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AGARD-AR-147 VOL. I

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AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARD ADVISORY REPORT No. 147

The Impact of Global Positioning System on Guidance and Controls Systems Design of Military Aircraft

Volume I

NORTH ATLANTIC TREATY ORGANIZATION

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NORTH ATLANTIC TREATY ORGANIZATION

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(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD) (12) 45

(9) AGARD Advisory Report No.147

(6) **REPORT FROM THE GUIDANCE AND**

CONTROL PANEL WORKING GROUP 04

on

THE IMPACT OF GLOBAL POSITIONING SYSTEM ON GUIDANCE AND

CONTROLS SYSTEMS DESIGN OF MILITARY AIRCRAFT, Volume I.

Edited by

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VOLUME I

(11) Sep 79

This report consists of one main document (Volume I) and four appendices (Volume II).

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- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
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Published September 1979

ISBN 92-835-1339-8

Printed by Technical Editing and Reproduction Ltd
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1 INTRODUCTION TO GCP/WG04

1.1 INTRODUCTION

In July 1976, AGARD published Advisory Report No. 88. This was the Aerospace Applications Studies Committee Study No. 6, "Use of Precision Positioning Systems by NATO". This study group started work at the end of 1973, and in its conclusion was a confident prediction that major benefit will arise in at least four important roles as related to Tactical Air applications of Precision Positioning System (PPS). These roles are:

a. All-weather coordinate bombing

b. RPV/drone operations

c. Operations involving target recognition with electro-optical sensors

d. Stand-off and Cruise Missiles

Also, the three general system capabilities were envisaged using PPS:

a. Passive terrain following system (non radiating forward looking sensor). This is now a TERCOM option.

b. Gradual replacement of existing navigation aids by PPS over time CAT I Microwave Landing System could even be eliminated with the advantage of no hardware needed in a tactical site.

c. With new "smart" munitions, the need for PPS could be reduced in the launch aircraft, but narrow field of view electro-optical sensors in the weapon terminal guidance may be more feasible if aided by an accurate navigation system such as provided by PPS.

The guidance and Control Panel proposed a Working Group to the National Delegates Board in March 1977 (which was approved) to follow-up the work of AASC Study No. 6 in various combat aircraft applications, and the following Objectives, Scope of Work, and Terms of Reference were agreed:

1.2 OBJECTIVES

The Global Positioning System, when it comes into operation, will offer a performance in navigation which has not been previously obtained except in very limited and special circumstances, combined with possibilities of system simplification and reduced cost. To make full use of these advantages, planning for application to aircraft systems should be started in the near future. However, it is believed that the full range of applications has yet to be explored in any detail, although a preliminary study has just been completed by the Aerospace Applications Study No. 6. The objective of the proposed Working Group is to contribute to a deeper exploration in the application to military aircraft.

1.3 SCOPE OF WORK

The Working Group should consider the integration of GPS in aircraft systems and make recommendations for implementation. The number of applications is likely to be very large. In order to limit the work and make progress in a reasonable timescale, it is proposed that the work of the group be confined to a particular range of military aircraft, namely interdiction, ground attack, interception and close combat.

Approximately four meetings of the Working Group are planned with the draft final report expected after one year.

1.4 TERMS OF REFERENCE

The Terms of Reference for the Working Group shall be as follows:

a. To study the application of GPS to interdiction, ground attack, interception and close combat aircraft.

b. To determine the extent with improved performance or new capabilities will be made possible.

c. To study the integration of GPS into guidance and control systems, determine the impact on system design, and indicate where simplification and cost savings may be brought about.

d. To make recommendations for further and more detailed study of the most promising applications.

e. To provide an Interim Report to the Panel not more than six months from the first meeting of the Working Group, and a draft Final Report after one year.

During the course of the deliberation of the Working Party, it was realized that the quantitative information that would come from only short studies of less than one year in the form of four worked examples of the application of NAVSTAR to four particular missions would be limited. However, the system integration and architecture were very important. These would lead to some general conclusions about the cost effectiveness of fitting NAVSTAR and identify a significant amount of existing avionic subsystems which should be eliminated. In Section 4, the main discussion draws on the US, French, German, and UK inputs including the considerations of countermeasures which are critical to the final balance of overall effectiveness of a system of the NAVSTAR type. Another important consideration taken into account by the WP was the possibility of other developments in weapon systems of the future, such as the use of electro-optical sensors, digital data bus, smart weapons, TERCOM navigation system, etc. Thus, the discussion in Section 4 leads to qualitative guidelines as to the potential of NAVSTAR and identifies roles for which it has significant potential advantages. Finally, Section 5 gives the overall conclusions and recommendations of the Working Group.

Volume 2 consists of four sections giving the results of the four specific studies of the application of NAVSTAR to close Air Support, Sea Patrol, interdiction/Strike and RPV's. The conclusions from the Appendices have been taken into account in the main report.

LIST OF ABBREVIATIONS

AJ	Anti-jam
AWACS	Airborne Warning & Control System
bps	bits per second
C/A	Coarse Acquisition
CAT 1	Category 1, aircraft landing limits
CEP	Circular Error Probability
chaff	strips of metal used to blind radar, usually dropped by aircraft
cm/s	centimeter per second
COIN	Counterinsurgency
CONUS	Continental United States
CRT	Cathode Ray Tube
CS	Control Segment
Data-Link	communication system connecting users and also transmitting data between users
dB	decible
DCA	Defensive Counter Air
DECCA	Navigational System, somewhat similar to LORAN
DR	Dead Reckoning
DSARC	Defense System Acquisition Review Council
EMP	Electromagnetic Pulse
FAC	Forward Air Controller
GDOP	Geometric Dilution of Precision
GPS	Global Positioning System
GT	Ground Transmitters
HOW	Hand Over Word
IFF	Identification Friend or Foe
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
IRCC	Inverted Range Control Center
J/S	jamming to signal ratio
km	kilometer
kw	kilowatt
L_1 Carrier	1575.42 MHz, bandwidth 20 MHz, used on GPS
L_2 Carrier	1227.6 MHz, bandwidth 20 MHz, used on GPS
L-band	390-1550 MHz
LEP	Linear Error Probability
LORAN	a hyperbolic Navigation System (Long Range)
m	meter
MAD	Magnetic Anomaly Detection
Mbps	mega bits per sec
MCS	Master Control System
MHz	Mega Hertz
ms	milliseconds
MS	Monitor Stations
m/s	meter per second
NDS	Navigational Development Satellites
nm	nautical mile
NNSS	Navy Navigation Satellite System
NRL	Naval Research Laboratories
OMEGA	very low frequency worldwide navigation system consisting of 8 ground stations
P	precise
PLSS	Precision Location Strike System
PRN	Pseudo Random Noise
rad	radian
RF	Radio Frequency
RPV	Remotely Piloted Vehicle
RSS	Root Sum Square
SLAR	Side Looking Airborne Radar
STRIDA	French Air Traffic Control System
SV	Space Vehicles
TACAN	Tactical Air Navigation
TERCOM	Terrain Contour Matching
TEREC	Tactical Electronic Reconnaissance Sensor
Timation	Navy project, similar to GPS but used crystal controlled clocks rather than atomic clocks
TIP	Transit Improvement Program
TLM	telemetry
UERE	User Equivalent Ranging Errors
ULS	Upload Station
USAF	United States Air Force
VAFB	Vandenberg AFB, CA
VHF	Very High Frequency
VLF	Very Low Frequency
VORTAC	VHF Omnidirectional Range TACAN
YPG	Yuma Proving Ground

3 HISTORY AND BACKGROUND

3.1 INTRODUCTION

The NAVSTAR/Global Positioning System is being developed to satisfy an operational need for a precision positioning system for use by the military and civil users. This system has been planned from the beginning to negate the undesirable aspects of existing navigation systems. The following discussion highlights the major events and developments which led to the development of NAVSTAR/GPS.

The main advantages of NAVSTAR/GPS are the precise position, velocity and time it provides to a user. It should improve the existing navigation and weapons delivery systems on a global basis. Further, its adoption can reverse the proliferation of position location and navigation systems. In the USA alone, there are already 71 different systems used:

9 types of TACAN
10 types of LORAN
23 types of ILS
21 types of DR
8 types of VOR

While reducing the proliferation of POS/NAV systems is the most frequently quoted reason for the development of NAVSTAR, other features such as the improved accuracy, the high resistance against jamming, reduction in maintenance/supply/repair and training costs and overcoming limitations in existing systems are also important advantages.

Some of the limitations in current navigation systems are:

VORTAC	:	short range, line of sight.
Omega and other VLF systems	:	atmospheric influences, sunspot activities.
Loran C and Decca	:	relatively expensive, is an addition to other equipment for other parts of the world.
Station Referenced Aids	:	overhaul and maintenance by other than US or NATO personnel.

Another important advantage of NAVSTAR/GPS will be control of the system is executed on US territory by US personnel. The development program is being managed by the US Air Force (USAF) with deputies from the NAVY, the ARMY, MARINES, NATO, the Defense Mapping Agency and the Coast Guard.

In summary, the main advantages of NAVSTAR/GPS are:

-A continuous global coverage.

-Precise position and velocity in three dimensions and time.

-Passive operation, i.e., the user does not have to transmit any signal which could betray his own position.

-Provides all weather operation.

-An unlimited number of (authorized) users.

-The system is a highly resistant to jamming.

Following a brief history of NAVSTAR in the next section, a complete system description is given, beginning on page 4-1.

3.2 NAVSTAR HISTORY AND SCHEDULE

The operational use of satellites for position location and navigational purposes dates from 1964 (development of TRANSIT). In order to get a better insight in the NAVSTAR/GPS concept, it seems appropriate to look back into the history, to describe the present status and to forecast the near future.

1964 Development of TRANSIT (NNSS, Navy Navigation Satellite System) (Ref. 16).
- Operated by US Navy Astronautic Group at Pacific Missile Range, Point Mugu, CA.
- 2-dimensional, all weather, position and velocity determination.
- SVs (Space Vehicles) broadcast their current known positions in successive two-minute data readouts while orbiting the earth.
- total 6 SVs, 3 SVs older than 7 years, 2 SVs older than 4 years.
- On the equator: on the average every 108 minutes a fix can be made.
- TRANSIT is not suited "for anyone with dynamics in their positioning or navigation problem" (Ref. 15).
- There exists a TIP (Transit Improvement Program): better orbital position/pseudo random noise code for making fixes in shorter time/less susceptible to interference.

1967 Commercial use of TRANSIT

1968 TRANSIT declared fully operational.
298 military users, about 500 civil users.
TRANSIT will work well into the 1990's (Ref. 19).

1967/1969 Development started of TIMATION by NRL (Naval Research Laboratories). Is similar to NAVSTAR/GPS, but would use crystal controlled clocks instead of atomic clocks as NAVSTAR will. Turned out to be too inaccurate. At the same time development of Project 621B started by the USAF (system with 20 SVs, 5 geostationary).

<u>1974 - 1979</u> <u>PHASE I OF NAVSTAR/GPS</u>

Objectives of Phase I:
- validation of the GPS concept
- validation of the preferred design
- definition of the system costs
- demonstration of the military value

July 1974 Launch of first Navigation Technology Satellite (NTS1), formerly a TIMATION satellite.

December 1976 Launch of NTS2, the first SV incorporating a GPS transmitter.

1978 Launch of 4 SVs, NDS (Navigational Development Satellites).

Demonstration and Evaluation Tests over the CONUS (Continental United States).

During Phase I the Master Control Station (MCS) will be at VAFB (Vandenburg Air Force Base), Monitor Stations (MS) at VAFB, Alaska, Hawaii, Guam.

1979 DSARC II, decision on continuation of GPS.

<u>1979 - 1983</u> <u>PHASE II OF NAVSTAR/GPS</u>

Objectives of Phase II:
- Operational test and evaluation
- Initially 8 hours per day with 4 SVs in view at test range in Yuma (CA).
- Control Segment (CS) evolves to fully operational configuration.

1981 During Phase II the MCS will be at VAFB. A "Central CONUS Control Center" however will be built in the middle of the US, which will be hardened for EMP.

1983 DSARC III, decision on production phase of GPS.

<u>1983 - 1987</u> <u>PHASE III OF NAVSTAR/GPS</u>

Objectives of Phase III:
- Continuation of operational testing.
- Launching of other SVs (Exact number determined by requirements of exact orbits, coverage required, etc.), total number of SVs nominally: 24, 8 per orbit plane.
- The Control Segment will be expanded and retrofited as necessary.
- All user equipment will be procured in limited production buys and in production lots following the final testing and evaluation.

1986 Initial operational capability.

3.3 SYSTEM DESCRIPTION

The NAVSTAR Global Positioning System (GPS) is a satellite-based navigation system that will provide extremely accurate timing and three-dimensional position and velocity information to properly equipped users anywhere on or near the earth. The system will be available continuously, worldwide, regardless of weather conditions.

NAVSTAR/GPS is a Joint Service Program with the United States Air Force as the executive service. The program is now in Phase I of three phases. Phase I (concept validation) calls for the deployment of six satellites in 1978-1979 which will permit demonstration and evaluation tests. The system will then be expanded in Phases II and III through deployment of additional satellites until the full-up operation 24-satellite configuration is achieved.

The NAVSTAR/GPS consists of three major segments: Space, Control, and User. The concept requires accurate knowledge of the position of multiple satellites versus time, and the transmit times of signals from these positions. Each satellite carries an atomic clock with stabilities of the order of 1 part in 10^{13}. Each clock is used to synchronize the timing of the dual-frequency, pseudo-random noise (PRN), spread-spectrum, L-band navigation signals which each satellite radiates continuously. These navigation signals also transmit information regarding the satellite ephemerides and clock bias. Geographically dispersed monitor sets receive these signals and thereby collect precise satellite information. This information is then transmitted to a master control station (MCS) which predicts future satellite positions, as well as the behavior of each clock. The MCS ensures that the satellite clocks are synchronized. The control segment periodically (usually daily) uploads information into each satellite's memory. Each satellite then continuously transmits its orbital parameters and system time. If a user had an accurate clock, synchronized to system time, he could determine the time delay between transmission and reception. By multiplying this time delay by the speed of light, he could determine his distance (range) from the satellite. By listening in this manner to three satellites, his position would be uniquely determined.

Equipping each user with a sufficiently accurate clock would be prohibitively expensive and cumbersome. To circumvent this difficulty, the user is equipped with an inexpensive crystal clock. The simultaneous reception of four navigation signals allows algebraic solution of three satellite-to-user ranges plus the time bias in the user's relatively inaccurate clock.

Time in each satellite is maintained with a bank of triply-redundant rubidium oscillators, with the addition of a more accurate cesium beam oscillator in the later stages of the program.

Each satellite transmits two spread-spectrum PRN navigation signals, one signal at 1575 MHz and a second signal at 1227 MHz. The signals are coherently generated and can be used to determine the signal delay due to atmospheric refraction. Both navigation signal carriers are bi-phase modulated with a sequence of binary digits (PRN sequences) at a rate of 1.023 and 10.23 Mbps. The ephemeris and satellite clock data are modulo two added to the PRN modulation sequence at a rate of 50 bps. The basic navigation signal is "spread" over a bandwidth of approximately 20 MHz by the PRN sequence. The PRN sequences are unique to each satellite so as to be statistically uncorrelated, permitting the use of common carrier frequencies for all satellites in the constellation. A coarse/acquisition (C/A) code (1.023 Mbps) is quadraphase modulated with the precise (P) (10.23 Mbps) code onto the same carrier to provide a rapid acquisition capability. For users which have no requirement for the higher accuracy provided by use of the "P Code" and desire a lower cost unit may use equipment designed to operate on the "E/S Code" only.

a. Control Segment. The control segment consists of a master control station (MCS), widely separated monitor stations (MS), and an upload station (ULS). Redundant master control, monitor and upload stations are planned for the operational system. The widely spaced MS, located on U.S. controlled territory, will passively monitor the satellites, accumulating ranging data using the navigation signals. This data will be relayed, along with meterological and status information, to the MCS in the CONUS. At the MCS, the ranging data will be corrected for transmission delays (e.g., ionospheric and tropospheric delays, relativistic effects) and processed by a filter algorithm to provide best estimates of Space Vehicle (SV) position, velocity, acceleration (e.g., due to solar pressure variations), and SV clock drift relative to master system time. Additionally, MS clock drifts relative to system time, polar wander parameters and tropospheric correction residuals will be calculated to generate progressively refined information defining a) the gravitational field influencing the satellite motion, b) MS locations and c) other observable system influences. The results thus derived will be used to generate more accurate future navigation messages to be loaded into the satellite memories via the ULS, also located in the CONUS, typically once a day.

b. User Segment. A typical user set consists of an antenna, receiver, data processor, and control/display unit. Some configurations will be integrated with auxiliary sensors such as inertial measurement units. The receiver measures pseudo-range and pseudo-range rate using the navigation signal from each of several satellites. The processor converts these data to three-dimensional position, velocity and system time. The position solution is developed in earth-centered coordinates, and is subsequently converted and presented on the display unit in either geodetic coordinates, Universal Transverse Mercator grid coordinates, or some other coordinate system desired by the user.

To fully exploit the potential system precision, the refraction effects on path length of the radio signal must be known. Hence, for high accuracy users, two radio frequencies with different propagation properties are used to measure the ionospheric delay and other medium effects (other users may employ a modeling technique to approximate the delay).

The NAVSTAR/GPS user equipment will provide accurate three (3) dimensional navigation and time data. When a sufficient number of satellites are in view, the horizontal Circular Error Probability (CEP) and the vertical navigation Linear Error Probability (LEP) are less than 10 meters for a set of user equipment distributed over the earth and uniformly distributed in time. The worst case accuracy will be less than 25 meters in CEP and LEP. The velocity accuracy will be less than 0.02 meters/second.

Position and velocity "fixes" in three dimensions, plus time, will be derived by the user equipments, to the accuracies shown, and displayed on a continuous basis. All users operate in the same common grid and can communicate their positions in the same reference frame. Atomic standard quality timing information is also available worldwide from GPS. The system requires no active transmission from the users, and, therefore, can support an unlimited number of users.

c. Space Segment. In its operational configuration, the complete GPS satellite constellation will consist of 24 satellites in circular, 12-hour, 10,900 nautical mile orbits with an inclination of 63 degrees to the equator. They will be deployed in three planes each containing eight satellites. This satellite constellation ensures that at least 6 satellites are always in view from any point on earth and that, on the average, nine satellites are in view, thus ensuring redundant satellite coverage for three-dimensional positioning and navigation on a worldwide basis.

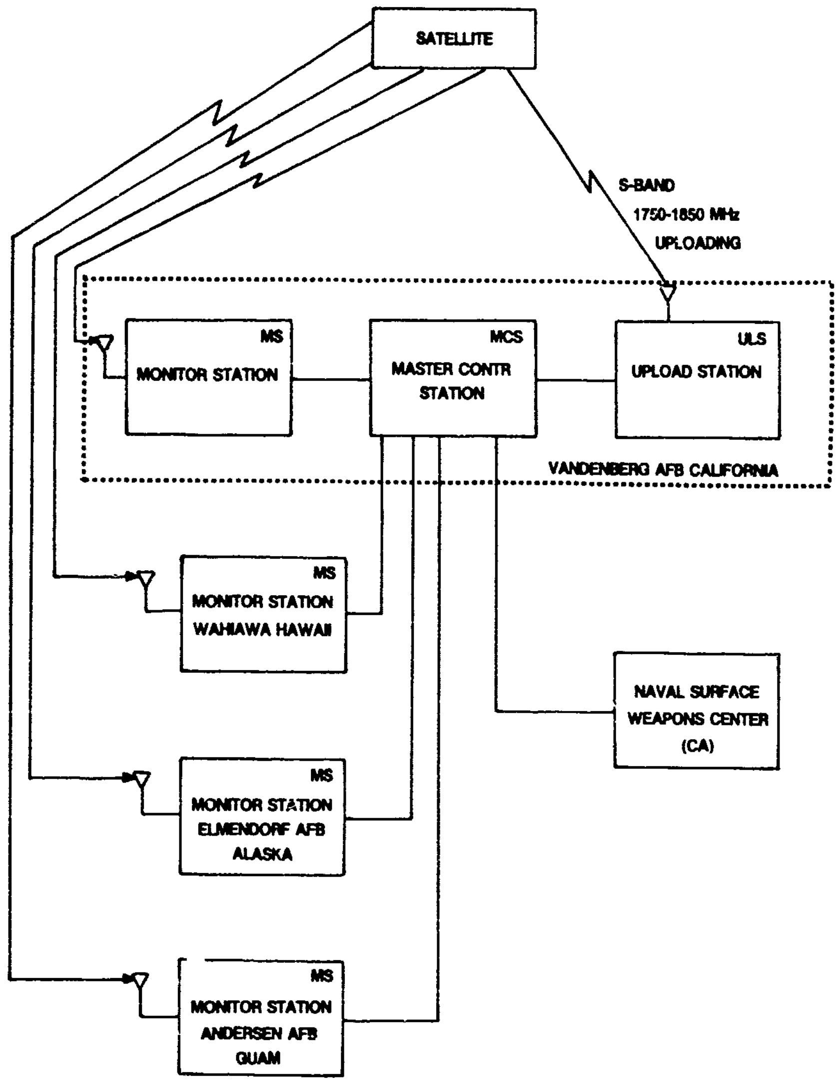


FIGURE 1
THE CONTROL SEGMENT IN PHASE I AND II OF NAVSTAR GPS

4 TECHNICAL ASPECTS OF NAVSTAR SYSTEM AND APPLICATIONS

4.1 NAVSTAR SYSTEM

Twent . SVs, in three orbits, will be transmitting signals to users on the earth. The satellite data is modulated at a rate of 50 bps along with a PRN (pseudo random noise) code which is unique for each satellite. The SV code generator is controlled by a precise atomic clock. The user determines his range from at least four SVs using PRN code, by shifting the phase of an identical PRN code generator in his receiver until it coincides with that from the applicable SV. The amount of time he must offset his code is a measure of the transmit time of the PRN signal from the SV, and, therefore, of the distance between user and SV. The user clock however is not a precise clock, and there will be an offset in time with respect to the SV clock. In addition, there will be propagation delays due to atmospheric and ionospheric influences. Therefore, the user will measure a pseudo-range:

$$R_i = (X_i-X)^2 + (Y_i-Y)^2 + c\, T_{A_i} + c(t_u - t_i)$$

R_i = measured pseudo range (determined from phase shift between PRN code transmitted by satellite and PRN code of the user receiver).

$X_i Y_i Z_i$ = coordinates of the i^{th} satellite in an earth centered coordinate system (transmitted by satellite as data message).

X Y Z = unknown coordinates of the user in the same coordinate system.

t_{A_i} = propagation delay (estimated from a model for tropospheric delay and computed from data in the navigation message for the ionospheric delay, or measured).

t_i = clock offset of space vehicle from the reference GPS time (can be extracted from data in the data message).

t_u = unknown clock offset of user from the reference GPS time.

c = speed of light.

The formula given above contains 4 unknowns. By measuring the pseudo ranges to 4 different satellites, the user can compute these unknowns, i.e., his position in space and time, by solving the four equations.

The receiver may also measure the doppler shift of the carrier signals from the emitter. By measuring the accumulated phase difference in this doppler signal over some interval, the receiver can infer the range change increment. Because there may be a difference between the carrier frequency and the user notion of this frequency, this range change increment is called the delta pseudo range.

All the information needed for a user to determine his position in space is contained in the signals transmitted by the SVs. In fact, there are two RF signals, at two different frequencies at L-band, both modulated via a PRN technique. One of the signals is called the C/A or coarse/ acquisition signal; the other is P, the precise signal. The C/A signal has simpler encoding than the P signal and can be used by all users for rapid acquisition if the level of jamming signals in the environment is not too high. The P signal, which spreads the bandwidth to 20 MHz, employs a very long PRN code sequence, which permits toleration of a higher level of jamming, but on the other hand does increase the acquisition time. A second feature of the two-frequency concept is the fact that a user equipped with a two-frequency receiver can deduce the ionospheric delay from the measured delay difference of the two navigation signals. Users who can only receive the C/A signal may estimate this delay from a standard algorithm.

The constellation of the 24 SVs is called the SPACE SEGMENT. They all orbit the earth in (near) circular orbits at 10,900 nm, completing one orbit in 12 hrs. Eight SVs are equally spaced with each of 3 planes included at 63 degrees. The space segment is described in section 4.3.

Messages are transmitted by the SVs, but the information contained in these comes from the Control Segment (CS). This CS consists of:

<u>Monitor Stations (MS)</u>: for tracking of the SVs, each equipped with user-like equipment, but with atomic clocks. One of the monitor station clocks is used as GPS reference time standard.

<u>Master Control Stations (MCS)</u>: which computes from the data received by the MSs and an (off-line) estimate of the SV position, the orbit and time data for the navigation message.

<u>Upload Station (ULS)</u>: which transmits the data, generated in the MCS, to the applicable SV.

The signals transmitted by the SVs are received by user equipment sets, which can be aboard aircraft, ships, other vehicles or can even be man-portable.

The validation of the GPS concept and testing of the prototype user equipment during Phase I is being accomplished at Yuma Arizona on an INVERTED TEST RANGE. A hybrid form of navigation is possible using ground transmitters and SVs. At the present time, two SVs and two ground transmitters are used when the satellite constellation is available. Testing is being continued using only SVs.

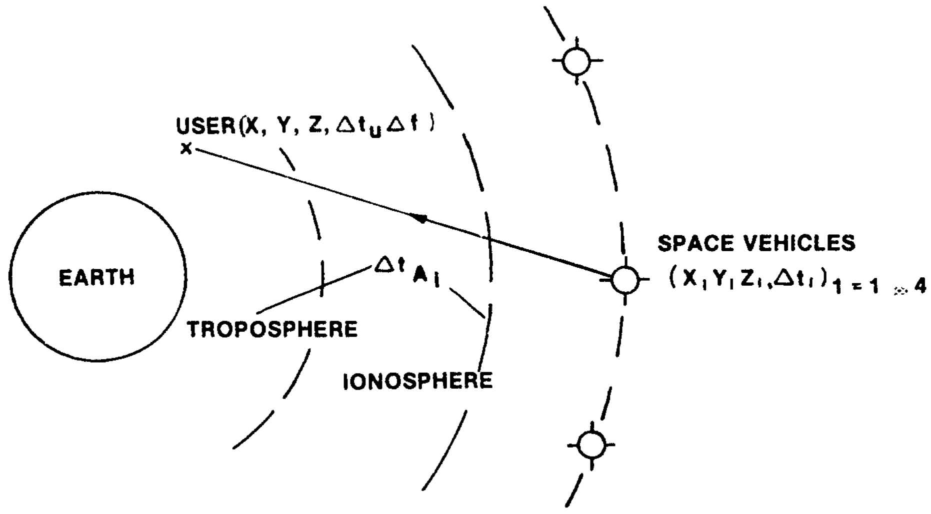


FIGURE 2 THE GPS CONCEPT

The overall accuracy obtainable with the most sophisticated receivers will be in the order of 10 meters. Some factors which influence this accuracy are the prediction processes of the SVs ephemerides (including uncertainties in solar radiation pressure), the prediction of the behavior of the atomic clock, and the prediction of tropospheric and ionospheric delay.

Dependent on the measure of sophistication of the receiver equipment, and integration within other sensors, a theoretical antijam (AJ) margin of 40-80 dB exists.

The Navigation Signals

Signal Characteristics

Two pseudo random noise signals are being transmitted by the SVs.

L_1 at 1575.42 MHz, bandwidth 20 MHz

L_2 at 1227.6 MHz, bandwidth 20 MHz

The C/A signal has a PRN code rate of 1.023 Mbps, and a sequence length of 1 ms; the P signal has a PRN code rate of 10.23 MHZ and a sequence length of 7 days. Onto both of the PRN sequences, data (including ephemeris and clock data) are modulated at 50 bps. Then the carriers are bi-phase modulated with the encoded C/A and P signal, the L_2 carrier with C/A or P. However, in the literature it is stated that the same data is modulated on C/A and P signals, the objective being the higher jam resistance of the P signals, because of the higher PRN code rate. The so-called processing gain of the PRN Spread Spectrum technique is the code rate divided by the information band-width.

Because the PRN sequences are unique for each satellite and their cross correlation is minimal, a common carrier for all satellites can be used.

The major reason for the use of two frequencies is to predict very accurately the propagation delay by the ionosphere, which extends between the user and the applicable SV. A user needs to have a dual frequency receiver for this feature. Users who do not have such a receiver can compute the ionospheric delay from a standard algorithm.

Due to the much longer code sequence, the acquisition of the P-signal is much longer than of the C/A signal. This acquisition time can be shortened by a prior knowledge or estimate of the phase difference between SV code and user code. This estimate may be derived from earlier position fixes and SV orbit parameters (contained in the navigation message for all SVs) or from use of the C/A signal (if the user is in a rather jamming free environment).

The Navigation Message

The navigation message is a 50 bps data bit stream.

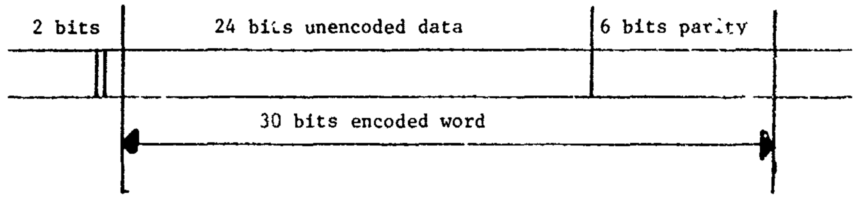
The data is confined in frames of 1500 bits (30 sec's) consisting of 5 subframes of 300 bits (6 sec's per subframe).

The next figure depicts the contents of one data frame:

subframe 1	TLM	HOW	clock corrections/age of data/ionospheric propagation model coefficients	
	1	31	61	300
subframe 2	TLM	HOW	SV orbit data: Keppler parameters/harmonic correction terms	
	301			600
subframe 3	TLM	HOW	SV orbit data: age of data	
	601			900
subframe 4	TLM	HOW	message data: 8 bit ANSCII characters	
	901			1200
subframe 5	TLM	HOW	almanacs for 24 SVs, 1 dummy almanac, health signals	
	1201			1500

If not changed by the Upload Station, all information is repeated every 30 seconds, except for subframe 5. This subframe contains every 30 seconds the almanacs (ephemerides, clock correction parameters and health status) of one of the space vehicles in a cycling way for all SVs (max, 25 SVs). The repetition rate for this data, therefore, is once per 25 x 30 = 750 sec.

The words in a subframe consist of ten 30-bit encoded words, forming, together with 2 bits of the previous word, a 32 bit word that is protected by a 26 out of 32 bit hamming code:



The following remarks apply to the navigation data itself:

- TLM and HOW words are SV generated.

  TLM, or "Telemetry," words contain: upload status
diagnostics
roll momentum dump counts

  HOW, or "Hand Over Word," words contain: SV time at leading edge of next subframe
subframe identification

- All other data words are generated by the Control Segment.
- The orbit parameters are given by Kepplerian parameters plus harmonics. This turned out to be the best way in view of accuracy and user computation time. The total number of parameters is 17.
- The range of GPS time is one week, the epoch being Saturday night, Sunday morning midnight.
- An "age of data" word provides a confidence level, as it represents the time difference between the reference time and the time of the last measurement update used to estimate the representation parameters.
- The message data in subframe 4 are designated "for future operational applications."
- The purpose of the almanacs in subframe 5 is to be an aid for acquisition of SV signals. These almanacs are in fact truncated versions of the data in subframes 1, 2 and 3 of all SVs. The almanacs will be renewed every 6 days as a minimum rate. The accuracy in terms of UERE which can be attained is 3-6 km for one week.

<u>Space Segment</u>

The full operational constellation will consist of 24 satellites in three orbits. This means that for a user on the earth at least 6 SVs, on the average 9 SVs, are visible. Orbit parameters: height 10,900 nm, inclination 63 degrees.

The SVs in Phase I are 3 axis stabilized with four skewed reaction wheels.

Power: solar cells (54 ft^2), 3 Ni Cadmium batteries, 15 amp hrs each, EOL power 384 watt.

Weight: approximately 1000 lbs.

Transmitter Power:	L_1 C/A signal	2[illegible] 9 dBW
	L_1 P signal	23.9 dBW
	L_2	19.1 dBW
	high power mode, L_1, C/A	27.9 dBW

Antennas: Forward conical spiral + biconical antenna

Aft conical spiral for S-band telemetry

12 element Helix antenna array for L-band Navigation.

The parameters mentioned here apply to the NAVSTAR Satellites being launched during Phase I.

<u>Control Segment</u>

The CS consists of:

- the MSC
- the MSs
- the ULS

The main task of the CS is the provision of ephemeris data for the SVs. The way this task is executed is described in this section.

Monitor Stations

The MSs are located on US territory, in Hawaii, Alaska, California and Guam. In Phase I and II there will be these four stations, and it is expected that extra MSs will be installed during Phase III. Each MS is unmanned and contains (may change for Phase III):

- user-type receiver (simultaneous reception of the navigation data of four satellites)

- an atomic frequency standard

- environmental data sensors (for measurement of tropospheric delay characteristics)

- a computer/processor for data collection and interfacing with the MCS

Each MS measures pseudo range and delta pseudo range and transmits these data, together with other parameters, in particular the TLM words, to the MCS.

Master Control Station

The MCS is located on the CONUS. During the first two phases of the GPS program, this will be at Vandenberg AFB, CA; in the third phase, at Fortuna AFS, SD. The operational MCS will be hardened for EMP.

Via dedicated communication lines, the data from the MSs are transmitted every 5 minutes to the MCS. On the basis of these data and data generated off-line at NWSC, best estimates are made by the MCS (by means of a Kalman estimator) of the:

- SV's position and velocity
- Clock drifts and offsets of SV clocks and MS clocks
- Tropospheric correction residuals
- Polar wander parameters
- Solar pressure constants

Navigation message to be uploaded is generated from the estimates and contains ephemeris and clock error data, clearances, special messages, and processor control information. The ultimate goal for accuracy of the navigation message is 3.9 meters (one-sigma level of sight error for a period of one day after uploading. The predicition errors come mainly from uncertainities in the gravitational force and solar pressure models, and frequency standard performance.

Upload Station

The ULS provides for the actual uploading and control of the SVs and is located near the MCS.

Naval Surface Weapons Center

During Phase I, the NSWC interfaces with the MCS as an ephemeris prediction support group. NSWC estimates the SV ephemeris, using data collected over a week time span. This process thus is off-line. In the MCS a recursive Kalman estimator provides a last minute best estimate. In fact, the non-linear ephemeris determination process is dealt with by the NSWC and the MCS in such a way that the MCS can linearize around the prediction made by NSWC.

The raw data from the MSs are preprocessed at the MCS (over time spans of 15 minutes) and transmitted to NSWC nightly. NSWC now predicts the SV ephemerides for a two week period from the data of the previous week. These predictions are transmitted to the MCS on a weekly basis.

User Segment

The user segment set typically consists of an antenna, a receiver, a data processor plus software and a control/display unit. Measured are the pseudo range and pseudo range rate which are converted by the processor to position, velocity in earth centered coordinates and time. These coordinates are converted subsequently into data, required by the user, and presented on the display.

In the NAVSTAR GPS program four different classes of user equipment are defined:

X: HIGH DYNAMIC
Y: MEDIUM DYNAMIC
Z: LOW COST RECEIVER
MV: MANPACK--VEHICULAR

The full position accuracy provided by NAVSTAR GPS can be obtained with a High Dynamic, Medium Dynamic and manpack type receiver, and in such receivers the distance - bearing - time to go will be internally calculated for a number of selectable waypoints. In Phase I the following programs for development of receiver equipment are being executed:

- Magnavox Research Laboratories under subcontract of General Dynamics Electronics Division., designs "flyable brassboards.

- Texas Instruments is working on a receiver for potential use in high performance aircraft and manpack.

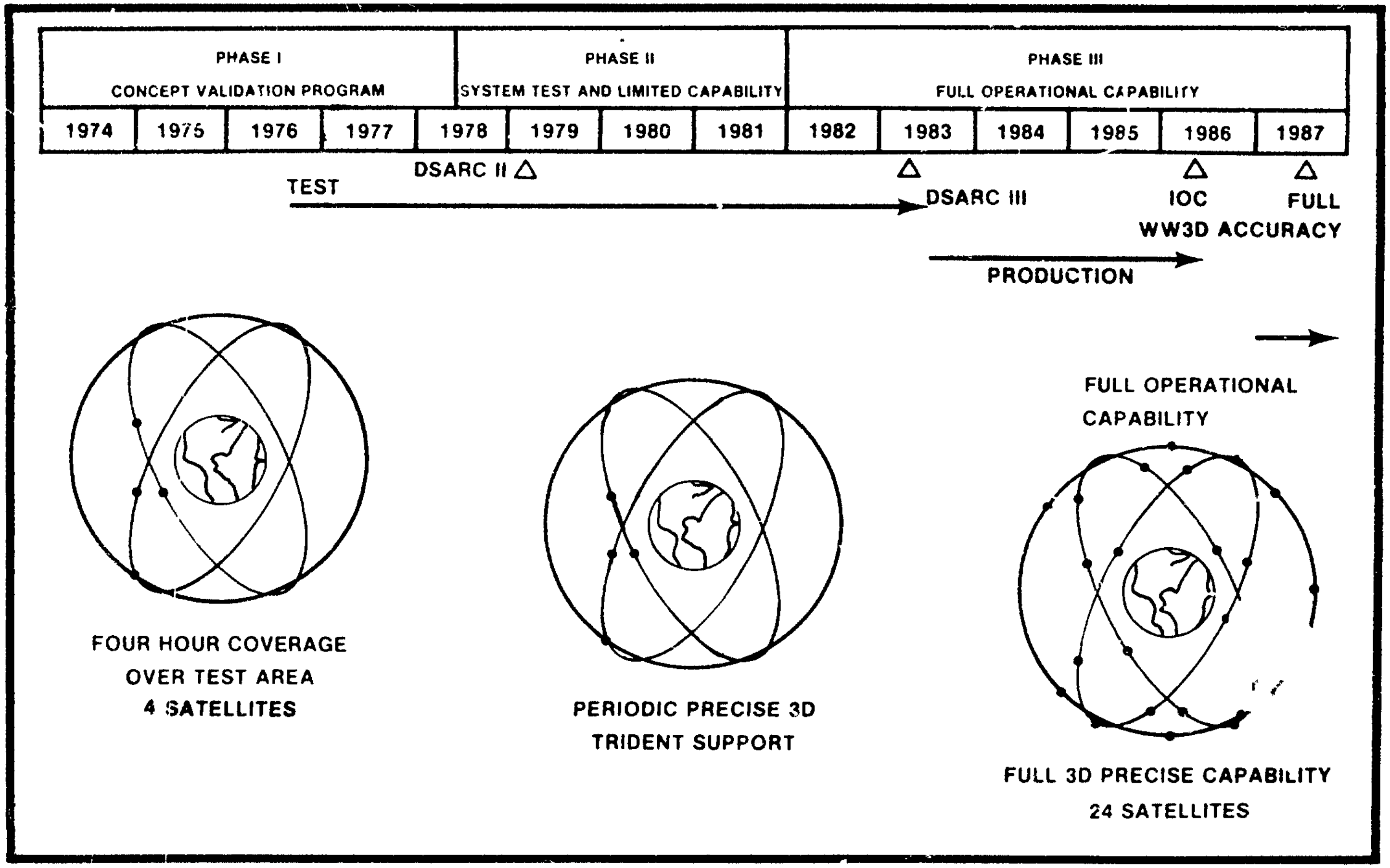

PHASE I
CONCEPT VALIDATION PROGRAM
PHASE II
SYSTEM TEST AND LIMITED CAPABILITY
PHASE III
FULL OPERATIONAL CAPABILITY
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
DSARC II
TEST
DSARC III
IOC
FULL
WW3D ACCURACY
PRODUCTION
FULL OPERATIONAL CAPABILITY
FOUR HOUR COVERAGE
OVER TEST AREA
4 SATELLITES
PERIODIC PRECISE 3D
TRIDENT SUPPORT
FULL 3D PRECISE CAPABILITY
24 SATELLITES

FIGURE 3

- Collins Radio Group of Rockwell International developed a receiver, capable of operating in a severe jamming environment. The receiver will employ a beam - or null steering antenna. This set as well as the Magnavox X-Set and the Texas Instruments high dynamic set will be applicable in blind bombing systems.

Software

A range and range rate computation to four satellites can be made in 100 to 200 ms, if acquisition of the PRN code is already accomplished and the orbit and clock parameters are already in the user equipment memory (extracted from the navigation message modulated on the PRN code). In order to accomplish the navigation function, the computed range and range rate are used to update a running estimate of user position using the Kalman filter technique. In case of the availability of an IMU (Inertial Measurement Unit), the running estimate is based on this system and the previous GPS measurements. In case of an unaided system (no IMU) the estimate is based on the previous GPS data, and a kinematic model for vehicle motion. There is an indication that the complete software for the low cost receiver can be implemented using a single microprocessor chip. As an example, in the next figure the navigational software configuration is shown of a specific X model receiver, in connection with an IMU.

Among other things, it can be noted from this figure that there is an emitter selection routine. Here the selection of the best set of four SVs is made based upon GDOP (Geometric Dilution of Precision), elevation angle, satellite health etc. The decision is made on the ground of the minimization of a weighted least-square performance index.

A very important feature of the IMU aided system is tracking and acquisition capability under severe jamming conditions.

Test Facility

During Phase I, the GPS concept has to be validated, the performance of the user equipment has to be tested and the military value of the system has to be shown. To this end, a test range is established in the Arizona desert at the Yuma Proving Grounds, (YPG) called the "inverted test range." Here, four pseudo satellites, or Ground Transmitters (GT) are installed on the ground and transmit signals similar to the "space satellites." These GTs are powered with solar cells. They are used for checking the accuracy of user equipment. To simulate the much longer real distance between user equipment and SV, an extra code offset is used. This also has the advantage that the simulation satellites can be used in combination with space vehicles when available.

In 1977, demonstrations of the GPS capabilities began with equipment installed in the AIR FORCE C-141, NAVY F-4 and P-3 aircraft and ARMY HH-1 helicopter. These aircraft are tracked by very precise laser trackers at the YPG to get the reference position of the vehicles. These trackers provide an accuracy of about 1m.

The orbits of the first SVs launched in Phase I and II are chosen in such a way as to maximize available test time at Yuma.

The GTs are controlled by the IRCC (Inverted Range Control Center) via UHF links. The controlled parameters are:

- turn on-turn off
- assignment of PRN code
- RF frequency control
- PRN code synchronization
- radiated signal power
- navigation message

As a counterpart of the MSs in the real system, at YPG a "Set X" is installed with an analogous function as the MSs. This set has omni-directional antennas for the reception of messages from the SV and four parabolic antennas directed toward the GTs.

There remains a number of differences between the real space and the YPG environment, including:

- transmitters are below the user

- navigation message is not fully identical (there are non applicable parts, ephemeris format is different, fixed coordinates instead of Keplerian type parameters).

- only L_1 is used

- only 4 PRN codes available

- GT clocks are delayed over 741376 P chips (0.07247 sec's) to approximate the average range to the SVs.

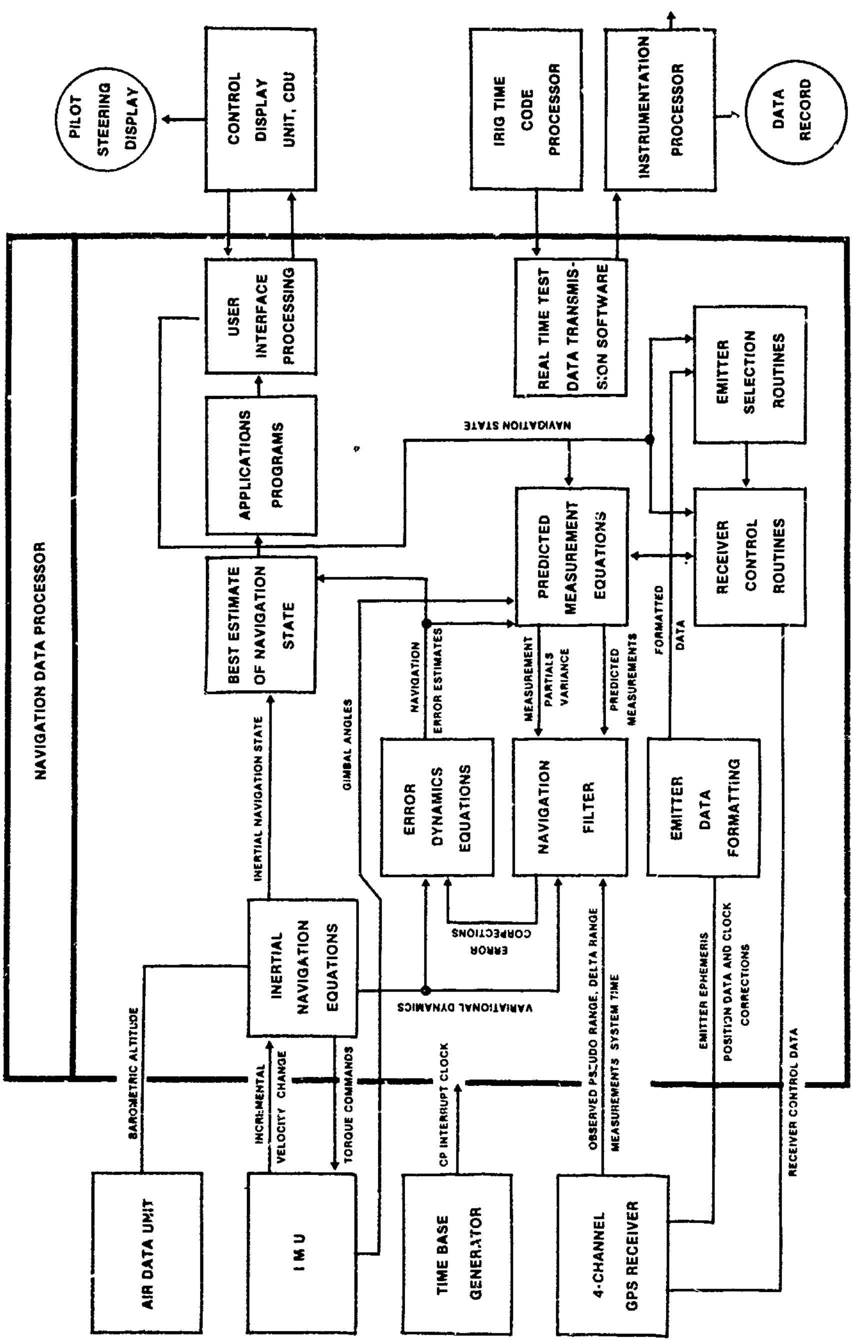
- the GDOP and the signal strength for a moving user varies strongly and rapidly because of the varying distance and orientation to the ground transmitter.

Some of these differences require special provisions in the design of GPS receivers to be tested with the inverted test range. However, they have been minimized and should be limited to the software.

Accuracy

A number of parameters affect the overall accuracy of the NAVSTAR GPS system. Among these are:

- The estimate of satellite position. This factor in turn is dependent on the accuracy of the ephemerides determination. It is expected that the prediction of the position of an SV can be made with an



PILOT STEERING DISPLAY
CONTROL DISPLAY UNIT, CDU
IRIG TIME CODE PROCESSOR
INSTRUMENTATION PROCESSOR
DATA RECORD
NAVIGATION DATA PROCESSOR
USER INTERFACE PROCESSING
REAL TIME TEST DATA TRANSMISSION SOFTWARE
APPLICATIONS PROGRAMS
NAVIGATION STATE
EMITTER SELECTION ROUTINES
BEST ESTIMATE OF NAVIGATION STATE
PREDICTED MEASUREMENT EQUATIONS
RECEIVER CONTROL ROUTINES
FORMATTED DATA
INERTIAL NAVIGATION STATE
GIMBAL ANGLES
NAVIGATION ERROR ESTIMATES
MEASUREMENT PARTIALS VARIANCE
PREDICTED MEASUREMENTS
ERROR DYNAMICS EQUATIONS
NAVIGATION FILTER
EMITTER DATA FORMATTING
INERTIAL NAVIGATION EQUATIONS
ERROR CORRECTIONS
VARIATIONAL DYNAMICS
BAROMETRIC ALTITUDE
INCREMENTAL VELOCITY CHANGE
TORQUE COMMANDS
CP INTERRUPT CLOCK
OBSERVED PSEUDO RANGE, DELTA RANGE MEASUREMENTS SYSTEM TIME
EMITTER EPHEMERIS
POSITION DATA AND CLOCK CORRECTIONS
RECEIVER CONTROL DATA
AIR DATA UNIT
IMU
TIME BASE GENERATOR
4-CHANNEL GPS RECEIVER

FIGURE 4

accuracy of about 3 m (1 sigma value).

- Satellite clock stability. It is expected that this will be 1 part in 10^{13}, or about 2 ns in 6 hrs.
- Solar radiation pressure uncertainties.
- Ionospheric propagation delay uncertainties.
- Tropospheric propagation delay uncertainties.
- User receiver noise.
- Multipath

The attainable accuracy in the NAVSTAR program is expressed in the so called UERE's, User Equivalent Ranging Errors, coming from each of these factors and by taking the root sum square (RSS) value of them.

It has to be recognized that this estimate is based on, among others, the following conditions:

- polar wander and earth precession are taken into account (produce predictable displacements of 10m).
- solar pressure is predicted.
- variation of earth rotation is incorporated (ms/day).
- relativistic clock behavior is incorporated.
- ionospheric delay is predicted with the aid of two frequencies.
- use is made of a dual frequency receiver.

It should be noted that it can be required to make an interpolation between fixes. The accuracy may then degrade during accelerations. However, it seems to be possible to call on four satellites within about 200 ms, even with a single channel receiver for the navigation message, which indicates the orbit parameters.

Anti-Jam Capability

Since NAVSTAR will have military application, it can be expected that much attention will be directed to:

1) The possibility of the system functioning in a hostile environment.

2) The possibility that the system could be degraded or destroyed by an enemy.

3) The possibility of making the system accessible exclusively to own forces.

The first point, functioning of the system in a hostile environment, is assured by the following features:

i) The system is passive, i.e., a user does not transmit any signal. This assures that a user will not betray his position to an enemy by using NAVSTAR GPS.

ii) The spread spectrum technique assures that the system will function under severe jamming conditions. In the open literature an idea of this AJ (Anti-Jam) capability is given by stating the tolerable jam-to-signal (J/S) ratio and by indicating at what distance this critical J/S ratio is reached for a 1 kw broadband jamming transmitter (over 20 MHz bandwidth).

For the 24 satellite configuration the following theoretical figures can be found:

- Without specific measures, a J/S of 40 dB is tolerable, merely by virture of the spread spectrum technique (the processing gain).
- With additional measures like the use of narrow antenna beams, automatic steering techniques and addition of an IMU it is stated that a J/S of 75 to 80 dB will be tolerable.

The next table shows what this means for each system as integrated in the host vehicle against a 1 kw groundbased jammer:

Receiver	Accuracy	Shortest tolerable distance to jammer (1 kw)	Application
High Dynamic	10 meter	100 nm	precise nav instrument approach
Medium Dynamic	10 meter	100 nm	" " " "
Low Cost	100 meter	170 nm	"3 dimensional TACAN"
High Dynamics + directional antenna	10 meter	10 nm	General Purpose
High Dynamics + directional antenna and inertial	10 meter	3 nm	Bombing Navigation
Manpack	10 meter	30 nm*	Portable

*Theoretical estimate. Tests results show considerably better performance due to ground absorption of the jammer signal and the attenuation due to obstacles located on the surface such as rocks, trees, etc.

4.2 NAVSTAR APPLICATIONS

Many applications of the GPS system can be imagined. Here only applications which are of interest to tactical air operations will be listed, without going into detail.

- way-point steering
- rendezvous
- bombing (maximum integration with bomb nav. systems like ARN-101)
- close air support
- reconnaissance, force location
- dropping supplies and troops
- controlling remotely piloted vehicles
- missile initialization, midcourse guidance
- coordinated operations Air Force/Army/Navy/Marine Corps

In addition, in peacetime, the system can be very valuable for position determination of aircraft during test of aircraft and aircraft equipment.

In general, the NAVSTAR GPS system could replace most of the existing position location and navigation systems which have an accuracy less that some tens of meters, provided the availability and the correctness of the data transmitted by the satellites is assured.

I COUNTER AIR OPERATIONS

General Considerations:

The ultimate objective of counter air operations is to gain and maintain air supremacy thereby preventing enemy forces from effectively interfering with friendly surface and air operations. This is accomplished through the destruction or neutralization of the enemy's air offensive and defensive systems.

Counter air operations are conducted to eliminate or diminish the enemy air threat; thus, they do not necessarily relate to specific surface operations. However, because both air and surface operations are significantly impaired in the face of effective enemy air opposition, the outcome of counter air operations exercises a direct influence on all other operations. Therefore, counter air operations may demand the highest priority of all air operations whenever enemy air power presents a significant threat.

Counter air operations include offensive and defensive air and surface-to-air actions. Offensive air actions are conducted throughout enemy territory at the initiative of tactical air forces and as such are the prime contributors to control of the air. Defensive air actions are conducted over or near friendly territory and are reactive to the initiative of enemy air forces. Defensive counter air actions contribute to local control of the air by thwarting or neutralizing enemy offensive air actions.

Control of the Air:

The freedom of movement and opportunities for offensive initiative resulting from control of the air make joint military objectives more readily achievable. Control of the air may range from full control by enemy to full control by friendly air forces. It may range from local control in a specific area to general control over the entire area of operations. Control of the air may also vary in time from temporary to prolonged periods. Within these extremes, situations occur which require the continued and varied applications of force to the counter air task.

In the absence of a hostile offensive air capability--either aircraft or missiles--security of friendly forces from air attack is gained by default. However, free exercise of friendly offensive air actions may be challenged by a well integrated and mobile surface-to-air defensive system. While the enemy air defense system may be the target of a specific counter air campaign, it can be anticipated that continued suppression of this threat must be carried on in conjunction with other actions. Specifically, configured strike aircraft may be employed to seek out ground based electromagnetic emitters and destroy or disable them through close-in attack or the use of standoff weapons.

These aircraft perform two basic counter air functions: support of counter air, air interdiction or close air support strike missions through suppression/destruction of hostile anti-aircraft gun and missile defenses; and systematic destruction of the enemy radar and communications networks. When a hostile air threat exists, counter air operations require interrelated air offensive and defensive actions. Because these actions are mutually supporting and interrelated, they require close coordination and centralized control.

Command, Control and Coordination:

It is essential that a single commander be assigned overall responsibility for gaining and maintaining air supremacy. As for joint force he provides a service which coordinates, integrates, and regulates the use of airspace within the boundaries established by the joint force commander.

The area commander must insure that optimum effectiveness is realized from each of the various air defense weapon systems and that no unnecessary restrictions are placed on their employment. He must also insure that air defense and air traffic control functions do not hinder or deter the conduct of offensive missions. The related functions of aircraft identification and air traffic control are essentail elements of effective air defense. The commander has the basic responsibility to establish rules and procedures for detection and identification, and to coordinate the manner in which friendly aircraft may enter, depart, or move within the defended area.

The air defense and air traffic control systems must accommodate the needs of all friendly forces to operate aircraft and must coordinate the movement of air traffic with the firing of artillery and ground based air defense weapons. To effect this control and coordination, representatives of the other Service components must be provided to the commander and appropriate air defense and air traffic control facilities established.

Offensive Counter Air Operations:

Offensive counter air operations of tactical air forces are conducted to seek out and destry enemy air power as close to its source as possible. These operations include air-to-ground attacks against air vehicles, support facilities, air defense systems, and air-to-air engagements to destroy hostile aircraft in enemy airspace. Examples of offensive counter air targets are:

(1) Airfields, tactical missile complexes and immediate supporting facilities.

(2) Command, control and guidance facilities.

(3) Petroleum, oil, lubrication, munitions and missile storage sites.

(4) Air vehicles.

(5) Surface-to-air defensive systems.

Targeting for offensive counter air strikes should be planned prior to hostilities and kept current, based on the latest intelligence concerning the enemy order of battle. Targets are arranged in order, with the highest priority assigned to those whose destruction would cause the greatest reduction in the enemy air capability. Counter air strikes initiated at the outset of hostilities and a ready and effective air defense can produce an immediate advantage in the air battle and result in early air superiority. Where enemy bases are in a sanctuary or area otherwise immune from attack, the counter air battle must be won through air-to-air engagement as enemy air forces appear.

The ratio of forces assigned to offensive and defensive counter air tasks will be determined by the commander. In making this determination, he must consider, among other factors, the level of the enemy air threat and the vulnerability of friendly forces to air attack. However, until air supremacy is gained, the emphasis should be on offensive counter air operations. Air defense, while vital to the total counter air program, is a relatively inefficient means of destroying enemy air potential and, by its very nature reacts only when the enemy exercises initiative action. Offensive pressure must be maintained so that the enemy is forced to withhold a significant portion of his air potential for defense of his own area.

Defensive Counter Air Operations. Air defense consists of all measures designed to nullify or reduce the effectiveness of attack by hostile airborne vehicles. The enemy's air potential is the primary factor when establishing air defense requirements. Air defense involves active and passive defensive measures.

Active Air Defense. The basic functions of active air defense measures are detection, identification, interception and destruction of airborne vehicles which threaten friendly forces and installations. Effective air defense requires centralized control of air defense weapons within an area of operations. Control agencies and communications-electronics facilities must provide the means for integrating air defense actions with all other air operations. Adequate early warning and defense in depth should be provided to allow engagement by multiple weapon systems. Identification criteria, weapon assignment procedures, and rules of engagement must be uniform and the activities of strike and support aircraft must be coordinated with air and surface-to-air defense activities. The primary air defense weapon systems are tactical fighter aircraft, air defense artillery and surface-to-air missiles. Fighter aircraft may be maintained on ground or air alert status with the objective of intercepting and destroying hostile aircraft before they reach their munitions release points.

Passive Air Defense. Passive air defense consists of those measures which do not involve the employment of active weapons. Passive air defense is generally the concern of individual unit commanders and includes radar coverage, warning systems, cover, concealment, camouflage, dispersion, frequent movement, and personnel indoctrination. It is seldom possible to stop a determined attack completely; therefore, all commanders must give continuous emphasis to passive defense measures. These measures must not, however, impose unnecessary or unacceptable restrictions upon operations or compromise the security of other friendly forces.

Types of Missions:

Counter Air Strikes. These missions involve offensive strikes against surface targets of the enemy airpower complex. The objective is to establish early air superiority by denying the enemy full use of his bases, aircraft, air defense weapons and control systems. Both offensive and defensive systems are targets for attack; however, offensive systems should normally have the highest target priority. The weight and scope of counter air strikes are dependent on force objectives and political constraints.

Fighter Sweeps. In addition to destroying or neutralizing enemy aircraft on the ground, fighter sweeps may be employed to challenge and destroy his air forces in the air. This mission must be vigorously pursued until the enemy no longer offers effective resistance. As destruction of his fighter capability progresses, our exercise of control of the air increases and the threat of effective enemy air attack diminishes.

Screens. Fighter screens are normally used to restrict enemy air movement. During conditions where enemy attack on friendly forces is likely, air defense may be enhanced by positioning a screen of airborne tactical fighters between the threat and friendly forces. A screen can be established over enemy territory along the line of contact or in friendly territory to intercept hostile aircraft before they can interface with friendly operations.

Combat Air Patrol. Fighter aircraft may be tasked to intercept and destroy enemy aircraft in a localized area. Air patrol can be conducted over an objective area, a friendly air or surface force, a critical combat zone or along a corridor. Combat air patrol differs from screening in that screens are imposed between the threat and the area or force being defended whereas, patrols are positioned over or near the area or force being protected.

Air Escort. When friendly air/airmobile forces enroute to an objective area are subject to enemy air attack, tactical fighter aircraft configured primarily for air-to-air combat may accompany the force. Air escorts are employed to prevent enemy air actions from disrupting friendly air/airborne operations. Escort aircraft may be tasked to defend such varied activities as air strike, airmobile, air reconnaissance, airlift, or air rescue operations. Air escort may also be employed to provide supporting firepower for airborne/airmobile operations.

Air Intercept Mission. When hostile offensive air action is a threat, air interception of enemy and unidentified aircraft is a vital task. Area air defense operations are normally established to permit air interception of intruding aircraft over or near friendly territory but sufficiently distant from vital target areas to permit defense in depth. Tactical air units charged with air defense and intercept responsibility maintain aircraft configured for air-to-air combat in a state of ground or air alert when a threat is imminent. The air intercept mission normally requires high performance, highly maneuverable fighter aircraft, and an integrated ground or airborne radar and communication system.

<u>Airspace Control:</u>

General Considerations:

(1) Air operations conducted throughout the combat zone require positive coordination, integration, and regulation to minimize interference between friendly forces and to expedite the safe and orderly flow of air traffic under all flight conditions. For effective air defense, positive regulation and identification of all air vehicles moving within the airspace over the combat zone is mandatory.

(2) Air defense and airspace control, which includes air traffic regulation identification, are correlative responsibilities.

<u>Specific Tasks:</u>

(1) <u>Counterair</u>. The counterair mission, also sometimes called the air supremacy mission, is one means of ensuring aerial defense of territory. It consists of declaring air space off-limits to any unathorized aircraft. Other means of achieving this include DCA stations and ground-air missiles, for example.

The counterair mission only refers to aerial defense by aircraft. In this sense, it actually encompasses the missions of interception and aerial combat, which are the means used to ensure the interdiction mission itself.

The counterair mission is based on radar surveillance of the air space in order to detect any suspicious presence in it and attempt to identify and locate the threat.

If necessary, an interception procedure is initiated. In peacetime, its purpose is to repulse the enemy or force him to land; in wartime, it can become a dog-fight and the attempt to destroy the intruder.

In France, the STRIDA system ensures the centralization of all flight plans, be they civil or military, on a computer, as well as the exchange of information among the surveillance radar of the national network. It permits military air traffic controllers to verify whether a radar echo corresponds to an established flight plan.

If this is not the case, it can interrogate the suspicious aircraft by an IFF (Identification Friend or Foe) system. Thus, weapons aircraft which are equipped with an IFF responder, are rapidly identified. Otherwise, STRIDA helps determine the interception trajectory in order to bring the interceptor into the best combat position, i.e., a position in which radar contact with the target is made under favorable conditions. GPS could enhance counterair operations by improving aircraft control during tactical interception as well as by providing accurate positioning for attack of enemy aircraft and air support targets.

(a) <u>Interception</u>. Thus, GPS should provide the capability to position an aircraft more precisely than is now possbile with other navigational aids. This capability could aid in positive control of aircraft from either airbrone platforms or ground based facilities. Controllers could instruct interceptor aircraft to proceed to a geographical point without close vectoring, a particularly advantageous capability in a radar or communications jamming environment. Moreover, tactical air employment decision makers would be able to employ resources more efficiently during rapidly changing battle situations since they would know precisely where all friendly aircraft were located at any instant. This assumes GPS coupling to some degree with advanced communications systems to provide a three-dimensional input into a real-time graphic display.

The purpose of the mission is the neutralization or destruction of objects in flight, as was indicated in the preceding paragraph. It is one means of ensuring interdiction.

Several minutes after takeoff, the interceptor is guided to the target by a radar station, which tracks the interceptor and the target simultaneously. The radar information is processed by a ground computer, which generates the interception trajectory to be followed. Thus, the air traffic controller can send the orders of velocity, heading and altitude to the interceptor pilot.

When the on-board radar has detected and locked onto the target, the maneuver is continued autonomously, under the responsibility of the pilot.

In peacetime, the pilot attempts to come as close as possible to the target in order to identify it and to advise it to turn back or make a soft landing, if that be the case.

In wartime, the pilot will attempt to get himself into a favorable position for deploying his weapons (missiles, rockets or gun).

When the position of the target is poorly defined, the interceptor proceeds first with the autonomous search for the target using his on-board radar, and then continues the mission as before.

The first phase of interception is the radar surveillance phase. There are three purposes for this surveillance:

- detection
- identification
- location

Detection and location only depend on the intrinsic characteristics of the radar devices (ranges, sensitivity, precision of warning), on which NAVSTAR has no effect.

On the other hand, the existence of the common time reference supplied by NAVSTAR would permit perfect synchronization of switching the modes used to respond to the interrogations of IFF radar according to a classified mode of operation. Today these modes are switched manually by the pilot around every half hour. It is necessary to be aware of the period of uncertainty which lasts several minutes during each switch before being certain that all the aircraft have locked onto the new mode. This task could be automated, thus freeing the pilot and avoiding any risk of forgetting.

A procedure such as this would improve the overall quality of identification. However, it would probably only justify itself when the presence of a NAVSTAR receiver in each aircraft served another operational purpose (interdiction, tactical support or penetration).

Assuming that the current IFF would be supplemented with a DATA-LINK in the future, we can imagine the dynamic improvement in the quality of location radar information without improving the actual principle of radar location. During each interrogation, the accepted aircraft transmit their NAVSTAR positions and velocities via data-link. These data are compared to the data generated by the radar unit, which deduces its errors from this and can reset its position and velocity estimates for other objectives.

If AWACS systems have been added to the ground radar surveillance network, the precision of the NAVSTAR position and velocity would allow all air traffic controllers to work in the same reference grid and facilitate the coordination of their efforts, especially for the mutual designation of objectives.

This possibility of providing a single reference grid as a result of the exceptional precision of NAVSTAR is one of the primary advantages of the system, particularly for the interception mission, which involves the participation of many ground operators, radar devices, and aircraft.

The basic problem of interception is knowing the position of the target relative to the interceptor. It would be useless to know the very precise geographic position of the interceptor from NAVSTAR if we did not also know the position of the target.

This is usually found by using radar. We can expect that in 1985, ground station radar units will be able to determine the geographic position of an object 200 nmi away with a high degree of precision.

Knowing that it suffices for an interceptor to be several nautical miles, or several dozen, from the target in order to initiate firing with modern weapons, it appears that NAVSTAR does not make a significant operational improvement in this respect, since the current navigation systems, to say nothing of the future navigation systems, have overall precision on the order of 1-3 nm during an interception mission.

However, we can predict that precise knowledge of the position of the interceptor might permit the precise approach to the target without using the on-board radar, thus reducing the risks of detection by the enemy aircraft or the possibility of the use of countermeasures. Actually, the radar would only be used during actual firing.

This argument alone could justify the use of NAVSTAR for an interception mission, whose end result greatly depends on the rapidity and secrecy of intervention.

Moreover, we can imagine that the aircraft of the future will be equipped with tracking computers which will make guidance to the target by ground equipment useless. This solution will also relieve the ground control crews and will help to increase their operational efficiency, with their mission being limited to identifying the intruder aircraft and transmitting its position and velocity to the interceptor.

Furthermore, the fact that the interceptor itself can realize a precise rendezvous with the target may actually make it possible to change to lower-performance, thus less expensive, air-air weapons by increasing the cost of the navigation and firing system relatively slightly. However, this development will definitely go against the current trend, which is to develop more and more sophisticated weapons systems - specifically, with respect to the range and precision of the on-board radar and weapons -for the very purpose of avoiding the need for coming into close contact with an enemy aircraft.

(b) Attack on Enemy Air Support Facilities. GPS should provide sufficient terminal accuracy to deliver standoff weapons against fixed area targets such as airfields at night or in adverse weather conditions. In general, the ability of aircrews to acquire targets should be improved and positioning data derived from reconnaissance/ surveillance sources could be used for cuing real-time cathode ray tube (CRT) displayed avionics to facilitate searching.

(c) Defense Suppression. GPS may enhance the capabilities of defense suppression systems to accurately locate and attack emitter targets. Positioning information derived from such systems as tactical electronic reconnaissance sensor (TEREC), side-looking airborne radar (SLAR), and PLSS could be translated into the GPS common grid system for use in targeting and updating the electronic order of battle. Increased operational flexibility could be achieved by using GPS as an aid to guidance for certain standoff weapons. The excepted accuracies achievable through GPS would permit attacking fixed area targets during day, night, and adverse weather by standoff weapons, thus reducing the threat of the enemy defensive envelope. Additionally, GPS positioning could be used to maximize the effectiveness of chaff employment. Chaff corridors or blankets positioned with reference to the GPS common grid would provide an improved capability for strike aircraft to locate and operate within the corridor or area.

II AIR INTERDICTION

Detailed integration of each air mission with the fire and movement of friendly forces is required because such strikes are conducted beyond the fire support coordination line. Since tactical air forces are able to operate throughout enemy held territory and attack industrial, supply and transportation complexes, a properly planned air interdiction campaign can deny the availability or movement of appreciable quantities of personnel and material. Although the effects of an air interdiction campaign are seldom immediately apparent, a coordinated and sustained campaign can contribute decisively to the attainment of area objectives.

The air interdiction effort must be based on intelligence collection by air reconnaissance or other means, and careful analysis of the enemy logistic system to identify vulnerable points. The air component commander will determine the categories of targets to be attacked and prepare and execute the necessary plans for air interdiction operations. Continuous coordination with the surface commanders is essential because the timing of attacks against specific targets or target systems may be critical to the successful accomplishment of surface actions.

In some situations, the enemy may possess sanctuaries for elements of his war base and logistic system. These situations can occur when enemy forces exploit adjacent friendly or neutral territory and/or when national constraints prevent unlimited attack against specified areas or target categories. Consistent with political constraints, an aggressive air interdiction campaign can be sustained against targets authorized for attack until the desired effects are achieved. In these situations, is is essential to recognize that unlimited objectives are not likely to be achieved with limited means.

Concept of Operations:

The commander initiates the interdiction program by issuing directives outlining the broad plan of operations. These directives describe the general area to be interdicted, the degree of neutralization to be achieved, the time the effects are desired and the relative priority of the tasks. Based on this guidance, the specific categories of targets to be struck will be selected and the necessary plans for the air interdiction campaign will be accomplished.

Personnel, supplies and equipment are required to sustain the enemy's war effort. Sea, air and land lines of communication must be established and operated to provide a continual flow of personnel and material. Supply and troop shipments originating in rear areas move along these lines of communication and pass through concentration points on their way to the areas of conflict. Air interdiction operations can disrupt this flow at its source and while transiting to the battle area. The overall effects of air interdiction are achieved through destruction, neutralization, delay and harassment of the enemy means for sustaining combat. In achieving these efforts, night and marginal weather capabilities as well as delayed effects weapons are employed.

Interdiction operations may not achieve complete isolation of the area of conflict. A carefully planned and executed air interdiction campaign, however, can rapidly reduce the enemy's battlefield reserves to critical levels and seriously limit his capability to continue effective action. Offensive friendly ground operations conducted in coordination with the air interdiction efforts accelerate comsumption of the enemy's battlefield reserves and capitalize on his reduction in combat effectiveness. Air interdiction operations also:

(1) Reduce the enemy's capability to mount an offensive.

(2) Restrict the enemy's freedom of action and increase vulnerability to friendly attack.

(3) Prevent the enemy from countering an increase in friendly strength.

The air interdiction program is conducted to destroy, neutralize or delay the enemy's military potential before it can be brought to bear effectively against friendly forces and to restrict the mobility of enemy forces by disrupting their lines of communications. Air interdiction involves offensive air strikes in support of the joint force mission.

In counterinsurgency (COIN) conflicts, air interdiction operations requires extremely discriminate actions. Lines of communications, often in sanctuaries, are difficult to locate and identify. Supplies usually come in from outside the insurgent area and stockpiles are well hidden and often widely dispersed in insurgent-controlled territory. Interdiction operations are generally conducted against targets which reduce the insurgent capability to assemble and launch offensive actions.

In certain circumstances, "free strike zones" may be designated and interdiction operations conducted against all personnel and material within these zones. As ground actions against the insurgent take on more of an offensive nature and insurgent base areas become objectives, air interdiction and close air support operations tend to coincide.

Mission Control:

Generally, the more limited the level of conflict, the greater the requirements for discriminate air interdiction action and the greater the requirement for control of air strikes. It is essential, therefore, that a means of control be provided to divert or recall airborne strike aircraft; however, discretion must be used to preclude compromising mission security and strike surprise. Normal control requirements consist of:

(1) Initial Contact. Strike flights provide information on flight identification, location, munitions, and assigned missions. The control facility establishes radio/radar contact, positive identification and advises of changes of mission.

(2) Enroute. Strike flights provide information of physical and operational conditions enroute to the target area. The control agencies monitor flight progress and provide information or direction on enroute operational conditions which may divert or affect the conduct of the mission progress data and hand-off mission control from one agency to another.

(3) Recovery. After the attack, the flight is controlled to its recovery base in a manner similar to enroute mission control. In-flight strike reports provide planning agencies current data for use in the direction and control of subsequent missions.

Additionally, political restraints and self-imposed operational restrictions may dictate a necessity for positive control of air interdiction strikes. This control may be exercised through ground or airborne control elements. The use of airborne reconnaissance elements can be particularly effective in accomplishing air interdiction actions against opportune targets.

The direction, control and coordination of air interdiction operations with other component force operations is accomplished through coordination with the various element commanders.

Mission Considerations:

Intelligence Considerations;

(1) The Nature of the Enemy's Transport System:

(a) A study of the enemy's transporatation system will reveal its most sensitive and vulnerable segments. The capability of the enemy to reroute, transship, or employ an entirely new means of transportation is an essential factor for evaluation. The extent of possible seepage of supplies through breaks in lines of communications must also be evaluated. Air interdiction operations cannot be expected to result in complete denial of resources to the enemy. However, they do seek to interrupt the movement of supplies to the extent that resources are reduced to a critical level.

(b) The length of the enemy's lines of communication from supply source to the area of employment will influence the depth to which the interdiction effort must be applied. If the enemy's lines of communication are long, they can be disrupted at a selected depth or along the entire length. If they are short, the points of attack will necessarily be close to the employment area. The more a line of communication is disrupted the harder it will be for the enemy to move, and the greater the effort required to repair the damage.

(2) Concentration Points: At various points along lines of communication, concentrations of personnel and material frequently develop. Attacks against these areas can be most effective and are complementary to operations directed against the lines of communication. Such points include:

(a) Transportation centers where various lines of communication converge and significant rerouting and reloading are accomplished.

(b) Supply depots and storage facilities.

(c) Repair and modification centers.

(d) Troop staging areas where personnel are processed and material for combat forces.

(3) Stockpiled Supplies: Before an enemy initiates an attack, he can normally be expected to stockpile supplies for his forces near the planned area of operation. If these stockpiles are extensive, the interruption of supply movement to the forward areas will have little immediate effect until the stored supplies are depleted. The destruction of these forward area stockpiles and the interruption of the flow between the stockpile and the consumer units are significant objectives of the interdiction effort.

(4) Turnaround Time:

(a) Traffic turnaround time depends primarily on distance from supplies to user and the speed of the supply carriers. This is an important factor in determining how long it will take the interdiction program to become effective. The longer the transport turnaround time, the more difficult and expensive it is to keep the forces supplied. The turnaround delay may reduce the amount of rear area interdiction effort required to attain the desired effect on the enemy's forward stockpiles.

(b) The shorter the transport turnaround time, the less difficult and expensive it is to keep the forces supplied. However, as the lines of communication are compressed, the concentration of resources at points along the line will increase and more profitable targets for attack may be presented. These concentration points are normally easier to locate, and the material and personnel are more vulnerable than when dispersed in or near the battle area.

(5) Reconstitution Facilities: Certain industrial installations constitute the enemy's capability to repair, rebuild and replenish lines of communications and modes of transportation. Attacks against these installations reduce the enemy's ability to sustain his logistic system and are complementary to long term air interdiction operations.

(a) Structural material plants.

(b) Vehicle and component part manufacturing factories.

(c) Industrial power plants.

Operational Considerations:

(1) Timing:

(a) The initial attacks at the outset of air interdiction operations should produce effects that can be utilized to advantage. Traffic over routes of communication moves on fairly regular and well-timed schedules. When these schedules are disrupted the congestion, stoppage and disorganization that results may be expected to provide immediate targets of significant value.

(b) A determined enemy will devise alternate means of maintaining his logistic capability. Successful operations against a particular segment of his lines of communications may cause a predictable rerouting of supplies to another segment or mode of the transporation system. Thus, lucrative targets for subsequent operations may result.

(c) Close-in air interdiction missions which may rapidly affect the land tactical situation must be coordinated with the ground force commander's plan of maneuver. Air interdiction actions of this nature may involve a concentration of effort on targets immediately adjacent to a battle sector or may be employed at some distance as feinting or diversionary operations. These close-in strikes can have a direct and immediate effect on the land situation by friendly land forces.

(2) Sustaining Interdiction Operations:

Interdiction is neither complete nor permanent. Some movement and resupply will continue to take place. This is especially true when the interdiction program is confined to a limited area.

Specific Operations:

Accurate navigation to and from targets/weapons launch points will be enhanced using GPS positioning. Optimum routes could be selected to reduce exposure to enemy defenses. The GPS common grid allows flexibility in coordinating operations with force elements of other service/nations. Once in the target/launch area, GPS positioning would expedite target acquisition. Delivery of air-to-surface weapons against heavily defended targets will require a standoff "launch and leave" tactic to increase the survivability of the delivery aircraft. A GPS-aided weapon guidance system could be used for area targets or in combination with other terminal seekers for targets where greater accuracy is required. Once target positions are established by reconnaissance or other mission aircraft, strike aircraft would deliver ordnance using these GPS coordinates. The expected accuracy of GPS positioning should permit destruction of fixed-area targets during periods of darkness and adverse weather. Maritime targets could also be accurately located on the GPS grid by ocean surveillance forces, providing constant positioning data for interdiction by tactical air forces when necessary. App. 3 considers Weapon Delivery Importance in the Interdiction Support role.

III CLOSE AIR SUPPORT OPERATIONS

General Considerations:

Close air support involves air action against hostile targets in proximity to friendly forces and requires detailed integration of each air mission with the fire and movement of those forces. Tactical air forces are applied against targets of immediate concern to surface forces when surface forces cannot produce the desired effect with organic weapons: surface forces are committed without normal organic weapons support; or the disposition of targets prevents successful attack by surface weapons. The close air support allocation of strike aircraft may be used to provide escort and suppressive supporting fires for airmobile and airborne forces, and to conduct surveillance and security for landing forces, patrol, and probing operations. The task of close air support is to provide selective and discriminate firepower, when and where needed in support of ground forces. Thus, close air support must be available, responsive, integrated, and controlled.

In terms of integration, close air support missions must be integrated with the organic fire of land forces to achieve mutual support. Close air support missions must also be closely integrated with the movement of land forces to insure air support is provided when and where required and to preclude inadvertant strikes against friendly forces. This detailed integration is accomplished through all echelons of command. These systems provide a means by which tactical air and land force organic firepower can be integrated to fulfill fire support requirements as they occur.

Target area control will be through a Forward Air Controller (FAC), who insures both direct coordination with the surface unit being supported and visual target acquisition by the strike force. Under conditions of reduced visibility, an air support radar team may provide final mission control.

Generally, tactical strike aircraft should possess the operational capability and versatile weapon systems needed to fulfill all close air support requirements. Close air support strikes are highly effective against hard, transiting or mobile targets. Typical targets are: enemy troop concentrations or formations; fixed positions; and mechanize''airmobile elements in the immediate battle area. The most favorable opportunities for close air support normally occur during fluid battle situations when enemy forces are on the move and are exposed to air attack. In all cases, effective close air support requires close coordination between the air and land commanders in planning and conducting operations.

Planning Considerations:

In planning for close air support, the enemy threat must be evaluated and specific targets identified. Target priorities must be established, the timing of strikes determined, desired effects evaluated, and weapon and sortie requirements calculated. Selection of each target for attack must be integrated in detail with the development of the scheme of maneuver and fire support plans of the supported land force.

Targets which can be attacked by organic surface weapons are listed in the ground commander's basic fire support plan. Close air support is developed in coordination with ground planners who calculate the weapons and sorties required to strike targets which may be beyond the capability of availability of land force organic weapons. The screening process provides the basis for a planning estimate of the sorties required for preplanned close air support.

To assure rapid response to any given situation, tactical aircraft may be maintained in either ground or air alert posture. Although not a type of alert, diversion of aircraft from other missions may be ordered in urgent situations requiring immediate action.

Coordination and Control:

Appropriate officials advise the land force component commander of the number of close air support sorties available, and the land force commander in turn specifies how these sorties will be distributed to subordinate units. Subordinate unit commanders request close air support as the battle situation requires. Operational elements work closely with the land force commands at all levels to complete the coordination required. Tactical air control elements provide: planning assistance; advice on air operational capabilities; coordination with land force organic fire; relay of immediate close air support requirement; and function as a ground or airborne controlling agency for strike aircraft in the target area.

Control elements direct strike aircraft to a designated point and assist in target acquisition by the strike aircraft. According to the situation, a controller may operate on the ground or from an airborne vehicle. In many situations, dictated by terrain, political boundaries, or other considerations, an airborne controller is essential for proper strike control.

Airborne elements must be equipped with communications and operations facilities necessary to communicate with strike and support aircraft, land force elements, and to interface with other component units.

Air Requests:

The land force unit commander requests close air support as the battle situation requires. His assigned air liaison officer advises him on the capabilities and limitations of tactical air support for each particular situation. Requests for close air support may be either immediate or preplanned.

Immediate mission requests are those made by a ground commander for close air support that is responsive to specific tactical situations and targets which develop during the course of the battle. By their nature, they cannot be preplanned. An immediate mission request by its urgency is limited to those items of information essential for coordination, control and execution of the mission. Immediate mission requests can be initiated by any land force unit echelon and are passed over the Air Force air request net, by any means available. Each request is simultaneously coordinated at all echelons. Requests for immediate missions may be fulfilled by aircraft on ground or air alert or by diversion of aircraft from other missions.

Preplanned requests are submitted by a land force commander for close air support that is responsive to anticipated targets in planned operations. These requests are initiated sufficiently in advance to permit detailed strike planning and pilot briefing prior to takeoff. Preplanned missions provide for the most efficient and economical use of available air forces because munitions can be precisely matched to target requirements and mission planning can be more complete. Moreover, these missions can be integrated into the following day's operations to assure timely accomplishment and preclude interference with either organic or other supporting fires. Preplanned requests are fulfilled from the daily tactical strike sorties allocated to close air support.

Concept of Operations:

Tactical forces are capable of conducting close air support operations day or night and under marginal weather conditions. The delivery of firepower, visually under natural or artificial illumination and electronically under self-contained or external control, provides the capability for tactical air forces to complement both direct and general fire support of land forces, day or night. Close air support by tactical air forces can be effectively employed in all phases of land operations.

a. Support of Offensive Ground Operations. Land forces on the offensive provide one of the most favorable situations for use of the close air support. Close air support is often able to provide the additional force necessary for land maneuver elements to breach enemy strong points, thereby creating an ideal situation for exploitation by friendly land forces. Tactical air attacks are directed against strong defensive positions, concentrations of enemy troops, suspected ambush sites, and other centers of resistance. In offensive actions, close air support must be concentrated in sufficient strength to achieve initial objectives, and must be continued until friendly land forces are in command of the situation. The enemy must be prevented from regrouping and initiating a counter-offensive

b. Support of Ground Exploitation Operations. Breakthrough operations should be immediately exploited. The counter air effort should have provided at least local control of the air while interdiction operations should have disrupted the enemy supply routes and limited his reinforcements. The battle situation will be fluid with the enemy on the move and vulnerable to air attack. Under these conditions, close air support operations are highly effective.

c. Support of Defensive Ground Operations. Close air support may be used both day and night to prevent defensive positions from being breached or overrun. At time, flarelift alone or the presence of air alert aircraft is enough to deter hostile attacks on friendly positions. Close air support can be employed to cover retrograde movements or reconnaissance forays into enemy territory. In these operations, identification of forces and positions and delivery accuracy are extremely important to minimize casualties.

d. Air Force Special Operations.

(1) In special operations, the Air Force commander provides the full spectrum of close air support to friendly land units. However, there are generally three categories of close air support missions in a special operations situation: column cover; escort missions; and strike missions.

(2) These operations are conducted in a conflict environment where indigenous paramilitary and local militia forces as well as military elements, are normally employed; and where enemy forces are generally composed of small units blended into the local populace.

(3) Strikes are frequently characterized by ill-defined targets in very close proximity to friendly forces, outposts, forts, or hamlets. Because of the fleeting nature of the enemy and the conflict environment, air alert missions are required for many friendly force activities.

(4) Cover or escort missions normally can assist the free movement of friendly patrols, reconnaissance teams, or combat sweeps by attacking suspected ambush sites or enemy forces which impede or threaten the progress of the friendly force. If tracking the insurgent force has been successful, close air support on a continuous and sustained basis may be required to keep the enemy pinned down until adequate land forces can be positioned for offensive actions. In this environment, tactical close air support may support both military and paramilitary counterinsurgency activities.

Specific Operations:

Certain specific close air support operations due to the nature of the terrain, the enemy, or the composition of friendly forces require individual discussion.

a. Airborne/Airmobile Operations. In airborne/airmobile operations, close air support is essential for drop/landing zone preparation and suppressive fire since organic heavy weapons are not normally available during the initial stages of the operation. Air escort of the force enroute may be required to provide security from enemy air attack or ground fire. Attacks may be required on air defensive forces along the air corridor of approach and must be directed against all targets in or near the objective area during and after landing to insure the security of the landing force. In airmobile operations involving force withdrawal, support by air alert aircraft tasked for that specific action is normally mandatory.

b. Airlift Operations. Close air support may be required for tactical airlift operations when hostile air or ground action might preclude mission accomplishment or impost unacceptable losses. Typical requirements would be suppressive fire for aerial resupply, defoliation, or air laid smoke screens.

c. Amphibious Operations. Close air support is of paramount importance to landing forces during amphibious assault operations when troops are in exposed positions without organic firepower. Air strikes are conducted immediately in advance of the assault to reduce enemy resistance to the landing. Once the landing force is ashore, close air support is directed toward assisting in the consolidation and buildup of the beachhead through responsive, closely integrated air attacks. Other types of amphibious operations which may require close air support are: raids, withdrawals, and demonstrations (diversionary feints).

d. Column Cover. Column movements may be covered by aircraft which provide protection by reconnaissance and/or attack of air or ground targets which threaten the column movement. A controller is normally airborne over the column which is located in one of the forward vehicles to coordinate the column cover mission and to control the strike. Tactical air forces can greatly assist armored forces in the exploitation of enemy disorganization and weakened resistance following a breakthrough. Strike aircraft often can be used to neutralize elements of potential enemy resistance before these elements can be brought into contact against friendly land forces. Additionally, they can be employed effectively to attack potential ambush points which could pose a threat to convoys supporting lines of communications in environments without stabilized front lines or where enemy guerrilla forces are active.

e. Counter-Mechanized Operations. When the enemy force engages in mechanized operations, a strong air effort must be made to disrupt and destroy hostile mechanized forces and formations. By denying the enemy the hardened firepower and mobility of such land elements as tanks, self-propelled weapons, and armored personnel carriers, a more permissive environment for exploitation of friendly force capabilities results. Counter-mechanized air operations normally combine close air support and air interdiction functions since mechanized forces may be expected to group beyond the area of close air support operations and then move rapidly toward their objective.

Use of NAVSTAR GPS in Close Air Support Mission:

a. Assumptions. Since GPS does not as yet exist as a fully operational system, a few assumptions are in order. First, it is expected that the system will perform to design specifications. At this point in time, achieving the technical performance parameters is not seen as a major hurdle. Almost all portions of the system have been verified by actual tests in other programs. In addition, studies have been conducted over the last ten years addressing key issues associated not only with the GPS receiver, but also its integration with other avionic equipment. Second, and related to the previous assumption, is the fact that significant benefits can be realized from the integration of GPS with other systems. Finally, it is assumed that the system will attain operational status within the approximate time frame currently projected.

b. Employment. The tactical air forces are required to perform a number of missions, including close air support. This role and mission must be successfully accomplished in a hostile and dynamic environment highly saturated with surface-to-air missiles and airborne combatants and intensified through jamming, intrusion and other electronic warfare techniques. The vulnerability is high for existing navigation systems in such an environment, thus generating the requirement for an accurate jam resistant positioning system with worldwide application. An operational GPS capable of operating in a hostile environment will also provide precise navigation capability in peacetime for military and civil community operation.

c. Extent of Improved Performance. Support of NATO ground forces in proximity to or in contact with enemy forces requires extensive coordination. The time involved in this coordination can be a major factor in the effectiveness of tactical air power. The key to successful close air support is accurate knowledge of the position of friendly forces and relative position of enemy forces. Tactical air control parties and other ground force elements, could be equipped with GPS manpacks which would provide accurate determination of position. GPS coordinates could then be passed to control centers, using automatic retransmission devices to make friendly locations continuously available.

Coupled with knowledge of the relative position of enemy forces, through a variety of techniques, close air support strikes may be called in with minimum delay. Target or FAC rendezvous coordinates passed to air crews would be entered into bomb/nav systems to permit direct flight to the target area. The attack aircraft would be operating in the same coordinate system as ground forces and would be able to select optimum attack approaches while preserving the element of surprise. Ordnance would then be delivered by visual attack, a combination of visual/coordinate attack, or coordinate attack depending on the situation and weather conditions. Target acquisition would be enhanced during attacks and reattacks, especially during periods of adverse weather. GPS equipment interfaced with other on-hand avionics systems would increase weapon delivery accuracy and reduce the possibility of delivery errors when attacking targets in proximity to friendly forces. It should also provide the capability to more accurately dispense illumination flares during night operations.

d. New Capabilities. The high accuracy and global coverage of GPS makes it a significant contributor to improved capabilities during night and adverse weather and at low level which improves air vehicle surviability in a high intensity combat environment. The satellite signals of the GPS are not subject to terrain masking and grid inaccuracies associated with present earth-based radio navigation systems. The result is a capability to navigate and position weapons with increased accuracy, not only during conditions of good visibility, but also at night in adverse conditions. GPS provided the capability to accurately pinpoint the absolute position of aircraft on a worldwide basis. This ability, coupled with accurate speed, drift, ground track, altitude and timing, provide a superior all weather navigation system.

e. Impact on Design. GPS can be used to bound and update an inertial system. Conversely the inertial system can be used to rate aid the GPS to facilitate operation in high dynamic maneuvers and/or a jamming environment. This would be accomplished by a Kalman filter. Avionics could be further simplified since GPS would aid in operating from bare base airfields where nav-aids are non-existent. Also, the installation of GPS may allow the deletion of several other navigation aids from the aircraft user equipment.

IV SEA PATROL

Maritime reconnaissance covers two main types of mission, namely the anti-submarine battle and the attack of surface vessels.

PREMILINARY DEFINITIONS AND PRESENT PROCEDURE

Anti-Submarine Battle

This consists of detecting the presence of an enemy submarine, determining its position, and releasing a torpedo to destroy it. Detection is the object of the surveillance phase, which can be done in three different manners:

- visual surveillance
- radar surveillance
- surveillance using passive buoys, directional or not, which are dropped in a known configuration ("pattern"). The purpose of passive buoys is to detect the presence of a submarine and alert the patroller of this.

The main difficulty with this phase is that due to the drift inherent in the navigation system of the aircraft and that of the buoys under the effect of sea and wind currents, the information supplied by the buoys may not be correctly interpreted by the patroller.

The solution which has currently been adopted for overcoming this problem and permitting the aircraft navigation system to operate in the same grid as the buoys consists of having the aircraft regularly pass over the vertical plane of the buoys in order to make readjustments and estimate the drifts.

The combined effect of these two types of drift is so great that it is necessary to equip the buoys with a radio emitter (an OTPI system), which makes it possible to fix them before passing over them.

If a suspicious presence is detected, the aircraft drops active buoys in the zone in question. These buoys can be omni-directional (thus, they only give range information) or directional (thus, they supply range and bearing information).

The supposed position of the submarine is determined from the information gathered from different buoys. The aircraft flys over the zone in question at a low altitude, describing concentric circles over the calculated position. When the submarine goes outside the circle, the aircraft detects it with its MAD (magnetic anomaly detection) system. This operation serves as confirmation of the previous calculations.

The aircraft is now ready to drop a torpedo. In order to ensure a good setting, it passes over the vertical plane of one of the active buoys used and returns to the buoy radial on which the submarine is supposed to be located. The drop point can be calculated on the basis of the estimated characteristics of the submarine and those of the torpedo; it can also be determined by a MAD contact. The torpedo automatically searches out and tracks the submarine without further assistance from the aircraft.

In certain cases, the search is conducted by the combined action of the patroller and helicopters or submarines. The location of the target is thus ensured by the support components. Once an enemy submarine has been located, the aircraft simply passes to the vertical plane of its support, then returns to the radial which is transmitted to him in order to drop the torpedo.

Attack of Surface Vessels

This consists of detecting a vessel, of identifying it, of fixing its location if it is an enemy vessel and of attacking it.

This mission can only be carried out badly by using the only means now available to reconnaissance aircraft. The only weapon used is the Martel missile, with passive radar guidance, which ensures only the destruction of the radar installation on the enemy ship.

On the other hand, combined operations, as now carried out, can be quite successful. The detection of a target can be made in two different ways, with the patrolling aircraft flying at a high altitude in both cases:

- ESM detection. The aircraft detects the radar transmissions from the enemy ship at such a distance that the waves reflected from the aircraft are too feeble to be detected by the ship.
- direct detection by means of the radar set on board the aircraft.

Detection is followed by an attempt to identify the target in order to evaluate its means of defence. In parallel with this, the position of the vessel relative to the aircraft is calculated using the equipment available in the aircraft. After stopping all transmissions, the aircraft makes a rapid descent down to an altitude of several hundred feet. In then moves towards the target whilst a formation of interceptor aircraft moves towards the locality of the manoeuvre. When the interceptors are close to the target the reconnaissance aircraft determines the position of the ship for the last time, by a brief use of its radar set. It transmits this position to the interceptors who then attack the vessel. The interceptors, approach along headings which are different from that of the reconnaissaince aircraft, to increase the effect of surprise in the case where the vessel might have been able to have detected the presence of the reconnaissance aircraft.

POSSIBLE IMPROVEMENTS BY USING NAVSTAR

Anti-Submarine Role

The use of buoys, whether it may be a question of passive, surveillance buoys or active buoys, to determine the precise position of the submarine involves a certain number of constraints if an attempt is made to conserve a reference grid common to all the elements engaged in the operation (system of buoys, patrol aircraft and, finally, the supporting helicopter or submarine). These constraints could be eliminated by the use of the NAVSTAR system.

A first solution would consist of equipping the reconnaissance aircraft and its support craft with NAVSTAR receivers. This would allow them to overcome the natural drifts in the navigation system and to calculate the drift of the buoys with a greater degree of accuracy. However, it would still be necessary to pass vertically over the buoys at regular time intervals in order to make this correction.

A significant step forward would be obtained by fitting NAVSTAR receivers to the buoys, also, and adding the calculated positions to the messages transmitted by the buoys to the aircraft.

The main advantages arising from this solution are as follows:

- very accurate knowledge of the positions of the buoys at each instant, permitting an accurate calculation of the submarine position no matter what the drift of the buoys might be.
- The possibility of operating in a unique system of geographical coordinates (common reference grid). This is a considerable advantage in the case of combined operations between several means of interceptors (patrol aircraft, helicopters, submarine), particularly as far as accurate target designation is concerned. In this case, it is obviously necessary for all the various elements engaged in the operation to be fitted with NAVSTAR receivers.
- Suppression of the need for navigation up-dating by flying vertically over the buoys. As a result, there is a considerable reduction in the workload on the aircrew (pilot and navigator) and a significant simplification at the level of the tactical navigation system.
- Elimination of CTPI systems in the buoys

The potential interest for such a system in this field would have to be found from a cost/effectiveness study. In particular, this would have to determine whether or not it was possible, or indeed useful, to fit a NAVSTAR receiver to every buoy.

In the case of passive buoys, which can remain in action for several hours, there is, in particular, a question of the quantity of power required. Hiwever, it should be noted that removal of the CTPI system would in some way compensate for the increased power requirement needed by the addition of the NAVSTAR receiver.

This problem seems to be less critical for active buoys whose time of use is shorter.

If, by this addition, their price should become too high, the possibility of recovery of the buoys could be considered. This recovery would become much more easy since the positions of the buoys would be known with a high degree of accuracy.

Finally, in the end phase of the submarine attack, the accuracy with which the active buoys and the torpedo could be launched would become higher and would lead to a considerable improvement in the effectiveness of intervention.

Attack of Surface Vessels

In the case of combined operations, NAVSTAR has two basic advantages:

- a reference grid common to all the elements engaged in the combat.
- perfect synchronisation of actions by using the NAVSTAR time reference.

These two advantages have already been mentioned in the case of close-support missions. It is only a question of their transposition to naval operations and they will require no further development for this additional use.

The introduction of an air-to-air missile truly adapted to this type of mission is also well worth consideration. As far as is known, work on such a missile has not been stopped, completely, at present. Nevertheless, it appears that the position of the ship will be calculated from ESM radar information or from data supplied by buoys. The improvements possible in the use of buoys have been developed in Section 2.1 and will not be repeated here.

There is also the possibility of an improvement in the calculation of the position of a ship by correlating the radar data from two patrolling aircraft. The error in locating a target from radar data is, above all, due to possible errors in elevation and azimuth, with the radial error being very much smaller. The position of a ship can be refined, absolutely, from radial data supplied by two aircraft whose own positions are known accurately by using NAVSTAR. All that is necessary is a "p, p" type of calculation with any ambiguity between the two possible solutions removed by elevation and azimuth data. Such a procedure allows a ship to be followed from a distance and also shows the direction of an attack mission by interceptor aircraft or missiles. Data exchange then assumes a great importance.

APPLICATION TO THE NEW GENERATION ATLANTIC

The advantages states in Section 2 are clearly transposable to the case of the New Generation Atlantic. However, the level of development which this programme will have reached when the NAVSTAR system becomes operational raises the question of any repercussions which a decision to use the NAVSTAR system could have on the existing weapon systems.

The organisation of piloting and navigation sub-systems around in multiplexed numerical link would allow for easy integration of the new equipment. Apart from the installation of the equipment itself, the only major adaptation would be a modification of the logic circuit to take account of and to use the NAVSTAR data.

The presence of NAVSTAR data on the numerical bus-bar makes them available, easily, for all uses, for the intertial navigation system, for the tactical table, for piloting controls, etc.

It appears that what is probably the best solution would be to use the NAVSTAR receiver in place of the OMEGA receiver provided, whose continued existence would then be of but little interest. By this means any logic adaptations will be reduced and will be limited to modification of the error model of the updating algorithm for updating inertia in the existing optimal filter.

The actual work of retrofit installation, as such, would consist of the following operations:

- installation of the NAVSTAR antennae
- fitting the equipment in suitable places
- fitting the control box and display in the navigator's position
- the production of interface circuits with the bus-bar.

Finally, fitting the NAVSTAR receivers to the buoys should pose no great difficulties, except as regards the amount of additional energy needed, which might not be small in the case of passive buoys (see Section 2.1). However, it should be remembered that the presence of a NAVSTAR receiver in a buoy would allow removal of the CTPI system necessary for location of the beacons by the patrolling aircraft.

V STRIKE RPV

TYPICAL MISSION OF A STRIKE RPV

Technological advances on the side of the potential enemy have created a situation in many parts of the world where very high losses of aircraft penetrating into enemy territory are to be expected. Air defence systems which are staggered in depth form an almost impenetrable curtain. This situation has led to the plan to replace manned aircraft by remotely piloted vehicles in certain missions. These RPV systems are expected to be stationed as far as 150 km in front of the enemy lines and their targets will be up to 150 km behind these lines. For the strike RPV considered in this chapter, a high subsonic speed (mach 0.8 to 0.9) and a high-low-low-high flight profile is assumed. The necessity of low level penetration requires some form of terrain following capability. The coordinates of the stationary and transient targets are assumed to be known with sufficient accuracy from prior reconnaissance missions. The RPV will drop its weapons in a low level delivery process.

In normal design, the strike RPV is guided by a precision navigation system to the target coordinates, no additional target acquisition and identification sensors are foreseen. This means that an extremely high accuracy is required for the navigation system. In a more advanced design, self-contained homing systems - eg multispectral sensors recognizing stored target signatures - can be used to extend the spectrum of targets. A still further advanced design could use a closed-loop system with on-board sensors, a data link and a ground pilot, to identify mobile targets. In all cases the required navigation accuracy is very high.

NAVSTAR GPS APPLICATION

It is assumed that the NAVSTAR GPS projected position accuracy of 5 m in each horizontal direction and 7 m vertically and the projected velocity accuracy of 3 cm/s in all three axes will be achieved with a statistical confidence of 50 percent. It can be expected, that the advent of such a precise navigation system will initiate a gradual process of replacement of conventional radio navigation systems by NAVSTAR GPS. The first step in this process will certainly be the addition of a GPS receiver to existing avionics systems. This will increase the efficiency of such systems, but an immediate cost reduction cannot be expected in this phase. The second step will be the simplified design of new avionics systems with reduced equipment. NAVSTAR GPS at this time will have been demonstrated as a cost effective alternative to conventional radio navigation aids, perhaps including the microwave landing systems for category one standard of performance.

The high navigation accuracy required for a successful strike RPV mission as described above can be obtained by use of NAVSTAR GPS. The avionics system of the RPV may be assumed to consist of a GPS receiver, a strapdown Inertial Navigation System (INS), a radar altimeter, air data sensors, a digital computer and the flight control system. The INS is updated using the NAVSTAR GPS velocity and position information and a Kalman Filter. In this way, the RPV position, velocity, attitude and heading are obtained with extremely high precision.

Updating the strap-down INS with the very precise velocity and position data of NAVSTAR GPS offers the possibility to use gyros and accelerometers of lower performance than in a pure inertial navigation mode. The inertial couplings of attitude, heading, velocity and position information in the INS renders it possible to estimate all these data with high accuracy, if a Kalman Filter is used to aid the INS with the GPS data. The high accuracy is derived from the accurate GPS data, and the INS is merely used to smooth these data. It can be expected that sensors of less than inertial quality will be sufficient for this smoothing process. This would lead to a significant cost reduction of the inertial system.

The low level penetration flight profile of the strike RPV requires some form of terrain following capability. The combination of NAVSTAR GPS with the stored terrain profile can possibly be used for terrain following. The precise knowledge of the actual position, of the intended mission and of the stored terrain profile renders it possible to derive the required guidance signals for terrain following. This solution of the terrain following problem, which hardly would be acceptable for manned aircraft, may prove to be practicable for unmanned vehicles, like the strike RPV considered here.

In Appendix 4 the problem is studied to what degree the specifications of the gyros and accelerometers of the strap-down INS can be reduced in the case of updating with NAVSTAR GPS.

SUMMARY

The application of NAVSTAR GPS in a strike RPV offers a very interesting potential. But it has to be stated that experimental programs must be carried out for feasibility demonstration. For a definite judgement of these possibilities, detailed experimental information is required particularly about the NAVSTAR GPS signal quality, its noise content and the dynamics of the errors; especially in a highly dynamic environment. If the design goals of NAVSTAR GPS can be reached in the operational system for strike RPV applications, the following benefits can be expected:

- The high navigation accuracy for a successful mission can be achieved.
- It appears possible that much simpler gyros and accelerometers can be used in the strap-down INS. This will reduce the high cost of the inertial equipment.
- Terrain following capability can be obtained by combining the precise position information of NAVSTAR GPS with the terrain profile stored in the computer.

5. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1 The conclusions of this report are based on technical performance information available at the time of writing. The quality of the results depend on the quality of the raw signal characteristics, both static and dynamic and very little practical information was in fact available.

2 The NAVSTAR Global Positioning System (GPS) will significantly reduce the proliferation of Ground Based Navigation Systems.

3 NAVSTAR/GPS will enhance the targeting accuracy of air launched weapons in air-to-air and air-to-ground operations and will be used in a complementary way to maximise the use of cheaper Inertial Navigation Systems, narrower field of view Electro Optic Sensors in the Aircraft and reduce the jamming susceptibility of the attack radar system by reducing the time of active radiation. Similarly, passive terrain following systems become more feasible combining the precise position fixing capability if NAVSTAR with stored terrain profile information.

4 The overall effectiveness of NATO weapon systems will be significantly improved through the utilisation of a common reference grid for all military operations.

5 NAVSTAR/GPS will provide a significant improvement in the Navigation/Positioning accuracy of NATO weapon systems over that which is currently available.

RECOMMENDATIONS

1 The Working Group supports the NATO GPS Project Steering Committee in recommending studies to address more fully the question of system vulnerability and monitoring systems.

2 Since detailed measurements of practical total system performance and the quality of raw signal characteristics, particularly during dynamic maneouvres of the receiving aircraft, are only just becoming available, more in-depth studies must be undertaken to evaluate the performance of various integrated systems employing NAVSTAR/GPS using results of experimental measurements of actual NAVSTAR accuracy (in particular dynamic errors).

3 In-depth analysis should be done to identify the retrofit impact including cost incurred to incorporate the NAVSTAR/GPS into the specific candidate systems.

4 Each participating NATO country should determine the total number of user equipments required for the full spectrum of NATO operations to better assess economies of scale and interoperability benefits from coordinating the procurement policies.

5 The maintenance concept should be established, including the levels at which maintenance is accomplished. For example, to line replaceable units (LRUs), modules or piece parts.

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REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-AR-147 Volume I	ISBN 92-835-1339-8	UNCLASSIFIED

5. Originator Advisory Group for Aerospace Research and Development
North Atlantic Treaty Organization
7 rue Ancelle, 92200 Neuilly sur Seine, France

6. Title REPORT OF THE GUIDANCE AND CONTROL PANEL WORKING GROUP 04 on THE IMPACT OF GLOBAL POSITIONING SYSTEM ON GUIDANCE AND CONTROLS SYSTEMS DESIGN OF MILITARY AIRCRAFT

7. Presented at

8. Editor(s)	9. Date
Mr G.C.Howell	September 1979

10. Editor's Address	11. Pages
Chief Superintendent, Royal Aircraft Establishment Clapham, Bedford MK41 6AE, UK	46 pages

12. Distribution Statement This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications.

13. Keywords/Descriptors

NAVSTAR/GPS	Close air support operation
Counter air operation	Sea patrol
Air interdiction	Strike RPV

15. Abstract

Working Group 04 was proposed by the Guidance and Control Panel as a follow-up to the Aerospace Applications Studies Committee No.6 "Use of precision positioning systems by NATO" (AR No.88).

The objectives of the working group were to consider the integration of GPS in aircraft systems and make recommendations for implementation. Considering the large number of possible applications, the work was confined to a particular range of military aircraft.

The report consists of two volumes:

Volume I includes NAVSTAR/GPS description, examination of technical aspects of the system, applications to Counter Air Operations, Air Interdiction, Close Air Support Operations, Sea Patrol and Strike RPV, and recommendations.

In volume II (Classified NATO-CONFIDENTIAL) which will be published later, are presented the results of four specific studies of the application of NAVSTAR to Close Air Support, Sea Patrol, Interdiction Strike, and Strike RPV.

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