An Airborne Digital Navigation System in an ASW Aircraft, MOD 1

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Efficient performance of an airborne antisubmarine warfare (ASW) mission requires accuracy and reliability in both long-range and tactical navigation. The system must be able to direct the aircraft to distant submarine contacts, and, when in the tactical area, it must be able to drop accurately short-range sensors. The positions of these sensors must be constantly and accurately maintained in a continuously moving sea environment. To accomplish these tasks, doppler, inertial, dead reckoning air mass information, and long-range navigation (Loran) are channeled into a digital computer, which uses this information to maintain the aircraft's position in geocentric latitude and longitude and in a tactical x-y system. Positions of submarine contacts, ships, and sonobouys are maintained in the tactical system. These positions are displayed to the Tactical Coordinator (TACO) on a display that is interfaced with the computer. In addition to a digital integrated navigation system, specialized techniques, such as aircraft navigation biasing and pattern correction of sonobouy fields, have been developed for ASW navigation. A system aimed at meeting the requirements of future ASW missions has been designed and flown over the past year in a long-range ASW aircraft.

Introduction

CONTINUING improvements in the speed, maneuverability, and general operational characteristics of modern submarines during the 1960's highlighted the need for an advanced antisubmarine platform, which would significantly enhance present antisubmarine capabilities and offer development potential to keep abreast of future submarine developments. Project A-NEW, managed by the United States Navy, was designed to meet such a need. In brief, a team, consisting of Naval personnel, Civil Service, and Contractors, hance airborne present antisubmarine capabilities and offer development potential to keep abreast of future submarine developments. Project A-NEW, managed by the United States Navy, was designed to meet such a need. In brief, a team consisting of Naval personnel, Civil Service, and Contractors was formed to study the antisubmarine warfare (ASW) problem, conduct laboratory simulation, and produce an airborne avionics system that would demonstrate the feasibility of using a digital data processing system as the heart of an ASW weapons system.

The A-NEW MOD 1 system uses the UNIVAC CP-754-8 computer. This is a general purpose, parallel operation, digital machine having a thin-film memory. This integrated real-time command and control system was installed in a United States Navy NP-3A Orion, this aircraft being a military version of the commercial Lockheed Electra. Flight testing began on January 18, 1964. As a result of the tests, the original system was modified in August 1964 and again in April 1965, these updates being identified as MOD 1.2 and 1.4. Improvements were made in equipment, and programs were changed to reflect the experience gained during the flight evaluation phases. At present further evaluation is being done by members of the A-NEW team at the Naval Air Test Center, Patuxent River, Md. Quantitative results are, naturally enough, classified, but experience to date has shown that the MOD 1 system greatly increased the antisubmarine capabilities of the aircraft *vis-a-vis* present Fleet P3s. The description that follows of the digitally controlled navigation system reflects the work and thinking of numerous personnel, both military and civilian, whose ingenuity and effect progressed MOD 1 beyond the mere feasibility stage to an effective ASW weapons system that will form the basis of future Fleet ASW aircraft.

Navigation System

An aircraft on an ASW mission needs a highly accurate navigation system capable of getting the aircraft to its operational area (which may involve a transit of 500 to 1000 miles over water) and subsequently permitting detection and localization of a submarine target using short-range acoustic sensors accurately placed in a continually moving sea environment. This latter requirement demands that a system should maintain accurate relative positioning, not only among aircraft, sonobuoys, and target, but also with respect to other participating aircraft and surface vessels.

In order to accomplish these tasks in MOD 1, certain basic navigation data are fed to the central computer. An APN-153V Doppler radar provides ground speed and drift angle; an air data computer provides true air speed; aircraft heading is obtained primarily from the true heading output of a Litton inertial platform (LN2C/ASN42) or from the altitude heading reference system (AHRS/ASN37), and, finally, Loran data in the form of Loran triad time differences from the AN/APN-145 receiver.

Given the previous data, the computer automatically calculates the continuous real-time aircraft position. In the MOD 1 system, the computer provides two types of aircraft position keeping: 1) a tactical position in Cartesian coordinates, and 2) a long-range position in geocentric latitude/longitude coordinates.

Man-Computer Interface

Before discussing the methods used to provide accurate tactical and long-range navigation, it is necessary to describe briefly the relationship of the three crew members involved with the navigation system to the computer. These are the pilot, navigator, and the tactical coordinator (TACO). The TACO, in ASW operations, is in "command" of the aircraft.

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He directs the dropping of sonobuoy patterns, the tracking of submarine contacts, the possible attacking of submarines, and must make all decisions with respect to the tactical situation.

The TACO is provided with several means of intercommunication with the computer. One such means is by a 16-in. cathode ray tube (CRT) that is designated as the situation display. The computer uses this display to present a graphical representation of the tactical situation. In addition to the various types of alphanumeric messages presented on this display, the computer displays a scaled replica of the tactical situation (i.e., the relative locations of the aircraft, sonobuoy positions, other aircraft and ships in the tactical area, and possible submarine positions). The aircraft and track symbol are updated every $\frac{1}{20}$ sec, thereby indicating continuous motion of the aircraft on the screen.

Coordinated with this display, the TACO has use of an electromechanical "joystick." The TACO may, by using the joystick, position a hook symbol on the situation display. The TACO may use this hook to designate position on the CRT, or he may use it in a computer-activated recentering function. The recentering function, along with variation of range scale function, gives the TACO flexible control over the display.

The TACO has an alphanumeric keyboard that is interfaced with the computer. In addition to this, he has a console with various computer-connected function switches. He may transmit information to the computer via the following equipment: 1) the hook in conjunction with the function switches; 2) the keyboard in conjunction with the function switches; and 3) function switches alone.

The computer communicates with the pilot by displaying symbolic and digital data on the pilot's situation display (9-in. CRT) and his bearing-distance heading indicator (BDHI). The navigation data presented on this display consist of an aircraft position and track vector along with the current destination or fly-to-point symbol. The computer provides the pilot with steering information via the BDHI. This information is based upon the aircraft's present position, heading, and the location of a designated destination or fly-to-point. The steering information consists of distance-to-go and a proposed aircraft track and is displayed as digital and analog data on the BDHI. This steering information is determined in one of two ways. If the aircraft is more than 8 miles distant from its intended destination, the bearing and distance-to-go are computed on the great circle course to the destination. If the aircraft is less than 8 miles distant, the information is provided by straight-line distance. This BDHI information is recomputed every second.

The pilot has a keyset that is tied in with the computer. One of the switches on this keyset is designated as the on-top switch. With this switch, the pilot can alert the computer whenever he considers the aircraft presently to be over some particular position or object. The significance of this switch will be made apparent in the discussion of the tactical navigation system.

The navigator in the A-NEW MOD 1 system has no means of direct communication with the computer. He may, however, transmit navigation information to the TACO for subsequent entry into the computer. Because the navigation system is highly automated, the navigator is only required to monitor the navigation equipment.

Tactical Navigation

The positions of sonobuoys, targets, and all data computed relative to the aircraft are maintained in the short range or tactical coordinate system. This coordinate system assumes a flat earth; i.e., the hemisphere, whose normal passes through the origin point, is distorted on to the tangential plane. Spherical distances on the earth are treated as linear distances on the plane. The origin of this Cartesian system is fixed upon some known geographical point, which is normally taken as the airfield from which the flight originated.

In addition to the tactical coordinates, there also is a display coordinate system. This system has as its origin the center of the display; therefore, the computer must maintain this display center as a position in the tactical coordinate system. The computer then may translate positions in the tactical system to the display system for subsequent projection of the tactical situation. The pilot initiates the navigation functions by depressing the on-top switch. He normally will carry out this procedure on takeoff from the field. The computer then sets the tactical coordinates of the aircraft to zero, the long range coordinates to those of the base, and begins to dead reckon the aircraft position. The primary mode of dead reckoning the aircraft position is that of the Doppler/air mass system. The computer samples and clears the Doppler accumulator values and attempts a Doppler computation once every $\frac{1}{2}$ sec. In addition to the accumulator value, one bit of the Doppler message indicates whether the AN/APN-153V considers the Doppler pulse train to have been valid within the preceding time interval. This Doppler accumulator value, along with the drift angle and heading angle, is used to compute the aircraft position increments, ground velocity vector, and wind velocity. The drift angle, transmitted to the computer by the Doppler receiver, is averaged over $\frac{1}{2}$ sec. This amounts to ten $\frac{1}{20}$-sec inputs. Ground speed and true air speed are smoothed by the computer.

When Doppler goes into memory (i.e., when the Doppler input is invalid), true air speed (TAS) information and the previously computed wind velocity are used as a backup mode of position dead reckoning. This procedure, using air data alone, will compute X-Y increments to the aircraft position.

In the tactical dropping of weapons or sonobuoys, the TACO indicates to the computer the positions in which he wishes the sonobuoys or weapons to be placed. He makes the indication via his hook and the situation display. Upon receipt of this command to drop a specific sonobuoy, the computer, using iterative ballistic equations, calculates an expendable release point that results in impact of the expendable at the desired point. A gate, or window, of the desired release point will be checked continually by the computer for actual release of the sonobuoy. To ascertain when the aircraft is within this window, it is necessary that the aircraft's position be determined at a higher rate than the $\frac{1}{2}$ sec provided by the Doppler/air data computations. This increase in updating frequency also is required by the intervalometer function computations. Therefore, between $\frac{1}{2}$ sec Doppler/air data computations, the aircraft position is extrapolated every $\frac{1}{20}$ sec. This extrapolation procedure uses $\frac{1}{10}$ of the distance traveled over the previous $\frac{1}{2}$ sec period to produce the X-Y aircraft position increments.

Although it is not necessary that the tactical coordinate system be accurately located with respect to geocentric latitude/longitude while in the tactical situation, it is necessary that the aircraft be correctly positioned in relation to deployed sensors (such as sonobuoys), so that contact information from these sensors can be correctly correlated. The tactical aircraft position is modified to fulfill this requirement.

Tactical Position Modification

Maintenance of a stabilized, tactical position-keeping system in a sea environment presents a somewhat unique problem. In order to retain correct spatial relationships among aircraft, sonobuoys, and targets, the A-NEW tactical navigation system uses a combination of bias velocities and position correcting.

Bias velocity

In analyzing the TACO's requirements, we see that he is primarily concerned with the aircraft-sonobuoy target rela-

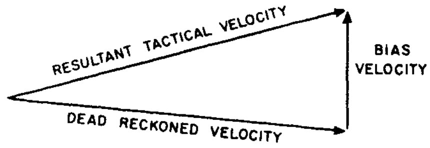

Fig. 1 Bias velocity.

tionship and not necessarily with a true geographical position. Therefore, instead of modifying the sonobuoy positions, the computer determines an artificial velocity and applies it to the aircraft tactical position. This velocity, designated as the bias velocity, is included in the $\frac{1}{2}$-sec dead-reckoning computations of the aircraft position. It is defined as the amount of correction necessary to compensate for errors due to sonobuoy drift, Doppler sea movement error (when applicable), and inherent navigation equipment errors. This bias velocity is obtained by dividing the error vector determined by two successive transits over a sonobuoy by the time elapsed between the two transits. If the bias velocity is applied to the aircraft's position-keeping system, then the aircraft can accurately return to deployed sonobuoy positions. (Figure 1 illustrates the Bias Velocity.)

Grid correct

One of the functional switches on the TACO's console is designated as grid correct. This switch, used in conjunction with the hook function and associated symbol on the situation display, allows the TACO to slew the tactical coordinates of the aircraft to those of the hook position. The amount of correction needed to slew the displayed aircraft position to that of the hook symbol is used to modify the aircraft's tactical coordinates.

Figure 2 depicts the results of a grid correct operation. Figure 2a represents the TACO's situation display prior to the depression of the grid correct switch. Figure 2b shows the same display after the grid correct operation. The only position affected by this function is that of the aircraft. All other positions remain the same on both the display and the tactical position-keeping system.

Pilot-controlled correct functions

The pilot is responsible for many of the tactical, position-modification functions. Most of these functions require the pilot to indicate to the computer the precise moment when he considers the aircraft to be over a particular position. He does this by depressing the on-top switch located on his console. The computer interprets the depression of the on-top switch as being associated with one of four different programed functions. The function associated with a particular on-top is determined by a specific sequence of operations associated with that function. The four functions are as follows: 1) the first on-top of the flight directs the computer to initiate the navigation functions; 2) the aircraft correct function is performed with all other on-top's with the following exception: 3) if there are nonpattern corrected buoys in the water following an aircraft correct, the computer will flash the aircraft symbol on the pilot's display for 10 sec. Within this period, an on-top indication directs the computer to perform a pattern correct function; and 4) the depression of the pilot's visual switch followed by an on-top directs the computer to perform a differential buoy drift function.

Aircraft correct

The aircraft correct function provides the computer with the necessary information to determine the bias velocity. At some past time, the aircraft will have dropped a sonobuoy or a smoke marker. The pilot then will return to this position and will fly over the buoy or smoke. Because of system and/or environmental drift, the pilot will notice a deviation in the displayed aircraft and sonobuoy positions. When he is over a buoy or smoke, the pilot will depress the on-top switch. The computer then will search the stored positions and will relate the closest of these to the buoy or smoke being "on-topped." If the computer is not able to locate a sonobuoy position or a smoke marker within 2400 yd of the aircraft position, then the correcting function will be aborted. If the previously mentioned criteria are met, the computer will correct the aircraft tactical position to that of the sonobuoy or smoke. The amount of correction necessary and the elapsed time since the dropping of the buoy are used to automatically compute the bias velocity.

Pattern correct

An initial drop of a pattern of sonobuoys may occur before a bias velocity has been included in the tactical navigation system. An error in the buoy positioning, proportionate to the time between the first buoy being dropped and each subsequent buoy, will accumulate. This is compensated for in the pattern correct function by using the correct amount of the bias vector (i.e., bias velocity multiplied by elapsed time). Bias velocity will be available as soon as the pilot on-tops the first buoy for an aircraft correct.

The standard procedure in stabilizing the tactical, position-keeping situation is to have the pattern correct function initiated, following the deploying of the tactical sonobuoy pattern. After all of the sonobuoys in the pattern have been positioned, the pilot will return the aircraft to the first sonobuoy dropped. He then will initiate the aircraft correct function by depressing the on-top switch when he is over the selected sonobuoy. The computer then performs the aircraft correction function. If this function is carried out successfully, the computer will alert the pilot that the pattern correct function is available. The pilot again must depress the on-top switch to complete the pattern correct function.

A pattern correct sequence is illustrated in the diagrams that follow. Figure 3a shows the aircraft that has returned to its initial buoy drop position. Because of the system errors and sea movement errors, the displayed aircraft and displayed

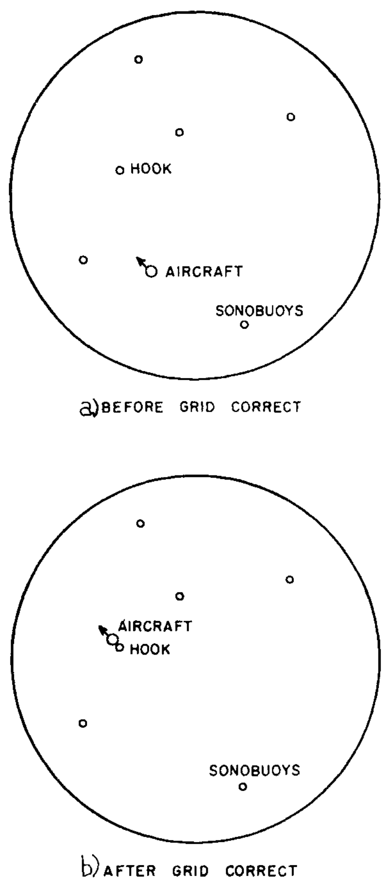

Fig. 2 Results of grid correct operation.

buoy position are not in coincidence. When the pilot presses the on-top switch, the aircraft will jump to the buoy position (Fig. 3b), and a bias value now will be available for use in the pattern correct mode. Figure 3c shows the displayed buoy positions after the proportional corrections have been applied. If the pilot does not depress the on-top switch within 10 sec of the aircraft correct on-top, the computer will abort the pattern correct function.

Differential buoy drift

It is not necessarily true that all the buoys of a pattern will be subjected to the same currents or winds. To account for the possibility of a particular sonobuoy being subjected to unusual movement because of the rips or local winds, the pilot is provided with a differential buoy drift function. This function is similar to the aircraft correct function in that the pilot will fly over the "stray" sonobuoy and indicate an on-top to the computer; however, the pilot differentiates this signal from that of the aircraft correct function by first depressing a visual switch located on his console. This operating sequence will indicate to the computer that the pilot wishes it to perform a search of stored sonobuoy positions. The computer will select the stored sonobuoy position closest to that buoy on-topped by the aircraft and make the necessary correction by slewing the buoy to the current aircraft position. This correction procedure differs from that of the aircraft correct function that slews the aircraft to the buoy. The resulting differential correction increments are not used to modify the bias velocity since this correction does not reflect general buoy drift.

Long-Range Navigation

In addition to the tactical *X*-*Y* position, the aircraft position also is maintained in geocentric latitude and longitude. This position keeping provides the TACO and the navigator

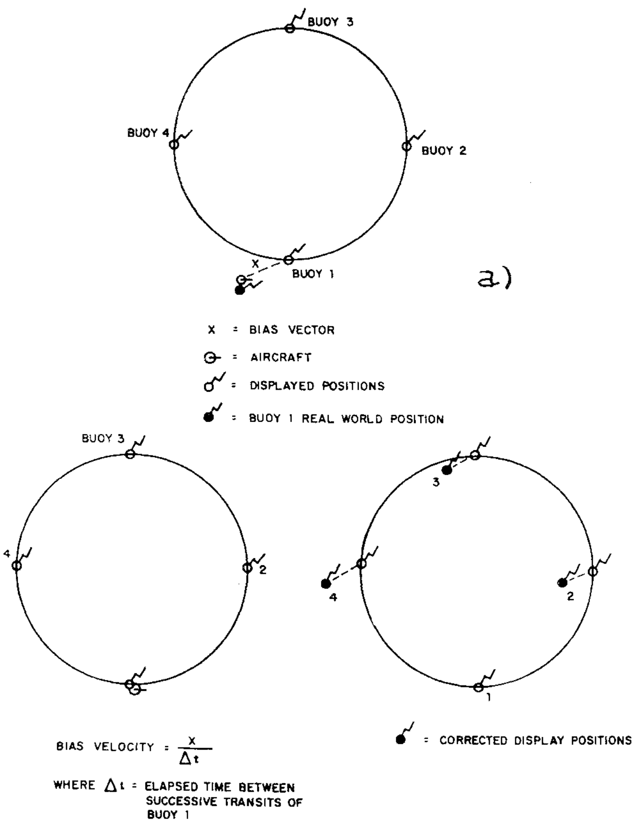

Fig. 3 Pattern correct sequence.

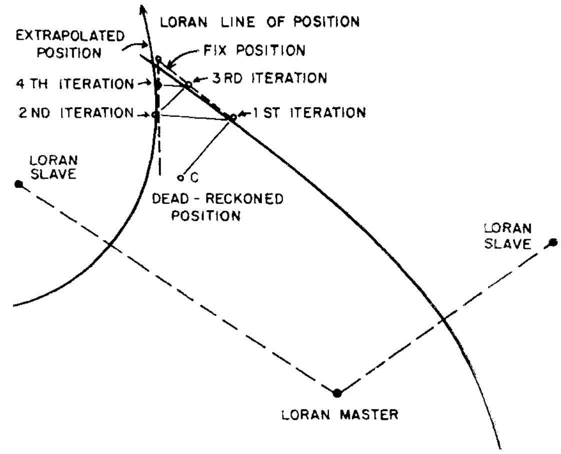

Fig. 4 Loran iteration process.

with the means to relate themselves to geographic positions. When the pilot initiates the navigation functions by depressing his on-top switch, the computer will set the latitude and longitude of the aircraft equal to those of a predetermined point on the airfield.

The same Doppler/air mass increments used in the tactical position keeping are converted into latitude and longitude increments. These accumulated increments then are used to update the aircraft's latitude/longitude. This updating procedure takes place every 30 sec.

The random errors inherent in the system tend to accumulate with time, and it is necessary to update periodically the dead-reckoned position to some absolute geographic position e.g., a Loran fix. The time differences determined by a Loran receiver provide the primary means of fixing the aircraft position. The computer samples the time differences once every minute, and if the Loran receiver has also indicated a "valid" signal, the Loran fixing or coordinate conversion is started.

The method of determining the latitude and longitude of the aircraft from the Loran time difference is similar to the inverse technique used by the Hydrographic Office in developing Loran charts. This method uses confocal hyperbolas and ellipses to prosecute a steepest method of descent approximation to the fix position.[1]

As shown in Fig. 4, the Loran time differences have determined the two intersecting hyperbolic lines of position. Point *C* indicates the present dead-reckoned position. Using spherical equations, the computer will determine what the time differences would have been if the aircraft were presently at this position. These computed time differences then are compared with the received time differences. If the computed times fall within a minimal gate of the received times, then the dead-reckoned position is taken as being correct. If the comparison fails, the dead-reckoned position is then slewed to the furthest hyperbolic line. This slewing is along the elliptical curve passing through the dead-reckoned position. The elliptical curve is a computational aid and is formed from the sum of the propagation times from a master and slave station.

Following the slewing, the computations and testing are repeated. This process continues until the dead-reckoned position falls within the minimal error gate or until four approximations have been completed. If the fourth approximation still does not meet the acceptance requirements, then a linear extrapolation of the four points is computed. This extrapolated position is then tested, and if this position also fails, the process is aborted for that 1-min period. It has been found that in a large percentage of the cases, this procedure is sufficient for successfully completing a Loran position fix.

Following a successful Loran fix, the computed latitude and longitude are displayed in tabular form. This displayed tableau is one of the many tableaus contained in the index mode of the computer. These tableaus of the index mode contain a variety of alphanumeric information pertinent to the ASW operation. The TACO may view these tableaus on his situation display by depressing the appropriate function switches. He also may modify or enter information into these tableaus via his keyset, thereby inputting information to the computer.

The Loran tableau, in addition to containing the Loran position, also contains the dead-reckoned latitude and longitude of the aircraft. The Loran position does not automatically correct the dead-reckoned position. However, the TACO may do a manual correct based on his assessment of the overall navigation pattern.

Lat-long correct

A "lat-long correct" function is incorporated to allow the TACO to correct manually to positions obtained other than by Loran, for example, by tactical air navigation (TACAN). The navigator communicates to the TACO the range and bearing from a TACAN station. The TACO then depresses the lat-long correct switch and enters, via his keyboard, the lat-longs of the TACAN station and the range and bearing from the aircraft to the station. The computer will, on receipt of this data, compute a new long-range position for the aircraft. The amount of correction applied to obtain the new long-range position also will be applied to the tactical position.

Summary

The foregoing discussion has outlined all the navigation functions that are related to the computer. Practical experience has shown that a computer-integrated system of this type offers significant gains in the ASW environment, in both the long and short range modes. Calculation errors have been minimized by the man being taken out of the "mathematical loop"; navigation relative to surface and subsurface objects has been improved greatly by the use of the various biasing techniques and, finally, the tactical crew has been given breathing space on which to arrive at rational tactical decisions.

Future Developments

Curently, an ASW simulation system is being developed at the Naval Air Development Center, Johnsville, Pa. This system, designated MOD 2, is a follow-up to MOD 1 and reflects the knowledge gained in developing MOD 1. The MOD 2 system will be used to develop new techniques in automated ASW exercises. The MOD 2 system is being followed by an airborne MOD 3 system that will be a third-generation A-NEW system, reflecting the developments of both MOD 1 and MOD 2. The MOD 3 system will be installed in an Orion aircraft. The navigation system will incorporate an OMEGA receiver, and the computer will provide astro-data to a periscopic sextant, mechanized to provide heading monitoring and correction.

Reference

[1] "Automatic Loran data processing for VS aircraft," Bureau of Naval Weapons, U.S. Navy, VS Data Processing Memo. RUDC—48020-3 (February 7, 1961).

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Tactical Avionics Maintenance Simulation

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This paper describes analytic and simulation techniques for the study of maintenance characteristics of tactical avionic systems and their ground support equipment. The techniques have been used to define tactical avionics and ground support equipment features required to assure avionic maintainability in the use environment and have been applied to a variety of avionics systems from the preliminary design phase through field use. Although much remains to be done, the experience to date shows that the techniques can translate operational support and maintainability requirements into design requirements when applied in a practical engineering environment. The brief summary presented here illustrates the approach by summarizing the techniques and presenting some typical results. It is believed that this data should be of interest both to maintenance and support specialists and to aerospace management personnel concerned with the problem of developing an integrated approach to maintenance and support engineering within their organizations. An analytical model and two simulation models are described. These models use avionic design parameter estimates as inputs (such as system reliability, test thoroughness, and maintenance task times), allow for various field and operational factors (such as flight schedule and logistics delays), and yield predicted operational characteristics as output (such as undetected fault probability and in-commission rate).

Introduction

THE avionic system designer and military user of avionic systems face a growing problem. The annual costs of maintaining avionic systems are approaching system purchase costs. The demand for skilled electronic technicians threatens to exceed the supply potentially available. With maintenance resources and personnel available, the in-commission rate and operational reliability in the field often are less than desired.

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