Enhanced Loran and GPS/WAAS System for Aviation

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ABSTRACT
As part of the on-going FAA program to determine if Loran can meet required navigation performance (RNP) 0.3 criteria, Locus and FreeFlight are developing a single unit system that integrates GPS/WAAS and Enhanced Loran sensors and are combining GPS and Loran H-field antennas. Locus' all-in-view Loran receiver has real-time additional secondary factor (ASF) correction capabilities, so Loran and GPS/WAAS accuracies can be directly compared during flight trials.

For this prototype, Locus is designing a power supply and interface board to enable Locus' SatMate 1030 receiver to operate off of FreeFlight's 2101 Approach Plus® Navigation System power, and developing software to mitigate noise from the 2101 that can affect SatMate operations. Locus is also adding a single-axis gyroscope (SAG) to improve Loran's dynamic performance.

FreeFlight is changing the 2101 enclosure to incorporate the Loran sensor and interface board and facilitate mounting of the integrated housing into a Dzus-mount rail system commonly used for avionics. FreeFlight is also developing software to control and display GPS/WAAS and Loran information and allow analysis and validation of accuracy and integrity models.

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.

This paper reviews program status, and includes flight data comparing GPS/WAAS and Loran.

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

As participants in the FAA program, 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 version of the integrated receiver was 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 it was mounted in an equipment rack in a 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.

In the on-going program, FFS and Locus are developing a single unit system that incorporates GPS/WAAS and enhanced Loran sensors in the same housing, and combined GPS/Loran antennas with both devices mounted within a conventional ADF radome. The prototype is based on the FFS 2101 Approach Plus Navigation System having a TSO-C129(A1) certification, but with the standard GPS sensor board replaced with the board used in the FFS 1201 GPS/WAAS receiver having TSO-C145a certification. In addition, the 2101 housing is 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.

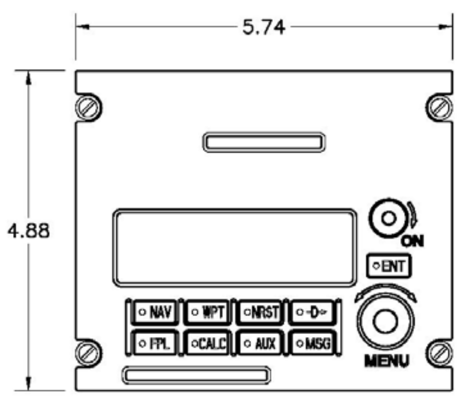

Figure 2b. Mechanical drawing of the single unit prototype system now in development. FFS has extended the 2101 enclosure height, and added a slot for the 1030 ASF flashcard above the display. The first prototype will be shown in August 2004.

LOCUS EFFORTS

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.

Finally, 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.

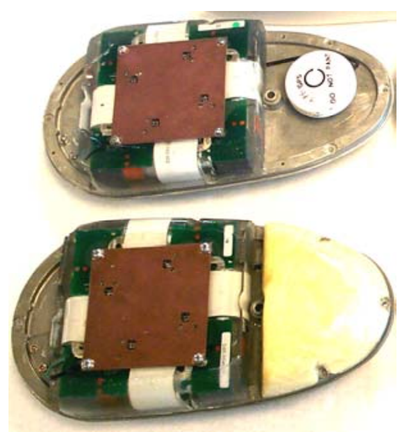

Figure 3. A combined GPS and Loran H-field antenna mounted within an ADF radome to facilitate flight tests. This earlier unit shows the H-field antenna and the GPS antenna before (top) and after (bottom) the GPS antenna was foamed for additional stabilization during flight tests.

FREEFLIGHT SYSTEMS EFFORTS

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.

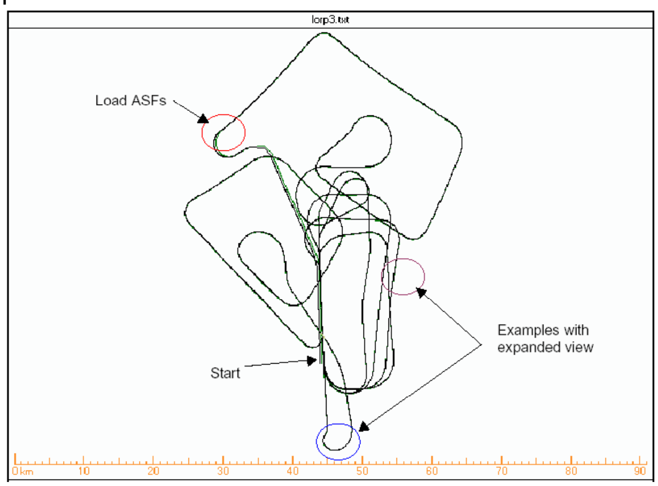

Figure 5 is the entire route of the December 2, 2003 flight test around Waco, Texas. In all flight data figures, green indicates the GPS/WAAS track, and black denotes the Loran track.

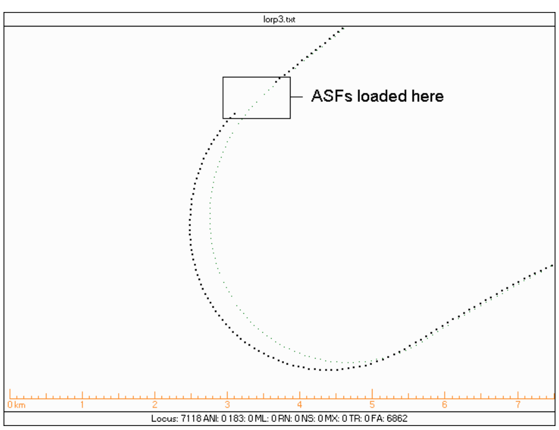

Figure 6 is an expanded view of the area where the SatMate was switched into the real-time ASF operation mode, and the discontinuity in the Loran path (black) is due to switching operational modes. When the ASFs are applied, then the GPS/WAAS (green) and Loran tracks are very similar.

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, and Figure 7b data were from approximately 15 km away. In the two Figure 7b tracks, which are representative of flight paths used during approaches, the cross track error between Loran and GPS/WAAS is between 3 and 12 meters. In both situations, the accuracy performance is obviously well under the RNP 0.3 requirement, even when using ASF corrections about 6 weeks old.

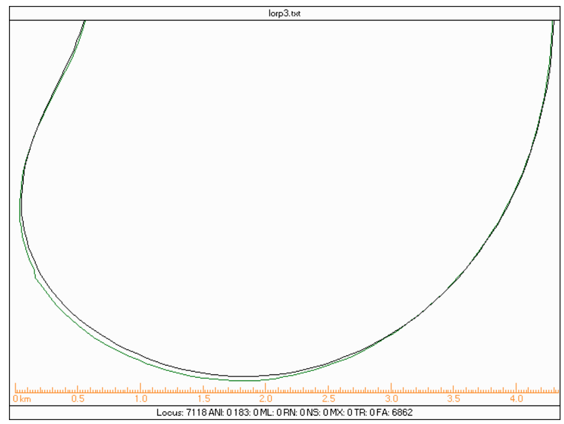

Figure 7a

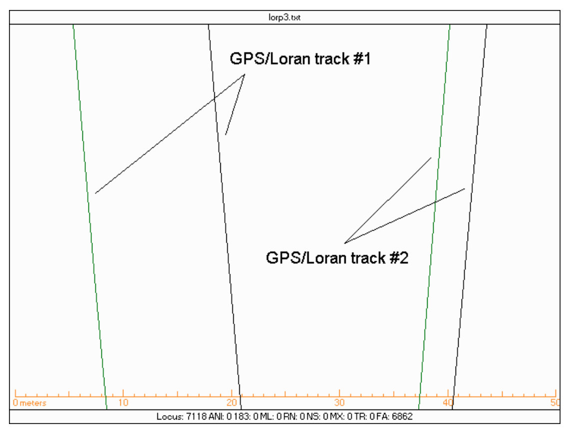

Figure 7b

Figures 7a and 7b. Expanded views of the two indicated areas from Figure 5. The GPS/WAAS and Loran tracks are quite similar, and in Figure 7b, which more closely resembles an approach, the cross track errors are approximately 3 and 12 meters.

RECENT FLIGHT TEST RESULTS

In March 2004, the AES conducted an additional series of flight tests over approximately the eastern one-third of the CONUS. Figure 8 illustrates the route covered in these flight trials, which is similar to the route covered in earlier flight trials. Approaches were flown at airports in the following cities: Madison, Wisconsin; Jacksonville, Florida; Stevensville, Maryland; Atlantic City, New Jersey; Farmingdale, New Jersey; Portland, Maine; Westerly, Rhode Island; and Norwalk, Ohio.

Figure 8. The entire route of the March 2004 flight trials. The AEC began these trials in Madison, Wisconsin, and then covered the East Coast from Jacksonville, Florida to Portland, Maine, before returning to Athens, Ohio.

At each of these airports, ASF corrections were generated as described above, and an ASF flashcard was burned for each airport. Since raw time of arrival (TOA) Loran data is recorded during all these FAA Loran flight trials, it is possible to apply ASF corrections derived at various times and locations to Loran data from a specific airport. Thus this program begins the establishment of a national Loran ASF database, and the tools developed enable post hoc analysis of the temporal and spatial variations in ASFs in various parts of the country.

Figures 9 and 10 show some representative data taken from two airports during these flight trials. Figure 9a depicts the entire route flown around the Portland, Maine airport, and although both GPS/WAAS and Loran tracks are drawn, it is not possible to distinguish the two at this level of magnification. Figure 9b is a close-up of the approach area indicated by the circle in Figure 9a. As illustrated, the cross track error between GPS/WAAS and Loran is 15-36 m for the five approaches flown in Portland.

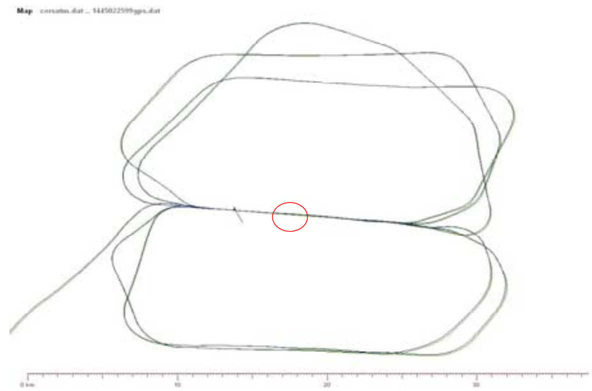

Figure 9a. The entire route around the Portland, Maine airport. Scale increments are 10 km.

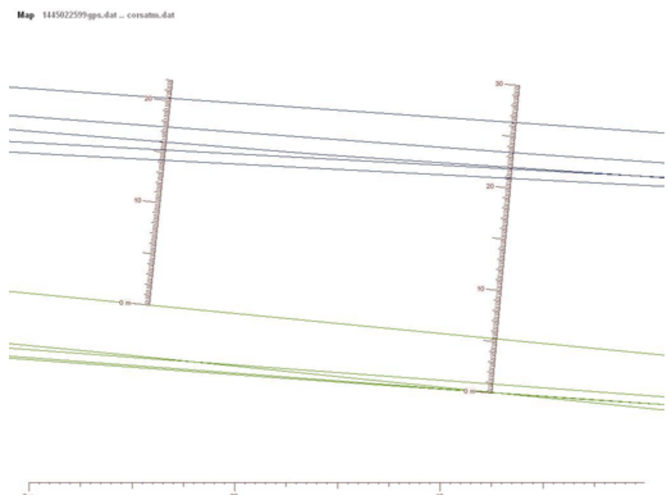

Figure 9b. Expanded view of the circled area over the Portland, Maine airport. Major scale increments here are 10m.

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.

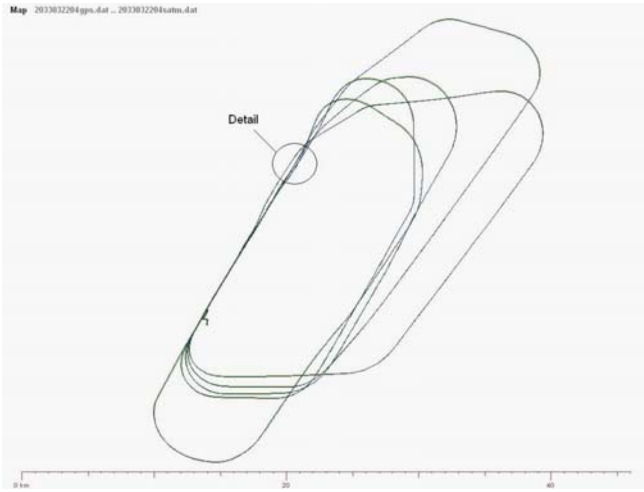

Figure 10a. The entire route around the Madison, Wisconsin airport. Scale increments are 10 km.

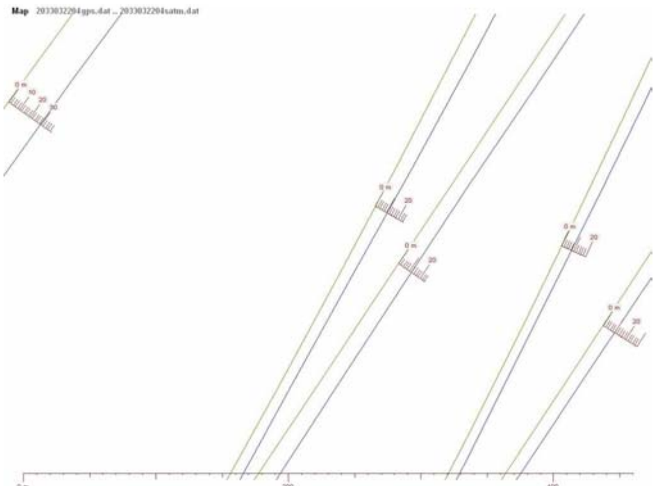

Figure 10b. Expanded view of the circled area over the Madison, Wisconsin airport. Major scale increments here are 10m.

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.

ACKNOWLEDGEMENTS

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