The eLoran Evaluation and Modernization Program

Acknowledging the Past Looking to the Future

eLoran

Mitchell J. Narins

Program Manager

Federal Aviation Administration

Navigation Services

International Loran Association Conference

Orlando, Florida

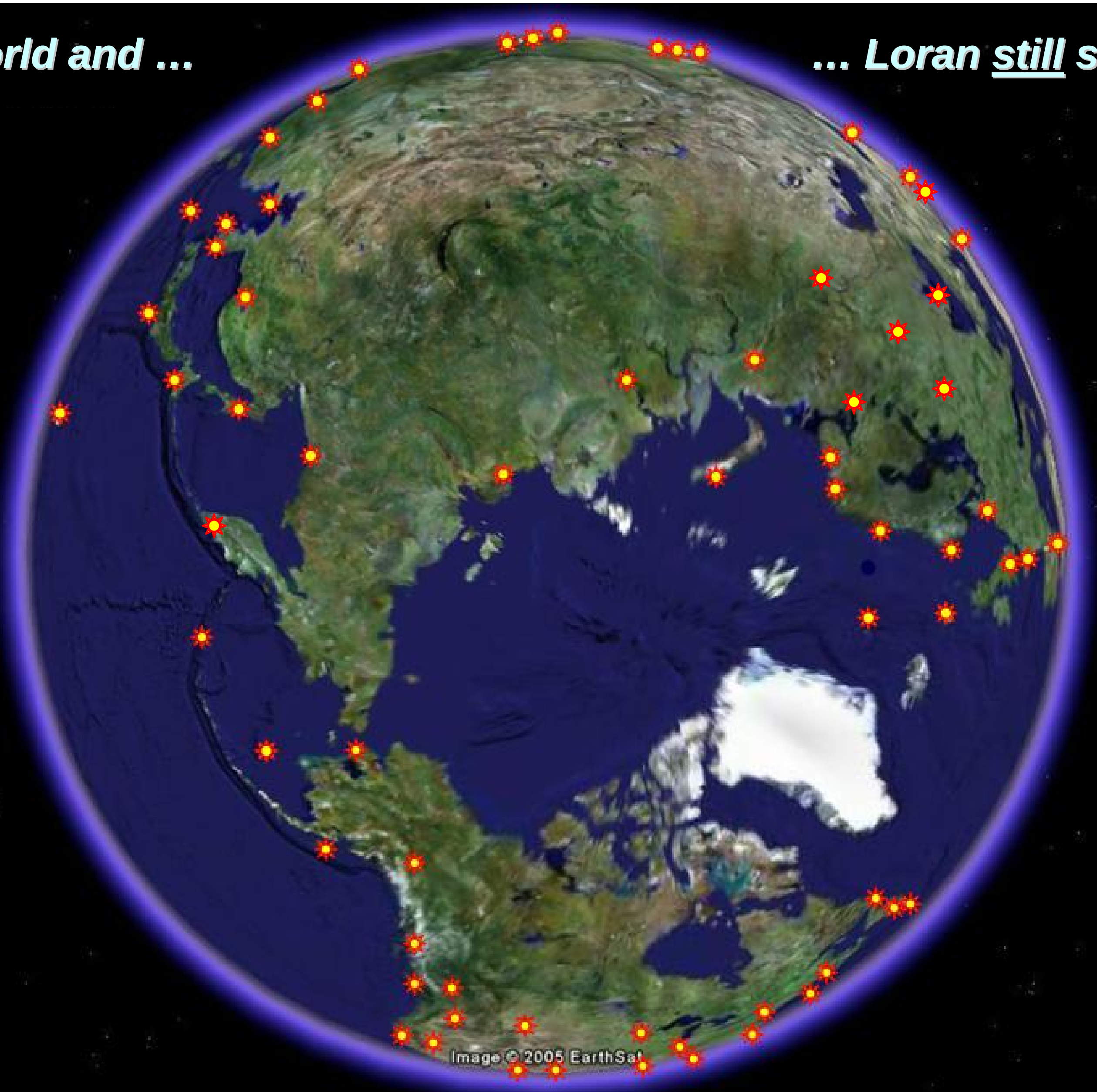
16 October 2007

eLoran Program - Logo Collection – Fall 2007

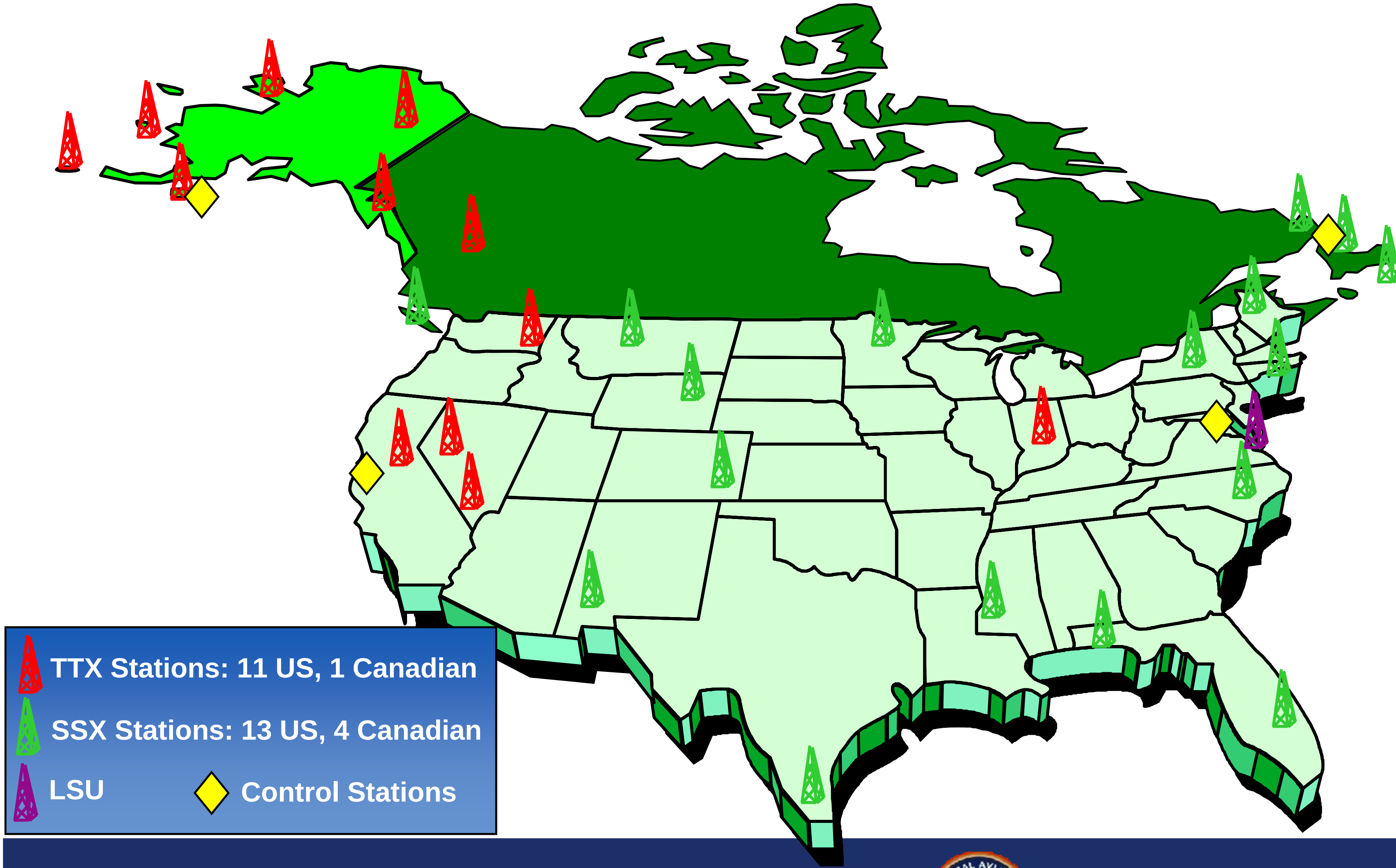
FAA NAVIGATION INTEGRATED PRODUCT TEAM
William J. Hughes FAA Technical Center
FEDERAL AVIATION ADMINISTRATION
UNITED STATES COAST GUARD 1790
UNITED STATES COAST GUARD Navigation Center
UNITED STATES COAST GUARD HOME OF THE LORANIMALS LORAN SUPPORT UNIT
ASD
USNO
NIST
FEDERAL AVIATION ADMINISTRATION Loran-C UNITED STATES COAST GUARD
the VOLPE center
UNITED STATES COAST GUARD ACADEMY 1876
COMMISSIONERS OF NORTHERN LIGHTHOUSES 1786
IRISH LIGHTHOUSE SERVICE
Liberté • Égalité • Fraternité RÉPUBLIQUE FRANÇAISE
Megapulse
International Loran Association
Illgen
Illgen Simulation Technologies, Inc.
NORTHROP GRUMMAN
DEFINING THE FUTURE
Rockwell Collins
Booz | Allen | Hamilton
Symmetricom
TIMING SOLUTIONS
ALION SCIENCE AND TECHNOLOGY
JJMA An Employee Owned Company
WR SYSTEMS
LOCUS
SI-TEX MARINE ELECTRONICS
reelektronika
FreeFlight SYSTEMS
Raytheon
PRIFYSGOL CYMRU UNIVERSITY OF WALES BANGOR 1884
UNIVERSITY OF CALGARY
PETERSON INTEGRATED GEOPOSITIONING
LELAND STANFORD JUNIOR UNIVERSITY ORGANIZED 1891
1804 OHIO UNIVERSITY
TU Delft
Technische Universiteit Delft
UNIVERSITY OF Rhode Island
UNIVERSITY of ALASKA
Many Traditions One Alaska
ELSIS AG
electronic logistics & security information systems
CrossRate TECHNOLOGY
VT Communications
AMA
UrsaNav
Follow the Stars
chronos TECHNOLOGY
HELIOS

It's a big world and …

… Loran still serves half of it!

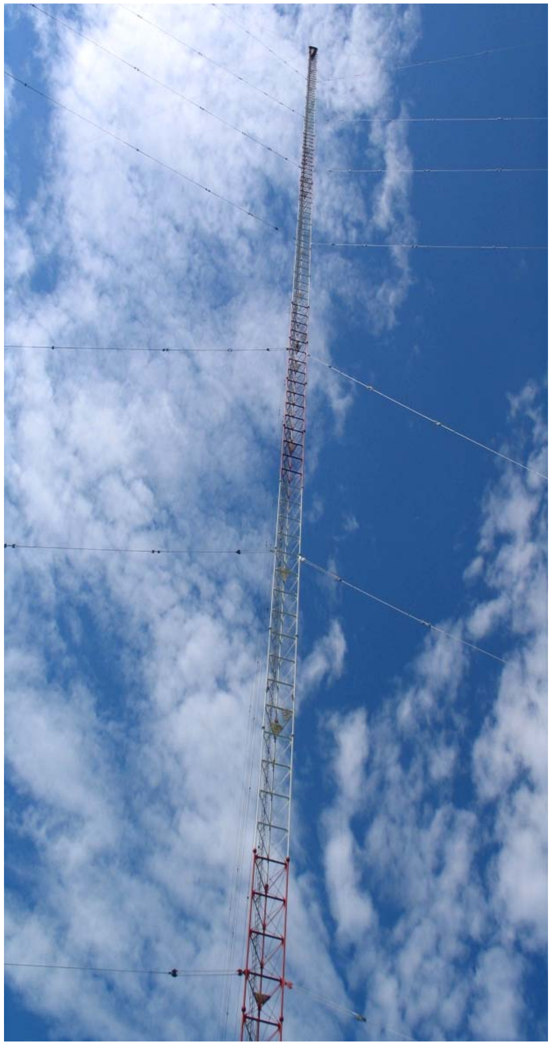


From Whence We Came - Loran-C 2001



Loran-C (according to the FRP)

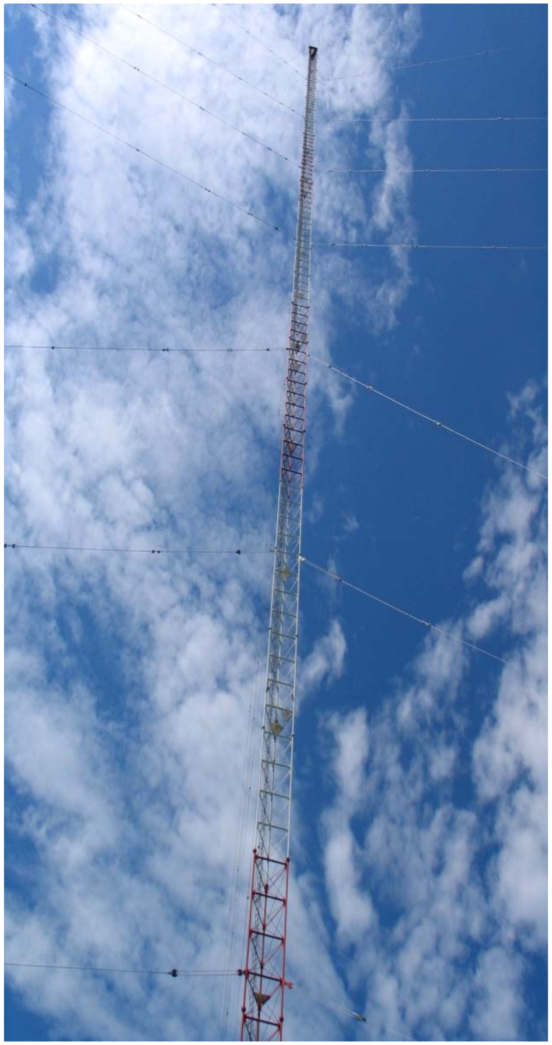
- **A hyperbolic radionavigation system…**
  - …operating between 90 kHz and 110 kHz…
  - …that uses a very tall antenna…
  - …that broadcasts primarily a groundwave
  - …at high power…
  - …that provides both lateral position…
  - …and a robust time and frequency standard
- **A supplemental system for enroute navigation in the US National Airspace System (NAS)**
- **A system for maritime navigation in the coastal confluence zone (CCZ)**
- **A Stratum 1 frequency standard (i.e., 1 x 10^{-11}) that also provides time within 100 ns of UTC (USNO)**



Loran-C (according to the FRP)

- **Provides:**
  - **A predicted 2drms accuracy of 0.25 nm (460 m) and a repeatable accuracy of 60-300 ft (18-90 m)***
  - **An availability of 99.7% (based on triad operation)***
  - **A level of Integrity based on exceeding certain operational parameters measured at the transmitters and at system area monitor sites.**
  - **Continuity no greater than 99.7% (its availability), but potentially worse depending on receiver characteristics and geometry of the triad being used, and…..**

If this was all that Loran could do, the US would have turned it off!



2001: …A Growing Awareness…

- **The Global Positioning System (GPS) is a major national and international asset with expanding and evolving uses in precision timing and in positioning-navigation services.**

- ***"There is a growing awareness within the transportation community that the safety and economic risks associated with loss or degradation of the GPS signal have been underestimated … Public policy must ensure that safety [and economic viability] are maintained in the event of loss of GPS."****

*"Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System," Volpe Center, August 29, 2001 – ***Released September 10, 2001!***

GPS Vulnerability – An Accepted Fact

- **GPS is vulnerable to unintentional and intentional disruptions covering small to extensive areas, for durations from minutes to days**
- **Illustrations:**
  - 1-5 watt intermittent jammers (confound detection) capable of disrupting the GPS signal are available today to place in harbor and shore areas
  - "Jamfest" testing in White Sands, NM (2005) recorded cell phone disruption within 20-25 min of jamming onset
  - San Diego disruption (Jan 07)
- **US public policy already requires that backup systems or procedures be available to mitigate GPS disruptions in critical applications (National Security Presidential Directive 39 Fact Sheet, December 15, 2004)**

US Loran-C Policy – 2001

"*While the Administration continues to evaluate the long-term need for continuation of the Loran-C radionavigation system, the Government will operate the Loran-C system in the short term. The U.S. Government will give users reasonable notice if it concludes that Loran-C is not needed or is not cost effective, so that users will have the opportunity to transition to alternative navigation aids.* With this continued sustainment of the Loran-C service, users will be able to realize additional benefits. Improvement of GPS time synchronization of the Loran-C chains and the use of digital receivers may support improved accuracy and coverage of the service. Loran-C will continue to provide a supplemental means of navigation. Current Loran-C receivers do not support non precision instrument approach operations."

– ***Para 3.2.5 B 1999 US Federal Radionavigation Plan***

2002 – FAA Loran Murder Board LORIPP and LORAPP Formed!

- **Loran Integrity Performance Panel (LORIPP)**
  - Co-Chairs
    - Dr. Per Enge, Stanford University
    - Dr. Ben Peterson, Peterson Integrated Geopositioning
  - Challenge: Determine whether an *eLoran* system can meet the stringent integrity requirements for non-precision approach in the US National Airspace System
  - Requirement: The probability of the system providing hazardous or misleading information < 1 x 10^{-7} per hour
  - Methodology: Utilize the processes and procedures successfully followed by WAAS

2002 – LORIPP and LORAPP Formed!

- **Loran Accuracy Performance Panel (LORAPP)**
  - Co-Chairs
    - Dr. Ben Peterson, Peterson Integrated Geopositioning (PIG)
    - CAPT Gordon Weeks, CO, USCG Loran Support Unit
  - Challenge: Determine whether an *eLoran* system can meet the stringent accuracy requirements for harbor entrance and approach
  - Requirement: The positioning accuracy of the system to be 8 – 20 meters.

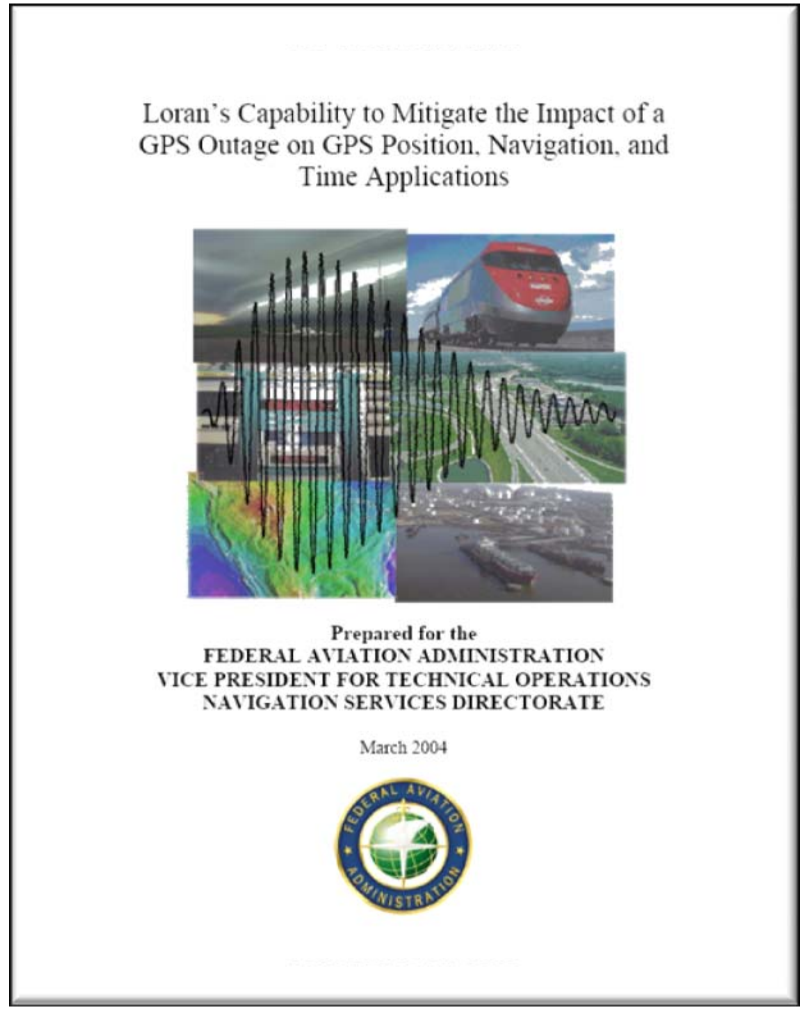
Loran- C vs. *eLoran* Metrics
FAA 2002 "*Murder Board*" Requirements

	Accuracy	Availability	Integrity	Continuity
Loran-C Definition of Capability* (US FRP)	0.25 nm (463 m)	0.997	10 second alarm/ 25 m error	0.997
FAA NPA (RNP 0.3)** Requirements	0.16 nm (307 m)	0.999 – 0.9999	0.9999999 (1 x 10-7)	0.999 - 0.9999 over 150 sec
US Coast Guard HEA Requirements	0.004 - 0.01 nm (8 – 20 m)	0.997 - 0.999	10 second alarm/ 25 m error (3×10^{-5})	0.9985 – 0.9997 over 3 hours

* Includes Stratum 1 timing and frequency capability
** Non-Precision Approach Required Navigation Performance

2004: Loran Evaluation Team's Conclusion

"The evaluation shows that the modernized Loran system could satisfy the current NPA, HEA, and timing/frequency requirements in the United States and could be used to mitigate the operational effects of a disruption in GPS services, thereby allowing the users to retain the benefits they derive from their use of GPS."



Loran's Capability to Mitigate the Impact of a GPS Outage on GPS Position, Navigation, and Time Applications

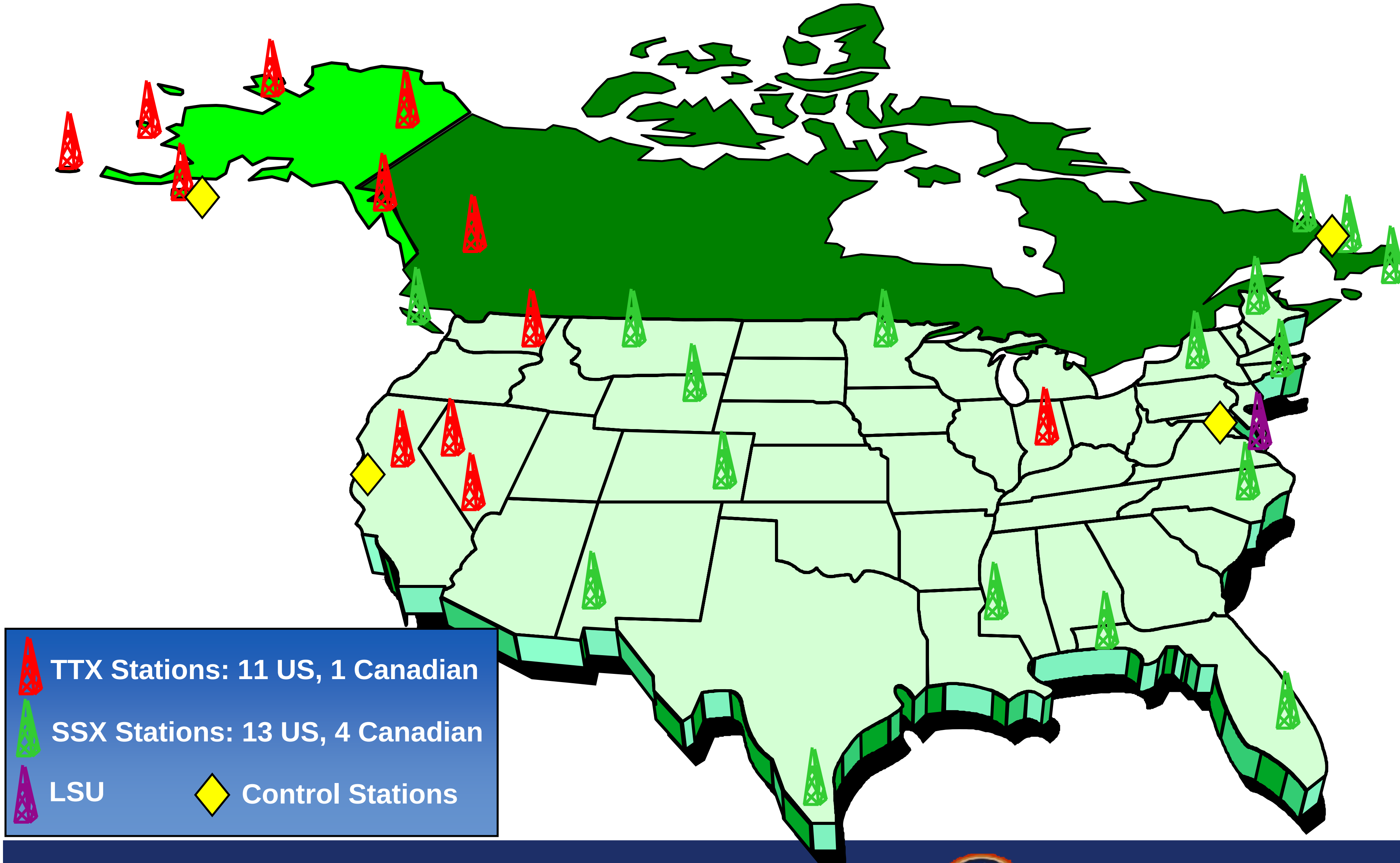
Prepared for the
FEDERAL AVIATION ADMINISTRATION
VICE PRESIDENT FOR TECHNICAL OPERATIONS
NAVIGATION SERVICES DIRECTORATE

March 2004

A Real Turning Point was Reached

Celebrate the Achievements!

Remember Loran-C in 2001

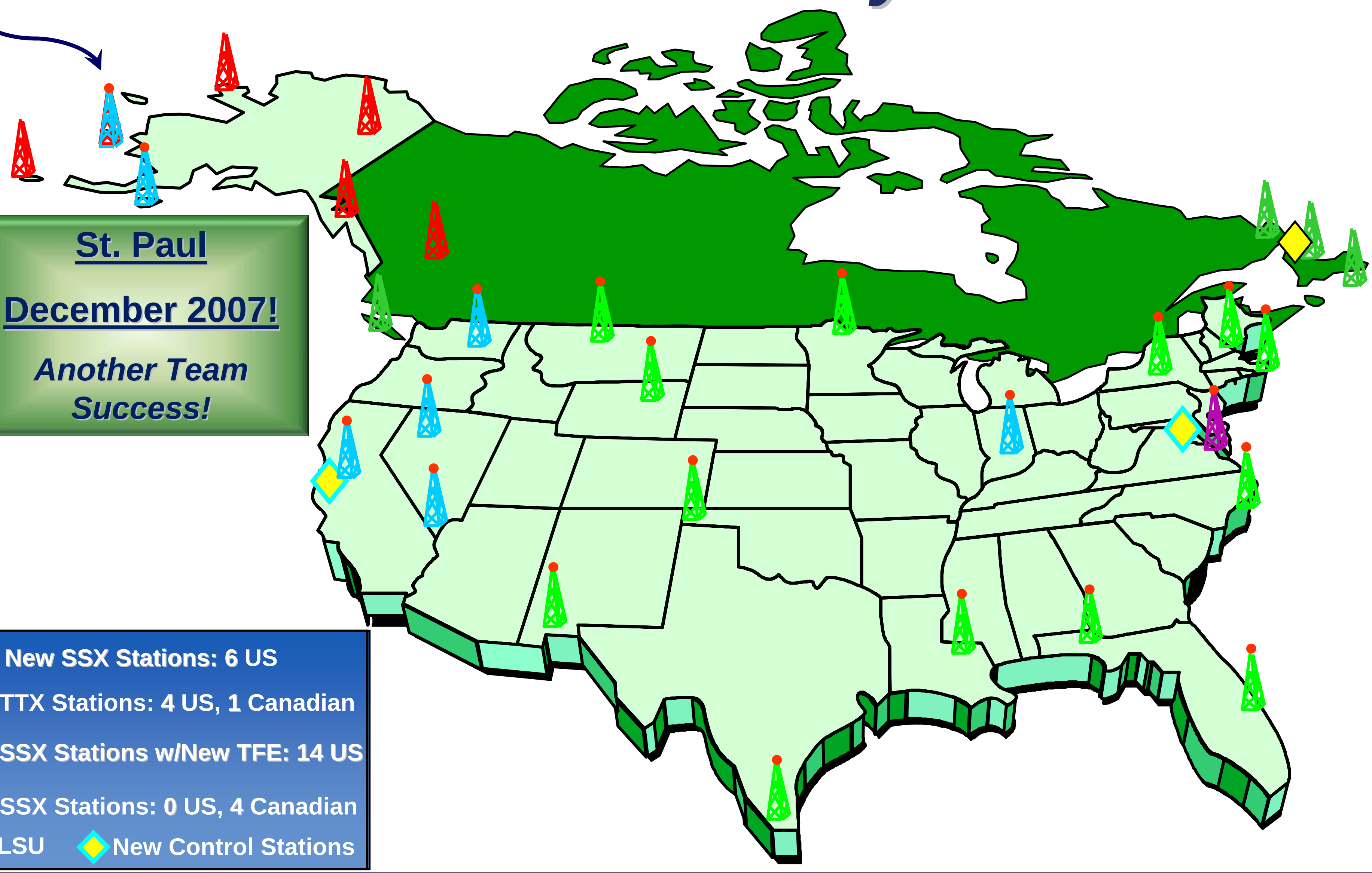


North American Loran System - 2008

St. Paul

December 2007!

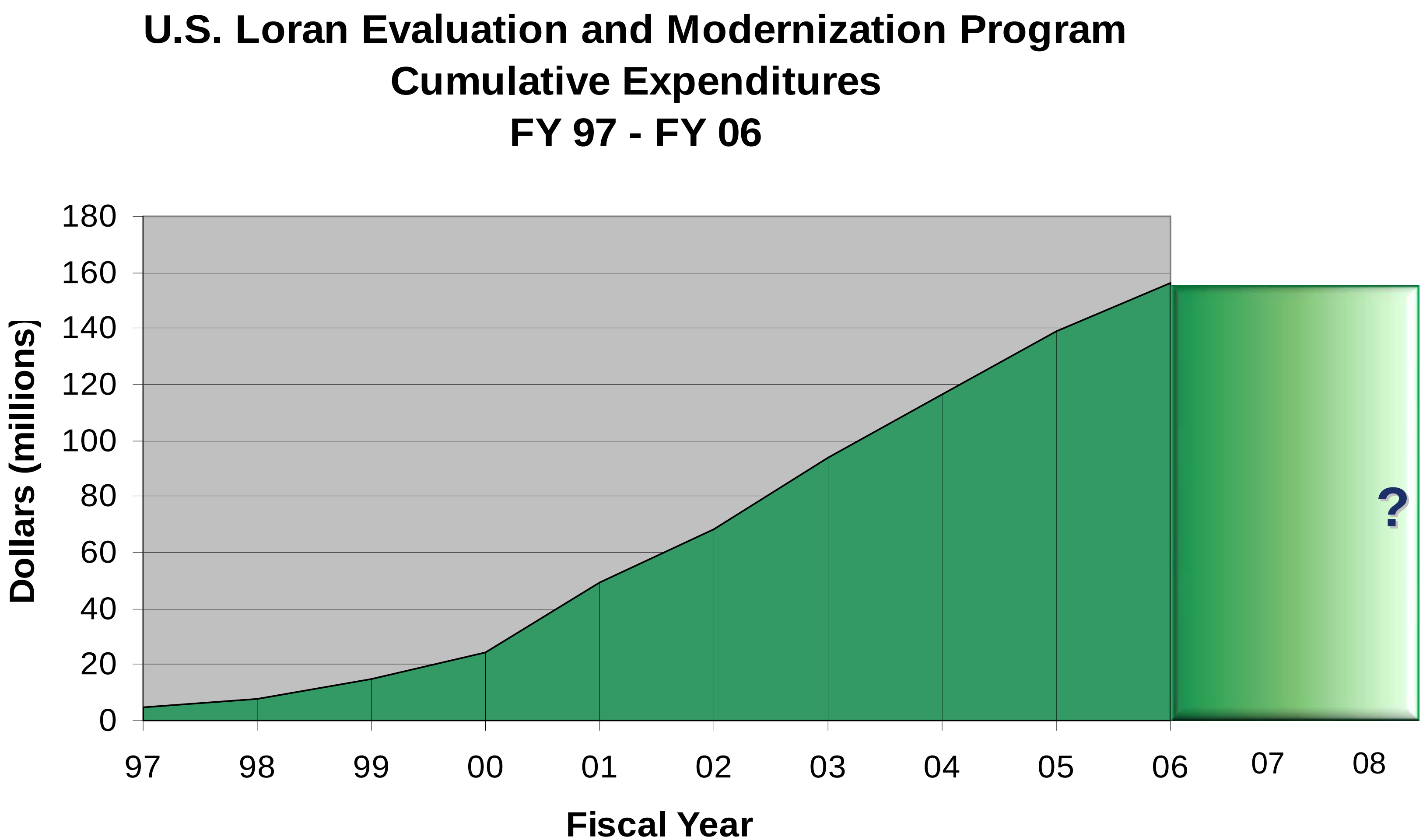
Another Team Success!



- New SSX Stations: 6 US
- TTX Stations: 4 US, 1 Canadian
- SSX Stations w/New TFE: 14 US
- SSX Stations: 0 US, 4 Canadian
- LSU
- New Control Stations

Why Teamwork Remains a Key Element

How we made it *so many* years



Independent Assessment Team Established Charter:

- **Conduct independent assessment of Loran**
  - Assemble team of experts to review and assess continuing need for the current US Loran infrastructure
  - Report findings and recommendations directly to Under Secretary of Transportation for Policy
- **Assess information from recent studies and working groups' reports**
  - Use, for example, Loran Accuracy Performance Panel (LORAPP) and Loran Integrity Performance Panel (LORIPP) working group reports; studies by Volpe Center, FAA, USCG, HSI, others
  - Supplement with information from key stakeholders and others as appropriate

2006: Loran Independent Assessment Team

Dr. Bradford Parkinson – Stanford University – Chair

James Doherty – IDA, former USCG NAVCEN – Exec Director

John Darrah – IDA, former Chief Scientist AF Space Command

Arnold Donahue – NAPA, former OMB

Dr. Leon Hirsch – IDA Research Staff Member

Donald Jewell – IDA, former AF Space Command

Dr. William Klepczynski – IDA, former US Naval Observatory

Dr. Judah Levine – NIST Time Services

L. Kirk Lewis – IDA, Executive Director GPS IRT

Dr. Edwin Stear – IDA, former VP Boeing and AF Chief Scientist

Philip Ward – IDA, former Texas Instruments (GPS receivers)

Pamela Rambow – IDA Research Assistant

IAT Key Questions

- **To what degree, and in what way, is GPS vulnerable to persistent outages or local transient discontinuities?**
- **What are the impacts of such events for safety-of-life, economic disruption, or inconvenience?**
- **What techniques or alternatives are available to ameliorate such situations?**
- **In what time frame and at what costs (and to whom) could such methods be implemented?**
- **To what degree would we expect the affected users to take advantage of these methods?**
  - What is the proper Government role?
- **What course of action is most reasonable for DOT?**

IAT Government Decision Options

- **Terminate Loran**
  - Declare end date for operations
  - Mothball or decommission infrastructure (~$150M)
- **Continue status quo***
  - No stated Government position
  - Continue current uncertainty & resulting turmoil
- **Decide that *eLoran* is primary GPS backup**
  - Complete *eLoran* upgrade
  - Establish *eLoran* as primary backup for 15-20 years

•****Status quo option means "terminate"***

• ***NO DECISION IS A TERMINATE DECISION***

•***Manufacturers and Users will not equip***

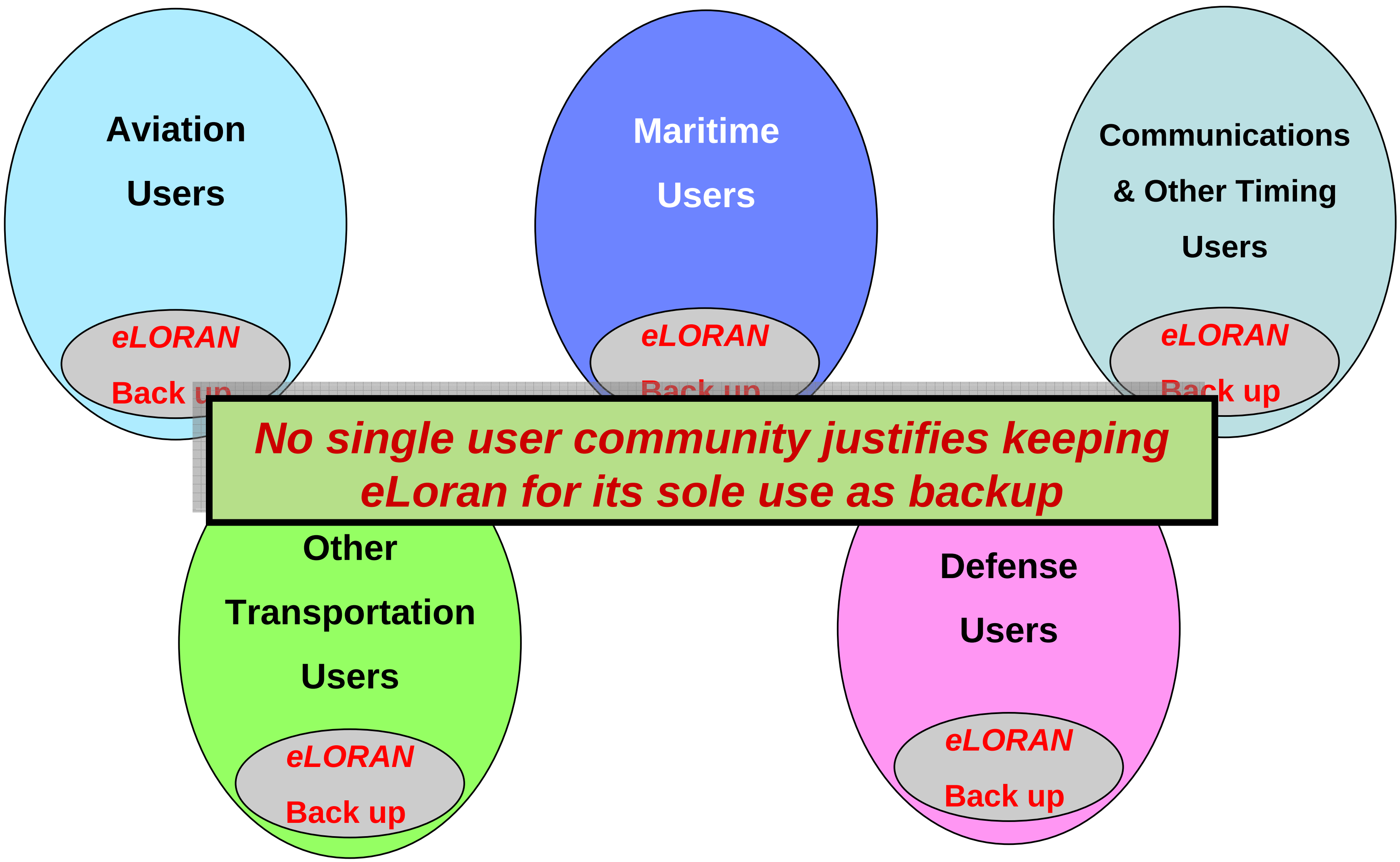
Information Presented to IAT: Backup Alternatives to GPS

•GPS needs dissimilar, complementary, multi-modal, and independent source of GPtS & PNT

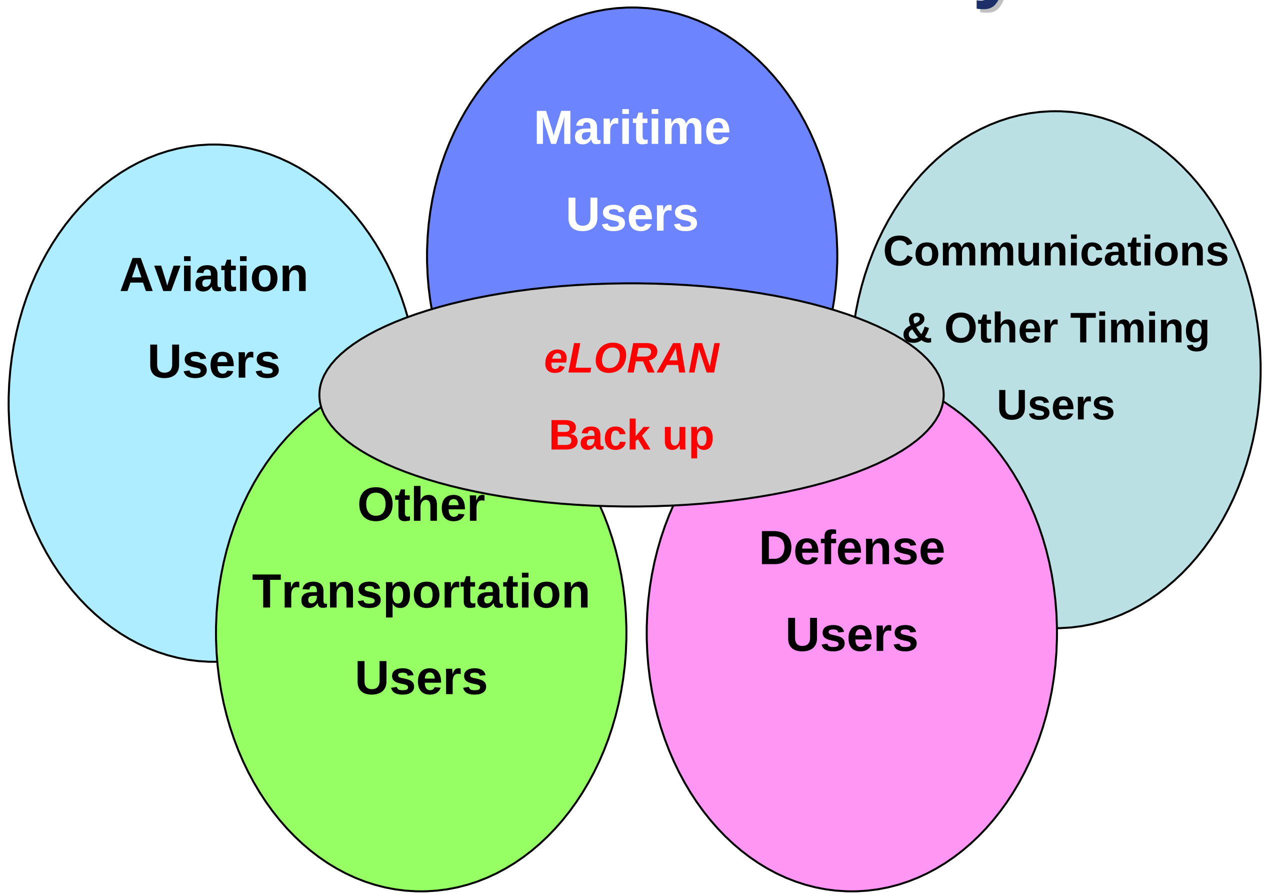
Service	PNT	Multi-Modal	Independent of GPS		
			System	Signal	User
Galileo	✓	✓	✓	✗	✗
eLoran	✓ (no 3D)	✓	✓	✓	✓
DGPS	✗	✓	✗	✓	✗
SBAS	✗ ✓	✓	✗ ✓	✗	✗
Radar	✗	✗	✓	✓	✓

•eLoran is frequency and signal diverse as well as much more powerful (virtually unjammable)

Information Presented to IAT: Current Situation – GPS is Primary



Information Presented to IAT: Combined Community Need



An ensemble of users needing backup could support continuing eLoran

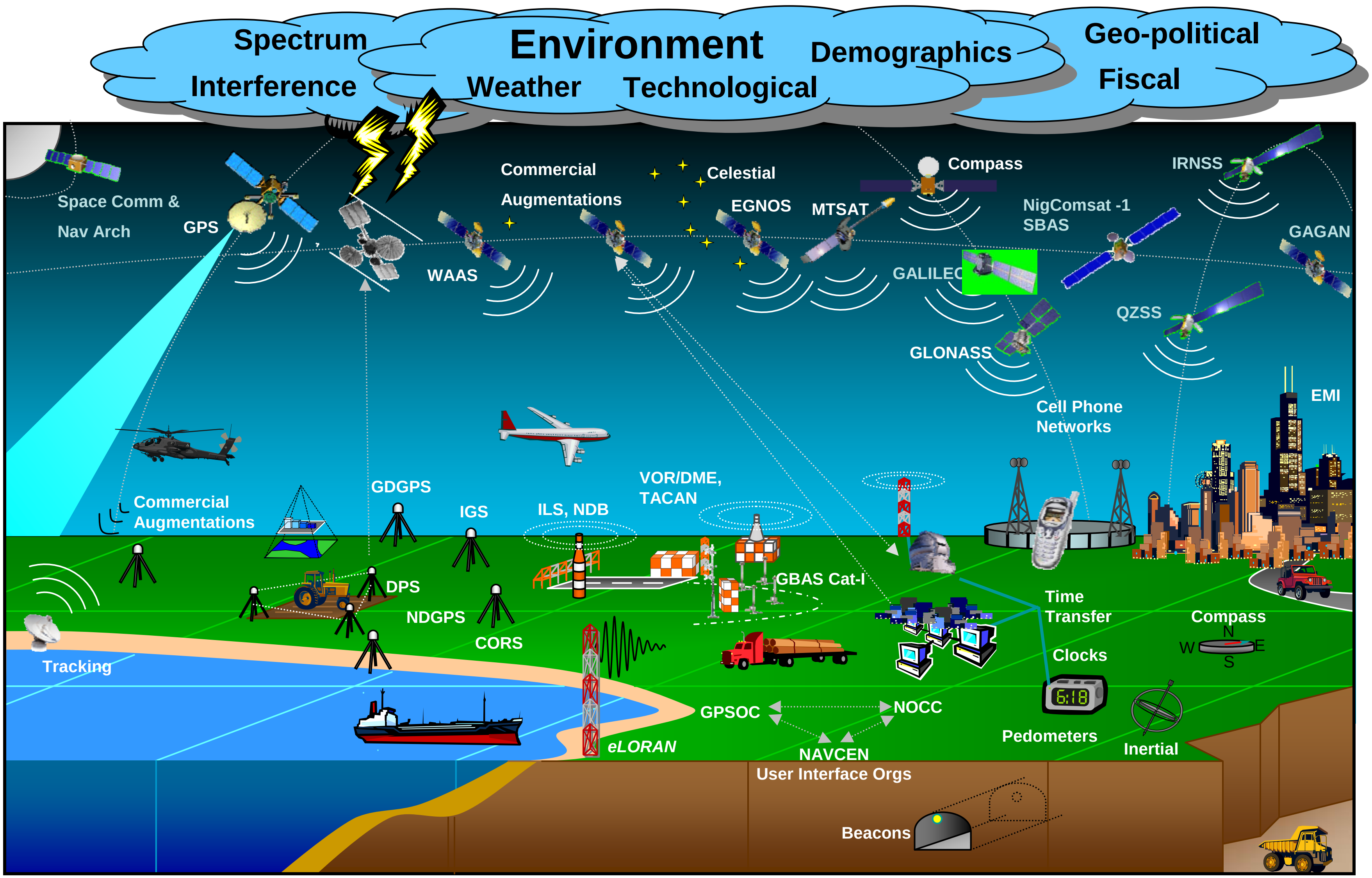
The IAT Conclusions not yet released;

- ***However:***
  - ***US House of Representatives*** *Department of Homeland Security Appropriations Committee*
    - *The Committee also understands that in late 2006, DOT convened an Independent Assessment Team, in cooperation with DHS, to complete yet another evaluation of Loran C. The Team concluded that Loran C should be retained and modernized to serve as a long term back up for GPS.*
  - ***US Senate*** *Department of Homeland Security Appropriations Committee*
    - *The Committee understands that a group composed of officials from the Departments of Homeland Security and Transportation, and other Federal agencies met earlier this year and unanimously agreed that the United States should maintain the Loran system.*

IAT Conclusions – Not Yet Released

- ***However:***
  - DHS Letter to US Senate Authorization Committee (20 Sept 2007)
    - *The Spaced-Based Positioning, Navigation and Timing (PNT) Executive Committee, co-chaired by the Deputy Secretaries of the Department of Defense (DOD) and the Department of Transportation (DOT), concurred with a joint Department of Homeland Security (DHS)-DOT policy recommendation* ***to pursue "enhanced" LORAN (eLoran) as a national PNT backup to the Global Positioning System (GPS) for the U.S. homeland.*** *As a result, DOT and DHS are jointly preparing proposed transition plans to move operations, maintenance, construction, and funding for the Loran system from DHS /Coast Guard to another government agency so that eLoran may be implemented, upon which the Secretary of Homeland Security and the Secretary of Transportation can base a final decision on the future of the current Loran system,* ***DHS and DOT are in the process of completing these actions and are scheduled to make a joint announcement of a decision on Loran by the end of this year****.*

Also Fits Nicely in Future PNT Evolved Architecture Baseline

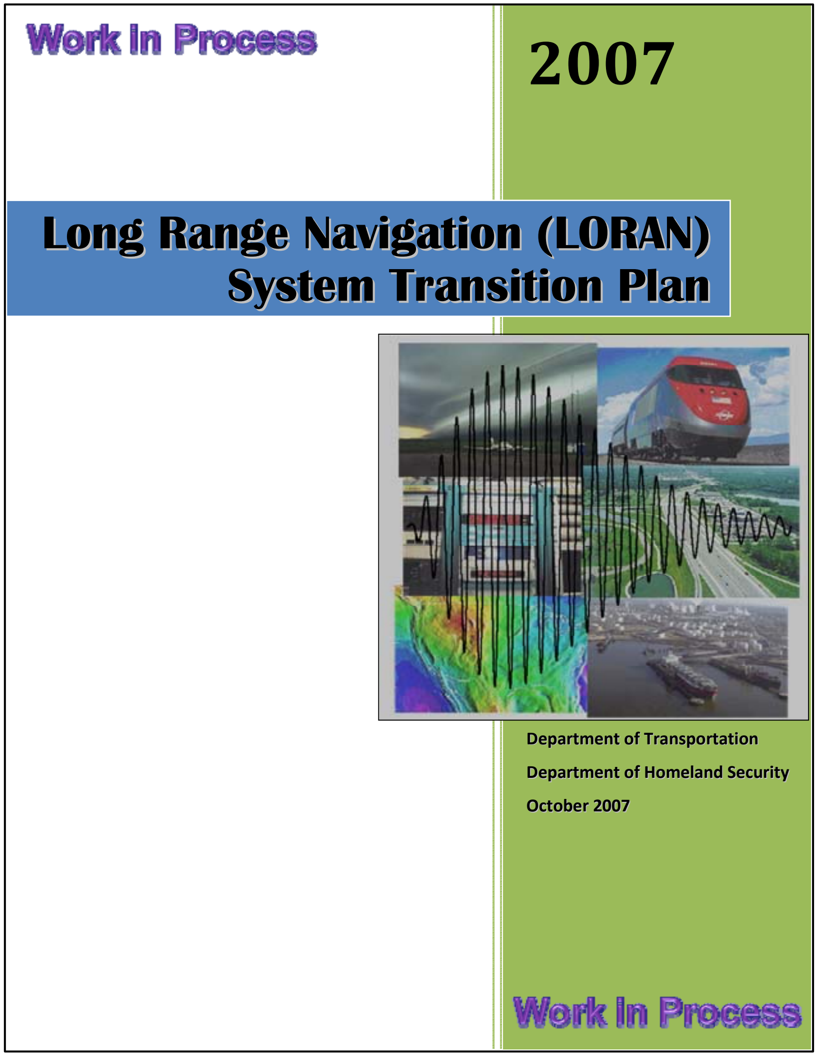


Standards Reference Frames Cryptography Science & Technology USNO NIST NGA NGS

Star Catalogs Launch Mapping/Charting/Geodesy NSA Industrial Base

Electro Optical Info. Modeling Laser Ranging Network Policies Testing

eLoran Transition Plan in Process



Key Issues to be Addressed

1. Outline of the steps necessary to transition the current Loran-C system to an enhanced Loran (*eLoran*) system that will support both the current Loran-C user communities and a broader set of position, navigation, and time users that require higher levels of accuracy, availability, integrity, and continuity than currently provided by Loran-C;
2. Outline of the steps necessary to transition the United States Coast Guard's current Loran system responsibility and authority to another U.S. Government agency; and
3. Establishment of the means to operate the system in the most effective and efficient manner.

eLoran Transition Plan in Process

Key Objectives

- Document system requirements and define an optimal concept of operations (CONOPS)
- Ensure quality and continuation of Loran PNT services and facilitate *eLoran* capabilities
- Reduce “total cost of ownership” by ensuring that the *eLoran* system will be operated in the most efficient and effective manner at a much reduced
- Reduce number/involvement of US Government personnel

Key Milestones

- Establish initial and final operational capability milestones of *eLoran* PNT services that will support multiple users communities

Key Ancillary Products

- *eLoran* Mission Need Statement
- *eLoran* System Requirements Document
- *eLoran* Signal Specification

Loran System Evolution Continues

*TBD as part of Transition Plan

Status Today	Loran-C	Modernized Loran	*eLoran*
Aviation			
EnRoute (RNP 2.0 ->1.0)	Yes	Yes	Yes
Terminal (RNP 0.3)	No	No	Yes
NPA (RNP 0.3)	No	No	Yes
Maritime			
Ocean	Yes	Yes	Yes
Coastal Confluence Zone	Yes	Yes	Yes
HEA	No	No	Yes
Time/Freq			
Stratum 1 Frequency (1×10^{-11})	Yes	Yes	Yes
Time of Day/Leap Second/ UTC Reference	No	Yes	Yes
Precise Time [<50 ns UTC(USNO)]	No	No	Yes

Summary of Necessary Major Changes – Loran-C → *eLoran*

Area	Major Change
Radionavigation policy	Airport survey to generate ASF database for NPA/enroute
	Harbor entrance survey to generate ASF database for HEA
Operational Doctrine	Time of transmission (TOT) control
	Off air to indicate out-of-tolerance conditions at station
	Continuous phase changes to correct timing errors at stations
	Long-term synchronization to UTC using at least one GNSS-independent means
System Equipment	All stations use solid state transmitters (SSX)
	New uninterruptible power supplies and antenna coupler
	New timing and frequency equipment (TFE) to control timing
	New cesium clocks (three per station)
	Improved monitor network using existing sites
	Loran Data Channel (LDC) - ability to add digital data to the Loran signal
	Installation of transmitter control set (TCS) and remote automated integrated Loran (RAIL) equipment allows for the monitoring and control of all station equipment
User Equipment	Ability to incorporate propagation delay tables for specific applications
	All-in-view capability (use all available stations regardless of chain)
	Improved cross rate interference mitigation
	Improved impulsive noise mitigation
	Ability to demodulate ninth pulse LDC communications
	Antennas (H field) to mitigate precipitation static (when necessary)

It's about time -- really!
The eLoran Clock

- **Loran Stations (US and Canadian) and the Loran Support Unit each have 3 new cesium clocks**
  - ***90**** very high stability clocks geographically dispersed across North America
- **All *90* clocks can be steered to UTC (USNO) (independently from GPS) with great accuracy**
- **Establishing a robust Loran clock akin to, but totally independent from the GPS clock, is a valuable national asset**

***(29 Loran Stations + LSU) x 3**

Findings - Precision Timing

- *"GPS serves as a precision timing source for 100,000,000 cell phone customers in North America and 250,000,000 worldwide."*

  B. Greene, VP, Lucent, brief to DOC GPS Forum, Jan. 2006

- *"Under no circumstances should the Government place total reliance on GPS and completely abandon its plans to continue to deploy eLoran."*
  - **Sprint Nextel Corp., comments in Federal Register, Feb. 2007**

- *"The proposal to develop an eLoran system would effectively address the need for a nationwide, distributed backup system. It is not clear that any widely reliable backup system exists now."*

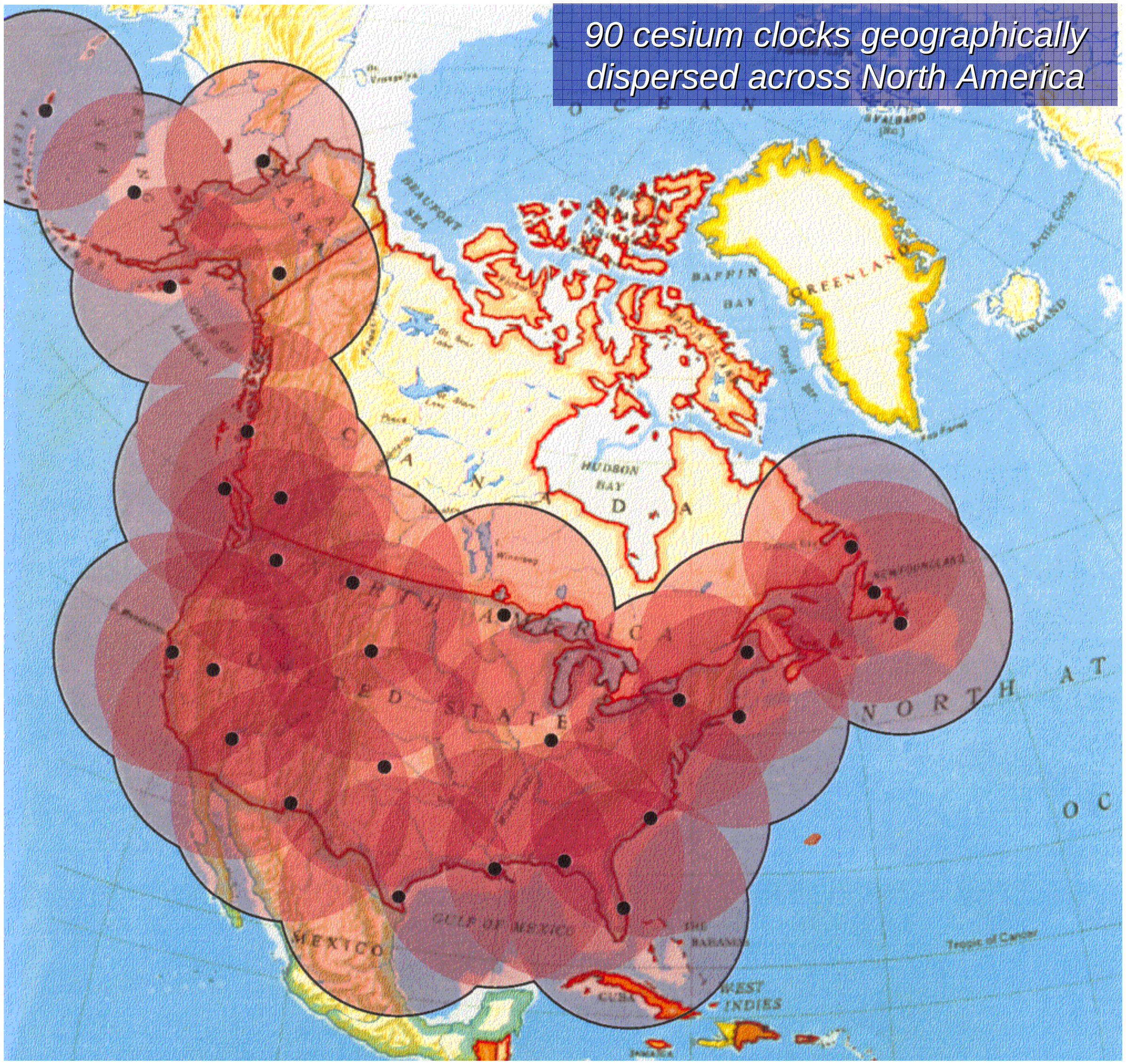
  M. Lombardi, NIST, DHS briefing, July 27, 2006

NIST Report on Time Backups for GPS

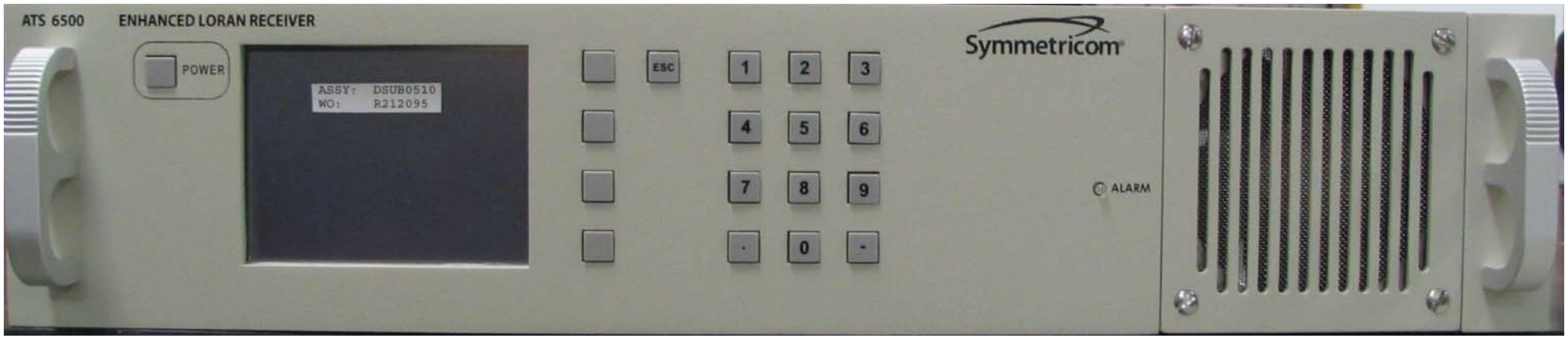
- **"We have reviewed all of the available broadcast signals that anchor the time and frequency infrastructure in the United States."**

- **"We conclude that *eLoran* is the best available backup provider to GPS as a reference source for precise time synchronization and frequency control."**

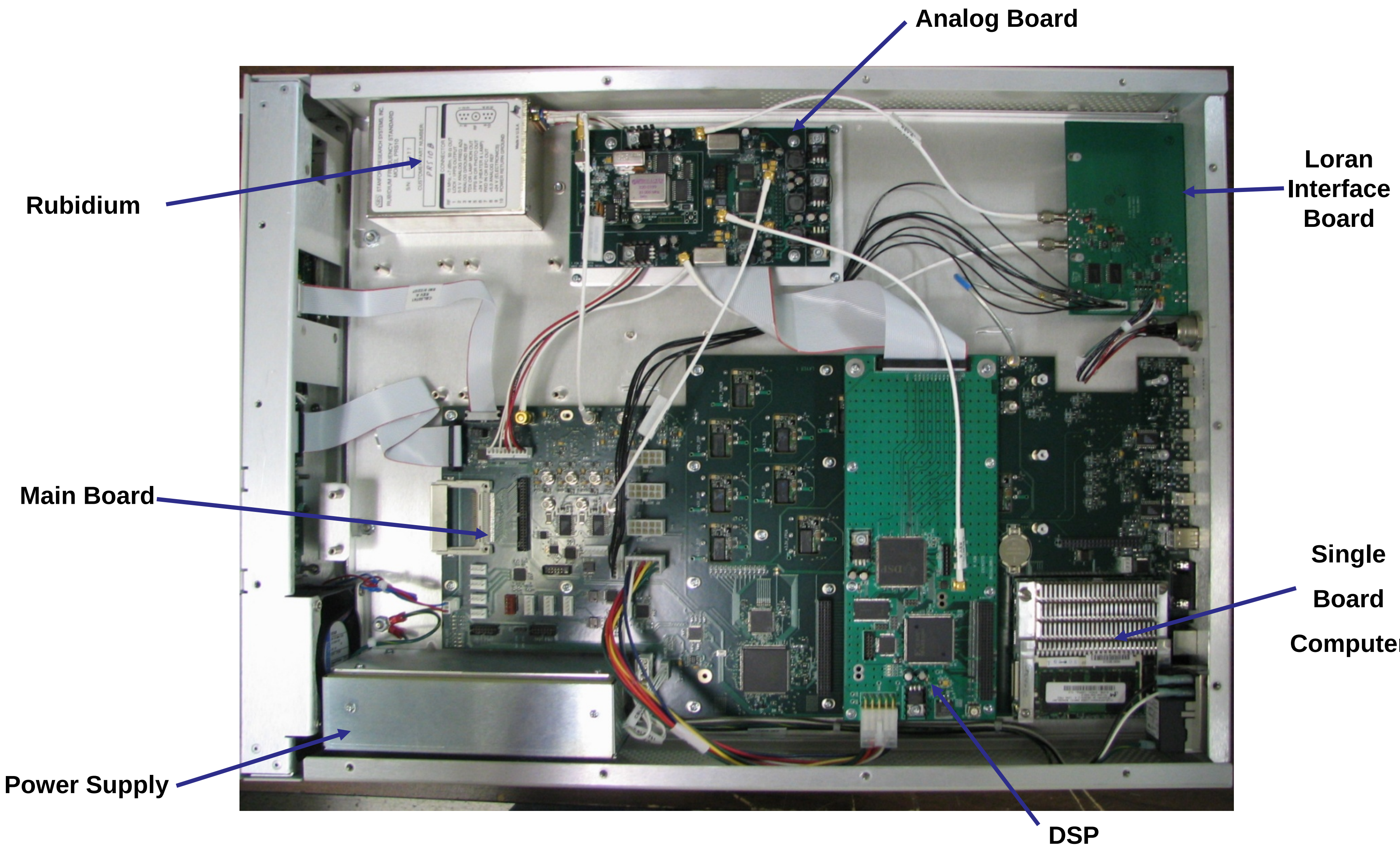
North American Loran Time Coverage



New *eLoran* Timing/Research/Monitor Receiver



New *eLoran* Timing/Research/Monitor Receiver



It's also about "*place*"
Geo-encryption – Something New

Who can receive the encrypted file?

Conventional Cryptographic Algorithms

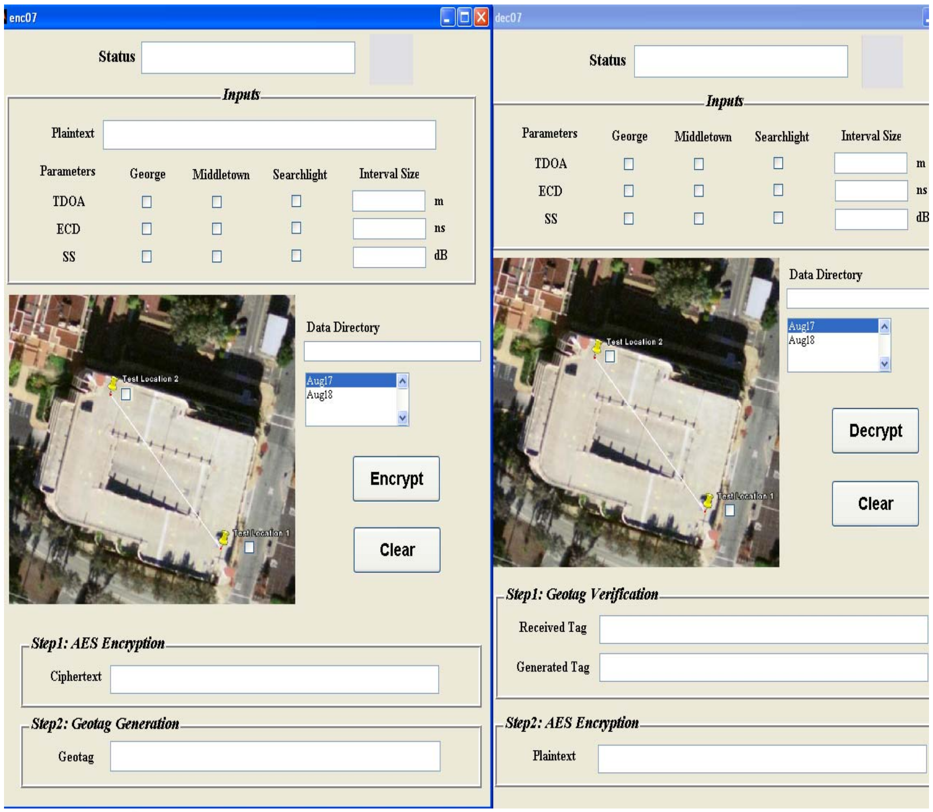
Who has the random key?

Geo-encryption and Signal Authentication

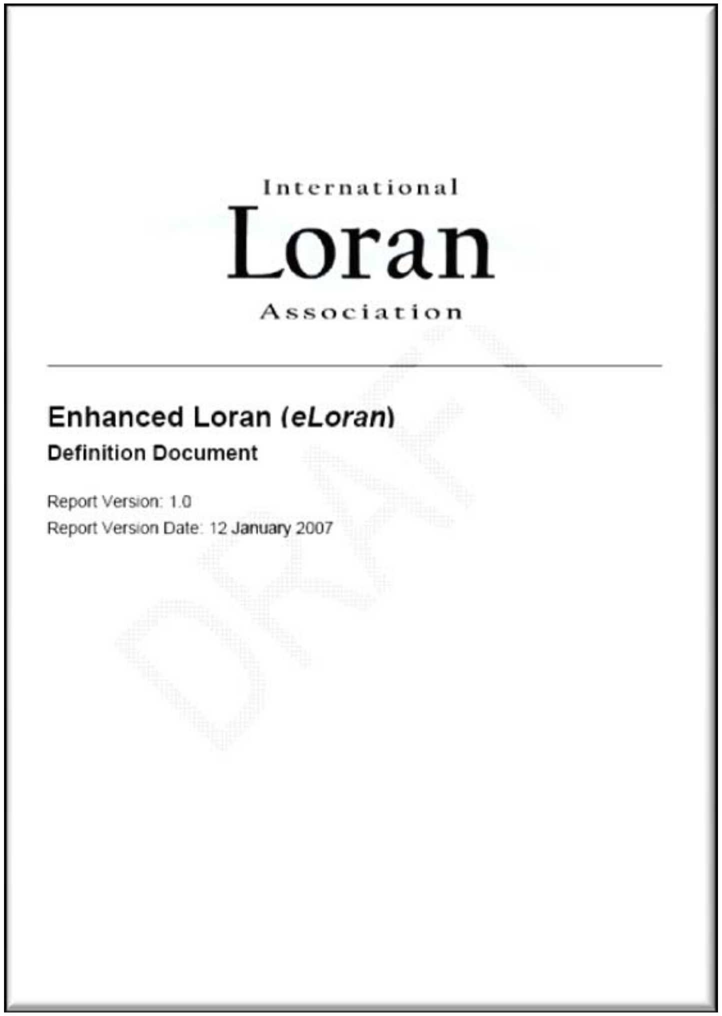
Who has the navigational receiver
& can locate at the ***right*** location

$\underline{3400\ m^2 / 153{,}295{,}000\ km^2 = 2.2 \times 10^{-11}}$

Data Collection Underway



Loran from an International Perspective


International Loran Association

Enhanced Loran (*eLoran*)
Definition Document

Report Version: 1.0
Report Version Date: 12 January 2007

DRAFT

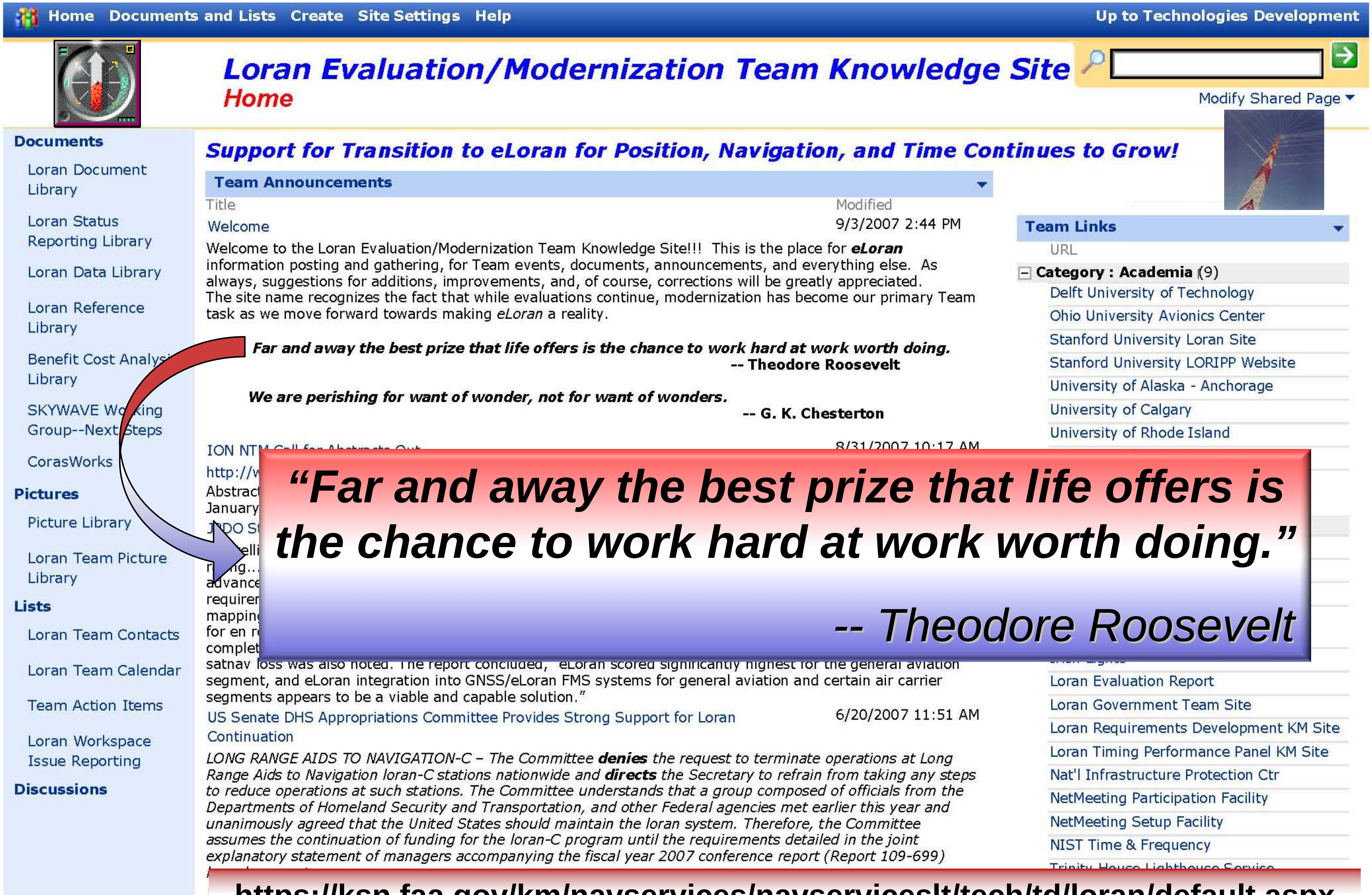
"It's not your grandparent's (or your parent's) Loran!"

Loran from an International Perspective

- **Enhanced Loran (*eLoran*) Definition Document published by the International Loran Association to provide a high-level definition of *eLoran* for policy makers, service providers, and users.**
- **Developed in November 2006 at the United States Coast Guard Navigation Center by an international team of authors.**
- **States that *eLoran***
  - is an internationally-standardized positioning, navigation, and timing (PNT) service for use by many modes of transport and in other applications that takes full advantage of 21st century technology.
  - meets the accuracy, availability, integrity, and continuity performance requirements for aviation non-precision instrument approaches, maritime harbor entrance and approach maneuvers, land-mobile vehicle navigation, and location-based services, and
  - is a precise source of time and frequency for applications such as telecommunications.
  - allows GNSS users to retain the safety, security, and economic benefits of GNSS, even when their satellite services are disrupted.

What's Next? – My Crystal Ball

- **2008 – 2011**
  - Decision on *eLoran!!!*
  - Completion of Modernization at St. Paul
  - Installation of commercial power at Shoal Cove
  - Initial Operational Capability (IOC) of *eLoran* precise time in CONUS
  - Proliferation of *eLoran* Time as primary reference system alternative
  - Commencement of RTCM work on *eLoran standards for Maritime*
  - Commencement of RTCA work on *eLoran* standards for Aviation
  - Testing/acceptance of prototype unmanned *eLoran* transmitting facility
- **2012 - 2015**
  - IOC of Harbor Entrance and Approach at selected locations in CONUS
  - Certification of *eLoran* avionics/ IOC of Non-Precision Approach at selected locations in CONUS
  - Completion of *eLoran* modernization in Alaska
  - Use of second (10^{th} Pulse) *eLoran* data channel for reduced WAAS message broadcasts (as a result of L5 availability)
  - Final Operational Capability (IOC) of *eLoran* precise time in CONUS/GPS-independent synchronization of *eLoran* clock



Home Documents and Lists Create Site Settings Help Up to Technologies Development

Loran Evaluation/Modernization Team Knowledge Site

Home

Modify Shared Page

Documents
- Loran Document Library
- Loran Status Reporting Library
- Loran Data Library
- Loran Reference Library
- Benefit Cost Analysis Library
- SKYWAVE Working Group--Next Steps
- CorasWorks

Pictures
- Picture Library
- Loran Team Picture Library

Lists
- Loran Team Contacts
- Loran Team Calendar
- Team Action Items
- Loran Workspace Issue Reporting

Discussions

Support for Transition to eLoran for Position, Navigation, and Time Continues to Grow!

Team Announcements

Title	Modified
Welcome	9/3/2007 2:44 PM

Welcome to the Loran Evaluation/Modernization Team Knowledge Site!!! This is the place for ***eLoran*** information posting and gathering, for Team events, documents, announcements, and everything else. As always, suggestions for additions, improvements, and, of course, corrections will be greatly appreciated. The site name recognizes the fact that while evaluations continue, modernization has become our primary Team task as we move forward towards making *eLoran* a reality.

Far and away the best prize that life offers is the chance to work hard at work worth doing.
-- Theodore Roosevelt

We are perishing for want of wonder, not for want of wonders.
-- G. K. Chesterton

ION NTM Call for Abstracts Out 8/31/2007 10:17 AM

http://w

Abstract
January
JPDO St
satelli
ring...
advance
requirer
mapping
for en r
complet
satnav loss was also noted. The report concluded, "eLoran scored significantly highest for the general aviation segment, and eLoran integration into GNSS/eLoran FMS systems for general aviation and certain air carrier segments appears to be a viable and capable solution."

US Senate DHS Appropriations Committee Provides Strong Support for Loran Continuation 6/20/2007 11:51 AM

LONG RANGE AIDS TO NAVIGATION-C – The Committee ***denies*** *the request to terminate operations at Long Range Aids to Navigation loran-C stations nationwide and* ***directs*** *the Secretary to refrain from taking any steps to reduce operations at such stations. The Committee understands that a group composed of officials from the Departments of Homeland Security and Transportation, and other Federal agencies met earlier this year and unanimously agreed that the United States should maintain the loran system. Therefore, the Committee assumes the continuation of funding for the loran-C program until the requirements detailed in the joint explanatory statement of managers accompanying the fiscal year 2007 conference report (Report 109-699)*

Team Links

URL

Category : Academia (9)
- Delft University of Technology
- Ohio University Avionics Center
- Stanford University Loran Site
- Stanford University LORIPP Website
- University of Alaska - Anchorage
- University of Calgary
- University of Rhode Island
- Loran Evaluation Report
- Loran Government Team Site
- Loran Requirements Development KM Site
- Loran Timing Performance Panel KM Site
- Nat'l Infrastructure Protection Ctr
- NetMeeting Participation Facility
- NetMeeting Setup Facility
- NIST Time & Frequency
- Trinity House Lighthouse Service

"Far and away the best prize that life offers is the chance to work hard at work worth doing."

-- Theodore Roosevelt

https://ksn.faa.gov/km/navservices/navservicelt/tech/td/loran/default.aspx

A Heartfelt *Thank You* to All!

1. ***The migration from a Loran-C radionavigation system to enhanced Loran (eLoran) has been and is key to the system's continuation.***
2. ***If it were not for the work of those in attendance here today and the work of many, many more dedicated people who could not be here, the Loran system in the United States, and perhaps the world, would have ceased to exist in the 21st Century*.**
3. ***We're not there yet, there's still much to do, but every team needs to celebrate its achievements – this team has much to celebrate -- and much to be thankful for!***

Summary

- **The Future is Bright!**
- **Modernization efforts are continuing**
  - St. Paul, Alaska Loran Station modernization ongoing
  - Airport and Harbor surveys to support NPA/HEA operations ongoing
  - GPS-Independent UTC Synchronization work ongoing
  - Navigation and Time receiver development ongoing
- ***eLoran* Decision "in process"**
- **Awaiting announcement by SecDOT and SecDHS this year! (really!)**

Questions

Timing accuracy model – Description & Comments

- **Non-differential (slide 2)**
  - Accuracy is rss sum of:
    - 30 ns for combination of receiver bias & transmitter accuracy
    - A noise term with noise at the 95% level, 10dB credit for clipping and 20 second averaging
    - A term based on map of seasonal variations in propagation
      - Because seasonal variations dominate in the rss sum, and western US has smaller seasonal variations, model shows better accuracy in west
- **Differential**
  - Differential Accuracy is rss sum of:
    - 30 ns for combination of receiver bias & base station error
    - Same noise term as above
    - A term proportional to distance from closest base station (currently 0.5 ns/nm)
- **Overall accuracy (in slide 3) is the minimum of the two accuracies above**
  - Slide 4 shows which is minimum, except for NE US, differential corrections do not help **timing** users, because **navigation** (HEA) users need to use much more distant stations, they still need differential corrections in the west
- **Current model suggest need for either station or monitor in Iowa/Nebraska**
  - Previous studies had suggested transmitter in this area would considerably enhance RNP availability.

Improvements Needed to Achieve *eLoran* Capability

- **Aviation - NPA**
  - Implementation of Loran Data Channel (LDC) via 9th-pulse communications to broadcast:
    - Station ID
    - Integrity Message
    - Early Skywave warning
  - Improved monitor system to detect skywave and out of tolerance condition
  - Time of Transmission (TOT) Control
  - ASF value(s) for each airport
  - Certified avionics (eLoran/multimode) to allow use of existing RNP 0.3 approach and landing procedures

Improvements Needed to Achieve *eLoran* Capability

- **Maritime - HEA**
  - Implementation of Loran Data Channel (LDC) via 9th-pulse communications to broadcast:
    - Station ID
    - Integrity Message
    - Differential Loran Information
  - Improved and expanded monitor system to provide real-time differential corrections to support 8m-20m accuracy requirement
  - Time of Transmission (TOT) Control
  - Harbor surveys to establish ASF grid
  - Maritime receivers (eLoran/multimode) to provide required accuracy

Improvements Needed to Achieve *eLoran* Capability

- **Time**
  - Implementation of Loran Data Channel (LDC) via 9th-pulse communications to broadcast:
    - Differential Loran Information
  - Improved and expanded monitor system to support precise time (<50ns)
  - Time of Transmission (TOT) Control
  - *eLoran* Time receivers to provide required accuracy
- **Frequency**
  - <u>*Nothing*</u> → We're already Stratum 1! (1 x 10^{-11})

GPS/WAAS/*eLoran* Receivers for Aviation

Phase I

Phase II

Example Aviation Tests: Rockwell/ Locus Integration of GPS-IMU-Loran

- **AHC-3000A AHRS modified to add IMU outputs**

GPS/WAAS/eLoran Receivers for Maritime

Tampa Bay Measurements Megapulse/Reelektronika Receiver April 2004