

Development and Status of Integrated GPS/Loran Prototype for Aviation

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BIOGRAPHY

Linn Roth is president of Locus, Inc., a Madison, WI company that specializes in spread-spectrum radios for industrial, utility, GPS and other applications and high performance digital Loran receivers for navigation and timing applications. Linn is a member of the Institute of Navigation and a Fellow of the Royal Institute of Navigation. He is President of the International Loran Association, and has received the ILA's Medal of Merit and President's Award. He received a B.A. from the University of California - Berkeley and a Ph.D. in Physiology from the University of California - San Francisco.

James Davis is a graduate of MIT, where he earned a BS, MS, and Ph.D. in Electrical Engineering. He has a long history in simulation and avionics, including positions with Rediffusion Simulation, IVEX Corp, and Lockheed Martin. Jim is currently Vice President for Engineering Programs at FreeFlight Systems, a developer and manufacturer of avionics equipment in Waco, Texas. He is an active member of the AIAA Modeling & Simulation Technical Committee, and his honors include election to the Moscow-based International Academy of Engineering.

Mitch Narins is the Senior System Engineer within the FAA's Navigation and Landing Product Team who has lead the FAA/USCG/Academic/Industry Team evaluating whether the Loran-C system can provide benefits to the aviation, maritime, and timing and frequency communities. Mr. Narins has held a number of program manager and lead engineer positions at the FAA, and previously held senior positions at the Naval Electronic Systems Command and at the Federal Communications Commission. He holds a Bachelor of Engineering (EE) degree from the City College of New York and a Master of Engineering Administration/Management degree from the George Washington University.

ABSTRACT

For the last several years, the FAA has been performing an evaluation of a modernized, or "enhanced" Loran (e-Loran) system to determine if it can meet FAA

requirements for accuracy, availability, continuity and integrity that accord with required navigation performance (RNP) specifications of 0.3 nmi for non-precision approach (NPA). As a part of this program, Locus, Inc. and FreeFlight Systems have worked to develop an integrated GPS/Loran prototype system using Locus' all-in-view SatMate 1030 Loran receiver and FreeFlight's 2101 Approach Plus GPS/WAAS navigation system, and to perform flight trials on the combined units in cooperation with the Avionics Engineering Center of Ohio University.

In the first phase of this program, Locus developed automated Loran station selection software and real-time additional secondary factor (ASF) correction capabilities on its SatMate 1030 receiver to enhance Loran accuracy, and integrated FreeFlight's GPS antenna and Locus' H-field Loran antenna in an ADF radome for flight-testing. FreeFlight modified the 2101 to provide front-panel GPS/Loran control and accept SatMate data, and added vertical and horizontal course deviation indicators (CDI) comparing GPS and Loran. Flight tests on this first, two-unit prototype system showed Loran accuracy well within RNP 0.3.

The second phase of this program is ongoing, and FreeFlight and Locus are working on a single unit prototype and performing additional GPS/Loran integration. Locus is designing a special power supply and interface board to permit operation of the SatMate 1030 using the same power supply as the 2101 Approach Plus, and FreeFlight is developing software to display GPS/WAAS and Loran information and allow analysis of accuracy and integrity models. The prototype GPS/WAAS/Loran system will be housed in a single enclosure that uses a Dzus-mount rail system commonly used for avionics. In addition, Locus is incorporating a single-axis gyroscope into the H-field antenna that further improves receiver performance under dynamic flight conditions.

This paper summarizes the GPS/Loran integration efforts and status of this program, and presents flight test results from the GPS/Loran prototype.

INTRODUCTION

The Federal Aviation Administration (FAA) and the United States Coast Guard (USCG) have been performing evaluations over the last several years to determine if an enhanced or e-Loran system can meet specified aviation and maritime performance requirements. The FAA criteria are required navigation performance (RNP) 0.3 nm for non-precision approach (NPA), which include 0.16 nm (307m) for accuracy, 0.999 – 0.9999 for availability, 0.999 -0.9999 for continuity, and 0.9999999 for integrity (with horizontal protection limit of 556m and 10 second alert).

In a two phase effort, Locus and FreeFlight Systems (FFS) have been developing a prototype integrated GPS/WAAS and enhanced Loran system that can be used for FAA flight trials to evaluate whether Loran can meet RNP 0.3 criteria.

The first phase of the program produced a two-unit, proof-of-concept prototype for initial flight-testing, and Locus added ASF capabilities to the SatMate 1030 so these corrections could be applied in real time to the Loran navigation solution. The original prototype is shown in Figure 1, as mounted in an equipment rack in the King Air, C-90SE twin turboprop used for the flight tests. The Avionics Engineering Center (AEC) of Ohio University conducted these tests, and the first flights with the original two-unit prototype were flown in Waco, Texas in December 2003, as reviewed below.

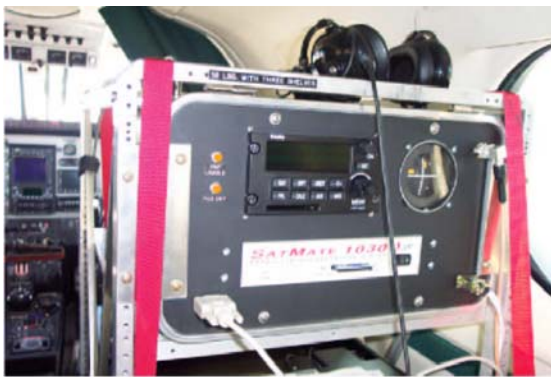


Figure 1. The first GPS/Loran prototype system as rack-mounted and strapped down in the AEC's King Air, C-90SE twin turboprop. In this prototype, a course deviation indicator (CDI) was added and is in the upper right of the front panel. The 2101 is top center and the SatMate receiver below has an ASF flashcard projecting from its front panel.

The second phase of the program is on going, and FFS and Locus are developing a single unit system that incorporates GPS/WAAS and enhanced Loran sensors in

the same housing. A combined GPS/Loran antenna is also being developed, with both devices mounted within a conventional ADF radome. The prototype is based on the FFS 2101 Approach Plus Navigation System, which has a TSO-C129 (A1) certification. However, the standard GPS sensor board typically used in the 2101 is being replaced by the FFS 1201 GPS/WAAS receiver, which has TSO-C145a certification. The 2101 housing is also being enlarged to enable a Locus SatMate 1030 receiver card and power supply board to mount within the modified enclosure. Figure 2a shows the current 2101 faceplate, and Figure 2b is a mechanical drawing of the single unit prototype concept. Note a flashcard has been added to the prototype to enable loading of ASF corrections for the SatMate receiver at specified test airports (see below).



Figure 2a. Face plate of the original 2101 system used in the two-unit prototype. FFS developed software to control the SatMate 1030 and display Loran information.

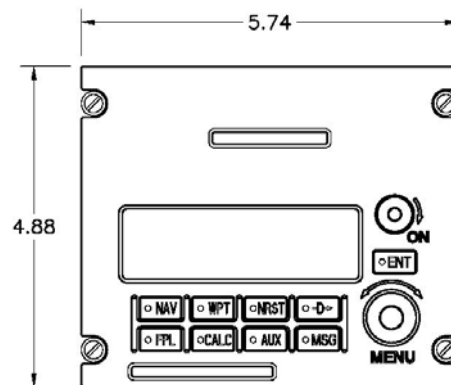


Figure 2b. Mechanical drawing of the single unit prototype system now in development. FFS has extended the 2101 enclosure height, and added a slot for the 1030 ASF flashcard above the display. The first prototype will be shown in August 2004.

PROTOTYPE DEVELOPMENT

To clarify the prototype development work, it is useful to describe work performed by each company. Locus efforts in this program can be summarized by briefly describing

several major tasks. The first was to design and fabricate a prototype custom interface and power supply board to provide the appropriate electronic interfaces between the SatMate and 2101 and to power the SatMate off of the 2101. Those design and fabrication tasks are in process and are expected to be completed in mid-August, when actual system integration is expected to begin. In addition, Locus is developing special software to mitigate interference generated by the 2101 that can affect the SatMate. Such interference is expected in any integration work, and work on mitigating technologies is underway.

As part of its efforts, Locus is adding a single axis gyroscope (SAG) to its H-field antenna in order to improve dynamic Loran performance. This work includes antenna hardware and receiver hardware and software development work, and the integration of the FFS GPS antenna with the Locus H-field antenna into a commercial automatic direction finder (ADF) radome to facilitate flight-testing. This antenna work is ongoing, and will result in an integrated GPS/Loran antenna that looks very similar to the unit in Figure 3, which was a combined antenna developed in an earlier FAA program.

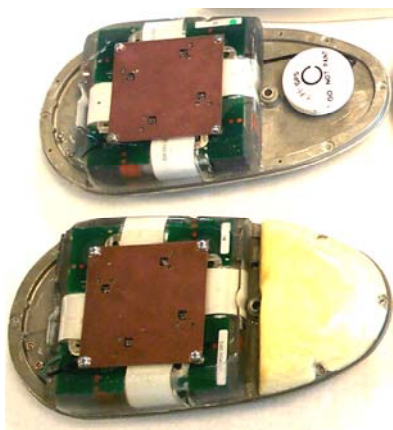


Figure 3. A combined GPS and Loran H-field antenna mounted within an ADF radome to facilitate flight tests. This earlier unit shows the H-field antenna and the GPS antenna before (top) and after (bottom) the GPS antenna was foamed for additional stabilization during flight tests.

Finally, Locus is developing a working draft of minimum operational performance standards (MOPS) appropriate for enhanced Loran receivers and antennas. This work involves review of RTCA DO-228 and DO-229C MOPS for GNSS antennas and receivers, respectively, to determine which sections of a Loran MOPS can be modeled on these existing GNSS standards.

FreeFlight Systems efforts in this program can also be briefly summarize as follows. An interface control document (ICD) was generated to detail hardware, software, and mechanical issues necessary to integrate the

1030 receiver and interface board within a 2101 device. Work is underway on GPS/Loran integration software to enable the 2101 to operate in GPS/WAAS mode, Loran mode, or a loosely coupled GPS/Loran mode. In addition, enclosure modifications have been initiated to enlarge the original 2101 enclosure slightly to accommodate the 1030 receiver and interface cards within the new enclosure, and to accept the ASF flashcard (see Figure 2b). It is expected that the first prototype enclosure will be complete in August, in time for the actual physical integration work to begin.

ASF GENERATION

An ASF database or grid does not exist that is appropriate for modern Loran operations. As a separate part of this FAA program, Locus developed a system that would enable the FAA Loran team to generate ASFs at an individual airport, and then fly Loran approaches to that airport on the same day. Since the SatMate 1030 can apply ASF corrections to the Loran navigation solution in real time, the ASF generation system made it possible to test whether Loran would meet the RNP 0.3 accuracy requirements using ASF corrections developed using contemporary Loran and GPS technology. Moreover, this work constituted initial efforts to build a national ASF database and facilitate studies on the temporal and spatial properties of ASFs. Finally, these data are being provided to the University of Wales, Bangor, in order to assist in the development of more accurate ASF computer models.

Locus' ASF generation system uses GPS to derive the ASF corrections, and also enables comparison of ASF corrections from E-field and H-field antennas. The system is comprised of a GPS/WAAS receiver, two SatMate 1030s with E-field and H-field antennas respectively, a PC with Locus' ASF software utility, a rugged enclosure, and a special power supply for portable operation. During flight tests conducted by Ohio University's AES, the ASF system was removed from the airplane and set up at each airport. Data were recorded for approximately one hour, then the software utility generated the ASF corrections, and these corrections were downloaded into a flashcard for insertion into the 1030. Several approaches were flown into that airport while GPS/WAAS and ASF-corrected Loran data were collected, and subsequently the crew flew to the next airport of interest. Figure 4a shows the ASF generation system, and Figure 4b pictures the system in operation at the Jacksonville Craig Airport during the March 2004 flight test program.



Figure 4a. Locus' ASF generation system. Starting from the bottom, a special power supply, two SatMate 1030s (one for each antenna type) and the PC with ASF software utility are installed in the rack. The GPS/WAAS receiver is mounted in the interior of the system.



Figure 4b. Locus' ASF generation system in operation at the Jacksonville Craig Airport during the March 2004 flight trials. The tripod is used to support Loran H-field (left), GPS (center), and Loran e-field (right) antennas.

INITIAL FLIGHT TEST RESULTS

On December 2, 2003, initial flight tests were conducted on the two-unit prototype GPS/Loran system in Waco, Texas. Because the ASF generation system was still in development at test time, ASFs that were generated on October 17, 2003 were used, and they were derived at the

FFS building, approximately 10 miles from the Texas State Technical College airport in Waco. The entire route of this initial flight test is shown in Figure 5, and at this level of magnification, it is difficult to tell the GPS/WAAS and Loran tracks apart, even though the ASF corrections were not applied at the beginning of the flight test. However, when the 1030 was switched into the ASF operational mode shortly after takeoff, as shown in Figure 6, there was an immediate and substantial improvement in the accuracy of the Loran position relative to GPS/WAAS position.

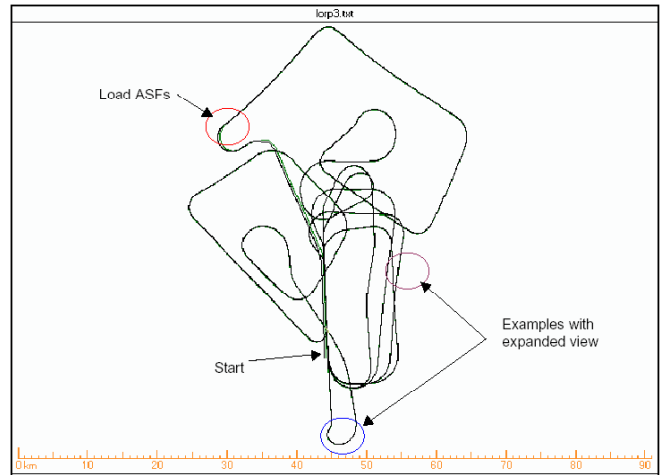


Figure 5 is the entire route of the December 2, 2003 flight test around Waco, Texas. In all flight data figures, green indicates the GPS/WAAS track, and black denotes the Loran track.

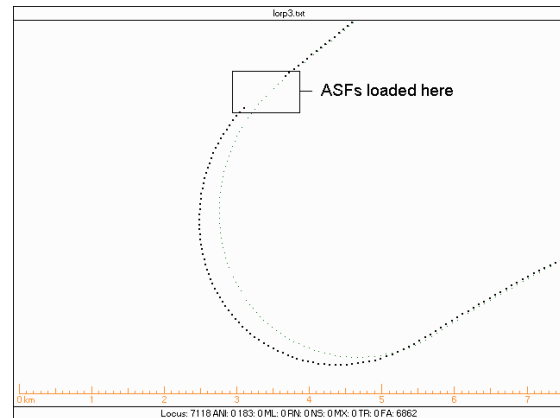


Figure 6 is an expanded view of the area where the SatMate was switched into the real-time ASF operation mode, and the discontinuity in the Loran path (black) is due to switching operational modes. When the ASFs are applied, then the GPS/WAAS (green) and Loran tracks are very similar.

To illustrate Loran accuracy after ASF are used in the navigation solution, Figures 7a and 7b show GPS/WAAS and Loran tracks at different points in the flight tests. Figure 7a data were taken about 12 km from the airport,

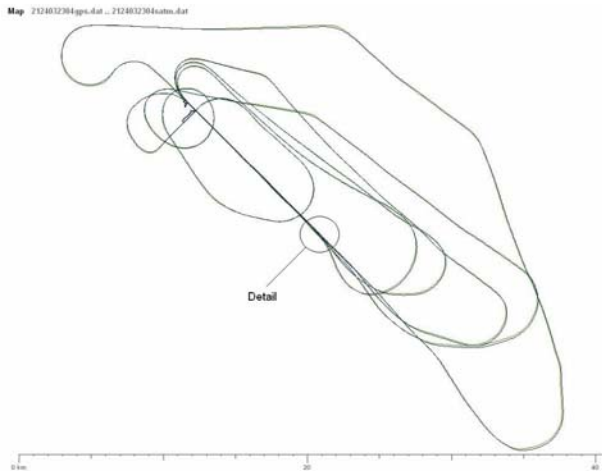


Figure 9a. The entire route around the Craig airport in Jacksonville, Florida. Major scale increments are 20 km.

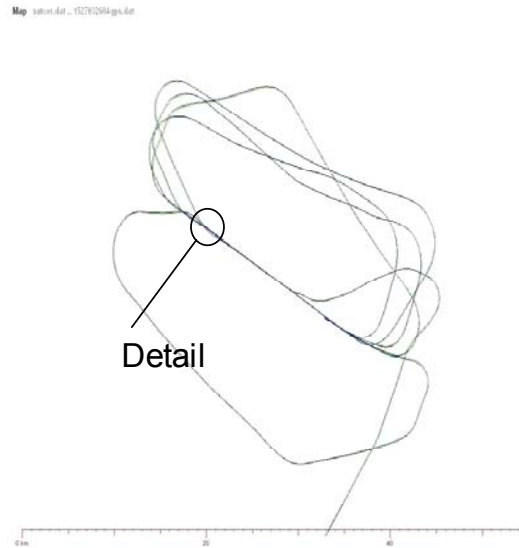


Figure 10a. The entire route around the Atlantic City, New Jersey airport. Scale increments are 20 km.

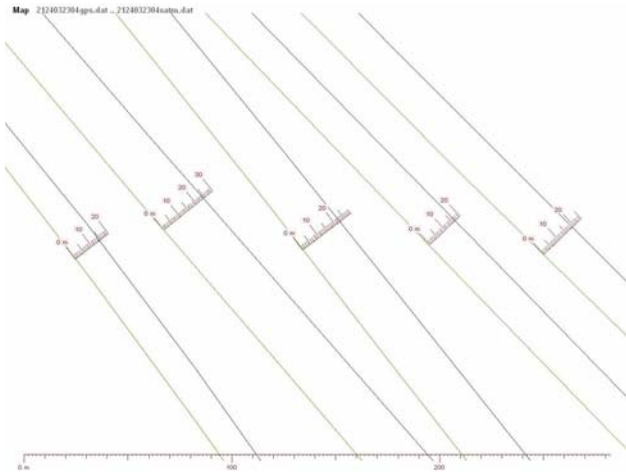


Figure 9b. Expanded view of the circled area over the Portland, Maine airport. Cross track scales are shown over each approach with major increments of 10m.

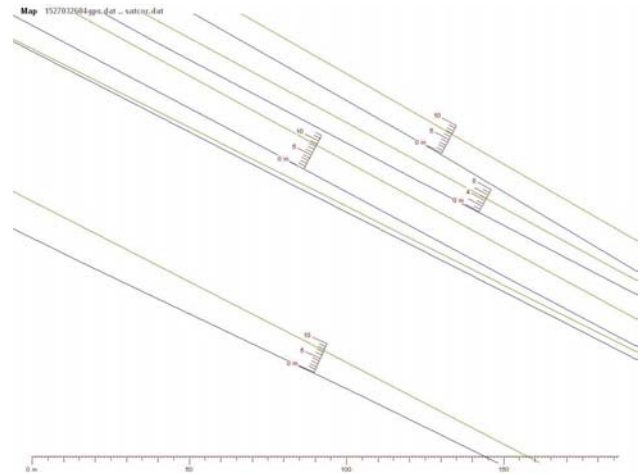


Figure 10b. Expanded view of the circled area over the Atlantic City, New Jersey airport. Cross track scales are shown over each approach with major increments of 5m.

Figure 10a shows the entire route around the Madison airport, and Figure 10b is an expanded view of the indicated approach area. Again, the GPS/WAAS and Loran tracks superimpose in the overall view, and the Loran cross track error ranges between 8 and 30 m during the approach phase.

CURRENT STATUS

The current program will be completed near the end of 2004 and is on schedule. Integration of the various components into the revised 2101 enclosure will begin this summer, and the first prototype system will be displayed in August. In addition, more flight trials will be conducted throughout the program in order to verify and validate new software/hardware and to determine if Loran accuracy meets RNP 0.3 requirements in other areas of the country.

CONCLUSION

A program to develop an integrated GPS/WAAS and Loran system for aviation applications is well underway and will be completed in 2004. During flight tests that covered a substantial portion of the CONUS, the first prototype demonstrated accuracies well within the RNP 0.3 requirements for non-precision approach, even when ASF corrections derived several weeks earlier were applied to the Loran navigation solution.

As part of this FAA program, a portable ASF collection and generation system has also been developed to facilitate studies at airports. That ASF system has been completed and is in use. Data generated by this effort can be considered the start of a national ASF database for aviation, which can then be used to study the temporal and spatial properties of ASFs and to improve computer ASF models.

Finally, drafts of MOPS for contemporary Loran receivers and antennas are nearly complete, and these can function as starting points for development of formal RTCA standards.

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