SOME ASPECTS OF PROJECT SPECKLED TROUT

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ABSTRACT

Project Speckled Trout concerns itself with the evaluation of navigation systems for the Air Force on a continuing basis. Four classes of navigation systems are currently being evaluated and intercompared:

1. Inertial
2. Omega
3. VLF, using both Omega and communication signals
4. Area.

In this paper, the results of a number of test flights will be presented. Frequency stability requirements as a function of navigational accuracy for the VLF navigation system will briefly be covered.

Finally, a few remarks on deriving PTTI information from electronic navigation systems will be made.

I. PROJECT SPECKLED TROUT

Project Speckled Trout is an ongoing program to operationally evaluate navigation equipments for the U. S. Air Force. The evaluation of off-the-shelf hardware is an essential part of the overall supply picture. Knowledge of existing capability can greatly reduce expenses and maximize the cost effectiveness of equipment purchases. In addition, utilizing knowledge of state-of-the-art equipment, realistic design and system specifications can be set down for future equipment development with a reasonable assessment of the risk involved.

Currently, four types of navigation systems are being evaluated on the Speckled Trout aircraft:

a. Inertial Navigation Systems (INS);
b. Omega Navigation Systems;
c. VLF Navigation Systems; and
d. Area Navigation (RNAV) Systems.

By way of introduction, Table I lists some of the general characteristics of the navigation systems carried on board Speckled Trout during the test flights. Four inertial navigation systems were in operation: two LTN 51's, an LTN 72 (manufactured by Litton Industries) and an INS 61B (manufactured by the Collins Radio Group of Rockwell International). The inertial navigation systems are self-contained, completely passive devices. An INS senses accelerations along a set of axes defined by a gyroscope aligned with the Earth's axis of rotation. Position is obtained by a double integration of the accelerations. Any errors in the measurement of the accelerations or the alignment of the measurement axes will also be integrated twice and will produce time divergent errors.

Only one Omega set was on board during this period. It was an ARN-115, manufactured by the Canadian Marconi Co. Omega navigation errors, although they are sometimes functions of time of day, can normally be considered as bounded. Usually, the navigation errors are associated with the propagation errors of VLF transmissions.

Two VLF navigation systems, the Ontrack II manufactured by the Communication Components Corp. and the GNS-500 manufactured by Global Navigation Systems, Inc., were carried. However, there were some periods when each was off the aircraft for maintenance. The errors associated with VLF navigation systems are either bounded or unbounded depending on the mode of operation of the particular set. In the hyperbolic mode, two pairs of phase measurements are being compared as in conventional Omega navigation; therefore, the errors will exhibit the same character as Omega errors. However, in the rho-rho mode, the errors associated with the VLF navigation systems are not bounded. In the rho-rho mode, since a phase comparison between the received signal and the signal from a local on-board oscillator is made, any uncompensated drift rate or calibration error of the local oscillator will be directly translated into a position error as a function of time. Both VLF navigation sets operated in the rho-rho mode.

Area Navigation (RNAV) Systems combine and filter navigational data from several sources and display that information to the flight crew. The error associated with the displayed position reflects the error of the input source. Two different navigation systems provided input to the RNAV system on board the Speckled Trout: the INS 61B and the standard VOR/DME system, which is the primary source of air navigation data throughout the U.S. On those flights outside the VOR/DME network, the primary navigational data being supplied to the RNAV system is inertial data. In this case, the position error is unbounded. However, when within VOR/DME coverage, the displayed position should not be in error by more than the error associated with the VOR/DME system.

II. SUMMARY OF RESULTS OF SPECKLED TROUT FLIGHTS

Reports which list the results of the various test flights are issued at fairly regular intervals. Each report contains for each flight during the covered period, flight path, duration of flight, the navigational data obtained on each system by manufacturer's name, and any notes of interest. The navigational data consists of the error for each of the navigation systems at the end of the flight. The error is defined as the difference between the system readout for some well-defined point on the airport at touchdown and the coordinates for that point obtained from C-5 Airfield Diagrams and/or Jeppesen Airport diagrams. The navigational error is listed in latitude/longitude offsets in nautical miles (nm) from the assumed position as well as radial error. The radial error is divided by the duration of the flight to derive a radial error rate/hour.

Listing the data contained in each of the reports for each flight is a little impractical for this paper. Therefore, it was decided to list summaries of the data contained in two of the more recent reports considered representative of the flights. The two reports selected were Report No. 75-09 and Report No. 76-01. These reports contain data from 39 flights throughout Europe, the Mid-East, the Pacific, and the U.S. The flights lasted between 1 and 9 hours. Table II lists simple averages of the data from each of the two reports and an average of all the data contained in these two reports. Column 1 lists the report from which the data presented was computed. The second column lists the months when the flights contained within each report were flown. The next four columns list the average radial error rate in nm/hr for each of the four inertial navigation systems flown during the test period. The next two columns list the average radial error rate for each of the two VLF navigation systems. Please note that no mention of specific manufacturer's equipment is made in this table so that the results listed here can in no way be interpreted as an endorsement of any one product.

The data listed for the one Omega navigation set in the next column are not the average radial error rates, but the average radial error in nautical miles. The last column lists the radial error for the RNAV system operated during this time frame. Radial error rather than radial error rate is listed here because the mode of operation of the Omega and RNAV systems was such that the errors should be bounded and not functions of time.

The results indicate that the four inertial units performed reasonable well throughout the test period. One of the inertial units, Set #1, performed exceptionally well exhibiting an average radial error rate of only 0.4 nm/hr.

The VLF navigation systems exhibited average radial error rates of 1.5 nm/hr and 2.6 nm/hr. If one attributes these error rates solely due to the unmodeled drift rate of the local oscillator with respect to the oscillators governing the VLF transmissions, then one obtains 2.6 parts in ten to the ninth and 4.4 parts in ten to ninth, respectively, for the unmodeled drift rates.

It should be noted that the VLF navigation sets in addition to exhibiting the unbounded error growth with time should also reflect to some degree the bounded error of the Omega navigation system, i.e., reflect some of the navigational error caused by propagation variations in the VLF transmissions. The average radial error of the Omega navigation set tested here was 2.3 nm. If we assume that the VLF navigation systems were affected, on the average, by the same constant error of 2.3 nm, we could then adjust the radial error by this amount and recompute a new average radial error rate. On doing this, the new average radial error rates for the two VLF navigation systems become 1.85 nm/hr and 0.71 nm.hr, respectively. These rates would correspond to an unmodeled fractional frequency difference or drift rate of 3.1 and 1.2 parts in ten to the ninth, respectively. These numbers are a little larger than expected considering that rubidium frequency standards were used on both these sets. The expected error rate is less than 0.1 nm/hr, corresponding to a drift rate of about 1 part in ten to the tenth. Tymczyszyn (1975) at this conference has reported on improvements in one of these systems which should remove the deficiency noted above. The improved system now accounts for propagation path variations during the calibration of the frequency prior to take-off.

III. SOME SPECULATION ON PTTI AND FUTURE NAVIGATION SYSTEMS

The VLF navigation sets discussed earlier seem to represent the future trend in navigation sets. Future navigation systems will contain either an atomic frequency standard or high precision crystal oscillator. Within the same dust cover, one can and most likely will find a powerful microprocessor. In addition, some systems will have the capability to receive and process a mixture of signals from VLF, LF, and VHF to UHF. The potential flexibility that some current and most future navigation systems will exhibit is staggering. It does not seem likely that future navigation equipment will need distinctions such as Loran-C or Omega. Most systems will process the best available signal or combination of signals in the most efficient mode to derive the best possible position fix.

In the past, PTTI information has usually been extracted from navigation systems through specially developed receivers. These receivers are usually cheaper than the equivalent navigation receiver for that system. The PTTI information derived from the navigation system can be either relative information or absolute information depending on whether the system has been calibrated. However, it appears that in the future it should be possible to derive absolute PTTI information from most electronic navigation systems using off-the-shelf navigation receivers with modified software. The trend of the future for PTTI seems to be a trade-off of hardware development for software development.

In the literature, several articles already have appeared with suggestions on how to extract both time and time interval from navigation systems. Future navigation receivers will most likely have the hardware and computing capability to implement these schemes.

With respect to the LF navigation system Loran-C, Ryerson (1969) indicated how the simultaneous use of Loran-C in both the hyperbolic and rho-rho mode could be used to extract absolute time and time interval provided there is a local oscillator at the receiver. Kelley (1969) and Uttam and Palsson (1975) discussed the use of Loran-C in a rho-rho mode for timing. All schemes involving clock calibration require deducing the distance to three or more stations. Two stations are required for the navigational fix; the third is used for calibrating the clock. Most Loran-C chains operate with four transmitting stations. Therefore, sufficient redundancy is already built into the system.

Experiments by Chi and Wardrip (1973) using Omega indicate that a timing precision of better than ± 5 μs is now attainable. However, knowledge of the accurate position of the receiver is presumed. Gaon (1974) incorporates the technique of composite Omega as put forth by Papousek and Reder (1973) to derive PTTI information from the Omega system. Smith (1974) and Burch and Sakran (1974) report on the Northrop ARN-99(V)2 Omega navigation set which operates in the rho-rho mode using a crystal oscillator as the basis for its timing.

It seems that Omega, utilizing the composite frequency technique in combination with the navigation signals being processed in both the hyperbolic and rho-rho mode, might offer the most precise way to get absolute PTTI information into the field. This conjecture is based on the fact that the composite frequency technique seems to offer the best way to minimize propagation effects.

IV. CONCLUSIONS

The reports of Project Speckled Trout are a valuable source of information. They will most likely be the basis for a number of studies. The deficiency of the VLF systems noted in this report seems now to be corrected. Future reports should verify this.

The signal processing techniques employed by the VLF navigation systems, if applied to future navigation receivers, seem to indicate that absolute PTTI information should be easily extracted from navigation systems. However, the mixing and matching of the various navigational signals in different operational modes will necessitate improved synchronization between all navigation systems.

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System	Error Properties	Operational Mode	Type of Operation	Sensing System
Inertial	Unbounded		Self-Contained	Acceleration
Omega	Bounded	Hyperbolic	Relies on Omega Transmitters (Passive)	Phase Comparison
VLF	{Bounded Unbounded}	{Hyperbolic Rho-Rho}	Relies on Omega Transmitter and/or VLF Communication Transmitter (Passive)	Phase Comparison
RNAV	Bounded	Rho-Theta	Primarily Relies on VOR/DME Stations (Active)	Pulse

Table I - Synopsis of Navigation Systems Being Tested on Speckled Trout

Report	When Flights Made	Inertial				VLF		Ω	RNAV
		#1	#2	#3	#4	#1	#2		
		nm/hr	nm/hr	nm/hr	nm/hr	nm/hr	nm/hr	nm	nm
75-09	Mar-May 75	0.4	0.5	0.5	0.7	1.9	1.1	2.6	0.8
76-01	Jun-Jul 75	0.4	0.5	0.8	0.8	3.3	1.8	1.9	0.5
Averages		0.4	0.5	0.7	0.8	2.6	1.5	2.3	0.7

Table II - Synopsis of Navigation Data from Speckled Trout

QUESTION AND ANSWER PERIOD

MR. BARSZCZEWSKI:

Barszczewski, NRC.

Again, there are a few points I would like to make. First of all, on this bounded and unbounded rate of error with VLF and Omega, if you talk of Omega and VLF you should talk in the same sets of units. I mean, if you operate hyperbolically, then the error is bounded by propagation, and there is no increase in an error rate.

Now, personally, I have no beef against either choice of VLF, Omega, Loran C, or whatever it is. We operate in the Arctic, and we take what we can get. The magnetic compass is no good. The VLF signals are there. You usually have a coverage of three stations, sometimes more. The coverage is quite good. There are strong signals, and so on.

Now, most of navigation systems will be, aided and of course the best aid is to have a competent navigator at the clock and air speed indicator. That is ultimate, but if you go by the electronic systems, you will probably use some sort of air speed indication and some heading. We have been using sort of a hybrid system like that for several years. We use a minicomputer to keep track as we go along, and we always manage to return, but we have had some problems with loss of information, generally due to failure of electronics.

Now, as far as the future, there is one little point I would like to make. I would like to see some of the beacons, LF beacons in particular, to be put on cesium frequency control because that would be an additional input that could be used for navigation.