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LORAN Modernization Program – Update 2004

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ABSTRACT

The views expressed herein are those of the author and are not to be construed as official or reflecting the views of the Commandant or the U. S. Coast Guard.

Loran is a land-based radionavigation system that provides navigation and timing information to users in the coverage area. Currently, the United States Loran system is operational throughout the Continental United States and Alaska. Loran has been identified as the best theoretical backup to the Global Positioning System for multimodal transportation and timing applications.

Since 1997, the Federal Aviation Administration, the U. S. Coast Guard, Academia, and Industry have been working together to modernize the Loran infrastructure and to improve the performance of the service to meet stringent requirements for maritime and aviation transportation. As a result of these efforts, several advances have been made in proving the technical feasibility of Differential-Loran and the Loran Data Channel. Additionally, nearly every component of the Loran system has been redesigned, and nine of the twenty-four U. S. Loran stations have been modernized.

By December 2005, plans call for all eighteen Loran stations in the Continental United States Loran system to be modernized, the new control system to be installed at both control stations, and the U. S. Loran system to be converted to Time-of-Transmission control. At this point, the modernized U. S. Loran system will be available to industry, users, and researchers nationwide who wish to integrate Loran into radionavigation and timing electronics to improve the robustness of their systems.

KEYWORDS: Loran, GPS, radionavigation, vulnerability, modernization.

1. INTRODUCTION

Loran is a pulsed low-frequency hyperbolic radionavigation system originally developed and used during World War II. Currently, the U. S. Loran system is comprised of twenty-four high-power terrestrial Loran stations (Lorstas), two control stations, and twenty-four monitor sites located throughout the Continental U. S. (CONUS) and Alaska. Today the Loran system remains operational (Figure 1), and the last generation of Loran equipment, doctrines, and performance are being modernized to serve a user community that is accustomed to the performance available from the Global Positioning System (GPS) for both navigation and timing applications.

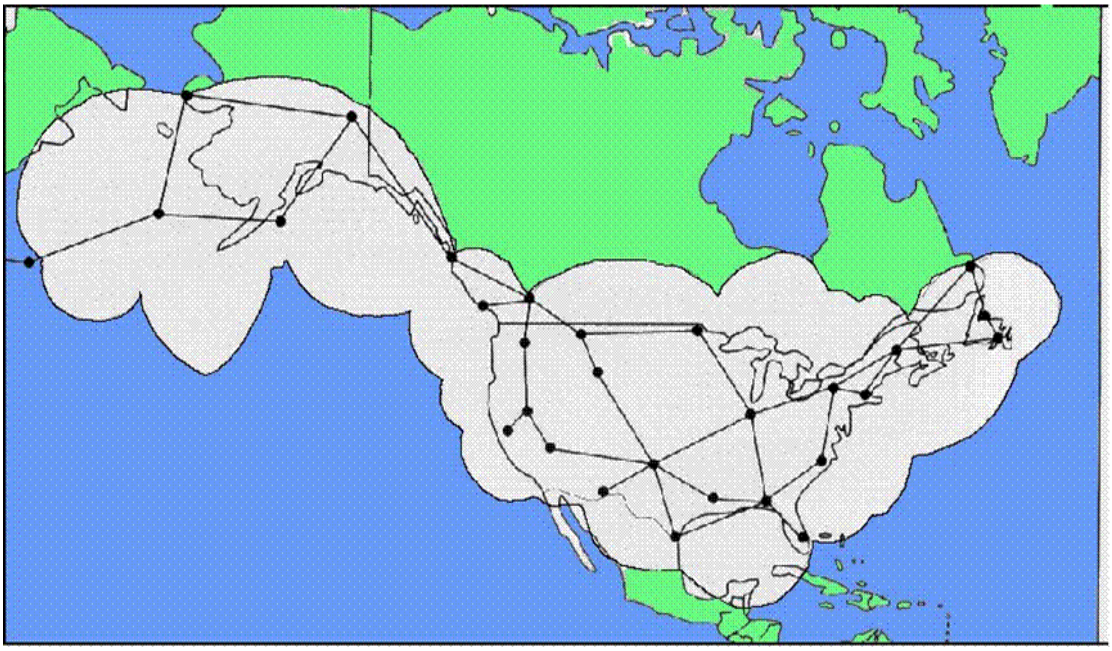

Figure 1. Coverage of the North American Loran system

The U. S. Department of Transportation (USDOT), the U. S. Coast Guard (USCG), and the Federal Aviation Administration (FAA) are executing a Memorandum of Agreement (MOA) "Regarding Recapitalization, Modernization, and Continued Operation of the Loran Radionavigation Service for Civil Airborne and Civil Marine Users." The agencies agreed to complete the research and development work needed to determine the viability of an enhanced Loran system to provide nonprecision airport approaches (NPA) in the National Airspace System (NAS) and an aid to navigation for the Harbor Entrance and Approach (HEA) phase of marine navigation.

As part of this work, the USDOT commissioned three study groups. The Loran Integrity Performance Panel (LORIPP) was chartered to determine if Loran performance could be enhanced to satisfy the requirements of NPA for aviation. The Loran Accuracy Performance Panel (LORAPP) was charged to investigate the technical feasibility of Loran enhancement to meet the requirements for HEA for maritime transportation. The Volpe Center was commissioned to develop the benefit-to-cost analysis for a Loran system meeting NPA and HEA requirements.

The LORAPP also developed the Differential-Loran technique and a method of using the Loran broadcast to transmit data. These successes show promise for a future Enhanced Loran system that delivers greatly improved performance that meets the requirements for a variety of applications including aviation and maritime transportation.

Additionally, the USCG and FAA coordinated the redesign of the subsystems that make up the U. S. Loran system. Major upgrades included new transmitters, new signal-control equipment, new system-control equipment, new Cesium time standards, new facilities monitor and control equipment, a new communications network, and new uninterruptible power supplies (UPS) for operations rooms and transmitters. These modernization initiatives improved both the supportability of the Lorstas and the performance of the broadcast signal, and they enable a new broadcast-control philosophy that will support the development of the next-generation of user equipment.

2. THE POTENTIAL OF LORAN

Loran and the GPS are complementary to each other; their characteristics, and therefore their strengths and weaknesses, are very different. For example, where Loran is affected by weather, the GPS is not. Conversely, where the GPS is a low-power system, Loran operates at a relatively high power. The two systems are very widely separated in the frequency spectrum, with the GPS broadcasting in bands between 1.0 gigahertz and 2.0 gigahertz and Loran broadcasting at 100 kilohertz. The idea of a low-power, low-cost GPS jammer is easily conceived; conversely, a low-power, low-cost Loran jammer is relatively unimaginable.

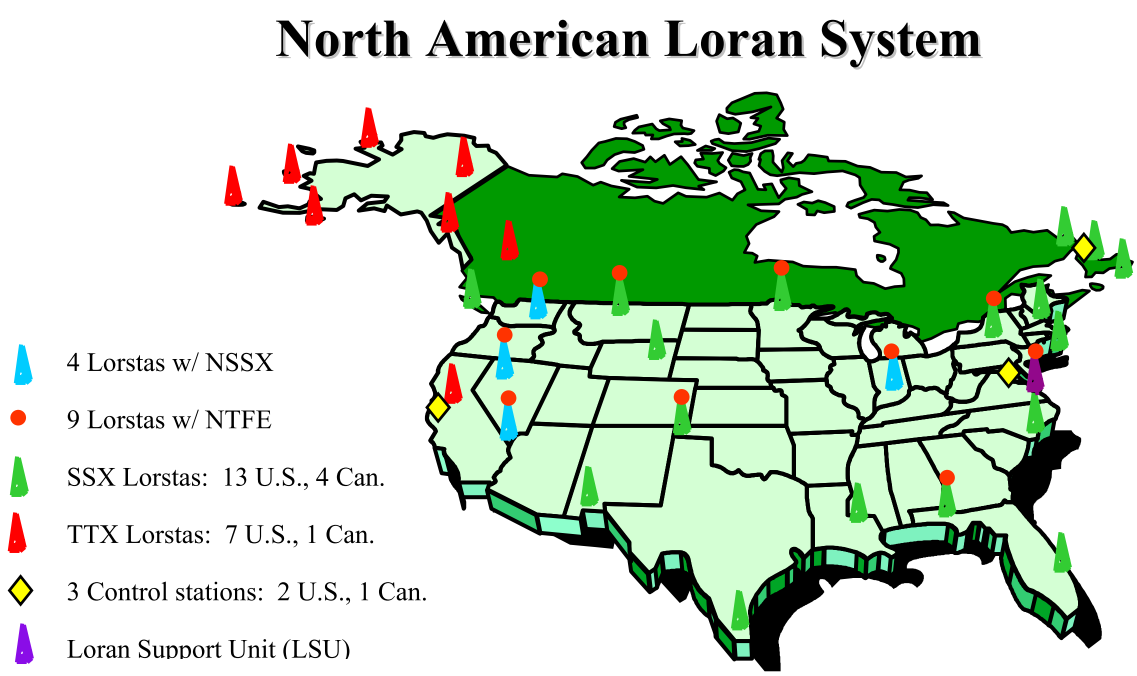

Figure 2. The Loran system showing modernization achievements to date

The existing Loran system was first made available to non-military users in the mid 1970's. Though Loran is still operational, much of the legacy Loran infrastructure is in need of replacement. Today, the Coast Guard and the FAA are working together with several other public and private organizations to modernize the Loran system. The modernization design is benefiting significantly from today's technology. The modernization efforts will enable the operation of Loran into the future by recapitalizing virtually every aspect of the infrastructure and making several improvements along with the recapitalization. The performance improvements being made are targeting the HEA, NPA, and timing requirements of a GPS Backup System. For the purposes of this paper, the name "Enhanced Loran" is used to define when and where the Loran system meets GPS-Backup requirements.

There are several initiatives associated with the development of Enhanced Loran that will result in improvements to the broadcast signal, new methods of control, new methods of data dissemination, and new receiver equipment. Highlight a few provider-side advancements are provided in this paper. Specifically, an update is given of several achievements with regard to Differential Loran, the Loran Data Channel, the recapitalization of Loran electronics, and the transition of Loran chains to Time-of-Transmission (TOT) control philosophy.

3. DIFFERENTIAL LORAN

Before Loran can serve as a backup to the GPS services currently in use in maritime transportation, the accuracy of Loran has to be improved significantly. This is because the accuracy requirement of the HEA phase of maritime navigation is 20 meters in a harbor, and legacy Loran offers a much poorer accuracy of only about 460 meters at sea. Thus Enhanced Loran must deliver an accuracy that is a 25-fold improvement over the accuracy of legacy Loran. The only hope of achieving this is by implementing real-time Differential Loran, something that had been attempted in the past without success.

To meet this challenge, the LORAPP developed and successfully tested the following techniques and technologies and then integrated them into an overall system that can be implemented nationwide.

- A mobile monitor was developed to gather and record Loran location-dependent correction information (called additional secondary factors, or "ASF's") along a harbor's channel.

- A shore-side monitor was developed and installed at several locations to gather and record real-time Loran time-dependent correction information at the time when the mobile monitor is operating in the harbor's channel.

- An information-modulation scheme was developed, called the 9th-Pulse Loran Data Channel, to modulate the shore-side monitor's corrections onto the Loran signal itself and send them directly to the user's receiver for real-time improvement of the Loran fix. The generation of the 9th Pulse is performed in software alone, without modification of the SSX hardware.

- A mobile communications receiver was developed to receive and demodulate the 9th-Pulse correction information.

- The mobile communications receiver, the mobile Loran receiver, and the ship's mobile GPS receiver were integrated by a Differential-Loran receiver that continuously: (1) calculates a Loran fix, (2) applies the location-dependent corrections, (3) applies the time-dependent corrections, (4) recalculates a Differential-

Loran fix, (5) compares the Differential-Loran fix to the ship's GPS position, and (6) records the offset between the Differential-Loran fix and the GPS fix.

With all of these pieces in place, the LORAPP performed a real-time proof of concept of the entire system. The mobile electronics suite was installed on a U. S. Army Corps of Engineers (USACE) survey vessel, the *M/V Shuman*, which was surveying a dredging project in the Chesapeake Bay. The shore-side monitor was installed at the Loran Support Unit (LSU) in Wildwood, NJ, and was linked to the LSU's Loran transmitter for modulation and broadcast.

The entire system was put into operation during the week of November 17, 2003. The LSU Loran transmitter broadcast the shore-side monitor's corrections, and the mobile Differential-Loran receiver on board the *M/V Shuman*, achieved 20-meter accuracy 90% of the time, and 25-meter accuracy 95% of the time during the real-time trial (Figure 3).[1] These results are promising, especially considering the monitor in New Jersey is not in an optimum location to serve an operations area in the Chesapeake Bay.

The achievement on board the *M/V Shuman* can be seen as a "radionavigation Wright Brothers flight." Although post-processed Differential Loran had been previously proven, this was the first time the whole-system concept of Differential Loran had been performed in real time in an actual navigation environment. By proving that Differential Loran can meet the stringent requirements of HEA navigation, the LORAPP has proven a promising option for a back up to the GPS.

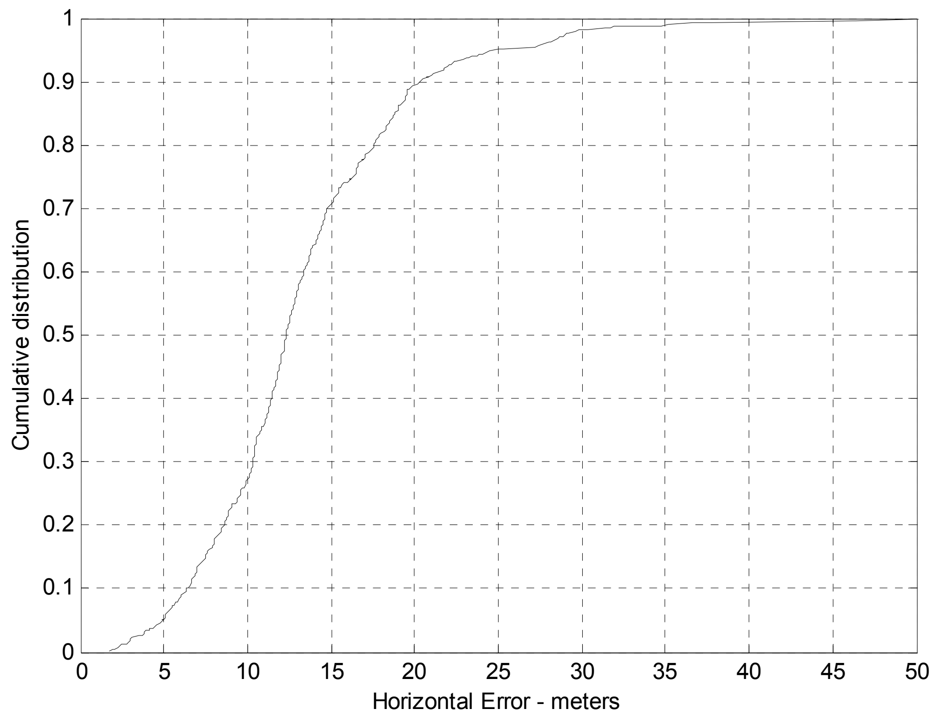

Figure 3. Cumulative accuracy distribution of 17 November 2003 Differential-Loran testing

Current efforts are being focused on the port of Boston, MA. A navigation-grade Differential-Loran monitor has been installed in the laboratory spaces of the Volpe National Transportation Systems Center in Cambridge, MA. Preliminary work has been accomplished, and future activities are planned for the spring of 2005. The goal is to establish Boston Harbor as the first waterway completely surveyed for Differential Loran for maritime navigation.

To develop Differential Loran for timing applications, the Volpe monitor will soon be upgraded to a timing-grade monitor. In addition, a timing-grade Loran monitor has been installed at the U. S. Naval Observatory (USNO), and negotiations are underway with stakeholders for several other Loran-monitor installations.

4. LORAN DATA CHANNEL (LDC or "9TH PULSE")

The Differential-Loran tests described in the previous section were performed with the LSU vacuum-tube transmitter (TTX) broadcasting the 9th Pulse information. Although valid, the Loran Recapitalization Project (LRP) is in the process of replacing all TTXs in the U. S. Loran System with solid-state transmitters (SSX). Therefore, the ability of the SSX to broadcast the 9th Pulse had to be proven for future operational implementation to be possible.

The new Lorsta timing software was modified to add and modulate a 9th pulse. On March 3, 2004, the LORAPP assembled at the LSU to test the modified software on the SSX baseline. The 9th pulse was added and modulated on a test signal sent to the SSX. A prototype communications receiver monitoring the SSX radio-frequency feedback loop successfully demodulated the test information. Various rates and master-secondary combinations were tested, all successfully.

Then, on October 15, 2004, the LORAPP performed a successful test of the 9th Pulse on the SSX, but this time using the actual broadcast from the LSU Loran broadcast antenna. The 9th Pulse data was transmitted with the Loran signal from New Jersey and demodulated successfully at the laboratory of Peterson Integrated Geopositioning, LLC, in Connecticut. Although the decision has not yet been made whether or not to implement the 9th Pulse in the operational Loran system, it has been shown to be technically feasible.

Lorsta Seneca, NY is planned to be the first operational Lorsta to receive the 9th Pulse, after the software is approved for operations. Test broadcasts will then be made to the user area. The timing information that is modulated will come from the monitors at the Volpe Center, USNO, and other timing monitors in the user area.

5. TIME OF TRANSMISSION (TOT) CONTROL

The modernized Lorsta electronics gives the Loran system the option of TOT control for determining the timing of the transmissions from Lorstas. This moves away from the traditional U.S. method of controlling Lorsta transmissions using the time of arrival (TOA) of the signals at system-area monitor (SAM) sites in the coverage area. Transitioning to TOT control will allow "all-in-view" receivers to be developed that are no longer constrained by Loran-chain geometry. Combining TOT control and Differential Loran will give the timing community much tighter traceability of the Loran signal to Universal Time Coordinated (UTC). The other requirement for TOT control is the modernization of the electronics at the control stations in Virginia and California.

6. LORAN ELECTRONICS RECAPITALIZATION

At the beginning of Loran modernization in 1997, the electronics at the Loran stations and at the control stations had aged beyond the intended service life. The task was to redesign and replace virtually every component in the entire Loran system to improve both supportability and performance.

6.1 Modernization – Past Accomplishments

In the early phases of the program, several projects were completed.

- The 72 Cesium-beam oscillators at all 24 Lorstas were upgraded.
- A new control and monitoring system for the Loran transmissions of all 24 Lorstas was installed.
- Uninterruptible power supplies were purchased for both the transmitters and the operations rooms of all Lorstas.
- A new monitoring system for Lorsta facilities was developed.
- The nationwide command and control communications network was upgraded.

6.2 Modernization of Lorstas

The present phase of the project involves installation of the final electronics suites at the Lorstas and control stations. Lorstas are classified into two groups, depending upon the type of transmitter they had at the beginning of the project, whether a 1960's TTX or a 1980's "legacy" SSX.

6.2.1 Modernization of TTX Lorstas

At the eleven TTX Lorstas, the TTX is being replaced with a new solid-state transmitter (NSSX), the Megapulse Accufix 7500 (Figure 4). Installation of the NSSX requires site construction of a new building at the Lorsta to house the electronics. The timing-and-frequency equipment in the operations rooms is also being replaced with the new timing and frequency equipment (NTFE) suite manufactured by Timing Solutions Corporation (Figure 5). The list of TTX Lorstas modernized to date with the NSSX and the NTFE follows.

- Lorsta George, Washington (9940 Whiskey, 5990 Yankee)
- Lorsta Dana, Indiana (8970 Master, 9960 Zulu)
- Lorsta Fallon, Nevada (9940 Master)
- Lorsta Searchlight, Nevada (9940 Yankee, 9610 Whiskey)

Modernization of the last CONUS TTX Lorsta in Middletown, CA, is planned for completion by early spring of 2005. This will complete the TTX replacements in CONUS. Modernization of the six Alaskan TTX Lorstas will begin in the summer of 2005 and continue in subsequent years. Plans exist to relocate the Lorsta at Port Clarence to a site closer to the city of Nome. This move is not expected for several years.

Because of this, the NTFE will be integrated with the TTX. This will enable all six Alaskan Lorstas for TOT operations and Differential-Loran broadcasts independent of – and prior to – completion of the NSSX installation schedule. Since Lorsta Port Clarence is dual-rated between both Alaskan chains, conversion of both chains to TOT control would otherwise have to wait for the move to Nome to be completed. The integration of the NTFE with the TTX will allow both Alaskan chains to be transitioned to TOT control by the fall of 2006.

Figure 4. The NSSX at Lorsta George, WA

Figure 5. The operations room at Lorsta George, WA

6.2.2 Modernization of legacy-SSX Lorstas

At the thirteen legacy-SSX Lorstas, the NTFE is being installed and integrated with the legacy SSX.[2] The NTFE allows TOT operations at the Lorsta and enables other performance enhancements; this is true for installations at both NSSX Lorstas and at legacy-SSX Lorstas. The list of Lorstas modernized with the NTFE follows.

- Lorsta Baudette, Minnesota (8290 Whiskey, 8970 Yankee)
- Lorsta Seneca, New York (9960 Master, 8970 X-ray)
- Lorsta Boise City, Oklahoma (9610 Master, 8970 Zulu)
- Lorsta Malone, Florida (7980 Master, 8970 Whiskey)
- Lorsta Havre, Montana (8290 Master)

Figure 6 shows the actual coverage of signals sent from the nine modernized Lorstas to date.[3] The colors indicate the number of stations in a given location where the users can expect to receive signals with strengths greater than 45 dB referenced to 1 micro-Volt/meter.

Modernization of the remaining eight legacy-SSX Lorstas is scheduled by December 2005. Along with the NSSX installations, this will mark the end of Loran electronics modernization at all CONUS Lorstas.

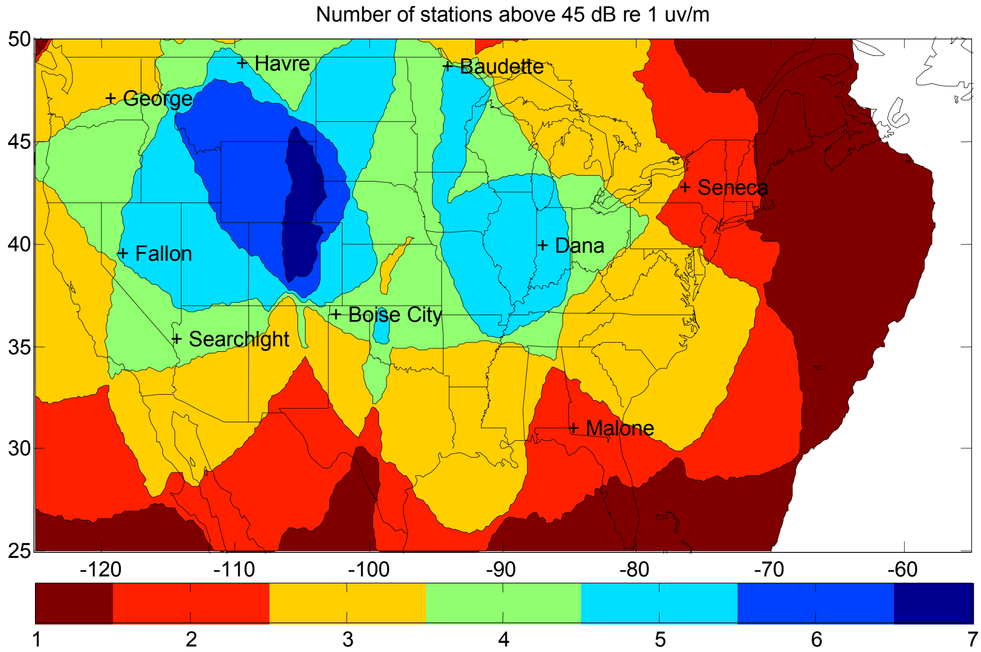

Figure 6. Coverage today of 9 modernized Lorstas

6.3 Modernization of the Control Stations

The legacy Loran control electronics at both control stations will be replaced with a redesigned version (Figure 7). This new Loran Consolidated Control System (NLCCS) will allow the control stations to control and monitor the modernized Lorstas under TOT operation.

Figure 7. The NLCCS baseline at LSU Wildwood, NJ

Currently the NLCCS has been installed and successfully tested at the Loran Support Unit. All required operations documentation has been completed, and operator training will begin in January 2005. The installations at both control stations are scheduled for completion by April 2005.

After completing the control stations, the plan is to transition the Great Lakes Chain to TOT control on a trial basis. While the decision to switch control methodologies has not yet been made officially, it is important to validate the TOT-control option and present it to decision-makers as early as possible. Installation of the NLCCS at the control stations and completion of NTFE installations at all eighteen CONUS Lorstas will make the transition to TOT control possible for all six CONUS Loran chains.

7. ENHANCED LORAN

For the purposes of this paper, Enhanced Loran is achieved when Loran meets the requirements for a GPS backup system for maritime HEA and aviation NPA. Enhanced Loran is an integration of several related initiatives. These include recapitalization of the Loran electronics, transition of Loran chains to TOT control, and implementation of Differential Loran in vulnerable areas of interest (including detailed surveys of harbors and airports and deployment of Differential-Loran monitors). The current project plan calls for Enhanced Loran to be available in CONUS by December 2008 and in Alaska by December 2009.

8. CONCLUSION

While a decision on the future of Loran has still not been formally announced, the Loran Modernization Program has a significant list of accomplishments, including the following.

- The feasibility of achieving 20-meter accuracy by using Differential Loran was proven in real time in an actual maritime environment (i.e., on a ship in the Chesapeake Bay using Differential-Loran corrections transmitted on an actual Loran broadcast).
- At four Lorstas, the TTX was replaced by the NSSX.
- At nine Lorstas, the timing & frequency electronics were replaced by the NTFE.
- All five stations of the Great Lakes Loran Chain have been modernized and are now ready for TOT operations.
- All six CONUS Master stations have been modernized and are ready for TOT operations.
- The NLCCS has been redesigned and satisfactorily tested.
- The 9^{th}-Pulse Loran Data Channel was successfully tested.

This progress is the direct result of the continuation of years of cooperation among Government, Academic, and Industry in focused design, manufacture, construction, and integration of the several components of the Loran system.

Current plans include the implementation of the NLCCS at both control stations by spring of 2005, the completion of the electronics modernization at all 18 CONUS Lorstas and the conversion of the CONUS Loran chains to TOT control by December 2005, the delivery of Enhanced Loran in CONUS by December 2008, and the delivery of Enhanced Loran to Alaska by December 2009.

With these enhancements, the Loran system will be positioned to offer a significantly improved service to the timing and multimodal-transportation user communities. Critical GPS-based applications will have an independent, complementary timing, positioning, and navigation service to help them alleviate security concerns. By improving the robustness of GPS-based applications, Loran will help the nation securely exploit the advantages in safety and efficiency that GPS offers.

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[1] This figure is courtesy of Dr. Benjamin Peterson, of Peterson Integrated Geopositioning, LLC.

[2] The legacy solid-state transmitters are scheduled for refurbishment in a future phase of the project.

[3] This figure is courtesy of Dr. Benjamin Peterson, of Peterson Integrated Geopositioning, LLC.