

Metrology for Automated Hull Layout

**January 31, 2010
Navy ManTech Program Project
Deliverables #10 and 12 under
Contract No. 2004-388 Task Order No. 18**

Final Report and Implementation Plan

Prepared for:



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Abstract

The purpose of the overall project is to determine candidate metrology technologies that have potential for savings within manufacturing at the Rhode Island, Quonset Point facility of Electric Boat Corporation (EB). The following four candidates were evaluated: an Indoor Global Position System (iGPS), Laser Tracker, Total Stations, and Romer Arm and Scanner.

The purpose of this report is to document the efforts taken during the evolution of the Mantech project, *Metrology for Automated Hull Layout*. It is noted that the statement of work changed from the original proposed project titled *Automated Install of Studs*. The new project statement of work changed from incorporating metrology technologies into the automatic location and installation of hull mounted studs to evaluating the use of various metrology tools to streamline manufacturing component layout and interfacing operations.

Project efforts consisted of the following:

- Defining operational, design and technical requirements for metrology tools to be evaluated
- Developing and performing pilot tests to determine the capabilities of the metrology equipment
- Developing a proposed system architecture for the metrology equipment
- Determining implementation viability in the Quonset Point manufacturing environment including a full cost/benefit analysis with return on investment
- Development of an implementation plan

Of the four metrology technologies explored, three technologies, the Laser Tracker, Total Stations, and Romer Arm were effective in performing the assigned tasks based on their versatility and mobility. These three technologies are well suited for the manufacturing dynamics at the Quonset Point facility. Based on the pilot test results, EB recommends implementing these three metrology technologies into the manufacturing operations. Because the remaining technology, iGPS, is limited in mobility due to excessive setup and breakdown time, it was not chosen as a candidate for implementation at EB.

EB has determined a total project savings of 6,341 hours per ship. Given the total funded project cost of \$1,114,371 and a total implementation cost of \$278,000, EB expects a return on investment of 2.9 ships.

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1.0 Project Summary

1.1 Background

The initial intent of this project was to utilize and incorporate metrology technologies into the automatic location and installation of hull mounted studs (titled *Automated Install of Studs*). This was a follow-on effort to the ManTech-funded *Laser Image Projection* project which developed a method to automatically locate the position of hull attached studs and immediately install the stud. However, as this project progressed, it was determined that, while the automatic installation of studs was technically feasible, the cost to integrate the metrology technology into a stud applicator was not economically practical at this time. While a suitable business case could not be developed for a onetime stud applicator, E General Dynamics Electric Boat (EB) recognized that many opportunities exist for the use of advanced metrology technology within the Quonset Point VIRGINIA Class manufacturing process. As a result, a new Statement of Work and accompanying business case were developed, issued and approved.

The project was re-titled *Metrology for Automated Hull Layout* and focused on the use of various metrology tools to streamline manufacturing component layout and interfacing operations. Four metrology technologies were explored:

- 1) Indoor Global Positioning System by Metris – iGPS
iSpace 8S system™ and probe with Spatial Analyzer™ Software
- 2) Absolute Laser Tracker by Hexagon Metrology – Laser Tracker
Leica AT901-LR Absolute Tracker System with T-Probe and T-Mack™
- 3) Targetless Total Stations by Maine Technical Source – Total Stations
Leica 754326 TCRP1201+ Powersearch Pinpoint R1000 Total Station™
- 4) Romer Arm and Scanner by Hexagon Metrology – Romer Arm and Scanner
Romer Infinite 2.0 SC3.6M (12') CMM – Scanshark V5 Tesa Laser Probe™

1.2 Project Objective

Many of the current processes for performing layouts, although accurate, are time consuming and cumbersome. The objective of this project was to utilize four metrology technologies in place of current processes to perform various operations with greater accuracy, shorter time spans and reduce manufacturing costs of VIRGINIA Class hulls.

1.3 Technical Approach

To begin development of the proposed automatic install of studs Support Structure Location System (SSLS), EB developed the System Requirements Specification (SRS), Reference (a) deliverable. The SSLS is the proposed system for locating and installing studs. The SRS defines both the operational requirements and system requirements necessary to proceed in project development. The operational requirements of the SRS define the operation environment, safety considerations, and accuracy/tolerance constraints. The system requirements of the SRS define the requirements for the data acquisition system and necessary requirements for the selected hardware. The hardware selected for this test program; iGPS, Laser Tracker, Total Stations, and Romer Arm meet the defined SRS requirements and were selected to proceed with SSLS development.

The SRS system requirements led to the development of the System Architecture, Reference (b) deliverable. The System Architecture outlines the path from design data to stud installation. A Macro-Process Map of the System Architecture is provided below.

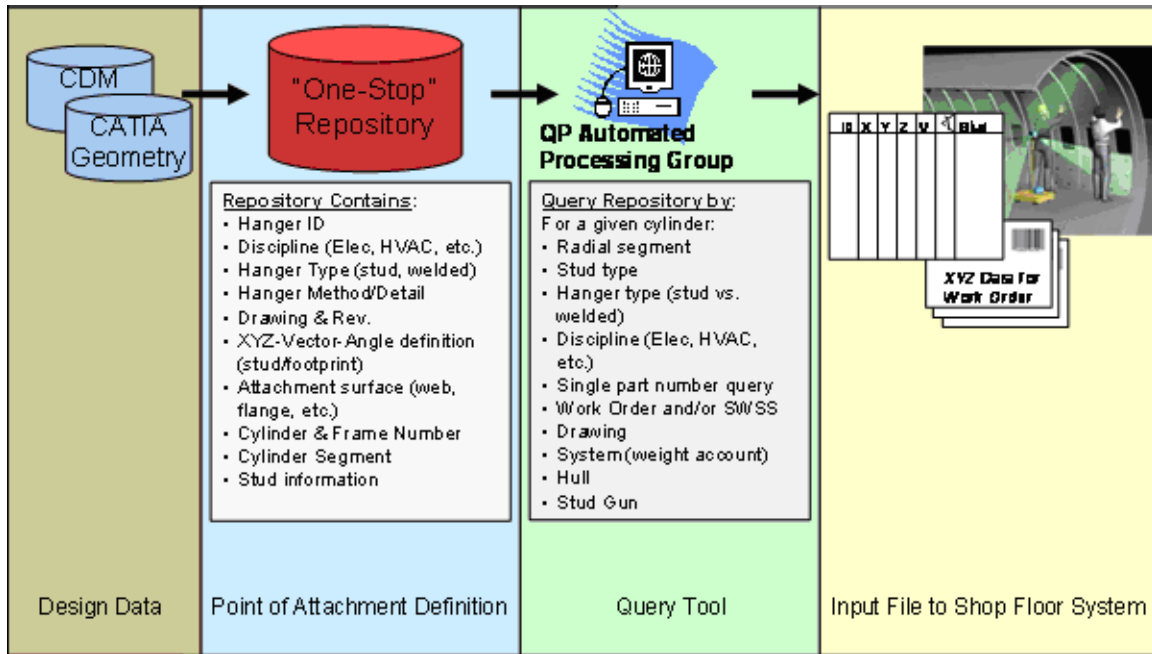


Figure 1: System Architecture Macro-Process Map

The 'One-Stop' repository tool collects CATIA Design information defining stud location based on the stud's physical geometric characteristics. The Query Tool allows EB to input specific information such as hull, drawing, discipline (electrical, HVAC, pipe hanger, etc.) to narrow down the studs to those required for installation in a particular work package. The input file is then generated to allow the SSLS to identify the applicable stud's three-dimensional position in space and immediately install the stud.

With the SRS and System Architecture defined, EB developed the Pilot Plan, Reference (c) deliverable, to define the proceedings for the pilot test program. The Pilot Plan defines the use case for the metrology technologies explored. Measures for EB personnel training on the use of each technology were established to ensure proper application and use of each individual technology. The Pilot Plan defines the plan for obtaining/preparing input file information, equipment set up, pilot test prerequisites, overcoming "line of sight" issues, and the pilot test validation steps.

Between the development of the Pilot Plan and performance of the Pilot Test Program, EB determined that the incorporation of the metrology technology was not economically feasible. The development of the automatic stud applicator revealed process issues that were major hurdles. For example, the surface area designated to receive a stud must be cleaned and have pre-heat applied (depending on weather conditions and stud type). To incorporate this capability into an automatic stud applicator, although technically possible, could not support a suitable business case to continue with the project.

Throughout the training phase, EB found that these metrology technologies could provide substantial benefit in other manufacturing operations throughout the Quonset Point facility.

As a result of this finding, and with the concurrence from all organizations of the project team, EB revised the Statement of Work as discussed in the Reference (d) contract modification.

This new Statement of Work allowed EB to explore opportunities throughout the manufacturing process to reduce construction costs. EB developed a detailed business case analysis for the opportunities. It was at this time that EB developed a revised Pilot Test program to evaluate the potential for cost savings for each of the metrology technologies described herein. Individual pilot tests were developed to determine both the capability of the equipment and time reduction over the previous methods. Where capabilities between technologies are similar, near identical pilot tests were performed to determine the best suited metrology tool to perform the job. For specific pilot tests and results, refer to the Reference (e) deliverable.

1.4 Metrology Technology Software Integration

All four metrology tools utilized SpatialAnalyzer™ (SA) software. SA is a traceable metrology 3D graphical software platform that can simultaneously communicate to virtually any number and type of dimensional measurement systems while simply performing complex analysis tasks. SA makes it easy for EB to layout, inspect, and set up parts and tools with the four metrology technologies explored.

SA allows for manipulation and analysis of design and measurement data. For instance, SA allows translation of the design model information and overlaying of the as-built condition for comparison. The figure below demonstrates the graphical plotting of measured key points overlaid on the design models.

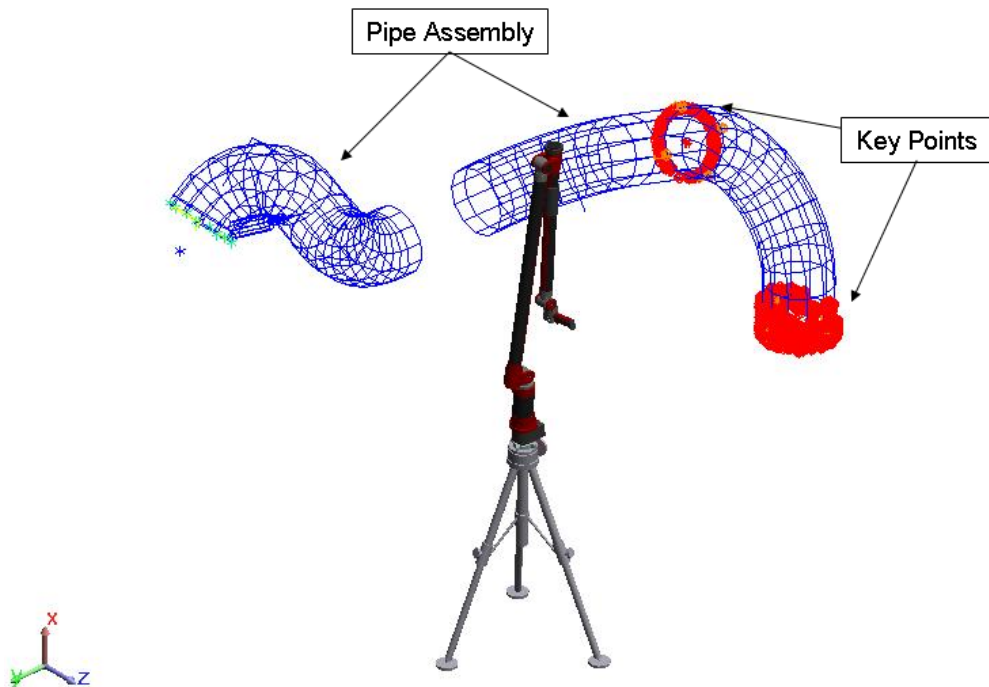


Figure 2: Romer Arm Pipe Configuration Survey

Figure 3: Not used (FOUO)

SA provides simple common interfaces for each of the technologies (e.g., all types of laser trackers (Leica, FARO, SMX, and API) have the same user interface). Once a user can run a job with a Leica laser tracker they can also run the job with a FARO, SMX or API type laser tracker. This capability enables measurement groups to share equipment and, therefore, choose the combination of measurement technologies that best fits the measurement job without having to retrain operators. This capability will allow EB to share as-built information with other shipyards (Norfolk, Portsmouth, Puget Sound, Northrop Grumman Shipbuilding-Newport News (NGSB-NN), or Pearl Harbor) using different types of equipment.

1.5 Results

The use of the Laser Tracker, Total Stations, and Romer Arm and Scanner in the pilot testing program was successful. Specific pilot test results are documented in the Reference (e) deliverable. The Quonset Point facility is a dynamic manufacturing environment with a variety of processes in various locations throughout the site. These three metrology technologies demonstrated ease of use, accuracy, versatility, and mobility making them well suited for the Quonset Point manufacturing environment. By using these three metrology technologies to perform the wide variety of manufacturing operations at the Quonset Point facility, EB estimates a total savings of 6,341 man hours per hull.

Based on the pilot test results performed, EB is confident that the predicted total savings will be realized based on the successes observed with the Laser Tracker, Total Stations, and Romer Arm and Scanner technologies.

The iGPS pilot tests yielded little success. Current building (Building 2003 and Highbay) dynamics limit the iGPS's ability to perform the intended functions. During pilot testing, the iGPS had to be transported from one area of operation to the next, each time requiring extensive set up, calibration, and breakdown time. Integrating the iGPS into building architecture provides little benefit due to the extensive size and layout of the buildings. Vertical outfitting, Rigging Operations and Hull Fixtures are all obstacles blocking "line of sight" from the iGPS hand held transponder to the fixed optical monuments.

Due to circumstances, some of the identified pilot test programs of the Reference (e) deliverable could not be performed within the period of performance (POP) of this project. The table below discusses the pilot tests that could not be performed.

Table 1: Pilot Tests Not Performed within the Period of Performance

Metrology Technology	Pilot Test	Rationale of not completing
Laser Tracker	Layout of mount locations	The first availability to perform this task falls outside the POP of this project.
Romer Arm and Scanner	Scanning of the major tank complex	The first availability to perform this task falls outside the POP of this project.
Total Stations	Layout of Array stud locations	The first availability to perform this task falls outside the POP of this project.
Total Stations	Set out of Hull fixture radius blocks	This pilot test was originally performed with iGPS. The comparison using the Total Stations could not be performed within the POP of this project due to availability.
iGPS	Elimination of optical alignment of horizontal pairing	A suitable system configuration for the iGPS could not be obtained to accommodate for the manufacturing environment. This pilot test was cancelled.
iGPS	Monitoring of missile tube fabrication	Due to the poor results using the iGPS for other pilot tests, a suitable business case for the iGPS could not be developed. The team decided to cancel further iGPS testing.

1.6 Conclusions

The EB, Quonset Point facility is a dynamic construction environment. Metrology tools used in this environment must be versatile in application and be easily transported from one location to the next without disruption to ongoing operations. Based on the results of the pilot test program, EB intends to implement the Laser Tracker, Total Stations, and Romer Arm and Scanner into the Quonset Point facility as the each demonstrated both versatility and mobility.

Attempts to incorporate the iGPS into the building structures were unsuccessful. Based on the iGPS pilot tests, EB does not intend to incorporate the iGPS into manufacturing operations.

2.0 Accomplishments

2.1 Developed the Early Layout Event Concept

This is the first application of this concept made possible by the advanced metrology technology. Traditionally, the actions described below are performed at different intervals throughout the construction process. The “Early Layout Event” allows for these actions to be completed in one event, minimizing interference with the trades and allowing for outfitting of some components to be performed sooner.

The Laser Tracker and Total Stations were used to perform the following at the single cylinder level:

- Perform Circularities
- Establish Grids
- Layout Lines
- Layout Internal and External Studs
- Layout Penetrations
- Profile Bevels

Benefits include:

- This Early Layout Event allows EB to establish an as-built condition of each hull cylinder
- Operations that were performed at different intervals in the vertical or horizontal outfitting stages can be performed at the single cylinder level
- Early layout allows the trades to work without interruption or without having to wait in queue for individual layouts to be performed

2.2 Accuracy Control Operations

- Increased the accuracy of the set up of the hull fixture radius blocks
- Decreased the time span required to perform hull and frame circularity checks
- Advanced “cut to suit” applications for outfitting major tank complexes
- Advanced soft targeting techniques
- Increased the accuracy of pipe configuration surveys

3.0 Completed Project Gantt Chart

The completed project Gantt chart is provided below. Please note that line items #39 (design/process specification) and #40 (implementation/deployment/training plan) are described at 50% complete as they are currently on going. The design/process specifications are still being developed as projects become available. For example, scanning of the major tanks complex process specification has not yet been completed as the project is not expected to begin until June 2010. The implementation/deployment/training plans are discussed in Section 5.0 of this report.

ID	Task Name	Duration	Start	Finish	2009												2010						
					Half 1, 2009						Half 2, 2009						Half 1, 2010						
					O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
1	MANTECH: Metrology for Automated Hull Layout	316 days	Mon 11/17/08	Fri 1/29/10	[Gantt bar spanning from Mon 11/17/08 to Fri 1/29/10]																		
2	Requirements Activities	130 days	Mon 11/17/08	Fri 5/15/09	[Gantt bar spanning from Mon 11/17/08 to Fri 5/15/09]																		
3	Document Requirements (operational, Technical)	58 days	Mon 11/17/08	Wed 2/4/09	[Gantt bar spanning from Mon 11/17/08 to Wed 2/4/09]																		
4	Deliverable #2a: Requirements Document	1 day	Tue 2/3/09	Tue 2/3/09	[Milestone diamond at Tue 2/3/09]																		
5	Investigate Available & Alternative Technologies / Prioritize / Calc. ROI	60 days	Mon 12/1/08	Fri 2/20/09	[Gantt bar spanning from Mon 12/1/08 to Fri 2/20/09]																		
6	Inv. Additional (In addition to Img Proj data) Data & User Interface Requirements	120 days	Mon 12/1/08	Fri 5/15/09	[Gantt bar spanning from Mon 12/1/08 to Fri 5/15/09]																		
7	Design Activities	163 days	Mon 11/17/08	Thu 7/2/09	[Gantt bar spanning from Mon 11/17/08 to Thu 7/2/09]																		
8	Identify Test Cases & Scenarios / Develop Plan for Pilot Test(s)	130 days	Mon 11/17/08	Fri 5/15/09	[Gantt bar spanning from Mon 11/17/08 to Fri 5/15/09]																		
9	Deliverable #3a: Pilot Test Plan	0 days	Tue 2/3/09	Tue 2/3/09	[Milestone diamond at Tue 2/3/09]																		
10	Design Proposed System Architecture	108 days	Thu 1/1/09	Mon 6/1/09	[Gantt bar spanning from Thu 1/1/09 to Mon 6/1/09]																		
11	Deliverable #6a: Proposed System Architecture	0 days	Thu 7/2/09	Thu 7/2/09	[Milestone diamond at Thu 7/2/09]																		
12	Analysis Activities	316 days	Mon 11/17/08	Fri 1/29/10	[Gantt bar spanning from Mon 11/17/08 to Fri 1/29/10]																		
13	Equipment Leasing	316 days	Mon 11/17/08	Fri 1/29/10	[Gantt bar spanning from Mon 11/17/08 to Fri 1/29/10]																		
14	Lease HW/SW (place PO)	30 days	Mon 11/17/08	Fri 12/26/08	[Gantt bar spanning from Mon 11/17/08 to Fri 12/26/08]																		
15	Train Users	60 days	Mon 4/20/09	Fri 7/10/09	[Gantt bar spanning from Mon 4/20/09 to Fri 7/10/09]																		
16	Conduct Pilot Test(s) / Validate Performance	206 days	Mon 4/20/09	Fri 1/29/10	[Gantt bar spanning from Mon 4/20/09 to Fri 1/29/10]																		
17	Deliverable #8a: Pilot Test Results	0 days	Thu 12/10/09	Thu 12/10/09	[Milestone diamond at Thu 12/10/09]																		
18	MANTECH: Automate Stud Install (Laser Tracker, Laser scanner, target-less total stations)	316 days	Mon 11/17/08	Fri 1/29/10	[Gantt bar spanning from Mon 11/17/08 to Fri 1/29/10]																		
19	Requirements Activities	130 days	Mon 11/17/08	Fri 5/15/09	[Gantt bar spanning from Mon 11/17/08 to Fri 5/15/09]																		
20	Document Operational Requirements	58 days	Mon 11/17/08	Wed 2/4/09	[Gantt bar spanning from Mon 11/17/08 to Wed 2/4/09]																		
21	Deliverable #2b: Requirements Document	0 days	Thu 1/15/09	Thu 1/15/09	[Milestone diamond at Thu 1/15/09]																		
22	Investigate Available & Alternative Technologies / Prioritize / Calc. ROI	60 days	Mon 12/1/08	Fri 2/20/09	[Gantt bar spanning from Mon 12/1/08 to Fri 2/20/09]																		
23	Inv. Additional (In addition to Img Proj data) Data Requirements	120 days	Mon 12/1/08	Fri 5/15/09	[Gantt bar spanning from Mon 12/1/08 to Fri 5/15/09]																		
24	Design Activities	163 days	Mon 11/17/08	Thu 7/2/09	[Gantt bar spanning from Mon 11/17/08 to Thu 7/2/09]																		
25	Identify Test Cases & Scenarios / Develop Plan for Pilot Test(s)	130 days	Mon 11/17/08	Fri 5/15/09	[Gantt bar spanning from Mon 11/17/08 to Fri 5/15/09]																		
26	Deliverable #3b: Pilot Test Plan	0 days	Tue 2/3/09	Tue 2/3/09	[Milestone diamond at Tue 2/3/09]																		
27	Design Proposed System Architecture	108 days	Thu 1/1/09	Mon 6/1/09	[Gantt bar spanning from Thu 1/1/09 to Mon 6/1/09]																		
28	Deliverable #6b: Proposed System Architecture	0 days	Thu 7/2/09	Thu 7/2/09	[Milestone diamond at Thu 7/2/09]																		
29	Analysis Activities	221 days	Mon 3/30/09	Fri 1/29/10	[Gantt bar spanning from Mon 3/30/09 to Fri 1/29/10]																		
30	Equipment Leasing	75 days	Mon 3/30/09	Fri 7/10/09	[Gantt bar spanning from Mon 3/30/09 to Fri 7/10/09]																		
31	Lease HW/SW (place PO)	10 days	Mon 3/30/09	Fri 4/10/09	[Gantt bar spanning from Mon 3/30/09 to Fri 4/10/09]																		
32	Train Users	60 days	Mon 4/20/09	Fri 7/10/09	[Gantt bar spanning from Mon 4/20/09 to Fri 7/10/09]																		
33	Conduct Pilot Test(s) / Validate Performance	206 days	Mon 4/20/09	Fri 1/29/10	[Gantt bar spanning from Mon 4/20/09 to Fri 1/29/10]																		
34	Deliverable #8b: Pilot Test Results	0 days	Thu 12/10/09	Thu 12/10/09	[Milestone diamond at Thu 12/10/09]																		
35	Program Management Activities / Implementation Planning	316 days	Mon 11/17/08	Fri 1/29/10	[Gantt bar spanning from Mon 11/17/08 to Fri 1/29/10]																		
36	Implementation Planning Activities	316 days	Mon 11/17/08	Fri 1/29/10	[Gantt bar spanning from Mon 11/17/08 to Fri 1/29/10]																		
37	Develop Detailed Business Case (Including Cost/Benefit Analysis)	206 days	Mon 4/20/09	Fri 1/29/10	[Gantt bar spanning from Mon 4/20/09 to Fri 1/29/10]																		
38	Update Automated Data Extraction (If needed)	175 days	Mon 11/17/08	Fri 7/17/09	[Gantt bar spanning from Mon 11/17/08 to Fri 7/17/09]																		
39	Develop Design / Process Specification	40 days	Wed 7/1/09	Tue 8/25/09	[Gantt bar spanning from Wed 7/1/09 to Tue 8/25/09]																		
40	Develop Implementation / Deployment / Training Curriculum Plans	115 days	Tue 8/25/09	Fri 1/29/10	[Gantt bar spanning from Tue 8/25/09 to Fri 1/29/10]																		
41	Quarterly Reporting Activities + Tech Transfer	272 days	Thu 1/15/09	Fri 1/29/10	[Gantt bar spanning from Thu 1/15/09 to Fri 1/29/10]																		
42	1Q - Design Review / Status Report (Deliverable #4)	10 days	Thu 1/15/09	Wed 1/28/09	[Gantt bar spanning from Thu 1/15/09 to Wed 1/28/09]																		
43	2Q - Design Review / Status Report (Incl. Go/No-Go) (Deliverable #5)	10 days	Wed 4/15/09	Tue 4/28/09	[Gantt bar spanning from Wed 4/15/09 to Tue 4/28/09]																		
44	3Q - Design Review / Status Report (Deliverable #7)	10 days	Wed 7/15/09	Tue 7/28/09	[Gantt bar spanning from Wed 7/15/09 to Tue 7/28/09]																		
45	4Q - Final Design Review/Report w/Tech Xfer Summary (Deliverable #9)	10 days	Thu 10/15/09	Wed 10/28/09	[Gantt bar spanning from Thu 10/15/09 to Wed 10/28/09]																		
46	Implementation Plan / Final ROI / Training Curriculum (Deliverable #10)	0 days	Fri 1/29/10	Fri 1/29/10	[Milestone diamond at Fri 1/29/10]																		
47	Tech Transfer Activities - (I.e., SPS Paper or other - Deliverable #11)	0 days	Fri 1/29/10	Fri 1/29/10	[Milestone diamond at Fri 1/29/10]																		
48	Final Report - (Deliverable #12)	0 days	Fri 1/29/10	Fri 1/29/10	[Milestone diamond at Fri 1/29/10]																		

4.0 Technology Transfer Status

- CNST 4th Quarterly Review, December 15, 2009
- ShipTech Symposium, March 8-10, 2010
- Naval Shipyard Laser Measurement Users Group (LMUG) – Bi-weekly telecons
 - Group includes members from NUWC, Puget Sound, Pearl Harbor, NGSB-NN, and others

5.0 Implementation Plan

Implementation of this project into standard operations will be a straight forward approach. EB has already set aside capital for procurement of one Laser Tracker, two Total Stations, and 1 Romer Arm and Scanner. To continue this effort seamlessly, the following actions are in place:

- Purchase Orders to exercise the “buyout at end of lease” option for the 2 Total Stations, Laser Tracker, and Romer Arm and scanner have been initiated.
- Software requests for four SpatialAnalyzer™ licenses have been initiated.
- Quonset Point Engineering will draft Department Instructions (DIs) for the operation of the metrology equipment to ensure consistency among users.
- Where needed, test forms will be created or amended to reflect the use of this equipment.
- The Laser Tracker and Romer Arm and Scanner have been returned to the vendor for refurbishment, cleaning, and upgrades.
- Procure Scissor Lifts for Accuracy Control (D951) use only to prevent issues with other departments/operations.

Table 2 below provides a breakdown of the implementation plan for each item.

Table 2: Metrology Technology Implementation Matrix

Metrology Technology Implementation Matrix			
Technology	Remaining Actions	ECD	Funding Source
Laser Tracker	Obtain Capital approval and Issue Capital Project Requests to purchase the equipment at the end of lease period	4/1/2010	Capital Expenditure
	Training/Department Instruction Development	4/1/2010	VIGINIA Direct
	SA License	4/1/2010	Capital Expenditure
Romer Arm & Scanner	Obtain Capital approval and Issue Capital Project Requests to purchase the equipment at the end of lease period	4/1/2010	Capital Expenditure
	Training/Department Instruction Development	4/1/2010	VIGINIA Direct
	SA License	4/1/2010	Capital Expenditure
Total Stations	Obtain Capital approval and Issue Capital Project Requests to purchase the equipment at the end of lease period	4/1/2010	Capital Expenditure
	Training/Department Instruction Development	4/1/2010	VIGINIA Direct
	2 SA licenses (one for each total station)	4/1/2010	Capital Expenditure
Scissor Lifts	Procurement of additional Scissor Lifts at QP for Accuracy Control use only	4/1/2010	Capital Expenditure

Note: Funding sources are consistent with those identified in the Reference (f) deliverable

Upon issuance of the purchase orders to the applicable vendors and receipt of the Laser Tracker and Romer Arm and Scanner at the Quonset Point facility, EB will continue the efforts discussed herein.

Long-term actions to ensure project effectiveness will consist of:

- Track and monitor actualized savings
- Continue to identify new applications and/or processes for equipment use.

6.0 Business Case and Return on Investment

Table 3 provides a breakdown of the implementation costs and estimated hourly savings for each technology. Considering ManTech project costs, the total return on investment is 2.9 ships.

Table 3: Business Case and ROI

Business Case Analysis and Return on Investment			
Technology/Method	Savings (hrs/hull)	Implementation Effort	Effort Cost
Laser Tracker	1,000	Lease Buyout	\$138,391
		Training/Department Instruction Development	\$1,000
Romer Arm & Scanner	1,120	Lease Buyout	\$54,999
		Training/Department Instruction Development	\$1,000
Total Stations	1,065	Lease Buyout	\$30,708
		Training/Department Instruction Development	\$1,000
Early Layout Event	3,156	Obtain Metrology Equipment	\$0
		Training/Department Instruction Development	\$1,000
SA Licenses	0	Lease Buyout	\$37,902
Scissor Lifts	0	Lease/buy	\$12,000
Total Savings/ship	6,341	Total Implementation Cost	\$278,000
Total ManTech Project Cost (Hardware, Software, Material, and Labor)			\$1,114,371

$$\text{ROI} = \frac{\text{Total Project Cost}}{\text{Savings/ship}} = \frac{\$1,114,371 + \$278,000}{\$475,575} = 2.9 \text{ ships}$$

7.0 References

- Reference (a) Automated Install of Studs – Deliverable 2 – *System Requirements*, Dated February 20, 2009
- Reference (b) Automated Install of Studs – Deliverable 6 – *System Architecture*, Dated July 6, 2009
- Reference (c) Automated Install of Studs – Deliverable 3 – *Pilot Plan*, Dated February 20, 2009
- Reference (d) CNST 2004-388, Task Order 18, Contract Mod 3, *Automated Install of Studs – SOW Change*, Dated October 16, 2009
- Reference (e) Metrology for Automated Hull layout – Deliverable 8 – *Pilot Test Results*, Dated December 9, 2009
- Reference (f) Automated Install of Studs – Deliverable 1 – *Technology Transition Plan*, Dated January 15, 2009