621B SATELLITE SYSTEM (U)

by Lieutenant Colonel J. A. Fiebelkorn*

(U) Synchronization of effort is the cornerstone of military tactics. It is this fact which influences the evaluation of System 621B as a time transfer device. System 621B is an illustrative example of the application of space technology to a surface problem. It is not a time transfer system. It is the Air Force activity to describe and promote development of a capability for defining the four-dimensional motion of a user. Four dimensions are emphasized in this case because the concern is not only with the user's position but with the time when he is there. While extensive effort has been put into briefing those who are concerned with their location, the system may be a little bit new to people who are concerned with time alone. Included in the pitch will be a description of what the system is capable of doing, so that you can evaluate it.

(U) Systems studies began in 1964 with the evaluation of concept capabilities. As time went on, technical evaluation and assessment have established that the space environment could contribute and could eliminate some of the operational deficiencies existing in position location systems. In 1967, a mission analysis supported the conclusion of our initial studies and a concept formulation study was initiated. This study addressed the performance, the cost of the equipment, and the schedule of the system for real time position fixing based on space-based aids. One of the products of that study was the realization that real time meant a degree of

---

*Project Officer, Policy and Plans Group, U. S. Air Force Headquarters, Washington, D. C., (202) OX-5-4062.

synchronization of which we had not previously heard. This extension of past practice occurred because the accuracies necessary for the position determination required that the transmission from multiple satellites be known precisely and simultaneously from all of these satellites.

(U) Two methods were immediately available to us. One method was to maintain a time standard on board each user, in which the time standards could be synchronized prior to the mission start. The other method was to continuously resynchronize all users during their operation. This resynchronizing approach held a lot of merit in terms of user cost, especially in light of the cost of atomic standards--portable precise time standards--existing at the time. It seemed preferable, if feasible, so the problem was addressed on the basis of continuous resynchronization. It was found that the problem was no more difficult from synchronized satellites than was the task of synchronizing the satellites themselves. Synchronizing satellites could be avoided if you used them as straight relays, as communication transponders; but that required the use of very large-scale computers in a master station or a control station on the ground, plus continuous tracking of all satellites. That complexity created operational problems.

(U) The weakness in the continuous resynchronization method is that an additional satellite is needed. You have four pieces of information which are unknowns, rather than three--the three dimensions of position. If you look at economic analyses, you see that when the user base gets large, the cost of those users and the time standards for them so far outweigh the cost of the additional satellite that it is, in fact, an economic trade to have continuous resynchronization. Even with the additional complexity, the evaluation found that the computation of the four dimensional state vector was within the current state-of-the-art at the time. This capability can be discussed in several different parts.

Within the space segment, there are at least four different constellations which have been evaluated and which give this kind of capability. They vary in altitude, number, orbital inclination, and many other factors.

(C) One such constellation is shown in Figure 1. Four satellites in 24-hour-period-orbits are launched so that they continuously dwell over one section of the world. This is done by using inclined eccentric orbits, phasing the satellites around their orbits and placing the ascending nodes of each of these orbits so that the ground track of all of the satellites exists in the same circle. What this amounts to is that each of these satellites has an ascending node 120 degrees different from the others. For this particular deployment, the middle satellite is geo-stationary or nearly geo-stationary. The eccentricity and the inclination angle involved are as shown.

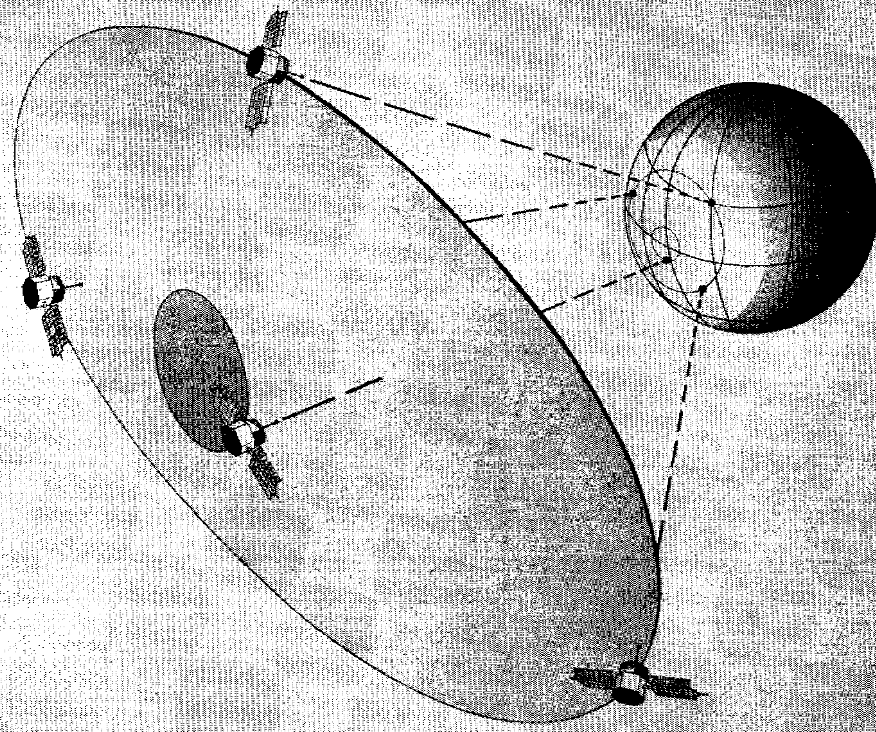
(C) This particular constellation will give coverage to a circle covering about a quarter of the earth. The satellites transmit to the users information from which the satellite position can be derived at any point in time. This has to be done down to a nanosecond or a few nanosecond intervals in order to obtain the accuracies involved. They also transmit the bias of their onboard time standard to the user. This bias is derived in the master station on the ground which handles this constellation. The problem of position location in the total operation of the system includes a position determination of satellites from the ground and then a position location of the user from the satellites. In addition to the master station which handles these four satellites, two or more calibration stations are established at geodetically known points. The overall task of the calibration stations is to transmit to the master station its position errors. The master station takes that error data and corrects the satellite data to make

CONFIDENTIAL

SYSTEM TECHNIQUE (U)

ORBITAL DEPLOYMENT

		REGIONAL SYSTEM "Y"	GLOBAL SYSTEM "X"
NUMBER OF CONSTELLATIONS		1	3
TOTAL NUMBER OF SATELLITES		4	15
INNER SAT	i(DEG)	5	
	ϵ	0.04	
OUTER SAT	i(DEG)	28.5	
	ϵ	0.27	



CONFIDENTIAL

AEROSPACE CORPORATION

the position determination correct to the geodetic spheroid. Any user, whether stationary or in motion, can solve equations of his 4-D state vector and determine his position with respect to his area geodetic ellipsoid, the reference in the particular area, and the error between his time standard (that is, the user's standard) and the one in the master station. The continuous nature of the transmission permits the error to be defined on demand, when the user wants it. Short-term stability of some of our electronic oscillators make it possible to consider one part in 10^{14} time accuracy within the user. The system does not work exclusively as a time standard however; therefore, the claims are made only for a system that bounds the time error.

(U) For non-moving users who are exclusively concerned with precise time, the 10^{14} value would have to be considered as a theoretical upper bound. We have no intention of making something to transfer 10^{14} at this time. Preliminary design has been performed on equipment necessary to use such a system. This equipment is for derivation of the four-dimensional vector and it has decidely more performance than an operational time synchronization would demand. Its existence does imply, however, that any equipped military unit on land, on the sea, or in the air could establish the time standard in an area.

(U) Aircraft equipment is configured for high-performance tactical types and general purpose operation. The size of equipment is approximately as shown in Figure 2. (This is validated by two different contractors.)

(U) Sea and land vehicles (see Figure 3) would have similar complexity.

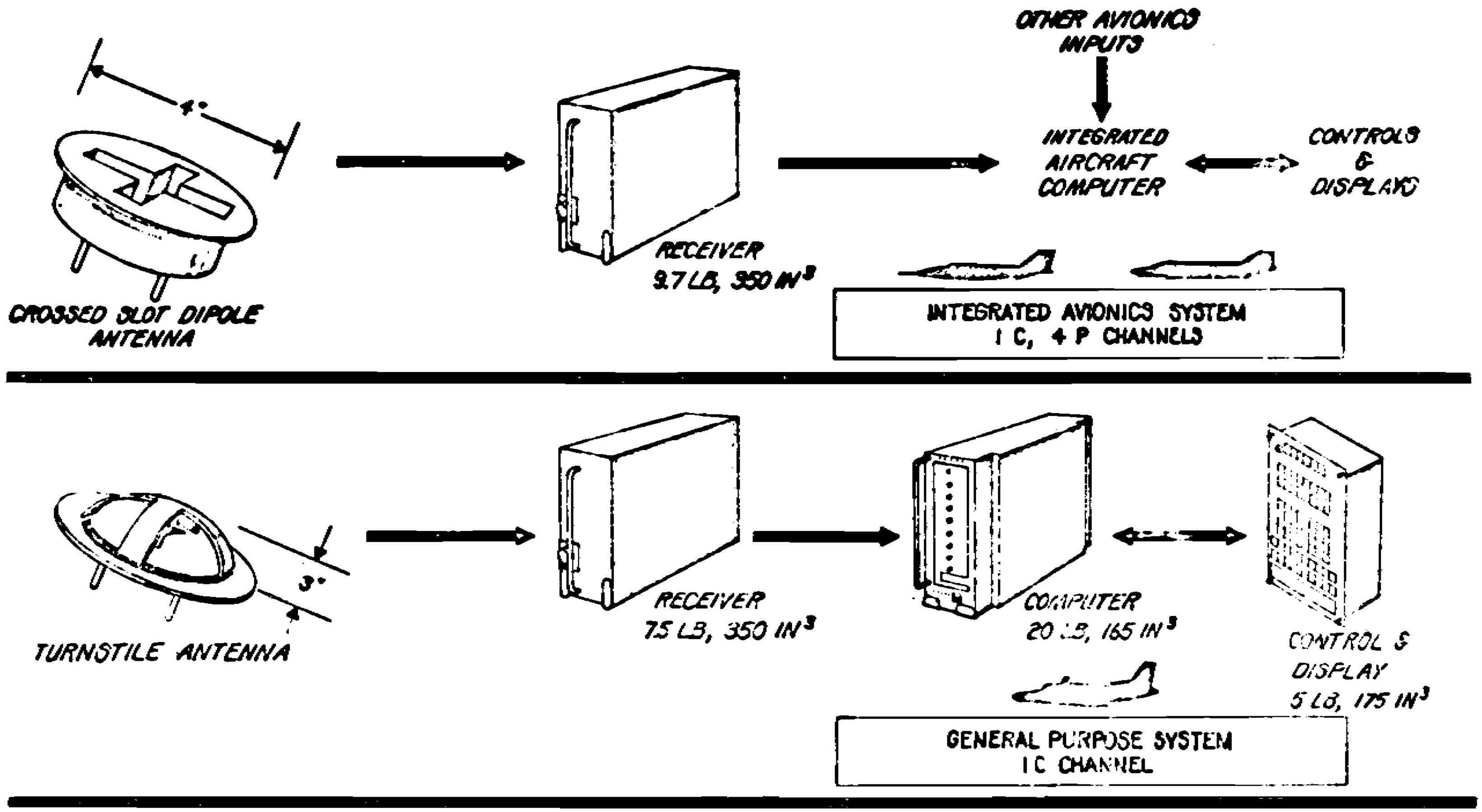
(U) The man pack (see Figure 4), the unit down in the lower left, would equip a force on foot. Each of these equipments, with the

7383/16

CONFIDENTIAL

SOME USER EQUIPMENT ARRANGEMENTS (U)

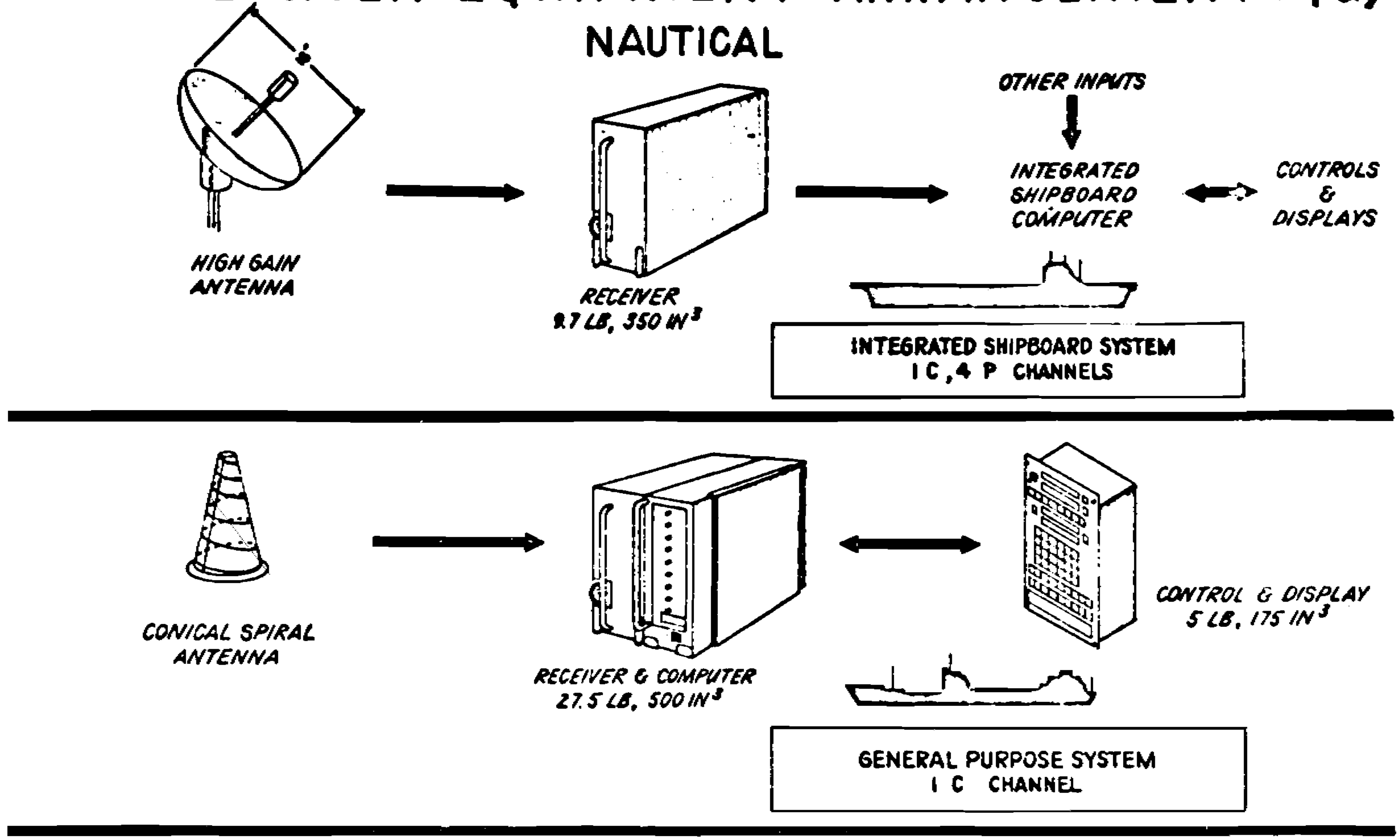
AERONAUTICAL



CONFIDENTIAL

13R205

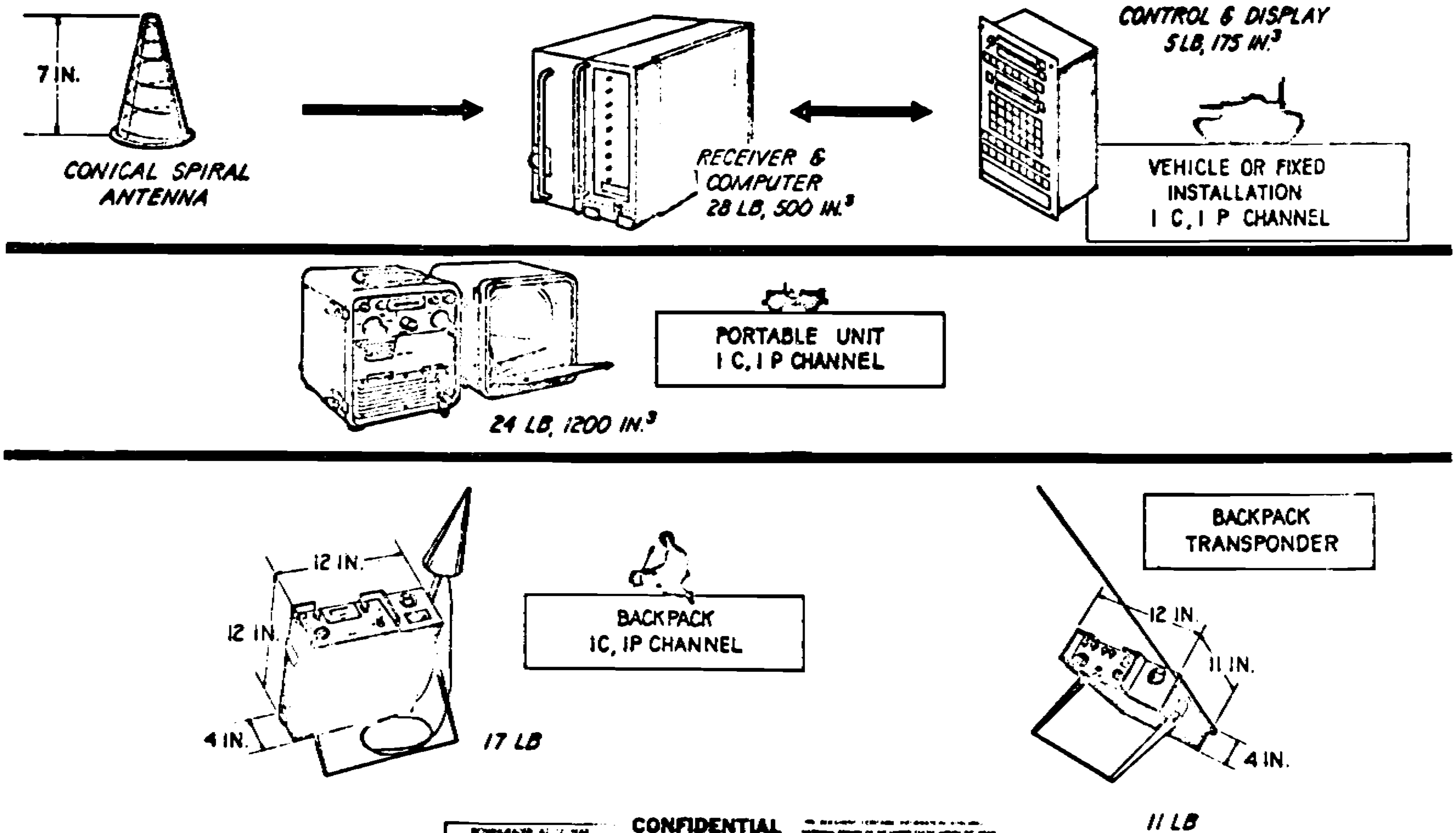
SOME USER EQUIPMENT ARRANGEMENTS (U)



CONFIDENTIAL

SOME USER EQUIPMENT ARRANGEMENTS (U)

GROUND

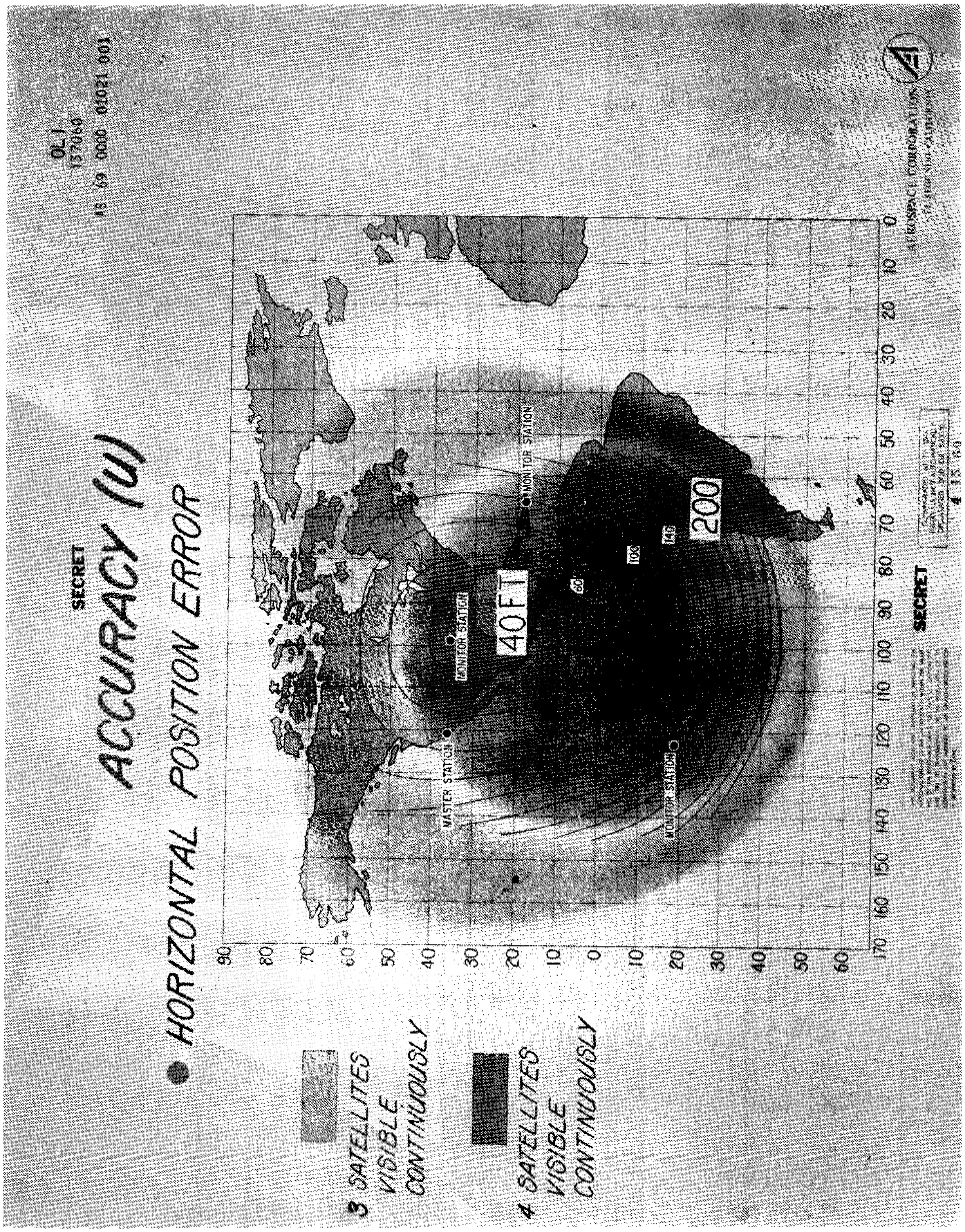


CONFIDENTIAL

exception of the transponder on the lower right, could solve for time corrections to its crystal oscillator. While current preliminary designs do not display time, the mechanization is relatively simple. In fact, the time correction is used within the equipment, and is then simply converted to a time display, if needed. Ground station and intercon-stellation coordination would require a fixed user type station in a position where at least two satellites from each constellation were visible at the same time. In this configuration, the time for the master station could be resolved using each of the two master stations involved and the differences established. Defining one as the master would permit global synchronization to that station's time.

(U) If a further calibration is taken as an international reference, total synchronization would be permitted to that international standard. The accuracy available from the system and coverage of four satellites from a single constellation are shown in Figure 5. The curves and closed areas are the worst case error. Twenty-four-hour-a-day, single fix position determination capability from one four-satellite constella-tion is available. Three-D coverage is defined by the inner circle. A two-dimensional capability, presuming time is always derived, is in the outer area.

(C) The relationship between position error and time synchronization error for the same conditions as described is shown in Figure 6. In this particular case, a specific monitor station existed at this point. All of these errors are with respect to that monitor. An additional monitor within the coverage here would have a similar pattern around it. So, what is shown is the time synchronization capability for some area on the East Coast. To receive on demand, 24-hour-a-day capa-bility, turn the equipment on. The approximate 2 nsec per foot horizontal CEP (Circular Error Probability) compared to the previous


SECRET
ACCURACY (U)
HORIZONTAL POSITION ERROR
3 SATELLITES VISIBLE CONTINUOUSLY
4 SATELLITES VISIBLE CONTINUOUSLY
MASTER STATION
MONITOR STATION
MONITOR STATION
MONITOR STATION
40 FT
60
100
140
200
AEROSPACE CORPORATION
SECRET

(S)(Gp-3) 1σ TIME SYNCHRONIZATION ERROR (WORST CASE WITH RESPECT TO TIME)

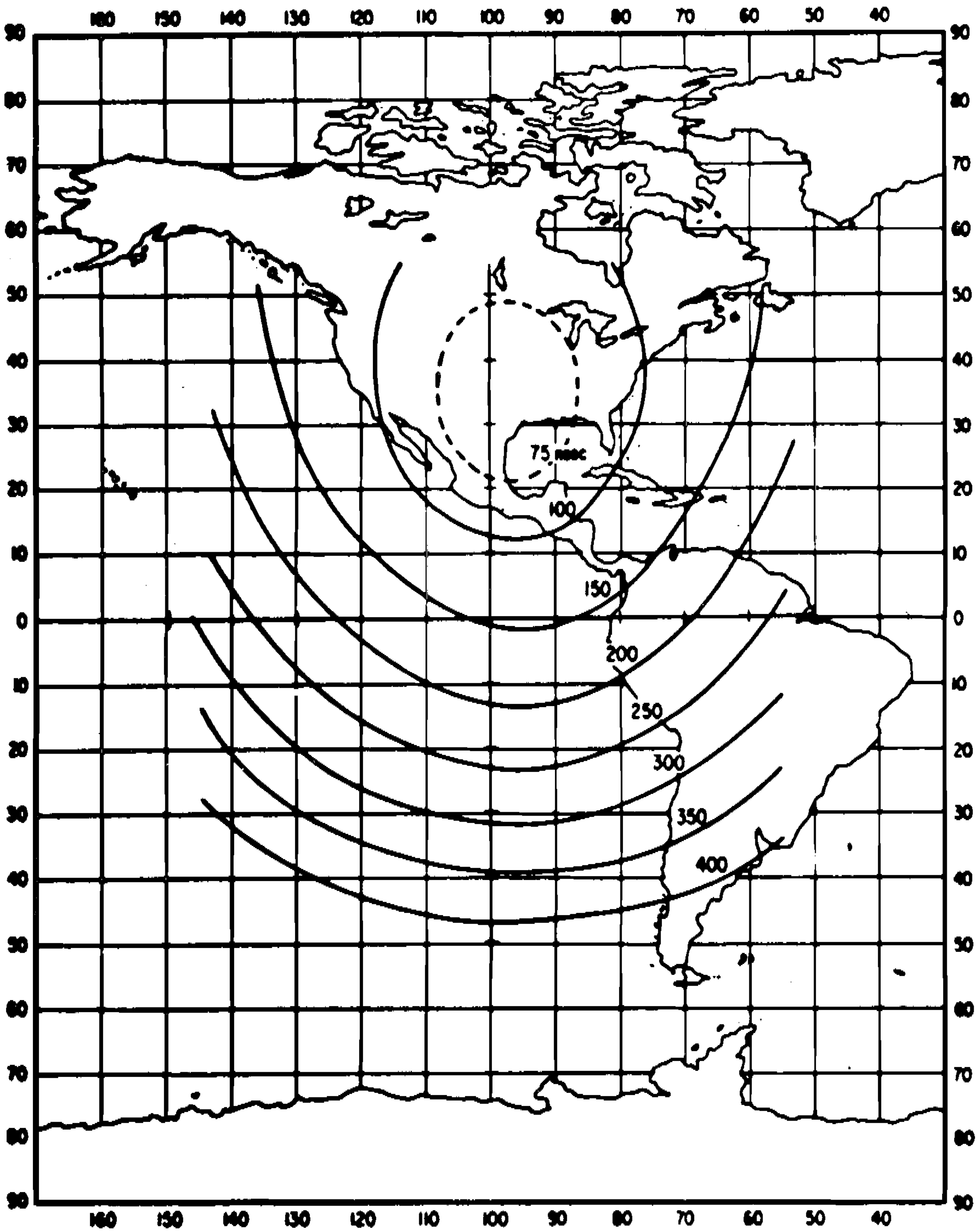
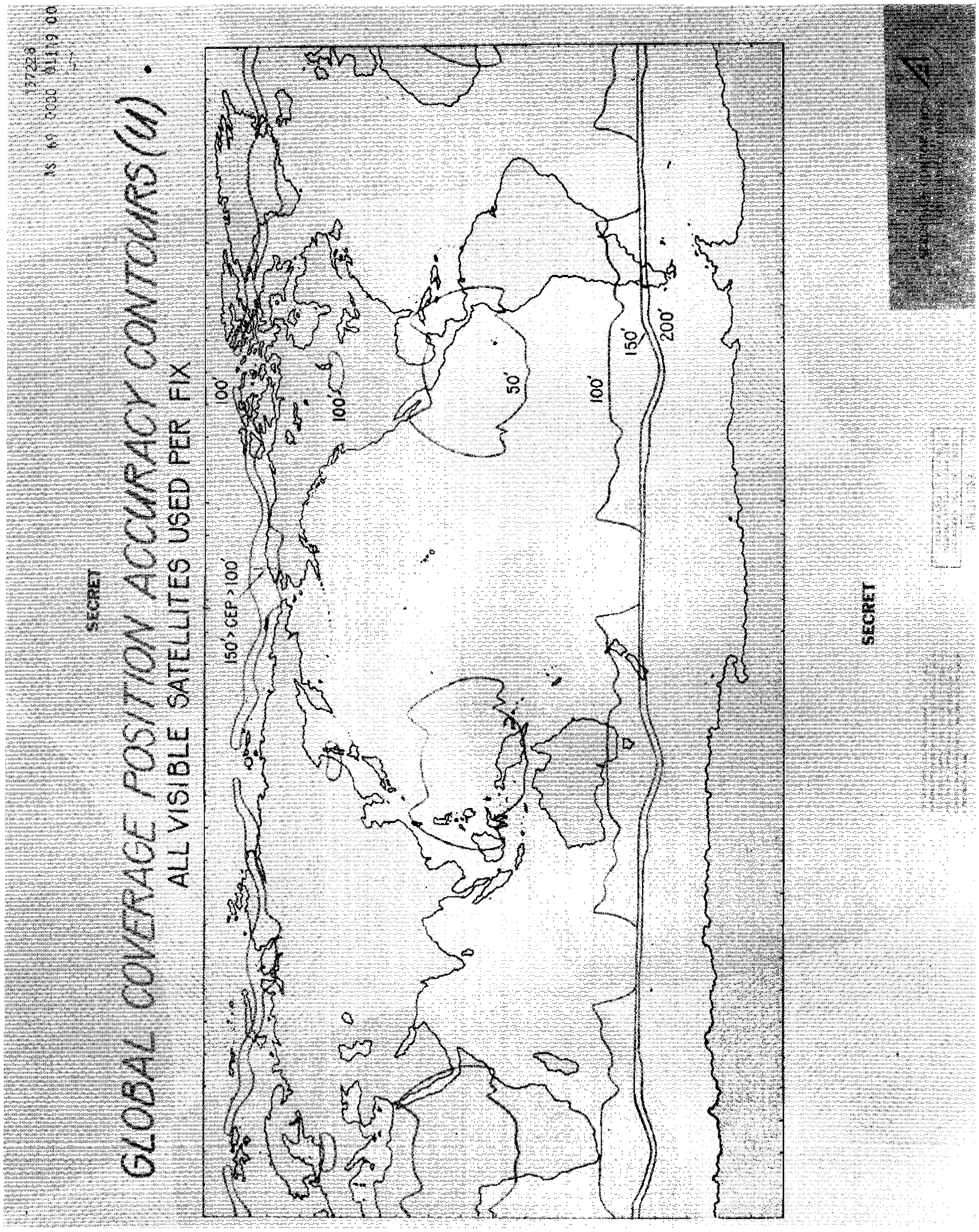


chart holds for fairly large areas. There is no time chart included for global scope.

(C) There is, however, a global position chart (see Figure 7) which can be used for reference with the same correction. These are the kinds of horizontal position errors, correctable by about 2 nsecs per foot of horizontal error, that give the time synchronization capability which a global system of this nature can allow. In this case, though, three five-satellite constellations are used, which together, give coverage from about 50 degrees south latitude to the North Pole. For time synchronization or intermittent fixes where you are dealing with less than four satellites in view, this area around the Antarctic is not a blank. For varying times, four satellites are in view, but 24-hour-a-day coverage is not available. This coverage is for a single fix, requiring approximately 1 sec of data. It is extremely doubtful that any area of the world would not have two or more satellites always visible. Reference works dealing with the subject say that you can probably have three satellites visible continuously over the south polar regions, but that coverage is not available 24-hours-a-day; therefore, it is shown as a blank in this particular figure. For stationary users two satellites are sufficient to resolve the one remaining variable-time.

(C) To summarize the time transfer performance, it can be said that System 621B gives a method of having at least two satellites in view, worldwide, at all times. For over 80 percent of the world, four are continuously available. Its capacity could be used for time transfer on demand to any spot on the earth for any prescribed reference--be it Greenwich, the Naval Observatory, or wherever--simply by turning a switch and reading a dial. Accuracy of better than 100 nsecs appears legitimate if several seconds of data are used. Computation would


GLOBAL COVERAGE POSITION ACCURACY CONTOURS (U)
ALL VISIBLE SATELLITES USED PER FIX
SECRET
150' > CEP > 100'
100'
100'
50'
100'
150'
200'
SECRET

require a few milliseconds.

(S) With regard to the requirements that this system would place on time transfer facilities, the necessity for on-demand performance makes the act of separate time transfer too long for use. In other words, the system cannot wait for any administrative or operational group to perform a separate supporting function. Its very mode of operation makes it faster than the management structure of time transfer. This does not imply that the system must be isolated from a source of national or international standards; it simply means that time transfer implies motion and no motion exceeds the speed of the RF waves. Do not immediately scrap your current equipment or organization, even though this equipment exists within the current technology. The question of program approval and funding still has to be answered. To give this capability, a program could be available by 1976 for a single constellation, and by about 1979 or 1980 for worldwide capability. It would cost about $50 million . That schedule presumes that funding is available for the launch vehicles and the design of satellites in the next fiscal year. The studies also show that while an order of magnitude improvement of time synchronization is available, the total cost savings for time transfer would be small; at best insufficient to pay for the development and launch of a single satellite. In conclusion, a marked improvement in time transfer stands ready as soon as the capability for precise positioning can be implemented.