be progressively increased up to the calculated yield strength of the structure. The purpose of the load test is to show correlation between prototype and analytical results.

3.2.5 NASSCO will collect data developed during the study and prepare a comprehensive final report to show recommended changes in the design and fabrication techniques of TPPSS. The report will include a target deformation tolerance table based upon geometry parameters assuming 0% strength reduction due to deformation.

3.3 **Project Timeline**:
The project will start approximately two weeks after contract award and last approximately one year. It is expected that the discovery and analysis phase will be partially concurrent and will last approximately two months Benchmarking will take approximately three months of non continuous traveling time. Prototyping and testing will last about six months to accommodate construction schedule. Conclusion and recommendation phase will consume the remainder of the allocated time.

4.0 GOVERNMENT FURNISHED INFORMATION.

4.1 None.

5.0 DELIVERY REQUIREMENTS

5.1 NASSCO will provide quarterly progress reports to the Project Technical Committee, the Ship Structure Committee Executive Director, and the Contract Specialist.

5.2 As a result of the study NASSCO will provide:

1) List of fairness standards high-lighting the difference between acceptance criteria.
2) Electronic models of TPPSS and analysis results.
3) TPPSS prototypes design, fabrication records, fairness measurements, load test procedure and deflection results.
4) TPPSS Target Deformation Tolerance Table

5.3 NASSCO will provide a print ready master final report and an electronic copy, including the above deliverables, formatted as per the SSC Report Style Manual. The final report will include all study findings as well as recommendations for improving the construction efficiency and the accuracy of TPPSS in the shipyard environment.

6.0 PERIOD OF PERFORMANCE.

6.1 Project Initiation Date: Start of fiscal 2011.

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

7.0 **COST ESTIMATE.**

7.1 Project Duration: 12 months.

7.2 Total Estimate: $99,666

7.3 The Independent Government Cost Estimate is not attached to this document.

8.0 REFERENCES.

8.1 None

9.0 SUGGESTED CONTRACTING STRATEGY.

9.1 Fixed price with quarterly progress payments. Cost not to exceed the value given in 7.2: final scope to be determined upon award and acceptance of contract terms and conditions.

9.2 All data provided will be “dual use” in nature and not restricted by ITAR requirements.

9.3 This proposal is subject to the negotiation of satisfactory terms and conditions.

11-07 Large Scale Crashworthiness Testing of Closed Structures to Derive a Weld Failure Criteria for Conventional and Laser Welding

Submitted by:
Petri Varsta
Helsinki University of Technology (TKK), Marine Technology
(02015 TKK, Finland, Phone: +358 9 451 3501, email: petri.varsta@tkk.fi)

1.0 OBJECTIVE.

1.1 This project will derive a weld failure criteria, both for conventional and laser welding, applicable for numerical deformation analysis, such as crashworthiness analysis.

2.0 BACKGROUND.

2.1 Commonly the behavior of the welds are not considered in the finite element based crashworthiness analysis of ship structures. More over the present plate failure criteria are not resulting in satisfactory results for all stress states, see Ehlers et al. Therefore an accurate weld failure model shall be derived and validated, which will also improve the general plate failure criteria. TKK is currently investigating the ultimate strength behavior of welds in small scale .

2.2 Justification for this project arises from the fact that the safety requirements of ship structures are increasing. Whereby the prediction of the structural integrity at a collision or grounding event becomes important. In other words, the knowledge of the size of the hole after the collision or grounding event will allow to evaluate the oil outflow (environmental pollution) or the water inflow (progressive flooding) more accurately.

3.0 REQUIREMENTS.

3.1 Scope.

3.1.1 The Contractor shall conduct an assessment of the currently available failure criteria for numerical analysis and identify the most potential approach applicable for weld failure.

3.1.2 The Contractor shall identify the new approach to be used for the weld failure criterion.

3.1.3 The Contractor shall address the potential modifications or new approaches for weld failure criterion and their parameters to be validated through experimental testing.

3.2 Tasks.

3.2.1 The Contractor shall identify the weld failure criterion parameters to be validated by experimental large scale testing of a closed structure.

3.2.2 The Contractor shall carry out the experimental study and provide the parameters for the criterion and derive the weld failure criterion.

3.3 Project Timeline. 4 Months to identify the weld failure criterion and the required parameters, 4 Months to carry out the experimental investigation to validate these parameters and 4 Months to derive the final criterion and to prepare the journal paper.

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 one significant journal paper describing the experimental findings, the weld failure criterion and its application to crashworthiness analysis of ship structures.

5.3 The Contractor shall provide a print ready master final report and an electronic copy, including the above deliverables, experimental information in numerical format, 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: $200000 ($150000 for labor cost for one project advisor, 1 FE and failure criteria analyst, and $50000 for experiments including measuring equipment and technicians labor cost)

Note: The detailed description in the form advised by SSC will be submitted upon project acceptance.

8.0 <u>REFERENCES</u>.

8.1 Reference.

Ehlers S, Broekhuijsen J, Alsos HS, Biehl F, Tabri K. Simulating the collision response of ship side structures: A failure criteria benchmark study. Int Ship Progress 2008;55:127-144.

9.0 <u>Facilities Requirements</u>.

9.1 The large scale testing for crashworthiness of the enclosed structure will require a laboratory with force cylinder of at least 1 MN.

11-08 Fatigue Crack Growth in Aluminum Structures under Ship Fatigue Loading Spectra

Submitted by: Robert A. Sielski

1.0 OBJECTIVE.

1.1 This project will develop a means of predicting fatigue crack growth for aluminum ship structures

2.0 BACKGROUND.

2.1 Aluminum ship structures are particularly susceptible to failure because of the relatively high rate of fatigue crack growth in aluminum. Assessment of the service time required before a crack will grow to a critical size that could cause hull girder failure is done through crack growth analysis using the range in the stress intensity factor (K) as a variable. Data relating the crack growth per fatigue loading cycle (da/dN) to K for aluminum alloys was provided by the recent Ship Structure Committee report SSC-448, Fracture Mechanics Characterization of Aluminum Alloys for Marine Structural Applications.

2.2 During a typical fatigue loading cycle on ship structure, the stress at the crack tip changes from tension to compression. During the time of compressive stress, and for part of the tension portion of the loading cycle, the stress intensity is less than the value needed to open the crack tip, K_{OP}, no crack growth occurs because of the effects of crack closure. Crack closure is accounted for during fatigue testing, such as that for SSC-448 by methods that determine K_{OP} by measuring the crack opening displacement during a loading cycle and observing nonlinearities in the load vs. crack opening displacement curve. With an estimate of K_{OP} so determined, the effective range of the stress intensity factor, $K_{effective}$, is determined. The plots of da/d/N vs. DK that are provided in sources such as SSC-448 are actually functions of $K_{effictive}$.

2.3 Predicting crack growth in actual ship structures requires a means of estimating the value of K_{OP} in order to determine $K_{effictive}$. The problem is difficult because in addition to full stress reversal happening during loading, the actual loading sequence is random in nature. In order to develop a method for estimating K_{OP} for fatigue crack growth calculations in aluminum ship structures an experimental program must be carried out. Such a program was conducted for steel tanker structures (Tomita et al., 2002) but no such experimentation has been performed for aluminum ships and craft.

2.4 The effects of crack closure can reduce the effective stress intensity factor by one-half or more. Because the da/dN vs. K relationship has an exponent of about 3, the rate of fatigue crack growth can be overly estimated by a factor of 8 or more if no proper account of crack closure is made. This project is needed because while it is important to understand the danger that an aluminum ship may be in from fatigue crack propagation, such calculations must be realistic.

3.0 REQUIREMENTS.

3.1 Scope. (Identify the phases of the project).

3.1.1 The Contractor shall conduct an assessment of available data on fatigue crack propagation of aluminum structures, particularly those under random loading with stress reversal.

3.1.2 The Contractor shall identify the typical fatigue loading spectra for aluminum ships and determine the range of stress intensity factors to which the structure would be subjected during its service life.

3.1.3 The contractor shall develop and conduct a test program for determining the value of K_{OP} during fatigue loading of aluminum ship structures.

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

3.2.1 The Contractor shall conduct a literature search for past efforts to determine fatigue crack growth during random loading with stress reversal.

3.2.2 The Contractor shall develop a typical fatigue loading spectrum for use assessing fatigue crack growth in aluminum structures. This loading should also include an estimate of fatigue crack sizes that will be used in the testing program in order to determine the range of stress intensity factors at the crack tip.

3.2.3 The Contractor shall design an experiment for testing a structure representative of an aluminum ship to determine fatigue crack growth rates during realistic random loading with stress reversal.

3.2.4 The Contractor shall develop a method for estimating the values of K_{OP} and $K_{effective}$ during calculations of fatigue crack growth in aluminum ship structures.

3.2.5 The Contractor shall prepare a report on the project using SSC standards as guidance.

3.3 Project Timeline. 12 months.

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>. (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 information for approval to the Project Technical Committee and the Ship Structure Committee Executive Director concerning the test materials, test specimen geometry, load fixtures, and intended load levels prior to the beginning of testing.

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 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: $150,000.

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

8.0 REFERENCES.

8.1 Tomita, Y., K. Hashimoto, N. Osawa, K. Terai, and Y. Wang. Study on Fatigue Design Load for Ships Based on Crack Growth Analysis, in Fatigue Testing and Analysis Under Variable Amplitude Loading, American Society for Testing and Materials Special Technical Publication STP 1439, 2002.

9.0 SUGGESTED CONTRACTING STRATEGY.

9.1 Full and open contracting beyond existing government level of effort contracts should be used for this project to ensure the participation of fracture experts that are not part of the usual teams bidding of government level of effort contracts.

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)

11-09 Strength and Fatigue Testing of Composite Patches for Ship Plating Fracture Repair

Submitted by: Dale G. Karr[1] and Anthony Waas[2]

[1] Department of Naval Architecture and Marine Engineering, University of Michigan, Ann Arbor, MI

[2] Department of Aerospace Engineering, University of Michigan, Ann Arbor, MI

1.0 OBJECTIVE.

1.1 It is the objective of this research to explore and experimentally validate the use of composite patches for preventing crack growth and extending the lifetime of aluminum and steel ship structures. A composite patch works as a crack arrestor by decreasing the stress in the area of the crack tip. Load is shed from the base plate through an adhesive layer to the composite patch. In addition, the added constraint of the composite patch can prevent these cracks from coalescing into a larger crack. Analytical capabilities exist for predicting the effectiveness of the composite patch configuration, but such analyses demand specific idealizations and assumptions that must be validated experimentally in order for this technology to be used in practice. Our proposed project seeks to develop this technology as a useful and reliable tool for aluminum and steel ship plating fracture repair and to foster its industrial acceptance and implementation.

2.0 BACKGROUND.

2.1 Repeated loading may result in the initiation of cracks in ship structure from fatigue. In particular, repeated loading in areas of stress concentrations leads to fatigue cracks that can grow to critical lengths and result in catastrophic structural failure of components and hull plating. Increased attention to maintenance and corrosion control is therefore particularly important for vessels designed with thinner plating afforded by higher-strength steels. Examples include the hull-structure cracking observed in Trans-Alaska Pipeline Service (TAPS) tankers [1,2,3].

2.2 An important consideration is the determination of critical crack length for a given hull material in order to assess potential for catastrophic failure [4,5]. Once cracking is detected, weld repairs may be conducted and structural modifications may be introduced. These approaches may solve the immediate problem temporarily but too often they move the initiation point for the crack to a new location. A solution is to lower the stress levels caused by load-induced conditions or structural imperfections so that fatigue crack initiation and growth are either prevented entirely or deferred for an acceptable amount of additional service life. The composite patch serves to do just that: reduce the stress intensity level. The reduction in stress intensity reduces substantially the crack growth rate. If it is assumed that microcracks or flaws already exist and the patch is placed in an area of high stress or an area where cracks will likely develop, the composite patch can prevent these cracks from growing or coalescing into larger cracks.

2.3 Composite patches have been proven effective in other industrial applications. In contrast to other repair methods, repairs carried out with composite patches are completed faster, exhibit good fatigue resistance, do not cause stress concentrations, result in low added weight, and are economically attractive [6,7]. In the aerospace community, composite patches are an “effective technique for improving fatigue life and maintaining high structural efficiency” [7,8]. It has been reported that high patch modulus materials attached to an aluminum base plate is a useful technique where surface preparation has enabled the development of adequate adhesive strength [7]. Aircraft components repaired with a composite patch have exhibited an 84% reduction in the stress intensity factor and a 1000% increase in the fatigue life [8]. Composite materials have also been used to rehabilitate steel bridges. Such repairs resulted in a 113% increase in the strength of damaged girders [9].

2.4 As in other industries, general use of composites in the marine industry is on the rise. Limited work in the marine field has been conducted with aluminum vessels [10]. Generally speaking, analytical and numerical studies of adhesively bonded composite patches used as crack arrestors have been investigated for cracked sheets and plates [11-16] and in particular within the context of ship structure repair [17,18]. The previous work by Edwards and Karr [17] and by Bone et al. [18] forms the basis for the proposed project. This project will extend the previous work to include steel plating and to include testing the composite patches under fatigue conditions [19-24].

2.5 In the previous project by the investigators, 1/6th inch and 1/8th inch thick aluminum plates were used as base plates. The tests were conducted using 7075-T6 aluminum with both glass and graphite patches. Both pre-impregnated and wet lay-up processes were tested for comparison. Additionally, both single and double-sided patches were tested. The aluminum specimens were 12 by 12 inch plates with 2-inch edge cracks. For each test, the crack itself was first machined to a chevron or V-style notch and then fatigued until an initial crack was evident. After this, 4 by 4 inch unidirectional fiber composite patches were placed over the cracked area. The specimens were then tested by applying monotonically increasing load. With just one layer of glass fibers on a 1/8-inch thick plate, the maximum tensile load increases by almost 40%. Putting a layer of carbon fiber patch on both sides of the crack improves the maximum tensile load by almost 55%. These average results were achieved using only a small 1.5 hp vacuum pump for 8 hours, and a room temperature cure of 2 weeks. The primary mode of failure for the test specimens was delamination. Effects of various adhesive systems and additional layers of composite patching were studied. A summary of the load capacity for some 1/16th plates is shown below. The arrow on the upper level test data points indicate that the plates failed by overall yielding rather than composite delamination. The plate was restored to 100% of its pre-cracked capacity, a nearly three-fold increase in static strength. These experiments provide a good basis for further systematic testing for steel plates and fatigue testing.

2.6 Of course elimination of all potential crack initiation sites or conditions in ship structures is not practical, and some dependence on other approaches must be available to preclude catastrophic failure. Major concerns are and will continue to be fitness for service during operation, where the effect of minor cracking is assessed; and life-extension considerations, where the effect of severe structural damage is assessed. When cracking of ship structure occurs during service, decisions must be made about repairs.

Depending on circumstances, immediate repairs may or may not be necessary. Cracks that are load induced must be repaired or an alternative load path provided. Composite patch repairs may be completed rapidly, may exhibit vastly improved fatigue resistance, reduce rather than increase stress concentrations, have lower added weight than metal doublers, and are very cost effective. Thus these composite repairs have the potential as an efficient, economical, and expedient way to extend time between major structural repairs. Our previous studies indicate great promise for this approach in that static strengths of cracked metal plating can be substantially increased. However, such repairs for ship structure must also retain their integrity under repeated loading conditions, hence the need for verification in a fatigue-testing program.

3.0 REQUIREMENTS.

3.1 Scope.

3.1.1 The Contractor shall conduct an assessment of candidate adhesive systems for glass and carbon fiber composite patches to steel plating.

3.1.2 The Contractor shall identify the optimum composite adhesive systems for both aluminum and steel plating.

3.1.3 The Contractor shall design and conduct static strength tests of these systems to supplement existing findings for aluminum plating.

3.1.4 The Contractor shall conduct fatigue tests of the selected designs for composite patching of pre-cracked plates.

3.2 Tasks and Timeline. The project consists of two major complementary components: the numerical analyses and the experiments plus our documentation efforts. The major tasks are as follows, with milestone completion and estimated work hours. The work hours are combinations of the Investigators and student based on a total of 500 hours for student work and 250 hours faculty. Portions of Professor Waas' hours are included as Laboratory director and not charged to proposed project. Portions of Professor Karr's hours are included in thesis supervision and not charged to the project.

3.2.1 The Contractor shall develop Finite Element Analyses for the steel plate systems to supplement the existing analyses of aluminum plates. Completion: 4 mo. from start date. (50 hours).

3.2.2 The Contractor shall analyze, using the Finite Element Software, the aluminum and steel systems to predict crack growth and plate/patch failure. Completion: 6 mo. from start date. (50 hours).

3.2.3 The Contractor shall design candidate crack/plate/patch systems for testing. Completion: 9 mo. from start date. (100 hours).

3.2.4 The Contractor shall develop experimental arrangement for the strength tests. The experiments will be conducted at the University of Michigan's Composite Structures Laboratory (Section **9**). Fixtures, such as that shown in Figure 2 below and used in previous projects, will be designed and constructed. Completion: 12 mo. from start date. (100 hours).

3.2.5 The Contractor shall develop experimental arrangement for the fatigue tests. Completion: 12 mo. from start date. (100 hours).

3.2.6 The Contractor shall perform strength and fatigue tests for the developed system designs. Completion: 22 mo. from start date. (250 hours).

3.2.7 The Contractor shall develop and deliver documentation of progress and final results. Completion: 24 mo. from start date. (100 hours).

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 a Preliminary Report on the Finite Element Analyses, Initial Static Tests, and Fatigue Life Predictions of the proposed fatigue tests, within 14 months of start date.

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 PERIOD OF PERFORMANCE.

6.1 Project Initiation Date: date of award.
6.2 Project Completion Date: 18 months from the date of award.

7.0 TIME, COST and MAN-HOUR ESTIMATE. These contractor direct costs are based on previous project participation expenses. Costs include one Graduate Student Research Assistant and faculty support for the project, and $20,000 (as cost sharing with the University) for purchases of fatigue testing equipment and supplies.

7.1 Project Duration: 18 months.
7.2 Project Man-hours: 750.
7.3 Total Estimate: $100,000.

8.0 REFERENCES.

1. U.S. Coast Guard Navigation and Vessel Inspection Circular No. 15-91, CH-1.
2. Sucharski, D. "Owner and Operators Viewpoint crude Oil Tanker Hull Structure Fracturing: An Owner's Perspective" In *Prevention of Fracture in Ship Structure*, Committee on Marine Structures, Marine Board, National Research Council, pp 87-124, 1997.
3. Report on the Trans-Alaska Pipeline Service (TAPS) Tanker Structural Failure Study, Office of Marine Study, Security and Environmental Protection, United States Coast Guard, June 25,1990.
4. Francis, PH, Lankford, J Jr., Lyle, FF Jr., "A Study of Subcritical Crack Growth in Steel Ships," *Ship Structure Committee Report No. 251*, 1975.
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10. Allan, RC, Bird, J and Clarke, JD, "Overview: Use of Adhesives in Repair of Cracks in Ship Structures," *Materials Science and Technology*, Vol. 4, No. 10, Oct 1988, pp. 853-859.
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12. Belhouari M, Serier B, Bouiadjra BB. Computation of the stress intensity factors for repaired cracks with bonded composite patch in mode I and mixed mode. Composite Structures, v 56, n 4, June, 2002, p 401-406.
13. Rastogi N, Soni SR, Denney JJ. Analysis of bonded composite patch repaired metallic structures: An overview. Collection of Technical Papers - AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics & Materials Conference, v 2, 1998, AIAA-98-1883, p 1578-1588.
14. Tsamasphyros GJ, Kanerakis GN, Karalekas D, Rapti D, Gdoutos EE, Zacharopoulos D, Marioli-Raga ZP. Study of composite patch repair by analytical and numerical methods. Fatigue and Fracture of Engineering Materials and Structures, v 24, n 10, October, 2001, p 631-636.
15. Qin M, Dzenis YA. Analysis of single lap adhesive composite joints with delaminated adherends. Composites Part B: Engineering, v 34, n 2, March, 2003, p 167-173.

16. Chung KH, Yang, WH, Cho MR. Fracture mechanics analysis of cracked plate repaired by composite patch. Key Engineering Materials, v 183 (I), 2000, p 43-48.

17. Edwards, M. and Karr, DG "Analysis of Composite Patches for Ship Plating Fracture Repair," *Ship Technology Research/Shiffstechnik*, Vol. 46, No. 4, pp. 231-237, 1999. 18. Bone, J. "Testing of Composite Patches for Ship Plating Fracture Repair," 2003, M.S. Thesis, University of Michigan. Also presented at the SNAME Annual Meeting, October, 2003, San Fransisco, CA.
19. Rao VV, Singh R, Malhotra SK. Residual strength and fatigue life assessment of composite patch repaired specimens. Composites Part B:Engineering, v 30, n 6, 1999, p 621-627.
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9.0 <u>FACILITIES REQUIRED</u>

9.1 Existing office space, computer equipment, state of the art software packages and laboratory facilities will used throughout the project duration at no charge to the project. The experiments will conducted at the University of Michigan Composite Structures Laboratory. The Composite Structures Laboratory was established in 1988 by the Department of Aerospace Engineering. Its activities involve research and training of graduate and undergraduate students in the Static and Dynamic Behavior of Structures made of advanced composite materials. During the last decade, the NASA Langley Research Center, the Office of Naval Research, the Air Force Office of Scientific Research, the Army Research Office, the Department of Energy, the National Science Foundation, and the Ship Structures Committee have funded research projects. In addition, funds have also been received from various industries, most notably the big three automakers and their allied industrial partners, the Automotive Composites Consortium. Most activities of the laboratory are conducted in the FXB Aerospace Building and spans several laboratory rooms designed for different types of experiments. Collectively, these rooms cover an area of approximately 2300 square feet.

9.2 Several servo hydraulic testing frames are available for mechanical characterization of composite structures. These include a large capacity (100k lbf. force-50k inch.lbf. torque) MTS tension-torsion combined loading test frame, a small capacity tension-torsion pneumatically driven test frame(3k lbf capacity), a biaxial planar loading frame (50k lbf capacity), a 10k lbf screw driven Riehle test frame, two miniaturized table top compression-tension loading frames (range from 1 lbf – 50klbf.), a Charpy impact hammer, an instrumented drop tower facility, a 12x6 pneumatically isolated optical table, a Kodak high speed digital camera(1k frames/sec.), and a CORDIN high speed variable framing rate camera(20 frames/microsecond). These loading devices are supplemented by state of the art data acquisition systems and several additional optical devices for interferometric measurements and speckle photographic measurements. The laboratory also has several load cells spanning a broad range of load capacities, displacement measuring mechanical and optical transducers. A well equipped optical and scanning electron micrography laboratory is available for users of the composite structures laboratory. Students training in the laboratory have access to a campus wide network of powerful workstations and personal computers for computational work.

11-10 Inspection Techniques for Marine Composite Construction

Submitted by: Eric Greene Associates, Inc.

1.0 OBJECTIVE.

1.1 An increasing number of marine structures are utilizing composite materials. Major structure and components can be built lighter and corrosion-resistant using composites. Upcoming projects, such as the US Navy's DD(X) Topside Structure and the USCG's Fast Response Cutter are slated to be built with composites. Additionally, the offshore oil industry is starting to build composite risers and habitability modules. Nondestructive Evaluation (NDE) techniques developed for aerospace structures are not viable for large marine structures. A state-of-the-art assessment of available NDE techniques for marine composite structures is required.

2.0 BACKGROUND.

2.1 Building large marine structures using composite materials for specialized applications is one of the few remaining areas of shipbuilding where the United States has remained competitive. The demand for speed and reduced manning should continue the trend towards advanced-material construction. Our analytical techniques and fabrication processes now allow us to undertake structures of ever-increasing size. What has not kept pace with marine composite technology is the ability to inspect large composite structures and assess structural integrity.

In 1990, Yoseph Bar-Cohen authored a report for the USCG R & D Center [8.1] This excellent report surveyed various NDE techniques as applied to composite panels with defects. However, Dr. Bar-Cohen worked for McDonnell Douglas when the report was done and techniques cited are still mostly used by only by the aerospace industry 20 years after his research.

Over the past two decades, the industry has moved towards laminates with higher fiber contents and higher strength materials. [8.2] Also, the industry has more "field" experience with various NDE techniques. FEA techniques have advanced to the point where we can now perform a Flaw Criticality Analysis to help us assess how large a defect is required before a composite structure fails. This helps us answer the question of how small a defect should we be looking for.

2.2 The US Navy has invested millions of dollars to qualify composites for use in topside structures on major surface combatants. Additionally, the Office of Naval Research is funding the design and process trials for a high speed vessel. Many of these prototype efforts never get deployed in the fleet because ship program managers simply do not have confidence in our ability to inspect and repair large composite structures. The US Coast Guard has also resisted composite construction for ship classes such as the 47-foot Motor Lifeboat, although a definite potential exists for lifecycle maintenance cost savings exist. Simply stated by one of the USCG's naval architects: with aluminum, the can easily see and repair cracked welds.

NDE techniques are required for cored composite structures as well as solid laminates. Recent investigations by Strand, et. al. [8.3] looked into reported widespread skin to core delaminations of balsa-cored boats and the resulting affect on structural performance. Destructive analysis (hole saws) are commonly used to verify what’s actually going on inside cored laminates. In order to advance the use of composite construction for military and commercial applications, cost-effective NDE methods need to be established and accepted by the industry.

3.0 REQUIREMENTS.

3.1 Scope

3.1.1 The Contractor shall conduct an assessment of current NDE methods for large, marine composite structures. The assessment shall survey the military, commercial and recreational industries. Sources shall include marine surveyors, manufacturers, platform owners and academia.

Concurrently, a separate assessment of flaw criticality is required to determine the lower limit size of as-built flaws or in-service damage that needs to be detected in order to ensure structural integrity.

3.1.2 The Contractor shall identify the most promising NDE approach that perhaps uses multiple NDE methods for large and small-scale inspection.

3.1.3 The Contractor shall address probability of defect detection as a function of size in the laminate.

3.2 Tasks

3.2.1 The Contractor shall conduct a state-of-the-art review of relevant large-scale composites NDE technology.
3.2.2 The Contractor shall construct laminates with defects of various sizes.
3.2.3 Laminates will be examined using candidate NDE techniques. Process will be videotaped.
3.2.4 The Contractor will provide assessment of Best Practice NDE Method(s) for Large Marine Structures.
3.2.5 A web site to post project results will be developed.
3.2.6 Produce project final report.

3.3 Project Timeline. See Figure 1.

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 project update via a web site titled www.CompositeSurveyor.com. The web site shall also be used as a technology transfer medium upon project completion.
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 PERIOD OF PERFORMANCE.

6.1 Project Initiation Date: October 1, 2006.

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: $99,995.
7.3 A Cost Estimate is contained in Figure 2.

8.0 REFERENCES.

8.1 Yoseph Bar-Cohen, “Nondestructive Evaluation (NDE) of Fiberglass Marine Structures State-of-the-Art Review,” USCG R & D Center, report no. CG-D-02-91.
8.2 Greene, Eric, MARINE COMPOSITES, copyright 2000.
8.3 Strand, Rick & O’Meara, Rich, 03 March 2005 Presentation at NSWCCD Meeting on Impact Testing

9.0 SUGGESTED CONTRACTING STRATEGY.

9.1 Suggested contracting strategy: Sole Source contract to Eric Greene Associates, Inc., Prime Contractor
The US Naval Academy and Structural Composites, Inc. will be utilized as subcontractors to construct and evaluate test laminates.

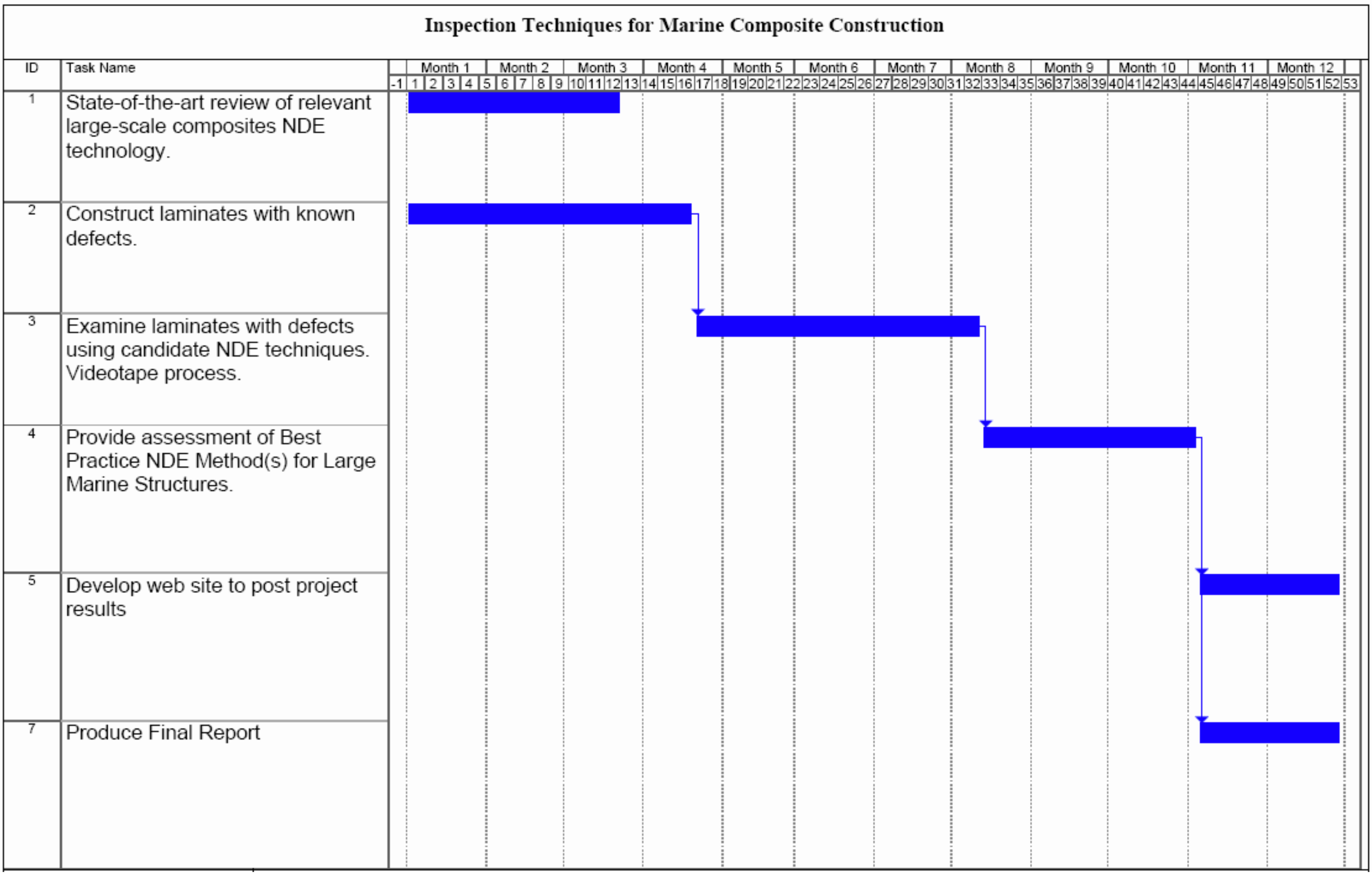

Figure 1. Project Timeline

PROJECT:	Inspection Techniques for Marine Composite Construction	
TASK NUMBER	DESCRIPTION	Task Total $
1	State-of-the-art review of relevant large-scale composites NDE technology.	$15,605
2	Construct laminates with known defects.	$17,512
3	Examine laminates with defects using candidate NDE techniques. Videotape process.	$38,105
4	Provide assessment of Best Practice NDE Method(s) for Large Marine Structures.	$13,655
5	Develop web site to post project results	$7,315
6	Produce Final Report	$7,803
	Project Total:	**$99,995**

LABOR	LABOR HOUR ESTIMATES By Task Sub-elements								
SUB TASKS	1	2	3	4	5	6			TOTALS
Naval Architect	160	160	160	140	75	80			775
									0
TOTAL HOURS	160	160	160	140	75	80			775
COST-unloaded	$ 11,440.00	$ 11,440.00	$ 11,440.00	$ 10,010.00	$ 5,362.50	$ 5,720.00			
Labor OH 23.91%	$ 2,735.30	$ 2,735.30	$ 2,735.30	$ 2,393.39	$ 1,282.17	$ 1,367.65			
G&A 5.00%	$ 572.00	$ 572.00	$ 572.00	$ 500.50	$ 268.13	$ 286.00			
Fee 7.50%	$ 858.00	$ 858.00	$ 858.00	$ 750.75	$ 402.19	$ 429.00			
Total Labor Cost	$ 15,605.30	$ 15,605.30	$ 15,605.30	$ 13,654.64	$ 7,314.99	$ 7,802.65			$ 75,588.19
	MATERIAL COST ESTIMATES By Task Sub-elements								
TASK NUMBER	1	2	3	4	5	6			TOTALS
Composite Material		$1,000.00							$1,000.00
									$0.00
									$0.00
									$0.00
									$0.00
MATERIAL TOTAL	$0.00	$1,000.00	$0.00	$0.00	$0.00	$0.00			$1,000.00
G&A 5.00%	$0.00	$50.00	$0.00	$0.00	$0.00	$0.00			$50.00
Fee 7.50%	$0.00	$75.00	$0.00	$0.00	$0.00	$0.00			$75.00
Total Material Cost	$0.00	$1,125.00	$0.00	$0.00	$0.00	$0.00			$ 1,125.00
	FABRICATION COST ESTIMATE By Sub-Task-elements								
TASK NUMBER	1	2	3	4	5	6			TOTALS
Structural Composites		$15,000.00							$15,000.00
									$0.00
									$0.00
									$0.00
									$0.00
EQUIPMENT TOTAL	$0.00	$15,000.00	$0.00	$0.00	$0.00	$0.00			$15,000.00
G&A 5.00%	$0.00	$750.00	$0.00	$0.00	$0.00	$0.00			$750.00
Fee 7.50%	$0.00	$1,125.00	$0.00	$0.00	$0.00	$0.00			$1,125.00
Total Equipment Cost									
	TRAVEL COST ESTIMATES By Task Sub-elements								
TASK NUMBER	1	2	3	4	5	6			TOTALS
LOCATION		Melbourne, FL							
AIRFARE		$500.00							$500.00
LODGING		$120.00							$120.00
MEALS		$75.00							$75.00
ODC									$0.00
TRAVEL TOTAL	$0.00	$695.00	$0.00	$0.00	$0.00	$0.00			$695.00
G&A 5.00%	$0.00	$34.75	$0.00	$0.00	$0.00	$0.00			$34.75
Fee 7.50%	$0.00	$52.13	$0.00	$0.00	$0.00	$0.00			$52.13
Total Travel Cost	$0.00	$781.88	$0.00	$0.00	$0.00	$0.00			$781.88
	TESTING SERVICES COST ESTIMATE By Task Sub-elements								
TASK NUMBER	1	2	3	4	5	6			TOTALS
USNA			$20,000.00						$20,000.00
									$0.00
									$0.00
									$0.00
									$0.00
									$0.00
									$0.00
TESTING TOTAL	$ -	$ -	$ 20,000.00	$ -	$ -	$ -			$ 20,000.00
G&A 5.00%	$0.00	$0.00	$1,000.00	$0.00	$0.00	$0.00			$24,782.00
Fee 7.50%	$0.00	$0.00	$1,500.00	$0.00	$0.00	$0.00			$26,640.65
Total Testing Cost	$0.00	$0.00	$22,500.00	$0.00	$0.00	$0.00			$ 22,500.00
TASK TOTALS	$ 15,605.30	$ 17,512.18	$ 38,105.30	$ 13,654.64	$ 7,314.99	$ 7,802.65			$ 99,995.07

Figure 2. Cost Estimate

11-11 Mean Stress Assessment in Fatigue Analysis and Design

Submitted by:
Stig Berge,
Marine Technology, Norwegian University of Science and Technology
(NO 7491 Trondheim, Norway. Fax +47 73595528 E-mail: stig.berge@ntnu.no)

and S.Petinov,
Strength of Materials, St.Petersburg State Polytechnic University
(Polytechnicheskaya St. 29, 195251 St.Petersburg, Russia
Phone: 7-812-552-6303 E-mail: Petinov@SP5198.spb.edu)

1.0 OBJECTIVE

1.1 The mean stress is an important component of loading history and fatigue of ship hull structural details. When tensile, it increases maximum stress in the load cycle and reduces fatigue life of structural components. The lack of commonality between different approaches makes it necessary to validate the models, and to harmonize the codes.

1.2 However, in case of combination of random and constant loading components the appropriate methodology of assessing effects of mean stress is lacking.

1.3 The objective of the project is to review the available data on the subject, to plan and carry out experiments on a structural steel, to analyze the results and to develop methodology of assessment of the mean stress effects in fatigue analyses for marine applications.

2.0 BACKGROUND

2.1 The design codes of hull and marine welded structures recently mostly neglected influence of mean stress on fatigue performance of critical details. A survey carried out in 2003 by ISSC reported that 6 out of 8 major classification societies used a mean stress correction factor. In the recently adopted Common Structural Rules for Tankers and Bulk Carriers (IACS, 2005) mean stress corrections are implemented, albeit in a very different form for tankers and bulk carriers respectively. Procedure of considering it suggested recently in IACS documents in the form of introducing an equivalent stress, which allows to take into account residual welding stress and mean stress due SW loading condition.

2.2 However, application of corrections and of equivalent stress may be regarded only as an approximation since it is based on implied assumption of combined cyclic stress with constant amplitude and mean stress.

2.3 Specific property of load sequences in marine applications is the combination of a narrow-banded random wave loading and of slowly varying (or constant) loading regarded the source of mean stress. This means that the implied experimental procedure and respective modeling of fatigue behavior of material should consider the effects of mean stress in conjunction with realistic variable amplitude loading. This would reveal specific properties of cyclic strain hardening or softening of particular material and the nature of the damage. Such approach to fatigue analysis of materials and structures would allow to physically and quantitative more precisely assess fatigue properties of hull structural components.

2.4 An important component of stress field in a ship structure is residual welding stress. Typically, areas of residual stress are superimposed with the stress concentration due to geometry of structural details. Occasional relatively high wave loads may cause part relief (shakedown) of residual stress in stress concentrations with resulting effect on the local load ratio and on fatigue resistance. These effects should be assessed based on the present knowledge and experimental program, feasible within the frames of the time and cost of the project. Respective recommendations should be developed.

2.5 These are the reasons for development of a procedure of fatigue analysis and design of structural components considering effects of mean stress.

3.0 REQUIREMENTS (Performing the following tasks)

3.1 Task 1: Literature survey

(1) Literature review of relevant available experimental data on the mean stress and residual stress effects related to the crack initiation phase of fatigue of structural steels and structural details.

3.2 Task 2: Construction of Test Equipment and Manufacturing of Specimens

(1) Construction and manufacturing of test equipment (grips providing precise axial loading, transducers for strain measurements and records)

(2) Manufacturing of steel specimens (a low carbon mild structural steel is assumed appropriate material)

(3) Development of software for test sequences aimed at providing parametric tests at variable standard deviation of the oscillating load component and mean load (a Gaussian correlated process with Raleigh load range distribution should be modeled)

3.3 Task 3: Experimental Procedure

(1) Tensile testing of selected material to characterize mechanical properties.

(2) Cyclic testing of hourglass specimens under strain-control conditions aimed at evaluation of the material fatigue failure criterion

(3) Cyclic testing of specimens at block-program loading sequences comprising constant-load component with varied parameters under strain-control conditions

(4) Cyclic testing of plate specimens with a stress concentration at block-program loading sequences comprising constant-load component with varied parameters

(5) Combined random-load plus constant load testing with varied parameters of specimens under strain-control conditions

(6) Fatigue testing of specimens at combined random-load plus constant load sequences in the range of fatigue lives where intelligible inelastic strain might be recorded and analyzed. The tests will be aimed at evaluation of appropriate criterion for material failure.

(7) Fatigue testing of welded specimens that contain large welding residual stresses, for investigation of:
Shake-down of residual stresses due to load cycles simulating extreme load cases for a hull structure
Fatigue strength (SN curve) for welded joints that have been subjected to shake-down, and for load histories with tensile, zero and compressive mean stress.

3.4 Task 4: Analysis of test results and development of appropriate fatigue model

(1) Analysis of constant strain-range and block-program loading tests results should be performed aimed at evaluation of similitude of inelastic material response. A preliminary fatigue model of material should be developed.

(2) Analysis of combined random-load plus constant load tests results aimed at validation check of the preliminary material model efficiency. Adjustment of the preliminary material model.

(3) Analysis of block-program loading tests results of specimens with stress concentration aimed at evaluation of similitude of inelastic material response in stress concentration. FE re-analysis of tests results. Validation of the material model.

(4) Analysis of welded test models that have been subjected to residual stress shake-down with respect to remaining residual stress, and fatigue strength for load histories with zero and compressive mean stress.

(5) Composing the progress reports, draft the final report, and presenting the final report to the Project Technical Committee (PTC).

3.5 Project Timeline. See Enclosure (1).

4.0 GOVERNMENT FURNISHED INFORMATION

4.1 Final Report Style Manual. See Enclosure (2).

5.0 DELIVERY REQUIREMENTS

5.1 Quarterly progress reports to the Project Technical Committee, the Ship Structure Committee Executive Director, and the Contract Specialist.

5.2 Final report presenting suggested material model and methodology of fatigue analysis considering effects of mean stress at the completion of the project (paper copy and on 3.5" diskette in MS Word format) including the above deliverables formatted as per the Final Report Style Manual).

6.0 PERIOD OF PERFORMANCE

6.1 Project Initiation Date: Date of Award.

6.2 Project Completion Date: 15 months from the Date of Award

7.0 COST ESTIMATE.

7.1 Project Duration: 18 months.

7.2 Total Estimate: $74,136.

7.3 The details of cost estimate are attached as enclosure (3).

REFERENCES

DNV Classification Note 30.7 (2001). *Fatigue Assessment of Ship Structures.* Det Norske Veritas, Høvik.

Ellyin, F (1997) Fatigue Damage, Crack Growth and Life Prediction. *Chapman & Hall, London*

Frost, NE, Marsh, KJ, and Pook, LP (1974) Metal Fatigue. *Clarendon Press, Oxford*

IACS (1998) Guidelines for Assessment of the Fatigue Design of Ship Structures. *Paris La Defence, November 30*

IACS (2004) Development of IACS Common Rules for the Structural Design of Double Skin Bulk Carriers. *Joint Bulker Project Workshop. Hamburg, 19 March*

IACS (2005a). Common Structural Rules for Double Hull Oil Tankers, International Association of Classification Societies.

IACS (2005b). Common Structural Rules for Bulk Carriers, International Association of Classification Societies.

ISSC (2003). Fatigue Strength Assessment, Report of Comm. V.2, S. Berge (ed.), International Ship and Offshore Structures Congress, Elsevier.

Petinov, SV (2003) Fatigue Analysis of Ship Structures. *Backbone Books, NJ*

Reemsnyder, HS (1995*)* Fatigue and Fracture of Ship Structures. *Symposium and Workshop on the Prevention of Fracture in Ship Structures. Washington, D.C.*

Enclosure (*b*)

Project cost estimate

1. Direct labor cost (2 Project advisers, 1 fatigue analyst, 2 FE analysts, 2 technicians and 3 senior students, both, in Norway and Russia) ($23,20, Norwegian team, $23,80, - Russian team),
   total - $47,000

2. Fringe (Government established labor tax, in Russia) – 26.2% of the direct labor cost,
   $6,236

3. Other direct costs (Travel, expendables)
   - $17,000

   Subtotal: $70,236

4. Overhead (University established): 0.1 of the total project cost (Russian share - $40,936)
   - $3,900

Totalcost: $74,136

Note: The detailed description in the form advised by SSC to be submitted if the project would be accepted

"Mean Stress Assessment in Fatigue Analysis and Design"

Project Timeline

Enclosure (*a*)

(Approximate; to be refined if accepted)

ID	Task Name	October	January	April	July	October	January	April
1	SSC Project							
2	Project Start							
3	Develop Work Plan							
4	Approval of the Work Plan							
5	Review of Literature							
6	QPR 1							
7	Manufacturing of specimens Performing of Fatigue tests, Phase 1 Analysis of results							
8	Deliverable							
9	QPR 2							
10	Fatigue tests, Phase 2 Analysis of results							
11	Deliverable							
12	QPR 3							
13	Fatigue tests, Phase 3 Development of the mean stress model							
14	Deliverable							
15	QPR 4							
16	Fatigue tests, Phase 3, and FE Modeling of stress fields							
17	Deliverable							
18	QPR 5							
19	Develop recommendations on the mean and residual stress effects assessment procedure							
20	QPR 6							
17	Final Report							
18	QPR 7							
19	Project Complete							

11-12 NURBS Based Structural Analysis With Geometrical Uncertainty

Submitted by: Professor Dale G. Karr and Dr. Hyun Chung
Department of Naval Architecture and Marine Engineering, University of Michigan, Ann Arbor, MI

1.0 OBJECTIVE.

In this research, we will develop statistical NURBS finite elements that will enable us to effectively perform analyses of structures with geometric uncertainties. The structural geometry will be defined by NURBS curves and surfaces as is common in CAD and this geometry will then directly be used in the variational stress and displacement analyses without model translation or remeshing. Two major applications of this new technology will be for the dimensional analysis of ship structural parts and for ship structural analysis. With NURBS finite elements, the uncertainty in the part shape or structural design with statistical distributions of geometrical imperfections and variations can be rigorously modeled and simulated. In addition, the statistical correlations of part variations can be quantified. Also as an example, the mean and the variance of part variations can be directly related to the mean and the variance of the assembly spring-back shapes. Multiple sources of variations in single part also can be modeled without loss of statistical correlations. Similarly, it is possible to predict the statistical distribution of assembled block shapes and residual stresses involved in assembling imperfect ship structural elements, without computationally expensive Monte-Carlo simulations.

2.0 BACKGROUND.

Dimensional variations are inherent to any assembled and manufactured product and it is especially true for such products as ships, which are made of several thousands or up to millions of parts, assembled through numerous manufacturing processes, and joined together often by heat-intensive welding that tends to cause distortions in the parts.
Dimensional quality or the control of the dimensional variations becomes even more important in modern ships that employ modular design, and/or stealth technology since the geometrical quality directly affects many of the key characteristics of the ship. Not only can it be critical in determining the final dimensional variation of an assembled product but also in selecting robust product/process design, which has a direct impact on the acquisition cost and production time durations.

Geometrical uncertainty has been a focus of many researchers. In order to accurately model and predict how the dimensional variation propagates through the assembly processes, several models have been proposed in the past. Many of them are based on the finite element method (FEM) since the parts behave as compliant materials during the assembly process. Many researchers have tried to include stochastic uncertainties into the deterministic finite element method. In the perspective of finite element methodology, the uncertainties to be included can be categorized as stochastic behavior: (a) in loads applied on the deterministic structure; (b) in the material and/or geometric parameter with determined loads; or (c) both. The analysis of dimensional variations and their propagation through the assembly processes generally falls into the second category since the major source of stochastic parameters is the variations in part geometry. The randomness in the material could be safely neglected in this case. The loads applied to the structures, e.g., the forces required to close the gap between non-nominal parts, could be stochastic in nature, however it is mostly derived from the randomness in the part geometry. Usually the geometric deviation from the nominal shape is relatively small compared to that of metal-forming, this research is primarily based on linear elastic finite element approaches.

Computer-Aided Design (CAD) tools are now well established in the ship analysis and design environments. A fundamental aspect of CAD is the use of B-Spline curves and surfaces to develop product models of ship structures at various scales. Unfortunately CAD models may not be suitable for direct use in structural design and Computer-Aided Engineering (CAE) analysis because new finite element models must be developed for stress analysis, assembly analysis, and design optimization. These requirements for new design and analysis models can be expensive and time consuming. A seamless environment which can manipulate data for CAD, stress analysis and design optimization would be extremely valuable. Our project seeks to develop this environment by establishing a new isogeometric structural analysis methodology with two major advancements; unification of the CAD and CAE modeling environment and inclusion of the variability and uncertainty in structural geometry.

The hypothesis in this research is that the geometric average and covariance properties can be obtained from the B-spline basis functions. The basic idea is that as the B-spline basis functions and their knot vector support such features as locality and continuity of the curve or surface, the geometric covariance of a finite element can be obtained from the basis function and their knot vector, assuming that the finite element model is constructed by B-Spline or NURBS finite elements. In other words, once B-Spline or NURBS finite elements are determined, the uncertainties of the structurally geometry can be directly related to the uncertainties in the stress and displacement analyses and thus can be directly obtained from the NURBS finite element analyses. This is accomplished with a *single analysis*, rather than multiply simulations to establish the new statistics. Exploratory work in this regard can be found in the referenced paper by Chung and Karr, PRADS 2004.

It can also be shown that only variance information of the control points is required for the variational simulation since the covariance is absorbed into the basis functions of the B-Spline curves. The approach still requires more elaborations since the control points are not on the actual curve or surface, so a careful transformation of control point to a nodal point is needed.

3.0 <u>REQUIREMENTS</u>.

3.1 Scope.

3.1.1 The Contractor shall formulate Statistical B-Spline Finite Elements

3.1.2 The Contractor shall formulate Statistical NURBS Finite Elements

3.1.3 The Contractor shall perform Monte-Carlo Simulation using traditional Finite Elements for comparison purposes.

3.1.4 The Contractor shall perform Isogeometric Finite Element Analysis using Statistical B-Spline and NURBS Finite Elements.

3.2 Tasks and Timeline.

The project will be under the supervision of Professor Dale Karr with the support of Dr. Hyun Chung as a post-doctoral researcher and a master's degree candidate.
Portions of the funding will be to provide graduate student support. Professor Karr's hours on the project will include thesis support, which will not be charged to the project.

3.2.1 The Contractor shall develop Geometrical variance-covariance matrices for Curve and Surface entities. Completion: 6 mo. from start date. (80 hours).

3.2.2 The Contractor shall develop Finite Elements for Beams and Plates, based on B-Spline representations. Completion: 9 mo. from start date. (80 hours).

3.2.3 The Contractor shall develop Finite Elements for Beams and Plates, based on Non-Uniform Rational B-Spline representations. Completion: 12 mo. from start date. (100 hours).

3.2.4 The Contractor shall develop Finite Element Analysis for the experimental arrangement using traditional Beam and Plate elements for comparison purposes. Completion: 12 mo. from start date. (60 hours).

3.2.5 The Contractor shall perform Finite Element Analysis for the experimental arrangement using proposed Statistical B-Spline and NURBS Beam, and Plate elements. Completion: 16 mo. from start date. (100 hours).

3.2.6 The Contractor shall develop and deliver documentation of progress and final results. Completion: 18 mo. from start date. (80 hours).

4.0 GOVERNMENT FURNISHED INFORMATION.

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

5.0 DELIVERY REQUIREMENTS.

5.1 The Contractor shall provide quarterly progress reports to the Project Technical Committee, the Ship Structure Committee Executive Director, and the Contract Specialists.

5.2 The Contractor shall provide a Preliminary Report on the Statistical B-Spline Finite Element Development within 8 months of start date.

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 PERIOD OF PERFORMANCE.

6.1 Project Initiation Date: date of award.
6.2 Project Completion Date: 18 months from the date of award.

7.0 TIME, COST AND MAN-HOUR ESTIMATE.

7.1 Project Duration: 18 months.
7.2 Project Man-hours: 500.
7.3 Total Estimate: $75,000.

8.0 REFERENCES.

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9.0 <u>FACILTIES REQUIRED</u>

9.1 Existing office space, computer equipment, state of the art software packages will be used throughout the project duration at no charge to the project.