KEEPING THE PULSE ALIVE THROUGH HEART TRANSPLANTS AND FACE-LIFTS

James (Jay) M. Boyer, Lieutenant Commander, *United States Coast Guard*

BIOGRAPHY

James (Jay) M. Boyer is a Lieutenant Commander in the United States Coast Guard and is presently assigned as the Chief of Engineering at the Coast Guard Loran Support Unit (LSU) in Wildwood, New Jersey. He has completed tours as Chief of the Transmitters Engineering Branch at LSU, as Commanding Officer of the U.S. Coast Guard Cutter ROANOKE ISLAND in Homer, Alaska; Executive Officer of the U.S. Coast Guard Cutter SEDGE in Homer, Alaska; as Operations, Navigator, Communications, and Electronics Material Officer aboard the U.S. Coast Guard Cutter IRIS in Astoria, Oregon; and as a Project Engineer at the Coast Guard Research & Development Center in Groton, Connecticut. LCDR Boyer received his BSEE degree from the South Dakota School of Mines & Technology and his MSEE degree from the University of Rhode Island.

ABSTRACT

Loran "upgrade and modernization" efforts began in 1997 at the U.S. Coast Guard Loran Support Unit following the signing of a Federal Aviation Administration (FAA)/U.S. Coast Guard (USCG) Interagency Agreement. The Loran Recapitalization Project (LRP) effort will modernize the Loran-C radionavigation infrastructure in order to preserve operations as a transition system. In the future, the goal may be to reduce or completely eliminate personnel at the Loran Transmitting Stations, greatly reduce all required equipment maintenance, and eventually outsource all maintenance, operations, training, and depot repair of the entire Loran System.

This paper presents the LRP mission and goals, in addition to the engineering design and status of all major LRP sub-tasks. The focus will be on the "North American Loran-C System of the Future."

INTRODUCTION

The United States Coast Guard has a long history of involvement in establishing and maintaining the Aids to Navigation (AtoN) infrastructure of the United States. Technological advances and Congressional language in the 20th Century expanded the Coast Guard's role in providing AtoN to include radio navigation aids. The most robust and reliable of the Coast Guard's radio navigation systems has been, and continues to be, the Loran-C Radio-navigation System. The ascendancy and pervasiveness of the Global Positioning System (GPS) and its augmentations hastened the decision to terminate other radio navigation systems, including Loran-C. The decision is being re-evaluated based largely on recent instances of GPS jamming and interference, user support, and Congressional budget programming.

In 1996, Congress directed the Department of Transportation (DOT), in cooperation with the Department of Commerce (DOC), to submit a plan defining the future use of and funding for operations, maintenance, and upgrades of the Loran-C system. The 1999 Federal Radionavigation Plan (FRP) allows for the short-term operation of Loran-C while the U.S. government evaluates the long-term need for the system.

Starting in Fiscal Year (FY) 1997, Congress, via the FAA, provided funding to modernize and upgrade the North American Loran-C System. Between FY 1997 and FY 1999, more than $10.2M was provided to execute 21 Loran modernization and upgrade projects. Another $10.25M was received in FY00 and $17.425M in FY01, which is the foundation for the LRP. The brunt of the planning and execution of these projects has been borne by the Loran Support Unit (LSU) located in Wildwood, NJ.

WHY RECAPITALIZE THE LORAN-C SYSTEM?

This project will modernize the Loran-C radionavigation infrastructure in order to preserve operations as a transition system. In the future, the goal may be to reduce or completely eliminate personnel at the Loran Transmitting Stations, greatly reduce all required equipment maintenance, and eventually outsource all maintenance, operations, and depot repair of the entire Loran System. System performance and integrity of the Loran System cannot be sustained without initiating major modernization efforts.

The 11 U.S. operated 1960's era, labor intensive, vacuum tube transmitters constitute the highest risk factor. The vacuum tube transmitters are particularly problematic, both to quality of operations and to the safety of servicing personnel. Vacuum tube transmitters provide approximately 80% of the Loran coverage in the continental United States and all of the Loran coverage in Alaska. The failure of a tube transmitter at any one of several tube type Loran Stations would have a significant effect on Loran coverage. For example, loss of the tube transmitter at Dana, IN would eliminate coverage for the entire Midwest and a large portion of the Atlantic seaboard for the duration of that failure. Failure of the tube transmitter at Fallon, NV would have a similar effect on West Coast coverage. Loss of St. Paul or Tok, AK would eliminate coverage in the Northern Pacific and Gulf of Alaska, respectively. Several of these particular tube transmitters are already experiencing insidious problems and our support personnel are putting in tremendous extra hours to keep these pieces of equipment working.

Many experienced Loran personnel are also reaching retirement age or transferring out of the Loran program. This decreasing knowledge base increases the risk to personnel and to system operations. The age of components making up the Loran System has placed an ever-increasing workload on Coast Guard personnel. In the past 60 months, the Loran system has required an unprecedented 142 technical assists by LSU to avoid unusable time. These assists resulted in 20 Crisis Contingency Projects and 44 Engineering Change Proposals/Orders.

CURRENT STATUS

The LRP effort has been designated as a Coast Guard non-major systems acquisition. On November 8, 1999 a project staff consisting of ten new positions was approved, with the majority of the positions located at the Loran Support Unit. LSU also has seven contract personnel onboard with more than 120 years of combined Loran experience to provide invaluable technical assistance.

As a result of an Interagency Agreement between the USCG and FAA, LSU has been recapitalizing Loran since 1997. Every project completed has been a stepping-stone for Loran recapitalization. Since funding will be coming to the Coast Guard in yearly distributions and could be stopped at any time, the LRP effort will be treated the same way as all of our projects, only on a larger scale. In order to keep the scope of the LRP initiative manageable, the LSU has broken up the project into several smaller sub-projects.

The LRP initiative will modernize the U.S. Loran System to meet present and future radionavigation requirements while leveraging technology and funds to optimize operations, support, and training, and reduce the total cost of ownership. What exactly does this mean? A complete replacement and/or upgrade of all electronics systems at all 29 Loran Transmitting Stations (LORSTAs), 29 Primary Chain Monitor Set (PCMS) Sites, and 3 Control Stations (CONSTAs) located throughout North America.

The following is a status update concerning major LRP initiatives:

Completed Initiatives:

- ☐ Installation of the Loran Consolidated Control System (LCCS) throughout North America. **[Completed in FY99]**
- ☐ Replacement of all PCMS equipment. **[Completed in FY00]**
- ☐ Installation of the Automatic Blink System. **[Completed in FY00]**
- ☐ Installation of Command & Control Wireless Backup Communications. **[Completed in FY00]**
- ☐ Frequency Standard Replacement. **[Completed in FY01]**
- ☐ Installation of Time of Transmission Monitoring Equipment (TTM) for synchronization of Loran Master station to Universal Time Coordinated. **[Completed in FY01]**

Underway Initiatives:

- ☐ Tube-Type Transmitter (TTX) replacement at up to 14 locations (includes LSU & Loran Training Center).
- ☐ Service Life Extension of all Solid State Transmitters (SSX) at 17 locations.
- ☐ New/refurbished buildings at all sites receiving replacement transmitters.
- ☐ Tower replacement/modernization at selected sites.
- ☐ Replacement of all Loran Timing and Frequency Equipment (TFE), including integration of new cesium beam oscillators, Automatic Blink System (ABS), and Universal Time Coordinated (UTC) synchronization functionality.
- ☐ Installation of the new Remote Automated Integrated Loran (RAIL) command and control equipment.
- ☐ Installation of new Uninterruptable Power Supply (UPS) systems; one for the Operations Room equipment and one for the transmitter system.
- ☐ Replacement of all Loran Casualty Control receivers.
- ☐ Major upgrades and improvements to the Loran Consolidated Control System (LCCS).
- ☐ Enhancements to the capabilities of the Loran System.
- ☐ Improvements with the availability, continuity, integrity, and accuracy of the Loran System.

The following sections provide some LRP history and also snapshots of where the Loran-C system was prior to 1997 and where it is now.

MAJOR MODERNIZATION INITIATIVES: "BEFORE" & "AFTER"

The North American Loran-C system can be looked at as a system with three major components, each with its own suite of equipment. The first component is the Loran Station (LORSTA), which consists of the timing and transmitting equipment needed to transmit the Loran signal to the user. The second component is the Primary Chain Monitor Set (PCMS) site, which consists of monitoring equipment necessary to ensure the Loran signal seen by the user is within published tolerances. The third component is the Control Station, which consists of command and control equipment that is operated 24x7 and remotely connects to the LORSTA equipment and PCMS equipment for a Loran chain. Figure 1 shows the location of all North American Loran Stations and Control Stations. The sections that follow provide a snapshot of what Loran was "BEFORE" and what Loran will be "AFTER" completion of major LRP efforts.

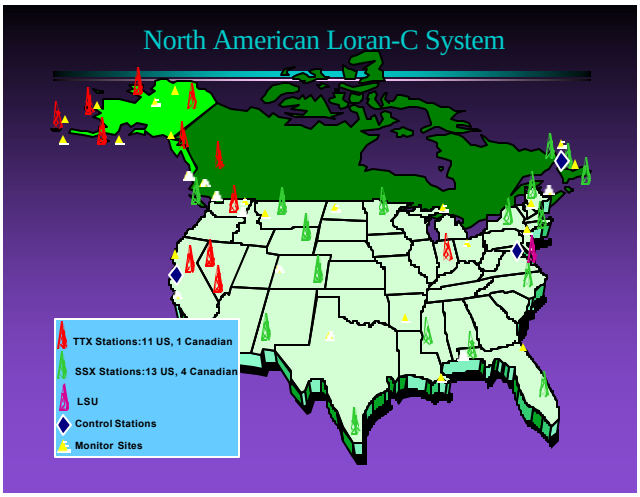

Figure 1: The North American Loran-C System

Control Stations - BEFORE & AFTER

Starting in 1997, all Control Station Equipment started being phased out by the Loran Consolidated Control System (LCCS). As reported in references 1 and 2, the six North American Control Stations; four in the U.S. and two in Canada that existed prior to 1997 have been consolidated to a total of three North American Control Stations: Alexandria, VA; Petaluma, CA; and St. Anthony, Newfoundland. The most recent of these consolidations took place in June of 2001 by consolidating the control functions at Kodiak, AK to Petaluma, CA. The U.S. Coast Guard alone is now saving over $1.5M/year in combined billet and support savings as a result of LCCS deployment.

PCMS Sites - BEFORE & AFTER

As reported in references 1 and 2, the Locus LRS-IIID receiver replaced the Austron 5000, 1960's vintage PDP-8 octal computer, antenna system, and notch filters at all 29 PCMS sites located throughout North America. In addition, new equipment racks were provided and the Elgar 102 Uniterruptable Power Supplies (UPS) were replaced with a Clary DT800R UPS.

Loran Stations - BEFORE

1960-1965 vintage Tube Type Transmitters (TTX) and 1976-1990 vintage Solid State Transmitters (SSX) are currently operating in the North American Loran System. 12 TTX and 17 SSX stations make up the inventory. 1970-1985 vintage timing and command and control equipment provides the critical timing and control signals to and from the transmitter system. The following Loran Station discussions will be divided into the Operations Room (timing/command & control equipment) and the transmitter system. Figure 2 shows typical Operations Room, TTX, and SSX equipment.

Figure 2: Operations Room, TTX, and SSX Equipment

Loran Stations (Operations Room) - AFTER

Numerous multi-year projects have been started within the last couple of years at LSU to modernize the LORSTA component of the Loran-C system. In FY01, LSU and LORSTA personnel completed the replacement of the HP 5061A cesium beam oscillators with new state-of-the-art HP 5071A oscillators. These new oscillators, considered the "heartbeat" of the Loran system, provide a nine percent improvement to the inherent repeatability of Loran. Typical drift rates are on the order of seven nanoseconds per day versus approximately 200 nanoseconds per day with the older technology. In addition, Time of Transmission Monitor (TTM) equipment has been installed at all Master LORSTAs as a tool to better synchronize Loran to Universal Time Coordinated (UTC). Figure 3 shows newly installed LORSTA oscillators and TTM equipment.

Figure 3: New Cesium Beam Oscillators and TTM Equipment (LORSTA Havre, MT)

LSU completed the installation of the Automatic Blink System (ABS) in FY00. ABS provides a signal integrity indication to Loran-C receivers. Signal integrity involves notifying the user through either "blinking" a secondary LORSTA or taking a master LORSTA "off air".

Work is well underway with the Remote Automated Integrated Loran (RAIL) System. RAIL is currently being Field Tested at LORSTAs Jupiter, FL; George, WA; Seneca, NY; Grangeville, LA; and Carolina Beach, NC. The RAIL system is a computer-based system that provides remote (via LCCS) and local command and control of LORSTA equipment. The specification for the requirements for our final form RAIL computer were recently advertised and the contract was awarded to Dell Computer Systems. The final form RAIL computer consists of a 993 MHz Pentium III processor with a GAGE Compuscope 1250 50Mhz PCI based digital oscilloscope card installed. Connections will be made via the future routers asynchronous ports. The operating system is Windows NT Version 4.0 and the RAIL software is written in Visual C++ with Roguewave Tools and Lab Windows/CVI Version 5.0 [4].

The RAIL system is being designed to integrate the various equipment installed at a LORSTA and automate as many functions as possible. By default, RAIL becomes the local command and control system for the LORSTA and the remote interface for LCCS. Here are some of the items being designed into the RAIL system:

- ☐ Replace the current Teletype communications system.
- ☐ Provide digital charts (replaces up to 14 mechanical, chart recorders).
- ☐ Replace the functionality of the Local Site Operating Set (LSOS).
- ☐ Interface with the Automatic Blink System.
- ☐ Interface with the Time of Transmission Monitor.
- ☐ Interface with the Cesium Beam Oscillators.
- ☐ Interface with the new Locus Casualty Control Receiver.

Examples of the prototype RAIL Graphical User Interface are shown in Figures 4 and 5. The RAIL Home Screen provides a complete picture of the current status of the LORSTA equipment. This screen contains all the data and alarms that must be monitored. A user can navigate to other screens that provide additional details.

Figure 4: RAIL Home Screen

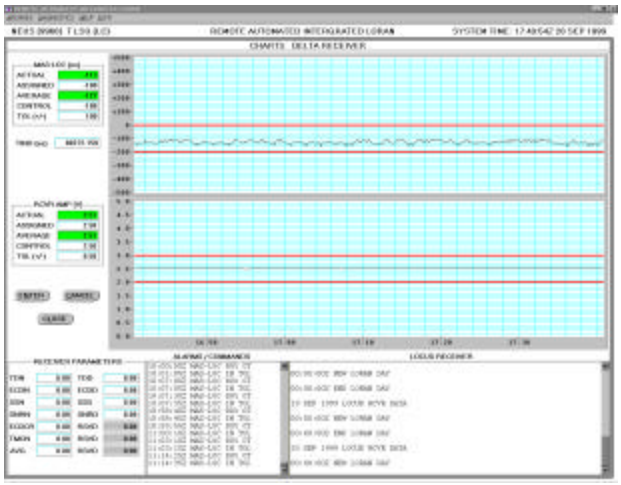

Figure 5: Example of RAIL Charts Screen

Final-form rack-mount RAIL hardware installations at the U.S. SSX stations will start over the next couple of months. In conjunction with the installation of RAIL, the Austron 2000 Casualty Control receivers will be replaced with the same Locus LRS-IIID monitor receivers used at all PCMS sites. Up to five Austron 2000 receivers will be replaced with one Locus receiver. Figure 6 shows the Austron 2000 and Locus receivers.

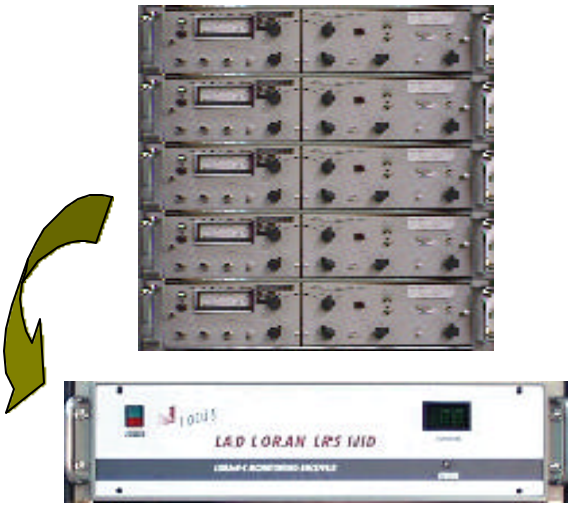

Figure 6: Austron 2000 and Locus LRS-IIID Casualty Control Receivers

Operations Room UPS system installations are also currently underway at all U.S. SSX stations. In conjunction with this installation, existing backup DC power systems, associated hardware and wiring, and conversion of all electrical distribution in accordance with National Electric Code (NEC) standards will be accomplished. The Operations Room UPS systems will not only provide battery backup to all operations room equipment (including the SSX Control Console), but will provide vital line filtering functions. Figure 7 shows one Operations Room UPS System. Transmitter UPS systems for selected SSX stations will also be procured and installed in FY02. The Field Test of a prototype transmitter UPS successfully ran a 32 Half Cycle Generator (HCG) SSX transmitter for 34 minutes on battery power! Figure 8 partially shows the transmitter UPS System.

Figure 7: APC Operations Room UPS System

Operations Room UPS's have been installed at Loran Stations Jupiter, FL; Grangeville, LA; Carolina Beach, NC; and Malone, FL; as well as at the Loran Support Unit. In this month of October installations will take place at Loran Stations Raymondville, TX as well Nantucket, MA. The installations will continue on at a rate of two a month until all SSX stations are complete. The installations at the present TTX stations will take place in conjunction with the TTX replacement project.

The Transmitter UPS has been installed at LSU and we are completing acceptance testing of this unit prior to installations at the SSX stations. The installations at the present TTX stations will take place in conjunction with the TTX replacement project.

Figure 8: APC Transmitter UPS System

A solicitation was prepared to replace the aging suite of Timing and Frequency Equipment (TFE) at all North American LORSTAs. Proposals were received and evaluated. Contract award took place at the end of September 2001. The award went to Timing Solutions Corporation of Boulder, Colorado. Timing Solutions Corp. is a timing reference company with significant experience in long and short term precision timing. They also have experience with the cesium oscillators that we are using at our Loran Stations, and with using GPS to synchronize signals to UTC.

The contract includes the equipment, spare parts, an extended warranty, documentation, and a training package. All of the equipment will be shipped to LSU for incoming inspection and staging for installation. The new suite of equipment will replace the current TFE providing "rock-solid" timing and will also include Automatic Blink System and Time of Transmission Monitor functionality

and provide an interface to the RAIL System. The new TFE system may resemble the suite of existing products shown in Figure 9.

As you can see, the Loran Station Operations Room is in the process of being completely replaced. What will the new Operations Room look like? Figure 10 shows what the new equipment may look like.

Figure 9: Potential new TFE system from Timing Solutions Corporation.

Figure 10: New TFE and RAIL Systems - Operations Room of the Future.

Loran Stations (Transmitter System) - AFTER

Not all of our efforts have been with LORSTA Operations Room modernization. For the past year and a half, LSU and Coast Guard Headquarters procurement specialists have been developing the solicitation for replacement transmitter systems. The primary thrust of this procurement is to replace the AN/FPN-44/45 Tube Type Transmitters at up to 14 locations. State of the art transmitters will enhance Loran Data Channel capability (discussed later in this paper), equipment reliability, and remote control capability, thereby increasing the potential to un-staff all Loran stations.

The biggest news for the transmitter project is that we have also had contract award on this purchase at the very end of September. The contract award went to Megapulse, Inc. in North Billerica, Massachusetts. Megapulse's general area of business is VLF/LF navigation, communication, and time and frequency transfer systems. Megapulse is best known as a major contributor to the development of Loran-C radionavigation and position fixing science and technology. Megapulse has been the sole supplier of solid state Loran-C transmitters over the last 20 years. All of the current solid state transmitters in the U.S. Coast Guard inventory were produced by Megapulse. Figure 11 shows what the new solid state transmitters from Megapulse that are replacing our aging tube-type transmitters may look like.

Figure11: Potential new solid state transmitter from Megapulse, Incorporated.

In addition to transmitter replacements, Coast Guard Headquarters, CG Facilities Design & Construction Center Pacific, and LSU have been working together to design the Loran transmitter site of the future. Each site receiving new transmitter systems will require major facility modifications. In FY01 building designs were completed for the first site to receive a new transmitter system and an effort will be completed to analyze and identify longevity or recapitalization issues for 24 USCG Loran-C transmitting antennae systems. Transmitter facility designs are centered around one major criterion - design the sites for unmanned operations. Figures 12 and 13 show a comparison between a typical manned LORSTA and what the unmanned Loran transmitting site of the future may look like.

Figure 12: A typical Loran Station.

Figure 13: Possible Loran Station of the Future.

A great success story in FY00 continued in FY01. This was the outcome of the Prototype Automated Loran Station (PALS) Field Test conducted at LORSTA Jupiter, FL. PALS developed and tested techniques, procedures, policies, equipment, systems, and infrastructure changes needed to reduce the operating costs of a Loran Station, as well as determining the capability of automating all routine functions. The primary goal of this project was to identify possible ways to reduce the operational costs while retaining required reliability and availability to the user.

In support of the PALS effort, several upgrades to station electronics were required. The following items were completed prior to the test:

(a) The Automatic Blink System was installed.

(b) LCCS Back-up Communications were installed.

(c) The RAIL prototype was installed.

(d) New HP 5071A cesium beam oscillators were installed.

(e) A prototype Operations Room UPS system was installed.

(f) A prototype transmitter UPS system was installed.

LORSTA Jupiter began the PALS field test on April 2, 2000. To date, the PALS field test has been a complete success. It has shown that a Loran Station with a solid state transmitter can be operated as an unmanned transmitter site, while continuing to meet the required 99.9% availability standard. The field test was originally scheduled for completion on October 31, 2000, but due to the overwhelming success, LORSTA Jupiter will continue in its present configuration. PALS Phase II expands testing of the PALS concept at additional Loran Stations in the Southeast U.S. (SEUS) Loran Chain: Loran Stations Grangeville, LA and Carolina Beach, NC. These stations have received the Operations Room UPS system and the RAIL System, but still need to receive the Transmitter UPS systems prior to the initiation of the PALS concept. Installation of this equipment into the LSU Master Configuration Baseline Equipment (MCBE) is also included with this phase of the project.

ENHANCED LORAN-C CAPABILITIES

The FAA has been directed to assess the continued development of Loran-C. The LSU, in cooperation with Stanford University, the Coast Guard Academy, and private FAA contractors is developing an enhanced Loran Communications Capability for GPS integrity and potentially for GPS correction data that meets the FAA's Wide Area Augmentation System (WAAS) requirements. Stanford University and FAA contractors are researching and developing the modulation scheme: Intrapulse Frequency Modulation (IFM) technique.

In conjunction with contractors and Stanford University, LSU will cooperate in the evaluation of viable data formats and technology to permit the modulation and demodulation of data messages transmitted via modulation of Loran signal pulse(s). Analysis of the effects of the various modulation schemes on cycle compensation, Envelope-to-Cycle Difference (ECD), and other parameters will be conducted. Also, the effects on legacy receivers will be analyzed.

On April 19 and 20, 2001, static tests were conducted using the LSU transmitter and a receiver at a fixed site in Waterford, CT, 193 nautical miles (NM) distant. Figure 14 shows the relative locations of the transmitter,

receiver, and the other LORAN transmitters in the area. For these tests a "canned" WAAS type message was transmitter. The results were excellent so we moved on to live flight trials. The details of the results of both the static tests are covered in detail in reference 5.

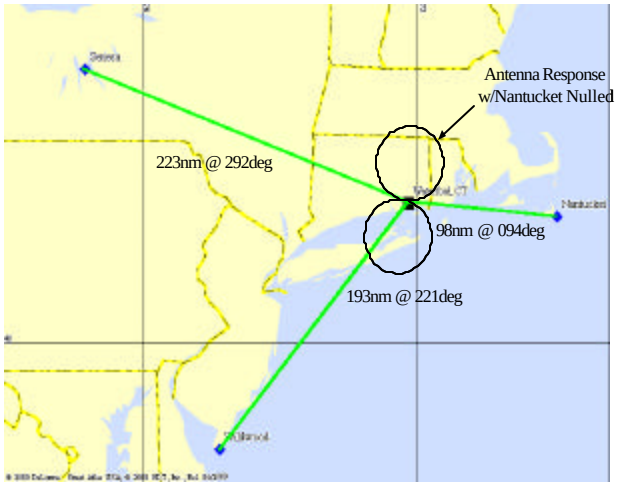

Figure 14: Locations of transmitters and receivers for static tests.

On May 10, 2001, flight tests were conducted using the King Air turboprop aircraft of the Ohio University Avionics Engineering Center. Two flight tests were conducted, the first departed Westerly, RI, went via Atlantic City, NJ, Wilmington, DE, Wilkes-Barre, PA, and returned to Westerly. On the leg from Wilmington to Wilkes-Barre, the Wildwood, transmitter went off-air and data was only collected to that point. The problem was fixed, and data was again collected during the return trip from Westerly to Ohio University in Athens, OH. Figure 15 shows the path and transmitter locations for the 10 May morning flight, In depth details of these results are in reference 5 as well. These tests too were a resounding success. Therefore further flight testing was conducted.

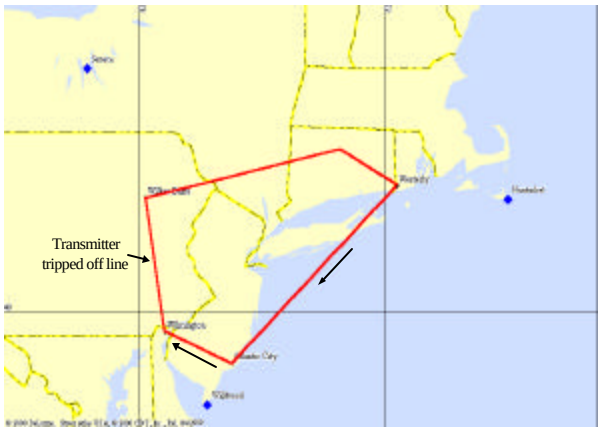

Figure 15: Paths and transmitter locations for the 10 May morning flight.

On June 6th and 7th, 2001, further tests were conducted using the FAA Technical Center's CONVAIR 580 turboprop aircraft operating out of Atlantic City. In these tests, the real time WAAS messages were successfully transmitted and received for the first time, and the antenna was steered in real time. These flight trials too were a great success, so we were now ready for our final flight trials in Alaska in August.

Live flight tests in Alaska took place in August 2001 with excellent results. Figure 16 depicts the flight paths for the Loran Data Channel tests and required coverage of the Tok signal. Further details of these results are reported separately in another paper at this conference and previously at ION-GPS in September 2001 in Salt Lake City, UT. See reference 6 for details.

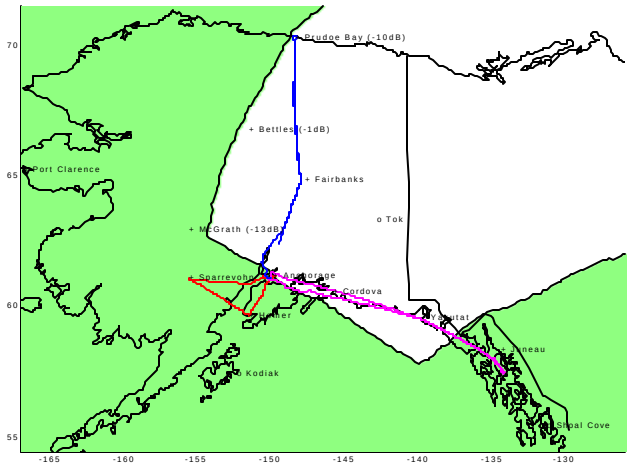

Figure 16: Fight Paths for LORAN Data Channel tests and required coverage of Tok signal**.** Green Shaded Area = Other signals stronger as predicted by smooth earth model. Numbers in ( ) are Tok signal strength relative to Port Clarence measured in 1988 FAA survey [12]. Paths of data collection flights are indicated by blue - Convair 580 on August 23rd, magenta - Convair 580 on August 24th, and red – Ohio University KingAir on August 24th.

In addition, the FAA and LSU will provide funds to the Coast Guard Academy to support continued development of a digital multi-chain navigation receiver. Figure 17 depicts how Loran-C may be integrated into the FAA's Wide Area Augmentation System (WAAS).

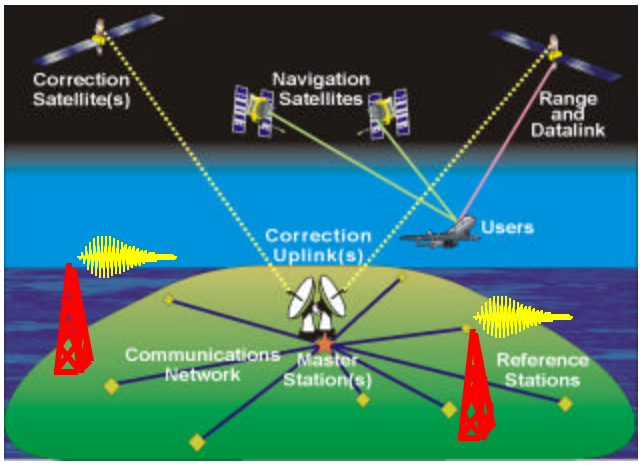

Figure 14: Loran-C to transmit WAAS data.

THE LORAN-C SYSTEM OF THE FUTURE…THE SKY'S THE LIMIT!

As you have just read, the North American Loran-C System is currently undergoing a complete face-lift. The Loran Recapitalization Project is paving the way to improve the availability, continuity, integrity, and accuracy of the world's premier radionavigation system.

FOR FURTHER INFORMATION, PLEASE CONTACT:

LCDR Jay Boyer
12001 Pacific Avenue
Wildwood, NJ 08260 USA
PHONE: +001-609-523-7350, FAX: 523-7264
JBoyer@lsu.uscg.mil
www.uscg.mil/hq/lsu/webpage/lsu.htm

ACKNOWLEDGEMENTS

I would like to thank all of the hard working engineers and technicians, military, civilian, and contractor, for all of their hard work on the LRP initiative. Thanks to our friends at G-SCE, G-SEC, G-ACS, G-OPN, G-WTT, FAA, NAVCEN, ELC, FD&CC Pacific, TRACEN Petaluma, CGA, MLCP, MLCA, District Seventeen, various ESUs/ESDs, all LORSTA personnel, and the Canadian Coast Guard, FY01 has been a very busy and successful year.

REFERENCES

1. LCDR Alan N. Arsenault & LT James (Jay) M. Boyer, " Loran Recapitalization Project (LRP) - Summer 2001 Update" Proceedings of the ION 57th Annual Meeting, Albuquerque, NM, June 2001.

2. LCDR Alan N. Arsenault, "Loran Recapitalization Project (LRP)," Proceedings of the 29th Annual Convention & Technical Symposium of the International Loran Association, Washington, DC, November, 2000.

3. LT Alan N. Arsenault, "U.S. Coast Guard Loran Consolidated Control System (LCCS)," Proceedings of the 26th Annual Convention & Technical Symposium of the International Loran Association, Ottawa, Canada, October, 1997.

4. LT Jim Koermer, "Modernizing the Loran-C System for the New Millennium," U.S. Coast Guard Radionavigation Bulletin, Spring/Summer Issue 2000, Number 34.

5. Dr. Ben Peterson, Mr. Ken Dykstra, Dr. Peter Swaszek, LT Jay Boyer, "High Speed LORAN-C Data Communications - June 2001 Update."Proceedings of the Institute of Navigation Annual Meeting, Albuquerque, NM, June 2001.

6. Dr. Ben Peterson, Mr. Ken Dykstra, Dr. Peter Swaszek, LCDR Jay Boyer, LT Kevin Carroll, & Mr. Mitch Narins, "High Speed Loran-C Data Communications - Flight Test Results." Proceedings of the Institute of Navigation - GPS Annual Meeting, Salt Lake City, UT, September 2001.