When covered with the polyvinyl chloride skin, the 40-PPI polyurethane foam and the 80-PPI polyurethane foam showed appreciable reductions in skin-friction drag compared to the rigid surface. However, the Scott 27-PPI polyurethane foam experienced a slight increase, and the foam rubber a large increase. The authors can offer no confident explanation for the large increase in drag for the foam rubber with PVC skin. The answer may lie in the previously discussed joint ridges of the foam rubber specimen, but no specific mechanism is apparent.

For the tests with the resilient material saturated with water and covered with PVC skin, the first three materials demonstrated a significant reduction in skin-friction coefficient, while the foam rubber again showed an increase.

An attempt was made to plot the skin-friction coefficients from Table 2 with the compression modulus of Table 2; however the scatter of the data was such that no conclusive trend was observed.

Conclusions

Appreciable reductions in flat-plate turbulent airflow skin-friction coefficient have been demonstrated for somewhat more durable and practical compliant surfaces that those tested by Looney and Blick[15]: 0.0025-in.-thick polyvinyl chloride skin backed by a resilient polyurethane foam either wet or dry. Since the skin was stretched over the foam rather than being bonded to the foam, it is possible that the very thin layer of air or water between the skin and the foam had some effect on the skin friction. In any case, the foam is a more convenient device to contain the damping fluid that an unstructured reservoir, especially if a liquid is used.

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Utilization of Satellite Navigation Techniques in Marine Operations

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1. Introduction

ELECTRONIC aids to navigation are currently used in many marine applications. The shore-based electronic navigation aids, such as Decca, Loran A and C, and Omega, have proven generally satisfactory in locations where adequate system signal coverage is provided. These regions of useful coverage range from approximately 250 to 1000 miles from the shore stations(s) for Decca and Loran, up to 5000 miles for Omega. None of these systems, however, provides the optimum performance combination of worldwide coverage, all-weather operation, and precise position-location capability. All of the aforementioned systems have performance limitations attributable to propagation anomalies and high path attenuation typical of earth-based systems operating beyond the radio horizon.

The Navy Navigation Satellite System (NNSS), operational since 1964, now provided a relatively simple means of position location and navigational data, without geographical coverage or weather limitations. System accuracy is satisfactory for the majority of oceanographic and marine exploration operations. Typically, position errors of about 0.1 naut mile have been experienced consistently.

Satellite navigation system implementation requirements are relatively modest from the user equipment point of view. Until fairly recently, the NNSS requirement for a small, general-purpose shipboard computer to provide real-time readout of position in latitude and longitude had been regarded as relatively costly compared with conventional electronic navigation aid equipments. However, the availability of quite adequate computers costing less than $10,000 coupled with the ability to automate fully the total navigation problem provided by the computer has resulted in rapid acceptance of the satellite navigation concept on a purely economic basis by both military and commercial/scientific users.

Currently, ITT Aerospace is supplying the shipboard satellite navigation user equipment for the Navy, as the AN/SRN-9. Several commercial versions of this equipment are also being supplied to oceanographic and marine exploration interests.

2. System Operation

The basic NNSS configuration is shown in Fig. 1. Polar orbiting satellites with an orbital period of about 108 min provide full earth coverage. The frequency of position fix availability is determined by the number of satellites in use,

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since only a fraction of the available orbits provide the needed line-of-sight visibility to a user at a fixed location on the earth's surface. The system is operational with a worst-case fix frequency of about two per day from a single orbiting satellite. For a four-satellite configuration, position availability is improved to once each 138 min at the equator. It can be seen that fix availability improves as the user moves north (or south) away from the equator.

The injection station accumulates tracking data on the position of each satellite from a worldwide net of tracking stations. These data are used to predict the future orbit of the satellite. This predicted ephemeris is injected into the satellite memory via a ground-to-space radio link about twice daily, although updates can occur at more frequent intervals if tracked orbital data indicate that a poor prediction has been made.

The satellite, in turn, transmits signals to an unlimited number of passive users over two simultaneously generated carrier frequencies, 150 MHz and 400 MHz. Both frequencies are derived with a fixed 3:8 relationship from the same stable oscillator. The satellite signals contain the predicted ephemeris previously stored in the satellite memory. These orbital data, along with measurement of doppler frequency shift by the shipboard user's receiver, serve as the basis for the position-location computation by the user.

The ephemeris from the user's receiver is entered into the shipboard user's digital computer to determine satellite position during each 2-min interval. At the same time, the receiver measures and accumulates the doppler frequency shift over each 2-min interval, which is equivalent to the change in slant range between the user and the satellite over each interval. Three computed satellite positions, along with three sets of accumulated doppler shift for the same 2-min intervals, yield a unique computational solution for the user's location, providing his altitude is known. In addition to altitude, the user must also supply estimates of his position, local time, and his course and speed as computational inputs. The user's computed position is read over directly in latitude and longitude, without ambiguity or requirement for application of any correction factors. Simultaneous reception of satellite signals at 150 and 400 MHz provides the user with the capability to correct for ionospheric refraction effects.

3. Shipboard User Equipment

The user equipment configuration for shipboard applications requiring a high degree of accuracy comprises the dual-frequency receiver and digital computer combination, which typically yield position fixes of about 0.1 naut mile error. Where reduced accuracy can be traded off against cost and complexity, one receiving channel (usually the 150-MHz frequency) can be eliminated. Single-channel operation at 400 MHz provides reduced accuracy, since the correction for atomospheric refraction is thus eliminated. Typical results for single 400-MHz channel operation indicate an error of about 0.25 naut mile during the day and about 0.1 naut mile at night, when refraction effects become negligible.

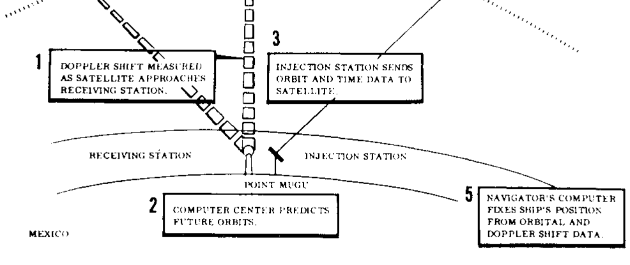

Fig. 1 Navy Navigation Satellite System geometry.

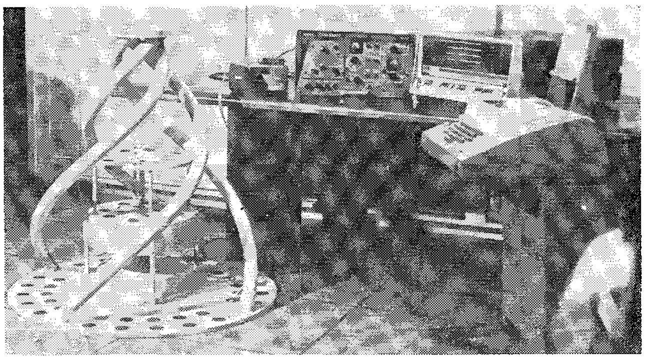

Fig. 2 Typical satellite navigation operating setup.

4. Equipment Details

Currently available user equipments essentially represent reduction to practice and refinement of the concepts initially formulated at the Applied Physics Laboratory of Johns Hopkins University during the development of the Navy Navigation Satellite System. These concepts emphasized automatic operation, minimum requirements for operator skill and participation and, in general, minimal hardware requirements. A good example of this is the receiving antenna. Unlike the large directive arrays, which must either manually or automatically be made to track, which are typically required for use with satellite systems, the NNSS receiving antenna is fixed, requires only upper-hemisphere directivity, and is relatively inexpensive.

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+Ø177Ø738
+Ø3713866
+ØØ7195Ø2   }
+ØØØ19762   }
+ØØØØ4562   }
+ØØ745573   }
+ØØ614415   }  KEPLER PARAMETERS
-ØØØØØ786   }
+ØØØ2ØØ79   }
+ØØ3ØØ113
+ØØ999798
3143591 2ØØØ
3356ØØ7 2ØØØ   }
3679582 2ØØØ   }
4Ø53Ø37 2ØØØ   }  LIST OF DOPPLER COUNTS
4361Ø11 2ØØØ   }
4557447 2ØØØ   }
ØØØØØØØ ØØØØ   }
ØØØØØØØ ØØØØ
+Ø26 +148
+Ø24 +113   }
+Ø19 +Ø79   }
+Ø11 +Ø48   }
+ØØ2 +Ø23   }  EPHEMERAL DATA
-ØØ9 +ØØ4   }
-Ø21 -ØØ8   }
+ØØØ +ØØØ   }
+ØØØ +ØØØ
HR/MIN/LAT/LON/CSE/SPD/ANT          LOCAL DATA INPUTS
Ø4  36   6Ø  -3Ø  3Ø7  9.3  255

HR=+      4.ØØØØØ
MIN=+    36.ØØØØØ

LAT=    6Ø.381Ø6 N }                COMPUTED POSITION
LON=    28.26647 W }
FRQ=31975.82ØØØ

RESIDUALS
-      1.984Ø1
-     15.28227  }
+     26.9Ø832  }
-      5.83626  }
-     26.74371  }  RESIDUALS
+     22.938Ø6  }
+       .ØØØØØ  }
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4 ITERATIONS
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Fig. 3 Sample computer input-output.

Ordinarily, the antenna is directly connected to the receiver input. However, for installations requiring cable runs in excess of 100 ft, an active preamplifier is installed at the base of the antenna to compensate for lead-in cable loss.

Each receiver channel for the dual-frequency system is of phase-lock design to provide the minimum noise bandwidth required to support the approximate 50 bit per sec satellite signal rate over the full excursion of anticipated doppler shifts. Once the desired signal is acquired by the phase-lock loop, the receiver automatically tracks the incoming signal as it changes in frequency due to doppler shift. Two independent receivers (except for a common stable oscillator) may be used. The ITT receiver has both channels slaved to a common VCO (voltage controlled oscillator). Reception of a signal on either the 150- or 400-MHz channel will thereby automatically lock up the other channel. This is highly desirable for holding lock during signal fades, since fades rarely occur on both channels at the same time. The stable oscillator is a commercially available, portable 5-MHz frequency standard with a few parts out of 10^{-10}.

In addition to the usual complement of rf and signal demodulation circuitry, the receiver also contains an integral data processor unit that formats and interfaces the satellite ephemeris and receiver-derived doppler and refraction measurements for direct insertion into an on-line digital computer, or alternatively for storage on punched paper tape.

The actual position fix computation can be implemented on any small-scale, digital computer, such as the Digital Equipment Corporation PDP-8/S (4096, 12 bit word memory). Programming for the PDP-8/S was accomplished initially at Lamont Geophysical Observatory by Talwani et al. This initial attempt sacrificed some precision in squeezing the program into the PDP-8/S' relatively small memory. Recently, ITT has commercially released a new, high-precision program for the PDP-8/S which requires only 3000 words of computer memory, leaving about 1000 words available for other uses. Figure 2 shows an operating configuration providing a receiver data output in the form of an alpha-numeric paper tape printout, in addition to the direct data interface to the computer.

5. Typical System Utilization

The specific steps involved in setting up and operating the shipboard user's equipment are relatively simple. Normally, the receiver does not require retuning from satellite pass to satellite pass, so that the operator need only observe that signal acquisition and synchronization has occurred from the front panel indication lamps.

At the end of the 18-min satellite pass, local data must be inserted into the computer, consisting of 1) day of the year, and GMT to within ±15 min, 2) estimate of latitude and longitude to within ±3°, 3) receiving antenna height, and 4) own ship's velocity and direction. Once local data have been inserted, computation can begin. The entry of local data can easily be automated, to reduce operator workload to a minimum.

Figure 3 shows the format for data entry, as well as that of the resulting solution. As previously mentioned, a minimum of three sets of doppler and refraction measurements are required for solving for the three problem unknowns: latitude, longitude, and frequency offset between the satellite-borne frequency standard and the reference oscillator used with the shipboard receiver.

The actual position computation is an iterative process that proceeds until the final two iterated positions differ by less than a predetermined factor. The total number of iterated positions differ by less than a predetermined factor. The total number of iterations required depends primarily upon the "closeness" of the initially input estimate of latitude and longitude.

6. Summary

In summary, the Navy Navigation Satellite System provides a unique capability for accurate and repeatable position location which is being exploited by marine and oceanographic exploration applications. Equipment requirements are relatively modest, both in initial cost and in the related areas of logistic and operational support.