The Road to an *eLoran* *Decision in the United States*

The Results of the Loran Technical Evaluation

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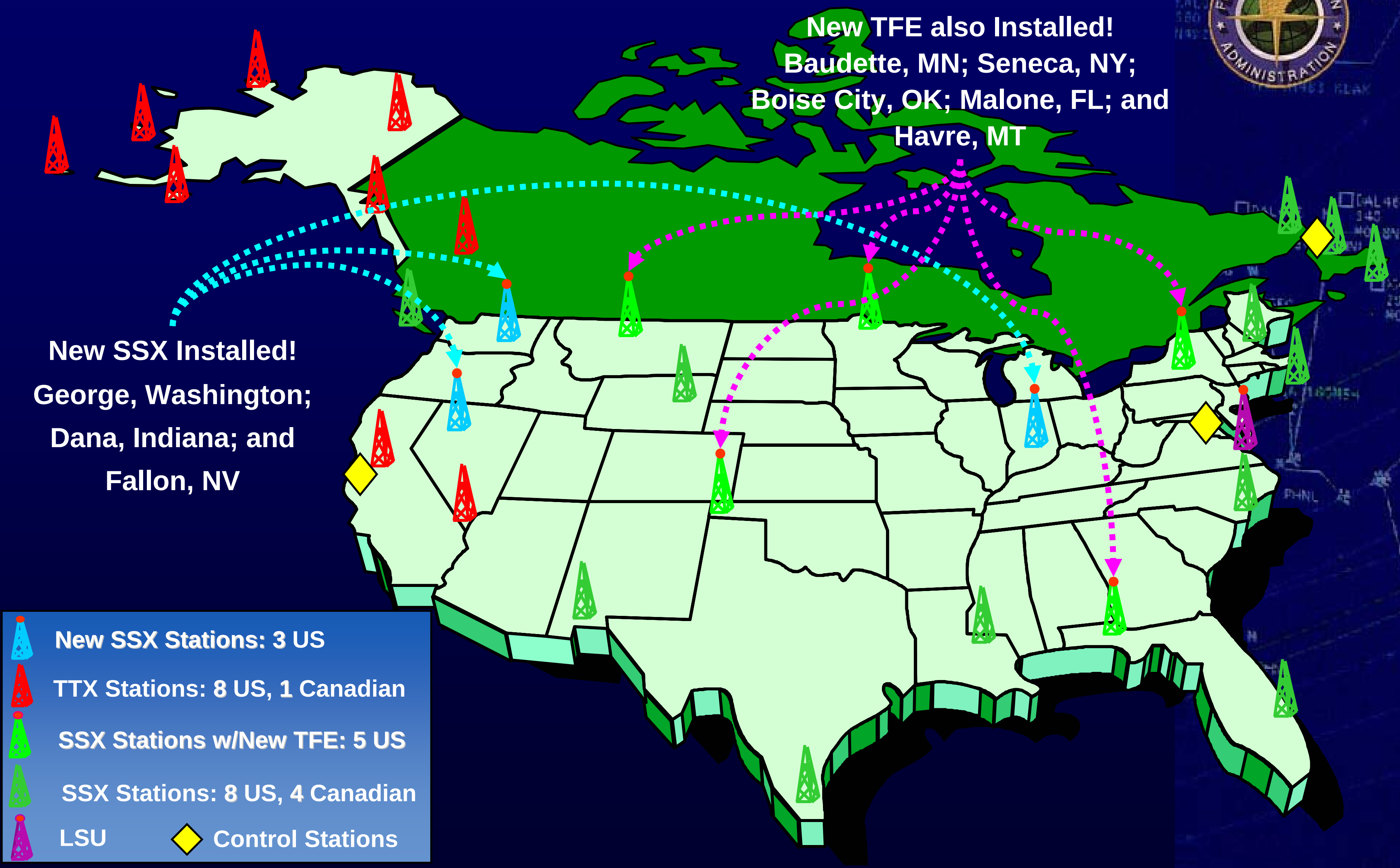
Federal Aviation Administration

International Loran Association

Convention and Technical Symposium
Tokyo, Japan
October 2004

North American Loran System



To understand *eLoran*, one must first understand Loran

- Loran is currently:
  - 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., 1×10^{-11}) that also provides time within 100 ns of UTC (USNO)

To understand *eLoran*, one must first understand Loran

- As a radionavigation system, Loran 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 is all Loran can do, the US will turn it off!***

*US Federal Radionavigation Plan (FRP)

Current US FRP Loran Policy

"The Government is evaluating the ability of an enhanced Loran system to support ***non-precision approach*** for aviation users, ***harbor entrance and approach*** for maritime users, and ***improved performance for time and frequency users***. If the Government concludes as a result of the evaluations that Loran-C *is not needed* or *is not cost effective*, the United States Coast Guard (USCG) will plan to disestablish the system by the end of fiscal year 2008 with appropriate public notice."

US DOT Navigation Task Force Report

"If Loran ***can meet*** requirements for non-precision approach for aviation users, harbor entrance and approach for maritime users, and improved performance for time and frequency users, and is cost effective, ***Loran should be included in the future radionavigation mix***."

The US Loran Decision Process

LORIPP

LORAPP

Volpe

FAATC

Loran Evaluation Team compile technical findings and BCA Data into Draft Report

December 2003 ✓

Internal FAA Review ✓

Internal USCG Review ✓

Department of Homeland Security

Loran Evaluation Team compile comments into Final Report

March 2004 ✓

PosNav Committee members review the report

PosNav Committee meets to discuss report findings and determine what recommendation should be forwarded to The Secretary of Transportation

June 2004 ✓

PosNav Committee recommends decision to SecDOT

Secretary of Transportation Announces Decision

Expected: CY 2004

The Report:

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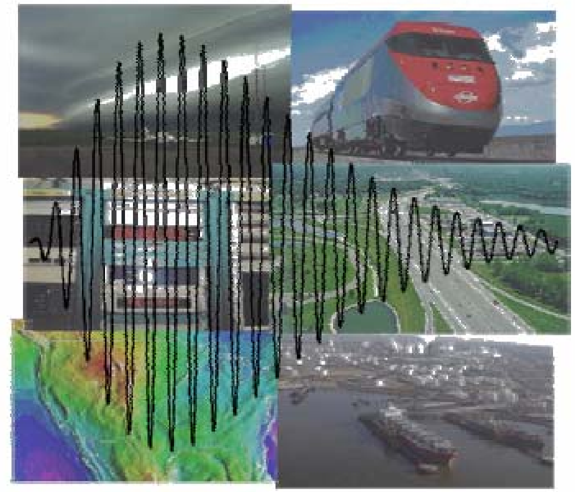
Loran's Capability to Mitigate the Impact of a GPS Outage on GPS Position, Navigation, and Time Applications



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

March 2004

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Navigation Must Fail-Soft / Fail-Safe

Navigation is no longer a nicety – it has become a necessity!

- **The FAA's definitions of three levels of fallback in the event of a GPS outage were used in the Loran Evaluation:**
  - **Redundant Capability** – a capability where interference has *no effect on operations* and navigation capabilities are similar to what can be accomplished using SatNav.
  - **Backup Capability** – a capability where SatNav interference *will affect operations* by requiring reliance on other unaffected ground-based Navaids or other radionavigation services and the following of alternative procedures. While carrying a backup capability *may* allow arrivals to or departures from a specific location, it must ensure the ability to reach a safe location.
  - **Operational Contingency** – a capability that relies on specific operational contingency procedures to *ensure safety* at the onset of and during SatNav interference. These procedures may *preclude or limit operations*, including access to or egress from certain locations.
- **The Report had to determine what role(s) Loran could play.**

Trade Spaces Identified in Report

- **Radionavigation Policy**

  The high-level statements of performance, certification, calibration, funding, etc. These are areas that require agency, multi-agency, or international action or agreements.

- **Operational Doctrine**

  The out-of-tolerance (OOT) limits, control parameters, off-air planning, etc to be employed in daily management of the system. These are areas that the USCG must integrate into their operational control process and procedures to satisfy all users requirements.

- **Transmitter, Monitor, and Control Equipment**

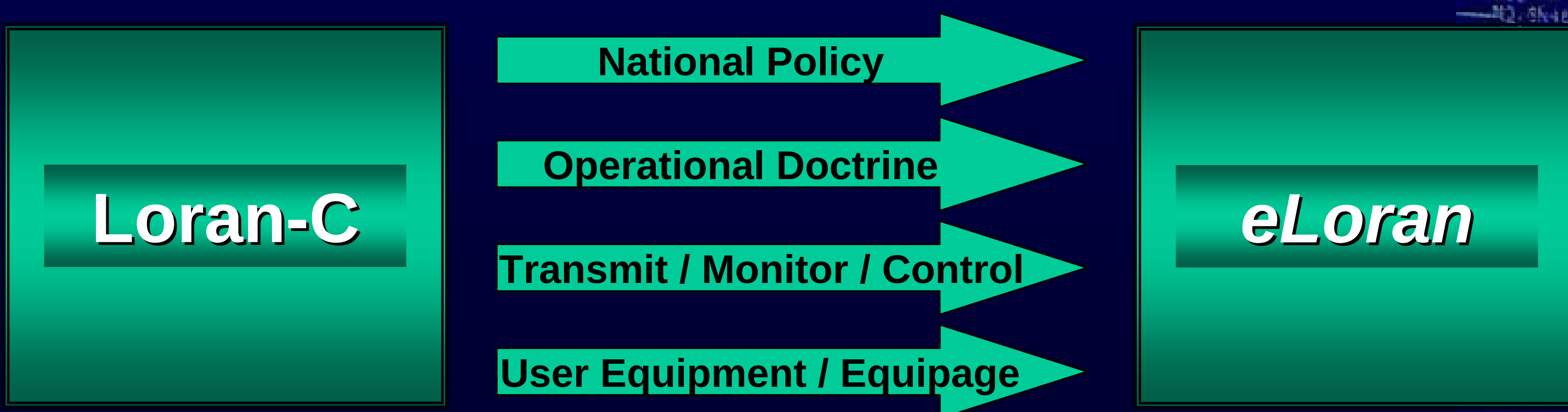
  The equipment used for signal generation, monitoring, and control. This trade space describes the equipment and modifications to the existing Loran-C infrastructure.

- **User Equipment**

  The sensor specification, antenna types, and algorithms used to define and implement user equipment. This trade space describes the parameters and conditions that must be met by the user equipment.

"Enhanced" Loran (eLoran)

"…If the decision is made to retain Loran as one of the federally provided radionavigation systems, the extent to which these modifications are accepted and implemented will define the actual characteristics of the resulting enhanced Loran (*eLoran*) system."



The Loran Evaluation Specifics

- Determine whether an enhanced Loran could provide the:
  - *Accuracy*
  - *Availability*
  - *Integrity*
  - *Continuity*

  a) to support Lateral Navigation through all phases of flight – including Non-Precision Approach (NPA)

  b) to support Harbor Entrance and Approach (HEA) for maritime users
- Determine what other ancillary benefits could be derived from the continued provision of enhanced Loran services
  - e.g., to support Stratum 1 frequency and timing users
- Determine if providing these services via Loran would be cost-beneficial (i.e., Benefits/Costs >1 and other things considered)*

* Not a part of the Technical Evaluation

The eLoran Technical Challenge

Current Capabilities vs. Future Requirements*

	Accuracy	Availability	Integrity	Continuity
Current 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

The Loran Evaluation Team Makeup

- A group of internationally recognized navigation experts with direct real-world technical and operational Loran-C experience
  - Transmission
  - Monitoring and control
  - User receiving equipment
  - Operational doctrine
  - Radionavigation policy

- The Loran "Body of Knowledge" has significantly improved as a result of the evaluation

Loran Evaluation Program Logo Collection

FAA Navigation Integrated Product Team

Federal Aviation Administration

William J. Hughes FAA Technical Center

United States Coast Guard 1790

United States Coast Guard Academy

United States Coast Guard Loran Support Unit

the Volpe center

Megapulse

Loran-C

ASD

LOCUS

United States Coast Guard Navigation Center

Northrop Grumman Information Technology

Rockwell Collins

Booz | Allen | Hamilton

JJMA An Employee Owned Company

TIMING SOLUTIONS

reelektronika

AMA

WR Systems

SI-TEX Marine Electronics

FreeFlight Systems

Leland Stanford Junior University Organized 1891

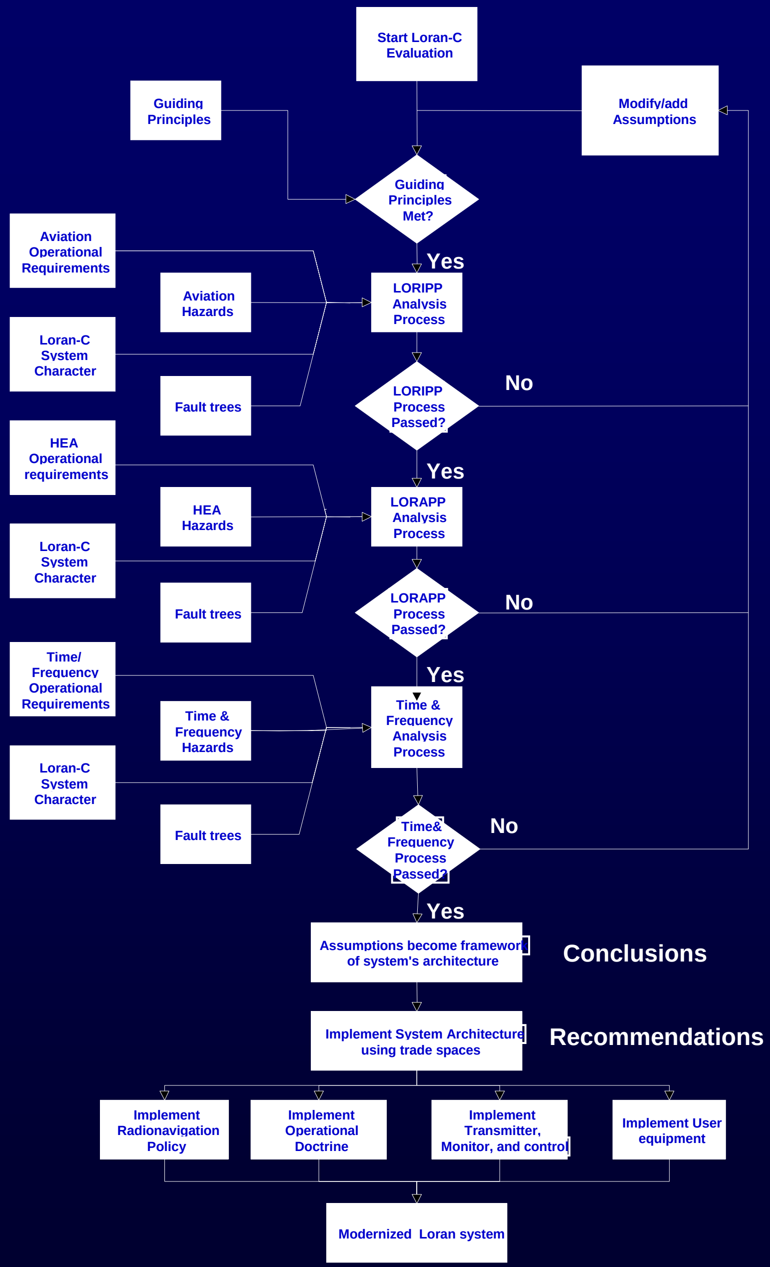
Peterson Integrated Geopositioning

Ohio University

Prifysgol Cymru University of Wales Bangor 1884

University of Rhode Island

University of Alaska

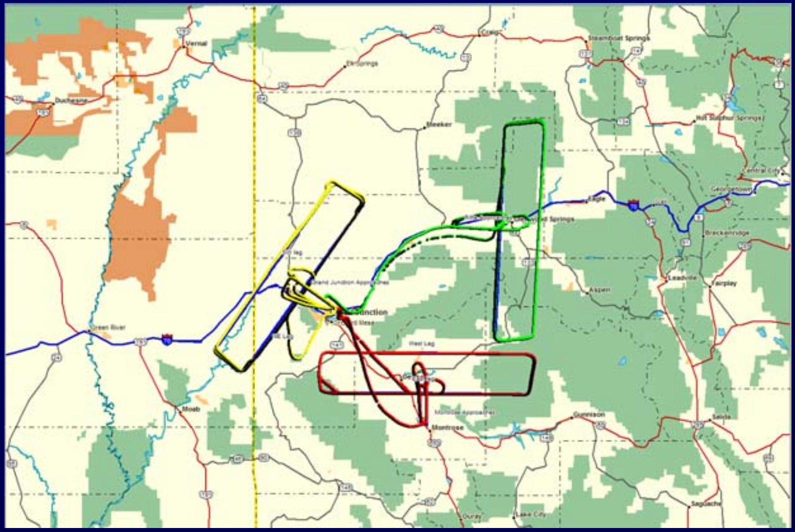


The Evaluation Process

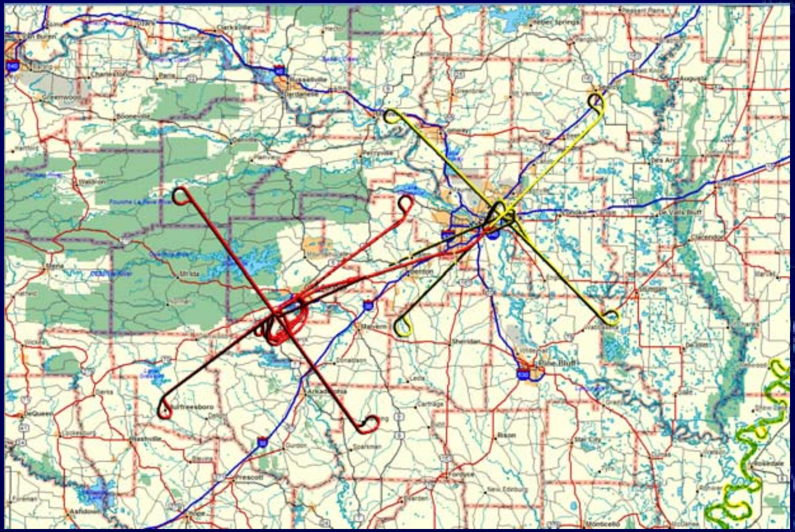
- Assumptions
- Experimentation
- Fault trees
- Analyses
- Thought Experiments
- Discussions
- Problem Resolutions
- Consensus

Utilized lessons from the WAAS Program

Loran Measurement Campaign
Lots of Miles – Lots of Data

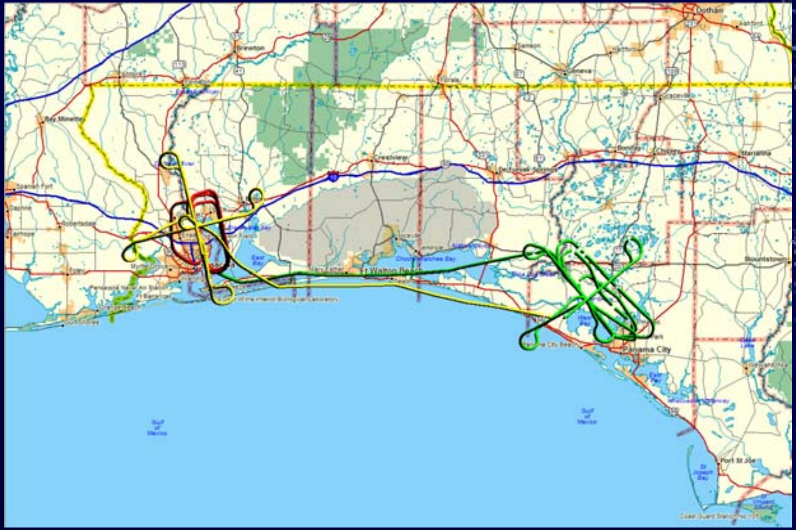


Grand Junction, Colorado



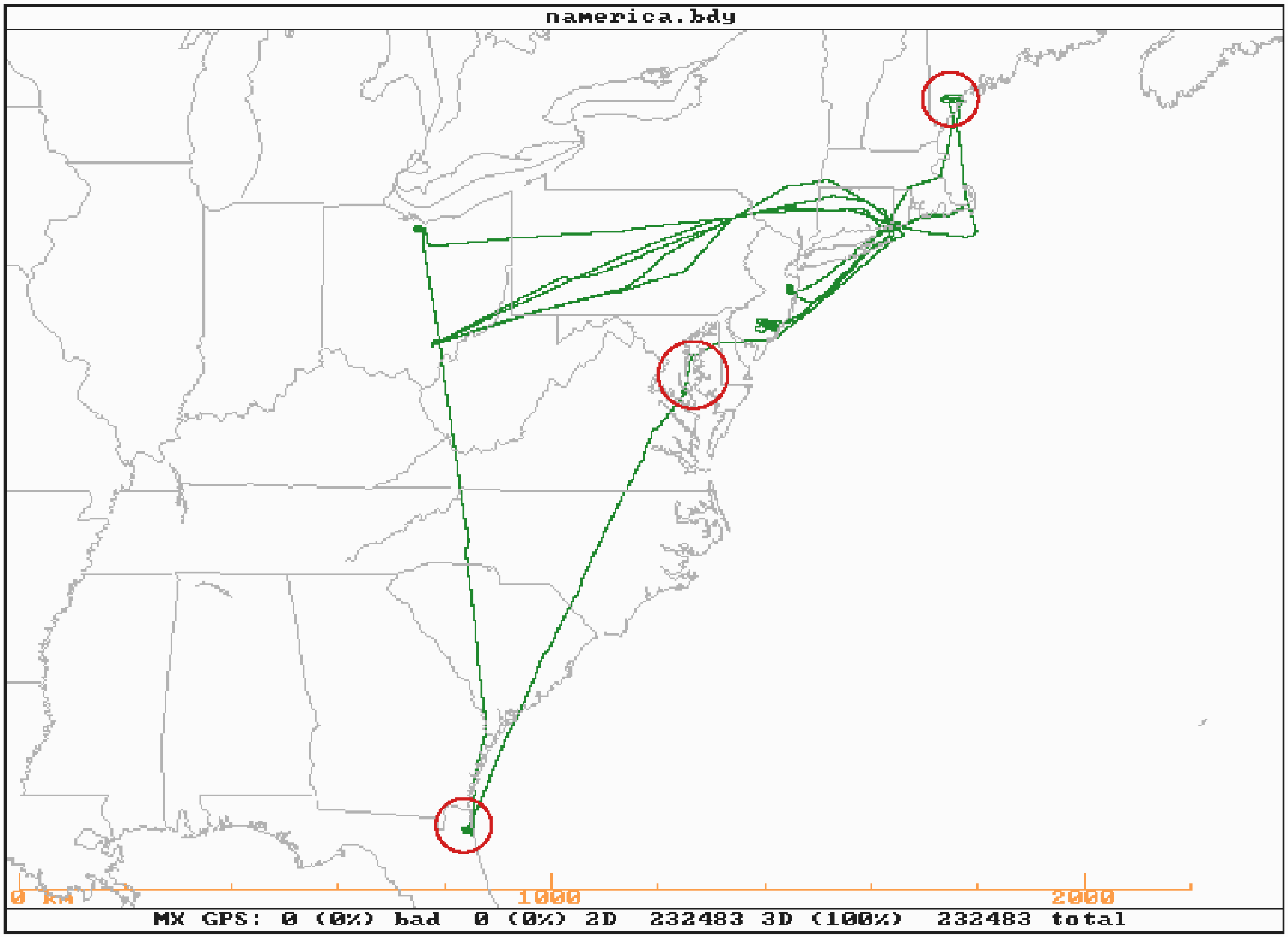
Little Rock, Arkansas

Monterey, California

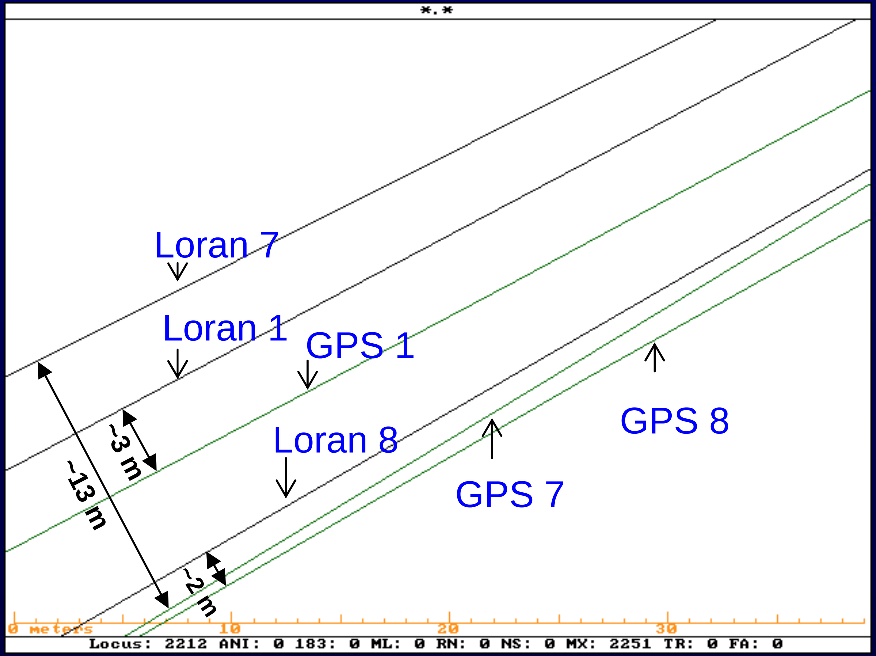


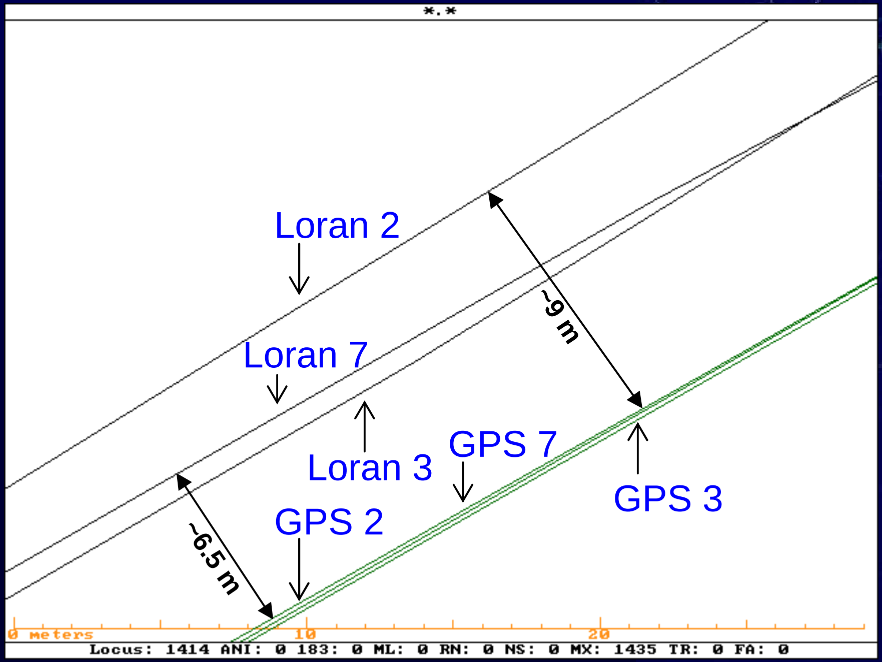
Pensacola/Destin, Florida

ASF Characterization Flights
August 2002 and March 2003



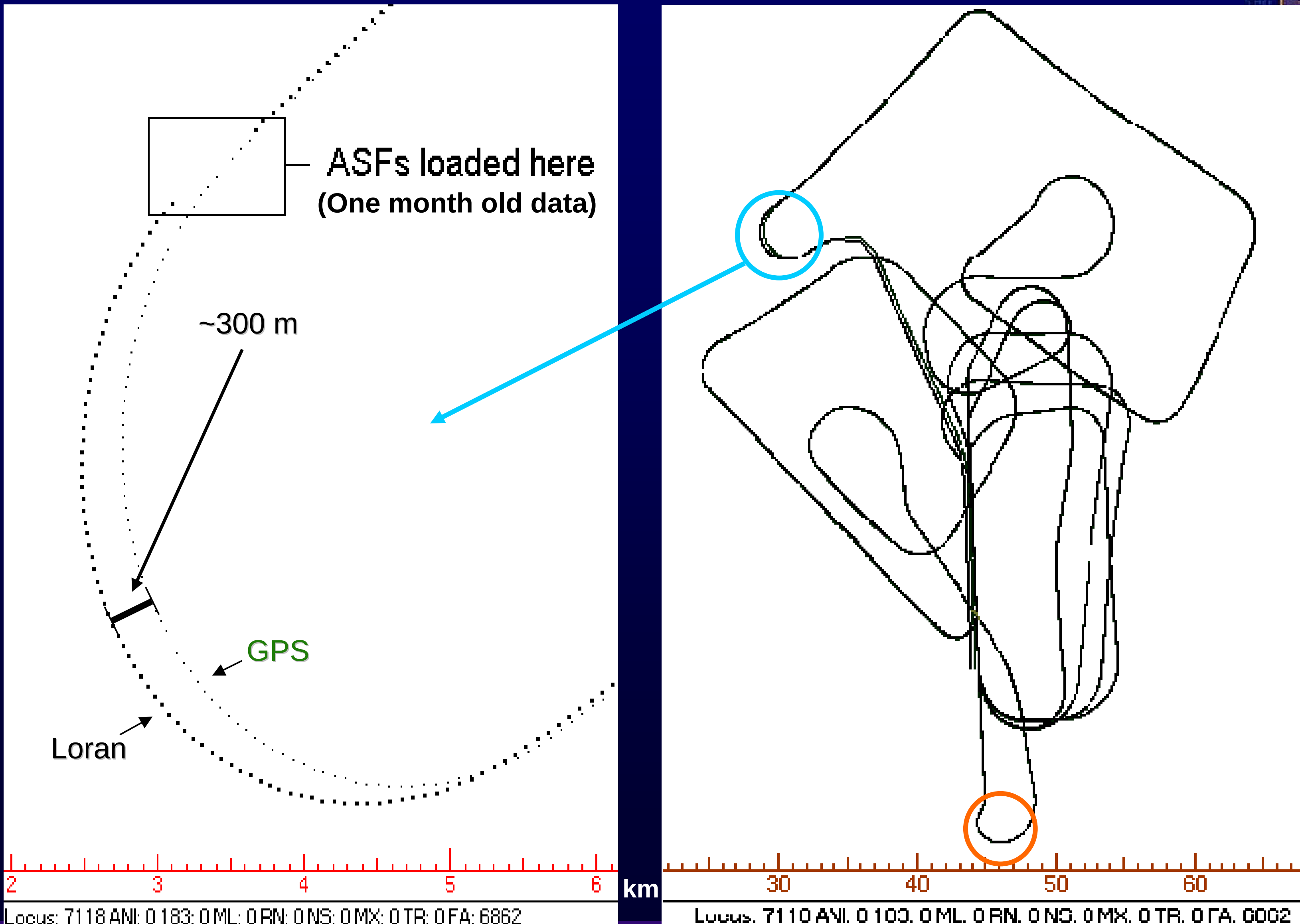
Exceptional Accuracy Results



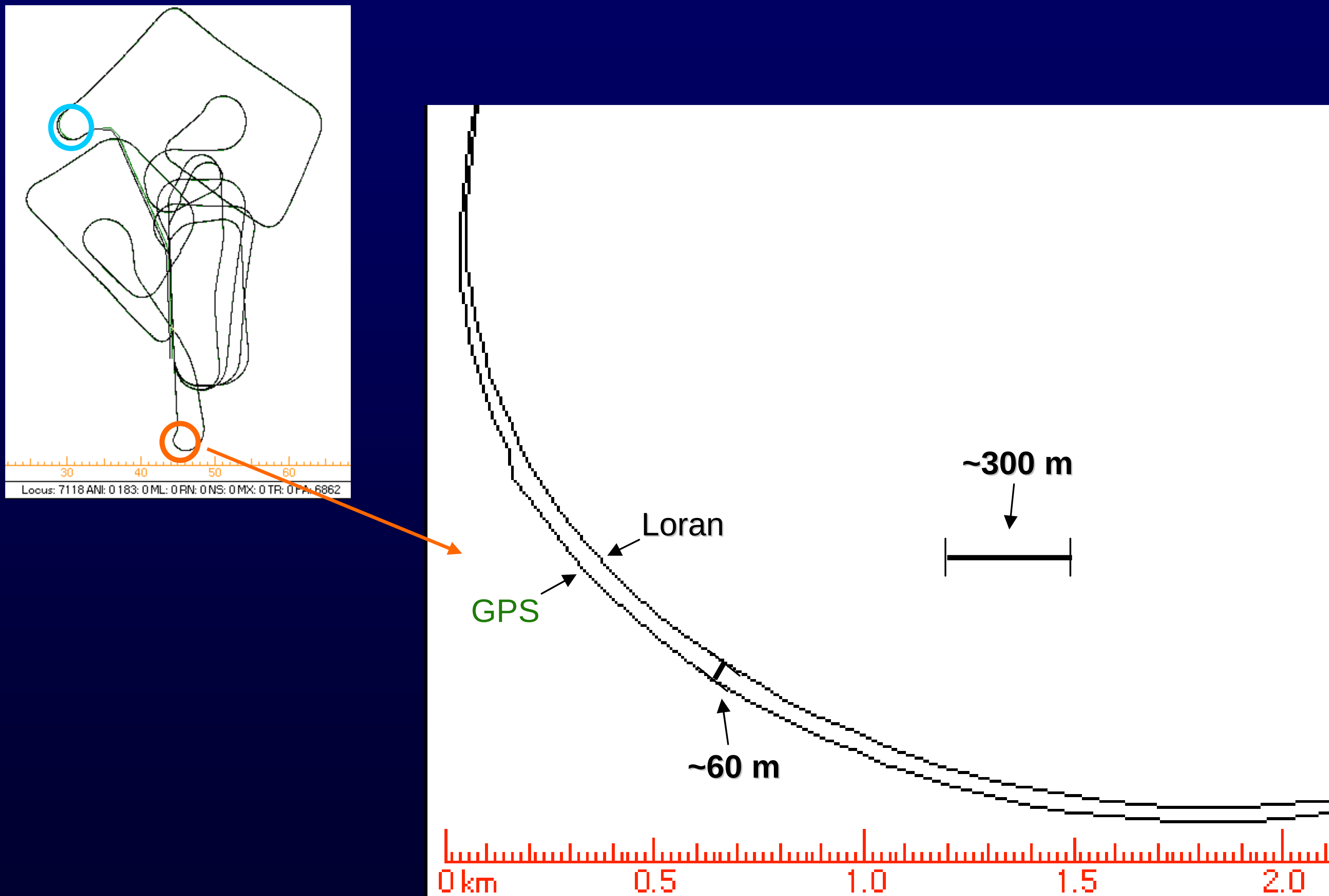


NPA Requirement: 307 m
HEA Requirement: 8-20 m

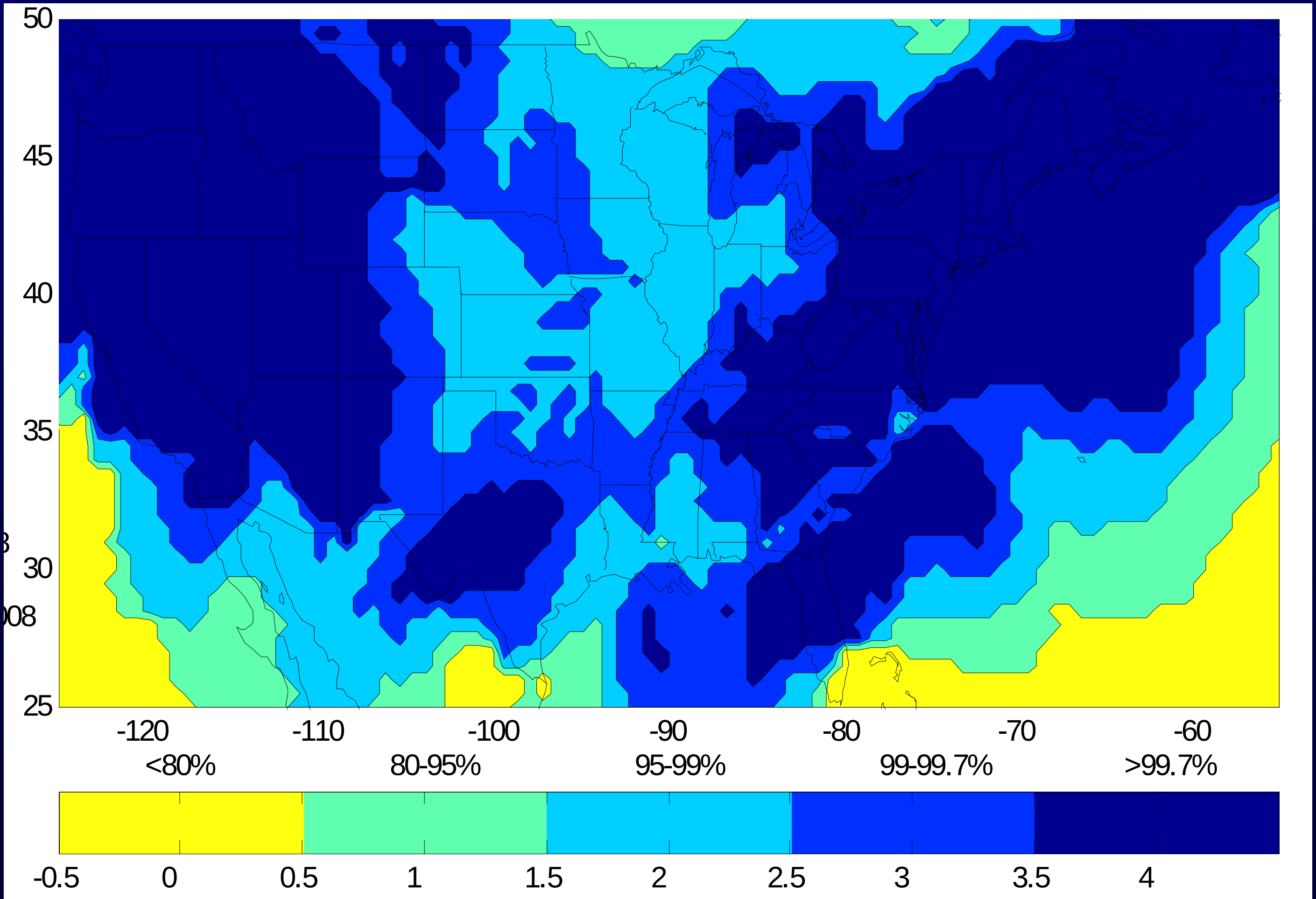
Waco, Texas – December 2003



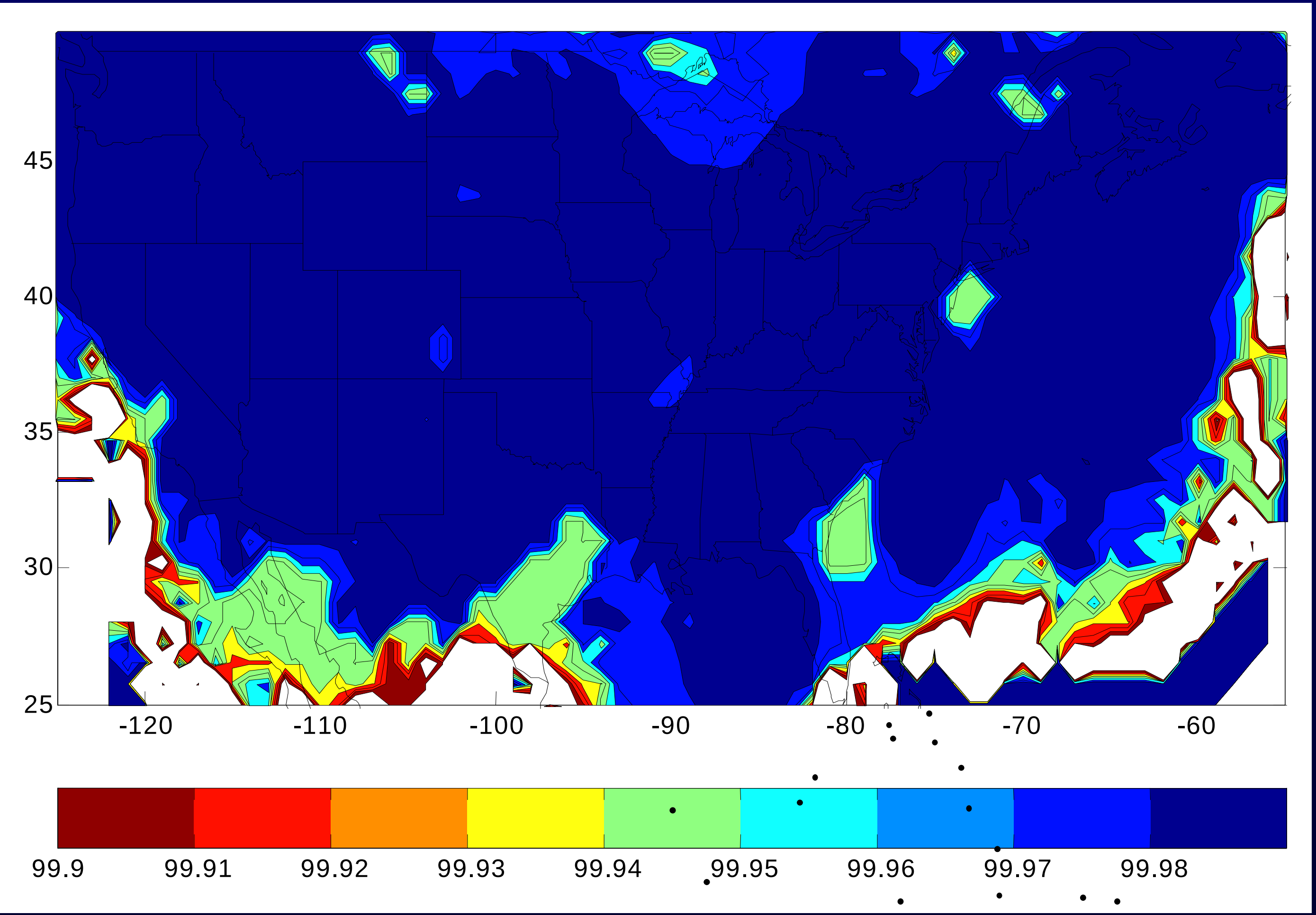
Waco, Texas – December 2003



Availability (All Year)



Continuity (All Year)



The Loran Clock

A Most Important Infrastructure Undertaking

- All North American Loran Stations and the Loran Support Unit have three new cesium clocks – ***87*** very high stability clocks ***geographically dispersed*** across North America
- Tests have shown that all 87clocks can be steered to UTC (USNO) with great accuracy
- Lays the groundwork for establishing a robust Loran clock akin to the GPS clock

Prototype Locus Loran Card in Rockwell Collins Multi-Mode Receiver

- **Rockwell Collins has continued the work *on their own* to incorporate low cost gyros into the integrated receiver solution**
- **Integrated GPS/Loran receiver for general aviation is also being developed by FreeFlight Systems and Locus under FAA contract**

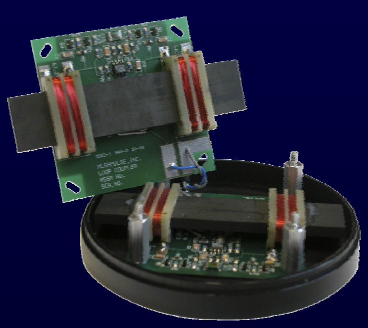
FreeFlight/Locus
GA Multi-Mode Receiver

- **Phase I Prototype (Two-box initial solution) similar to GPS/WAAS/Loran Rockwell Collins MMR/Locus development**
- **Phase I Prototype testing of Integrated GPS/WAAS/Loran receiver testing progressing at this time**

FreeFlight/Locus GA Multi-Mode Receiver

- **Phase II Prototype will be available for testing Summer 2004**

Megapulse/Reelektronika/Si-Tek Multi-Mode Marine Receiver



Signal Processor
77 x 51 mm

Front End & ADC
77 x 47 mm

GPS – WAAS

Prototype will be available for testing Spring 2004

New Loran/GPS/WAAS Megapulse/Reelektronika Receiver

The 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."

"This conclusion is based on an analysis of the applications' performance requirements; expected modification of radionavigation policies, operating procedures, transmitter, monitor and control processes, and user equipment specifications; completion of the identified Loran-C infrastructure changes; and results from numerous field tests. Collectively, these create the architecture for the modernized Loran system."

Next Step:

- Await Department of Transportation Decision

Questions

Backup

Evaluation Participants

- **Government**
  - FAA
    - Navigation and Landing Systems Engineering, AND-740
    - Navigation and Landing System Architecture, ASD-140
    - CNS Test and Evaluation, ACB-440
    - Flight Standards, AFS-400
    - Aircraft Certification, AIR-130
    - Special Programs, AVN-5
  - US Coast Guard
    - HQ Aids to Navigation
    - Navigation Center
    - Loran Support Unit
    - Command and Control Center
  - Volpe National Transportation System Center

Evaluation Participants

- **Industry**
  - Booz|Allen|Hamilton
  - FreeFlight Systems
  - Illgen Simulation Technologies, Inc.
  - JJMA
  - Locus, Inc.
  - Megapulse, Inc.
  - Peterson Integrated Geopositioning
  - Reelektronika
  - Rockwell Collins
  - Si-Tex Marine
  - Timing Solutions
  - WR Systems
- **Academia**
  - Ohio University
  - Stanford University
  - US Coast Guard Academy
  - University of Rhode Island
  - University of Alaska
  - University of Wales

30 Second Description of the Modernized Loran-C System

The modernized Loran-C system that is being considered for the mix of federally provided radionavigation systems is a low frequency, terrestrial navigation system operating in the 90-110 kHz frequency band, and synchronized to Universal Time Coordinated. This system has a recapitalized infrastructure and a new communication modulation scheme, which allows for operations that satisfy the integrity, accuracy, continuity and availability performance requirements for non-precision approaches and harbor entrance approaches, as well as non-navigation time and frequency applications. The changes to the system include: modern solid-state-transmitters, new time and frequency equipment suites, modified monitor and control equipment and revised operational procedures that new receiver technology can exploit. It employs a receiver that integrates this system with GPS so as to allow a user to continue operations in the event of a GPS outage, and to continue achieve the associated economic benefit obtained by their navigation or time/frequency applications. Legacy receiver and use of Loran-C in a stand alone mode is possible

Loran Evaluation Activities
Numerous Interrelationships

- To determine Loran ***Accuracy*** Potential:
  - Loran Accuracy Performance Panel (LORAPP)
  - Receiver/Integrated receiver studies
  - ASF* studies and calibration (for both conductivity and terrain)
  - Differential Loran study
- To determine Loran ***Availability*** Potential:
  - H-Field Antenna/P-static testing
  - CONUS All-in-view receiver analysis
  - Noise analysis
  - SSX and TFE modification evaluations
- To determine Loran ***Integrity*** Potential:
  - Loran Integrity Performance Panel (LORIPP)
  - Time of Transmission/ASF studies
- To determine Loran ***Continuity*** Potential:
  - Receiver/Integrated receiver/antenna studies

*additional secondary factors

Loran Issue 1: Accuracy

- **Current Accuracy:** **0.25 nm, 2drms, 95%**
- **Target Accuracy (NPA):** **0.16 nm (307 m) - RNP 0.3**
  0.43 nm (802 m) - RNP 0.5
- **Target Accuracy (HEA):** **8 – 20 m, 2drms, 95%**

Issues	**Potential Mitigations**
– Old timing sources	☑ New cesium clocks
– Old timing equipment	☑ New timing suite
– Tube technology	☑ Solid State Transmitter (SSX) technology
– Simple prop. model	☐ New ASF* tables/algorithms
– No real-time corrections	☑ LORAPP (Differential Loran)

*Additional Secondary Factors

Loran Issue 2: Availability

- **Current Availability:** **0.997**
- **Target Availability (NPA):** **0.999 - 0.9999**
- **Target Availability (HEA):** **0.997 – 0.999 ☑**

Issues	**Potential Mitigations**
– Precipitation Static	☑ H-Field Antenna
– Atmospheric Noise	☑ H-Field, All-in View receiver
– Loss of Station Power	☑ UPS
– Lightning	☑ New Lightning Protection
– Chain/Stick Availability	☑ All-in-view (AIV) receivers
– Tube overloads	☑ Solid State Transmitters

Loran Issue 3: Integrity

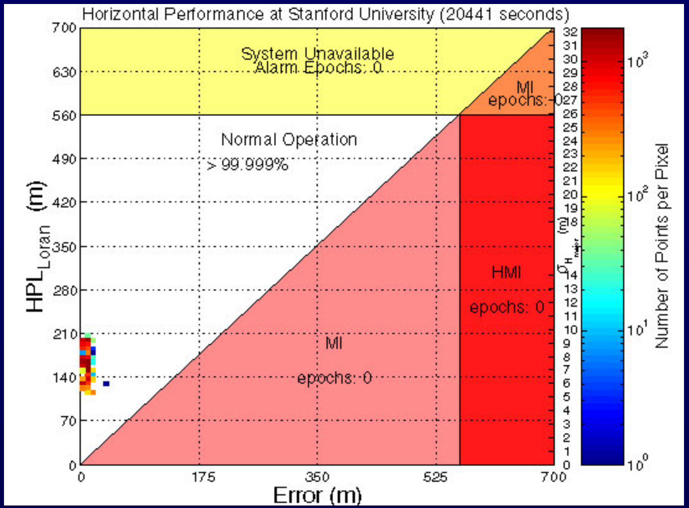
- **Current Integrity:** **10 sec. alert @ ± 100ns or other specified error conditions**
- **Target Integrity (NPA):** **0.9999999* 556m HPL, 10 sec. alert**
- **Target Integrity (HEA):** **0.99997****

Issues	**Potential Mitigations**
– Presumed Integrity/ Auto Blink System	☑ Loran Integrity Panel (LORIPP) ☑ Loran Accuracy Panel (LORAPP)

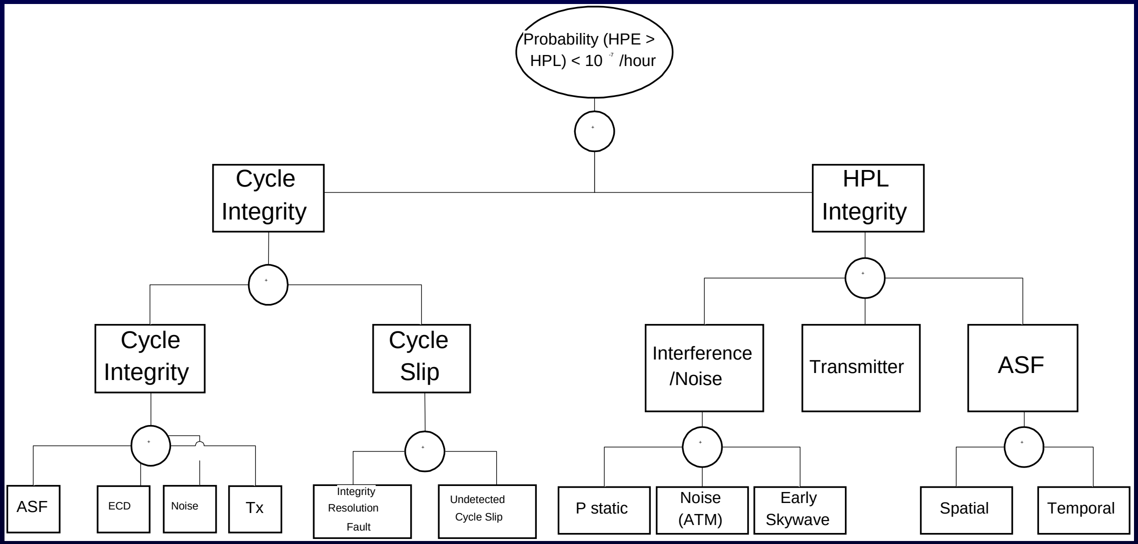
***For Aviation: The probability of providing Hazardous or Misleading Information (HMI) is 1 x 10^{-7}**

****For Maritime: The probability of providing Hazardous or Misleading Information (HMI) is 3 x 10^{-5}**

Integrity



Horizontal Performance at Stanford University (20441 seconds)
System Unavailable
Alarm Epochs: 0
MI
epochs: 0
Normal Operation
> 99.999%
HMI
epochs: 0
MI
epochs: 0
HPL Loran (m)
Error (m)
Number of Points per Pixel



Probability (HPE > HPL) < 10 -7 /hour
Cycle Integrity
HPL Integrity
Cycle Integrity
Cycle Slip
Interference /Noise
Transmitter
ASF
ASF
ECD
Noise
Tx
Integrity Resolution Fault
Undetected Cycle Slip
P static
Noise (ATM)
Early Skywave
Spatial
Temporal

Loran Issue 4: Continuity

- **Current Continuity:** **0.997**
- **Target Continuity (NPA):** **0.999 - 0.9999**
- **Target Continuity (HEA):** **0.9985 – 0.9997**

Issues	**Potential Mitigations**
Same as **Availability** plus:	
– Receiver acquisition time	☑ New DSP technology
	☑ New SSX Switch Units
	☑ AIV/Integrated Receiver