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Project Summary

LORAN-C Tetroon Transponder and Tracking System

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An advanced system for tracking multiple regional scale Lagrangian markers was developed. The system consists of a miniature tetroon-borne transponder and a small computerized receiving station capable of providing continuous real-time data on tetroon location (latitude/longitude) and altitude.

The transponder consists of a telemetry subsystem, a LORAN-C receiver, and a 403 MHz transmitter. The telemetry subsystem measures atmospheric temperature and pressure, converts the data into frequencies, and then transmits these data together with a transponder ID frequency to a remote receiving station. Multiple tetroons can be discriminated at a range of up to 160 km. The transponder weighs less than 365 g and can be flown on a 1 m^3 tetroon. Battery life is 2 to 6 days. The data acquisition system consists of an FM receiver, a LORAN-C navigator, a frequency to digital converter, and a microcomputer. The receiving station can be ground-based or mounted in a single engine aircraft.

LORAN-C position fix uncertainty is 3.7 km. The system was tested both in the laboratory and in regional-scale field tests. The path and height uncertainties were for those tests ±0.3 km and ±30 m, respectively.

This Project Summary was developed by EPA's Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Monitoring the movement of air masses is important in gaining the needed understanding of the origin and predicting the fate of air pollution. One method of observing atmospheric trajectories and seeing the frequency and causes for erroneous trajectory estimates is the use of Lagrangian balloon markers which have been released into the air mass of interest. These balloons, called tetroons (*tetra*hadral ball*oons* are superpressured to float at a specific atmospheric density level. Tetroons, launched with expendable transponders, have traditionally been tracked by ground-based radar deployed in a fixed or mobile mode. A new methodology for tracking tetroons on regional scales has been developed and offers a relatively inexpensive technique to document and improve fundamental understanding of atmospheric transport processes.

Development History

Several different balloon tracking devices were investigated for use in this project. A tracking device based on the LORAN-C navigational signals appears to be the most readily adaptable navigational system. LORAN-C or *LO*ng *R*ange *A*id to *N*avigation is a pulsed, low frequency radio-navigation system used by ocean-going vessels and commercial and private aircraft. The navigational signals are emitted on a carrier frequency of 100 kHz from transmitter chains and are propagated as both ground (which follow the surface of the earth) or sky (which bounce off the ionosphere) waves. Transmission of the signal from each chain is coordinated from a single master station within each chain. The signals from each station in a given chain are time-delayed at preset intervals. The location of a giver receiver is determined by the difference in arrival times of the various stations signals. Ground wave coverage includes all coastal waters and most of the inland area of the U.S. Within this area, location uncertainties are less than ±38 m 95% of the time. Sky wave propagation fields include all of the U.S. but at position fix uncertainties of about ±3.7 km 95% of the time. This error is acceptable since in a large-scale trajectory study on the order of 1000 km, the error would be less than 0.5% of the overall distance.

Three different prototypes of the LORAN-C transponder and tracking system were developed and tested. The final acceptable transponder prototype used a very efficient, low-powered, continuous FM transmitter in conjunction with a very sensitive tracking receiver. The FM transmitter had an efficiency of 30% at 50 mW output. The corresponding receiver preamplifier system consisted of a gallium arsenide field effect transistor to lower the noise from 6 db to about 0.5 db. Thus the relatively low transmitter power was easily recovered by the sensitive receiving station. The receiver system was also portable and capable of being operated in a small single engine aircraft or the rear seat of an automobile. Tests of the prototype transponder and tracking station in the CrossAppalachian Tracer Experiment long range trajectory study (CAPTEX '83) revealed areas for design improvement. The most notable problem was with the transponder transmitter. Transmitter carrier frequency drift caused by large temperature changes was of such a magnitude that, in some cases, the carrier frequency drifted out of the reception range of the base station receiver. Power output of the transponder transmitter (50 mW) also limited reception range to about 80 km. This design was modified to increase the transmitter output to 250 mW which doubled the reception range. Carrier frequency drift was also reduced. The efficiency of the base station receiver was also updated to current state-of-the-art technology with improved operating characteristics.

Technical Description

Transponder

The transponder package consists of three functional modules powered by three 3.4 V lithium batteries: (1) a LORAN-C receiver, (2) a telemetry or house-keeping section, and (3) an FM transmitter. Lithium battery life expectancy is on the order of 2 days for AA size batteries and 6 days for C size batteries. Each component is inexpensive, making the cost of the total unit about $200.00. The transponder and AA batteries together weigh 260 g. Size C batteries add an additional 115 g mass to the transponder. The package is compact (50 mm dia. and 235 mm long) and can be flown on a 1 m^3 tetroon. FAA regulations governing the operation of unmanned free balloons does not apply since the weight to size ratio is 3.2 g cm^{-2}. Consequently there are no restrictions on their use.

Base Station

The base or receiving station consists of an antenna, a pre-amplifier section, a 400.15 - 406.00 MHz receiver, a LORAN-C navigator, a frequency to digital converter, and a microcomputer for data acquisition and control. The most critical portion of the base station is the series of pre-amps which amplify the relatively small transponder signal. All of the base station components are small enough to be mounted either in a small van or single engine airplane. The onetime acquistion cost of these components is about $9000.00.

System Evaluation

All transponder prototypes and tracking devices were tested to evaluate system performance. These tests included transponder performance and calibration checks in a pressure/temperature chamber, transponder position accuracy checks, transponder signal degradation checks, and base station reception range and system reliability. Transponder and receiving station prototypes which failed to perform satisfactorily were successively modified until adequate prototypes were designed. Transponder prototype #3 and corresponding tracking system passed initial tests and were subsequently tested during CAPTEX '83.

Local Field Tests

Transponder-relayed LORAN-C signal accuracy and discrimination capability of the FM receiver were checked in two local field tests. Reliability and accuracy of the transponder relayed LORAN-C signals were checked by lifting a transponder with a tethered balloon to 100 m AGL and comparing the transponder LORAN-C output to that of a second ground-based LORAN-C receiver at the same location. The ground-based receiver and the transponder LORAN-C signals agreed with each other and the known latitude and longitude of the location to within 0.04 min latitude or longitude. Repeated checks showed no difference in compared LORAN-C readings.

Discrimination capability of multiple transponders by the FM receiving station was checked by placing four transponders on a tethered balloon. The carrier frequency of each transmitter was tuned such that only 1 MHz separated each transponder from its nearest neighbor. Each transponder was easily distinguished from the other three in this mode regardless of distance to the receiver, and LORAN-C and telemetry signals were correctly acquired. Hence, multiple targets launched simultaneously are expected to be easily followed.

Operation Field Use

Following local evaluations, the prototype transponder was used during CAPTEX '83. A total of 27 tetroons with accompanying transponders were launched and tracked from a dual engine airplane for various distances. Eighteen tetroons were released from Dayton, Ohio (39° 54.03' N, 84° 11.86' W) during the period 25 September through 28 October. The remaining tetroons were released from a location near Sudbury, Ontario, Canada (46° 38.60' N, 80° 54.90' W). The tetroons were released in support of the diverse aspects of CAPTEX '83 and were, therefore, launched to various heights. On occasion, multiple tetroons were launched simultaneously. Single transponders were tracked almost continuously, except for aircraft refueling periods. Transponder signals were detected and identified at ranges up to 80 km from the tracking aircraft. For multi-transponder tracking, the aircraft tracked a single tetroon for 15 to 30 minutes, then located and tracked another tetroon for another 15 to 30 minutes. Time required to lock-on to a transponder and to obtain reliable readings was from 5 to 20 minutes. Once locked on, three to four readings were logged and plotted during the 15 to 30 minute tracking period. After reviewing the signals, those considered most reliable were printed and stored by the microcomputer.

Ten of the eighteen transponders were tracked for periods of greater than 10 hours. Five transponders were tracked for distances over 500 km, with one for a distance of nearly 1000 km. Some tetroons could have been tracked for longer time periods but were abandoned due to deteriorating weather conditions. Other tetroons launched near the ground became entangled in vegetation but their transponders continued to transmit for several days thereafter.

Supplementary Tests

Following CAPTEX '83 the transponder was modified to minimize carrier frequency drift and increase transmission range. The transponder and tracking system were subsequently tested in 3 flights on 04

April 1986 for signal degradation and transmission range. The tracking system was mounted in a single engine aircraft while the transponder was flown from a tethered balloon about 120 m above ground level. The test was conducted from 1100 to 1830 hours MST and consisted of a series of fly-aways from the transponder. Transmission range was observed to be about 160 km. All data collected within the 160 km radius was found to be strong and reliable. When the tracking station exceeded 160 km, the transmitted signal rapidly degraded into the background noise. The signal was easily reacquired after the tracking station returned to the 160 km limit.

Precision and accuracy of the LORAN-C navigator output was well within acceptable error limits. The largest deviation from true location was 6.82 km obtained at 1124 hours and was due to intermittent interference of the LORAN-C signal by some other local source. All other location errors were less than 2 km, even when the tracking stations were located at 160 km from the transponder. The average error, excluding the 1124 data was 0.31 km with a standard deviation of 0.44.

Conclusions and Recommendations

The transponder and receiving station show great potential for both long and short range tetroon tracking projects but are probably better suited for the former. The system is now useable and is recommended for operation in future trajectory studies.

The system was developed using public funding provided, in part, through the sponsoring agency. Microcomputer programs and base receiving station schematics excluding the antenna and preamps are available from the Air Resources Laboratory Field Research Division located in Idaho Falls, ID. Transponder and base receiving antenna schematics are held by the E. F. P. Co. of Logan, Utah.

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***John F. Clarke** is the EPA Project Officer (see below).*
The complete report, entitled "LORAN-C Tetroon Transponder and Tracking System," (Order No. PB 87-116 687/AS; Cost: $13.95, subject to change) will be available only from:
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