GPS . . . Wave Of The Future

Continued development of GPS is making its "Buck Rogers" capabilities available at down-to-earth prices

By PETER LERT

"JUST WHEN YOU THOUGHT IT WAS SAFE TO GO BACK IN THE AVIONICS SHOP . . ."

We live in an age of rapid technological advance, but what's really striking is that the rate of advance seems to be constantly speeding up. Ten years ago, LORAN was limited to a very few of the largest or most specialized aircraft; now, it's become a fully mature system, and is the navaid of choice for many pilots. Five years ago, satellite navigation was barely on the horizon for the most expensively-equipped airliners or corporate jets; now it's suddenly starting to appear in a size and price range that brings it within reach of the smallest single-engine aircraft. In my survey on LORANs in the July 1991 issue of SPORT AVIATION, I mentioned that GPS was coming, but that it was still expensive, and would probably remain on the wrong side of $1000 for another 5 years or so. At the moment, GPS units are the hottest item in Trade-A-Plane, and by the time you read this under-$1000 receivers will be readily available. May I have a second helping of crow, please? . . .

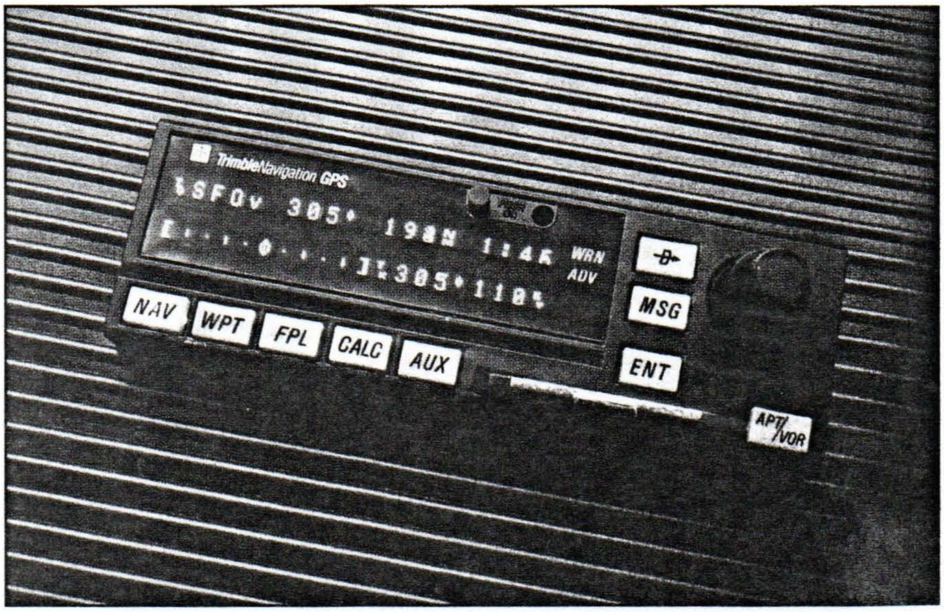
LOOK DOWN, LOOK UP . . .

It seems paradoxical, yet we flyers have almost always navigated by looking down - whether by pilotage, looking down at towns, lakes, rivers, roads and so forth, or more recently by radio, using ADFs, VORs, DMEs, and even LORAN to electronically "look down" at appropriate ground-based transmitters. Only in the earlier days of long-range overwater flying did we depend on celestial navigation - a technique so arduous and arcane that it required a separate highly trained crewmember to carry it out.

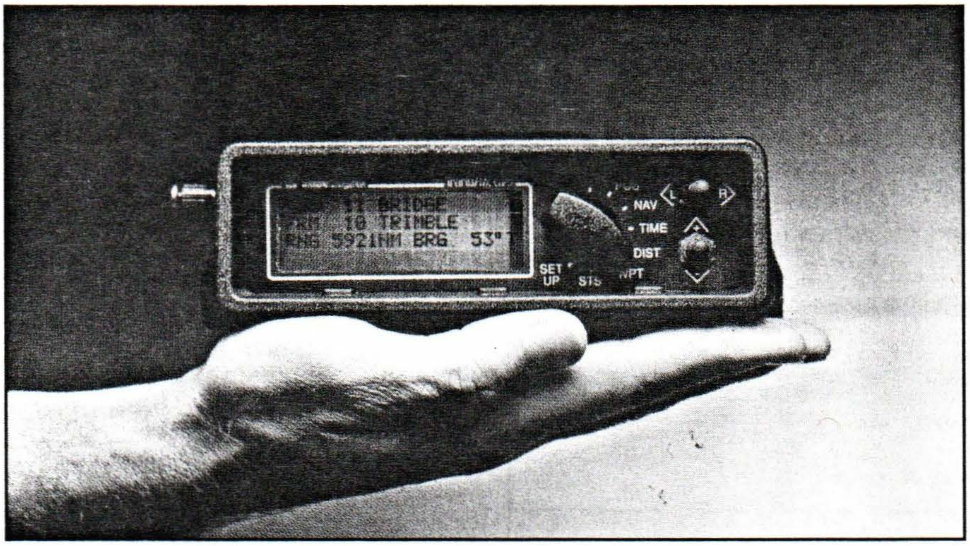
On the other hand, sailors and earthbound travelers crossing regions devoid of recognizable landmarks have "looked up" for centuries. Long before the development of "scientific" celestial navigation, with its sextants, chronometers, and mathematical tables, so-called "primitive" cultures used the sun, moon, stars, and planets for navigation, often with extremely accurate results. Early Polynesians, for example, made routine trading voyages between tiny islands separated by thousands of miles of open ocean, while the desert nomads of northern Africa moved on foot between similarly tiny oases separated by hundreds of miles of trackless, shifting sands. Examine the history of any culture living in a region without large, easily recognized landmarks - whether it's Polynesians, Touaregs, or North American Plains Indians - and you'll find a sophisticated system of astronomy and navigation.

Now, it's starting to appear that things are coming full circle: the latest generation of navigational equipment, whether for aircraft, boats, vehicles, or even pedestrians, once again "looks up to the stars." This time, though, the stars are ones we've put up there ourselves: the satellites of the Global Positioning System, or GPS.

Actually, GPS isn't the first "Satnav" system. As long as 20 years ago, the U. S. Navy defined a requirement for a navigation system that could provide accuracy comparable to that of celestial navigation (say, within a nautical mile or two for a proficient navigator taking his sextant "shots" from a big, stable platform like a battleship), but without celestial navigation's requirements for good weather (ya gotta see the stars to use them!) or a highly-trained navigator. The result was the series of "Transit" satellites. Some are still operational today, and many recreational as well as professional sailors use them; in fact, as a ferry pilot, I've used the system myself. It has disadvantages, though: since it's based on satellites in low orbit (the best we could do in the early 1960s), it'll only provide an exact fix every 45 minutes to a couple of hours. That's fine for a ship - or even for, say, a Beech Baron try-



Trimble Navigation's TNL 2000/3000



Trimble Navigation's Transpack . . .

ing to find its way from Oakland to Honolulu - but not very useful for day-to-day flying. Similarly, it's only accurate to a mile or so. That was still more than adequate for the 1960s military mission; when you're tossing multimegaton warheads, you don't quibble about a few hundred or even thousand feet one way or the other.

By now, though, requirements have changed, particularly military ones. Why are military requirements important to us humble EAAers? Because GPS, while available to both military and civilian users, was originally developed by the Department of Defense for its military "clients" - and their requirements were for a reliable (and essentially "unjammable") system that could locate a tank, an artillery piece, or even a lowly footslogger to within a few meters, or guide a cruise missile right to Saddam's mustache. Much of the "pinpoint accuracy" of Allied weapons during the Gulf War was based in whole or in part on GPS.

IS IT REALLY BETTER?

The advantages of GPS over other systems, even including LORAN, are considerable - so much so, in fact, that LORAN manufacturers have realized that the only way to deal with the GPS "threat" is to enter that market as well. I suspect that future years may show some erosion of the LORAN market per se, but not all that much attrition among the manufacturers; they'll just change their product lines.

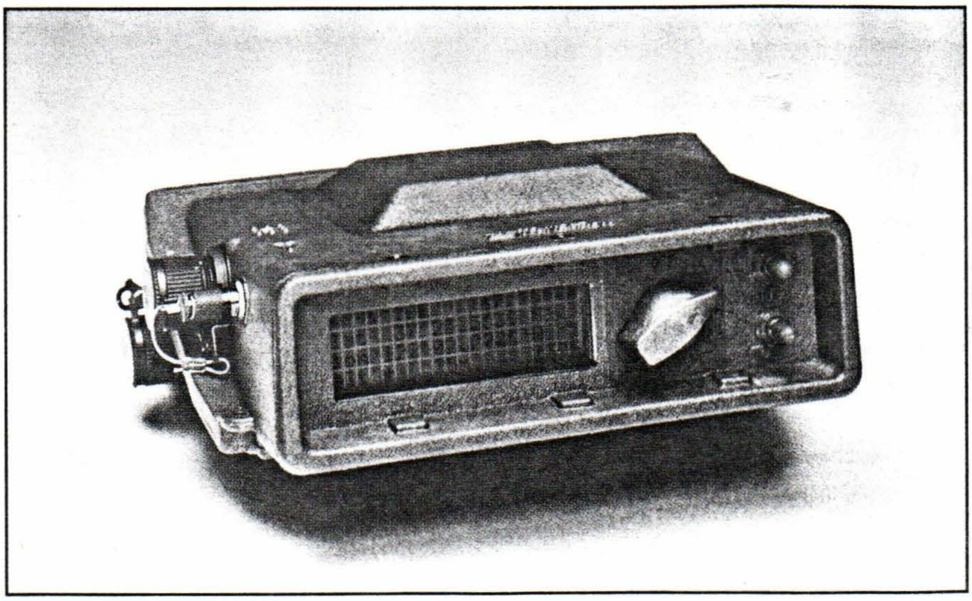
One of the most obvious of GPS's advantages, of course, is its worldwide coverage, rather than LORAN's limitation to within about 1000 nm of each transmitter chain. On a recent ferry flight delivering Ed Swearingen's 2-place turboprop SA-32T to South Africa, I used a GARMIN GPS-100 AVD as my primary navaid. The little portable unit, simply stuck to the glareshield and using its own finger-size built-in antenna, never missed a beat all the way, giving me positions accurate to about 50 feet even over the most desolate wastes of southern Ethiopia, hundreds of miles from the nearest navaid.

At the moment, the full "constellation" of 21 operational and 3 spare satellites isn't in orbit yet, so there can be occasional gaps in coverage. Unlike the late and unlamented U.S. Mid-continent LORAN gap, however, these gaps exist in time, not in space - just wait a bit, and another satellite will rise over your local horizon. On the Africa trip, the worst I ever saw was a couple of half-hour periods in which only three satellites were available, requiring manual input of altitude for a position fix; most of the time, the unit saw at least four "birds" and switched automatically to full 3D navigation. When the constellation is complete, any user should have at least five satellites at least 10 degrees above the horizon at all times.

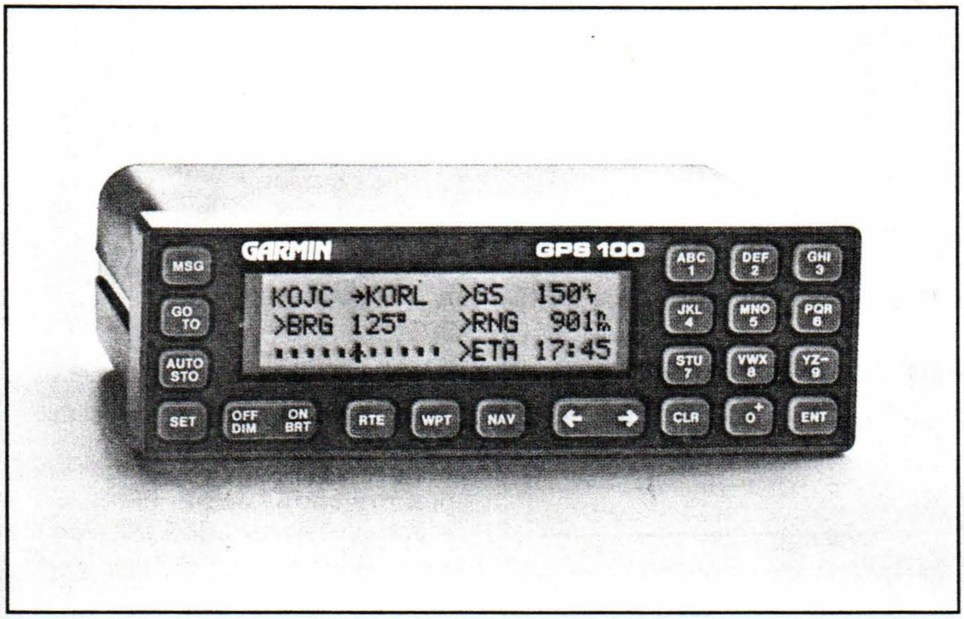
Accuracy and fast response is another very significant advantage. Most aviation LORAN displays resolve 1/10th of a nautical mile - a bit over 600 feet - but may not necessarily be accurate closer than half a mile or more, particularly in fringe areas. Their accuracy can also be compromised by degraded signals, electrical noise, or station geometry - while in certain conditions (for example, dry snow) and depending on aircraft installation, they can lose the signal altogether. Moreover, some older units can "lock on" to an incorrect pulse of the transmitted signal, introducing errors of several miles, sometimes without warning the pilot. Non-precision instrument approaches based on LORAN are just beginning to be explored, and require specially-certificated LORAN units and procedures.

GPS, on the other hand, is inherently an order of magnitude more accurate - and due to the nature of its signals, is pretty much impervious to noise or interference. There are no "cycle skips" or "false lock-ons"; the unit either works accurately, or not at all. On the Africa trip, the only glitch I saw in the GARMIN GPS was when the airplane took a lightning strike over the Adriatic Sea and the unit blanked out altogether (as did most of the other avionics as well!); turning it off and back on cleared it, and it reacquired the signals "on the fly" within about half a minute.

Typical GPS accuracy - in three dimensions - is about 50 feet for most



. . . and Trimpack



Garmin Communication and Navigation's GPS 100

civil units. If the DoD ever proceeds with their threatened intentional degradation of the civilian signal, this could drop to as bad as 300 feet, although several GPS manufacturers already claim to have found ways around this. With such fine resolution of position comes very rapid response to position changes, again about an order of magnitude faster than most LORANs. For example, one of my favorite tricks when showing off the GARMIN system to other pilots along the way was to take it off the glareshield and walk around the ramp with it. After no more than about 10 paces it would display track and groundspeed - say, 1.7 knots! - while responding almost instantly to changes in direction. Set to read in metric units, the unit could guide me back to within less than 10m of my tiedown spot. The future looks bright for non-precision approaches almost anywhere based on GPS, and a technique known as "differential GPS" may someday allow GPS to provide precision three-dimensional approach guidance as well.

RECENT LOW-COST GPS SYSTEMS

Trimble Navigation

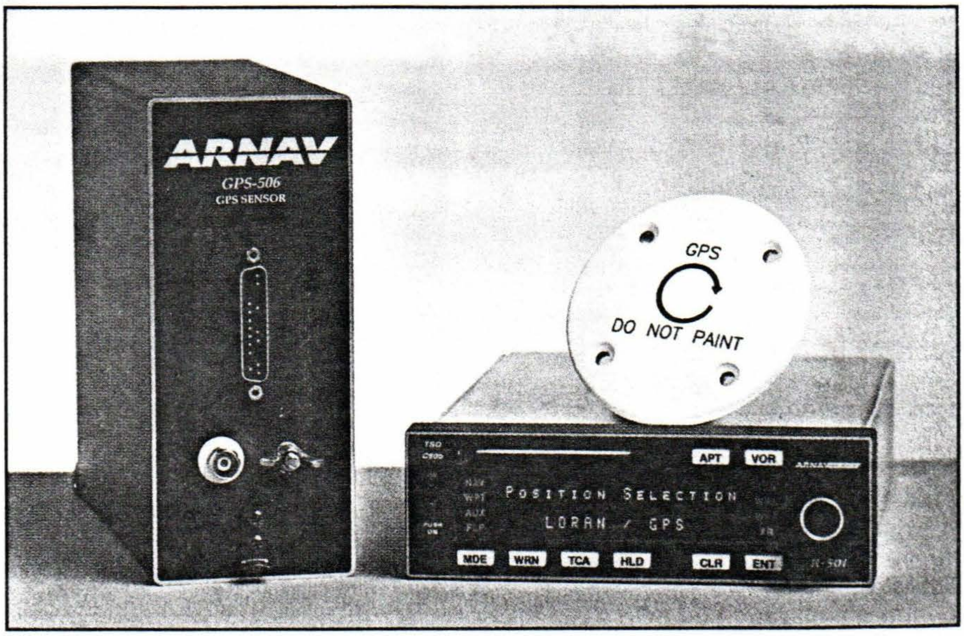
GPS for lightplanes was pioneered a couple of years ago by Trimble Navigation, a California firm hitherto known for its excellent (and pricey) marine LORANs and other nav equipment. Trimble's first lightplane unit was actually not intended specifically for aircraft, but rather as a multirole basic GPS; the "Trimpack" incorporated a two-channel receiver, batteries, built-in low profile antenna, and display in a very rugged and weatherproof portable unit about the size and shape of a binocular case. Up to 100 - later 1000 - waypoints could be stored. A more recent version, the "Transpack", has the same physical characteristics, an even more advanced receiver, and at around $1700 costs less since it's not built to military specifications.

I first used a Trimpack flying back across the North Atlantic after the 1989 Paris Air Show, and was instantly impressed by its basic position accuracy and navigation performance. At the same time, since fewer satellites were in orbit back then, I had to deal with service outages of up to several hours at a time. Moreover, as one already spoiled by database LORANs, I found the need to slew the coordinates for each waypoint into the unit somewhat tiresome. While the "patch" antenna built into the unit's case functioned fine in the bubble-canopy SA-32, I've found during flights in more conventional airplanes that an external antenna (for $800!) is necessary to ensure continuous coverage, since the unit needs an unobstructed view of the sky. (This will become less critical as more satellites come online, but will always remain a factor.) Even so, the Trimpack and Transpack were in a position to grab a good initial market share, and became a mainstay among us ferry pilots.

More recently, Trimble has entered the dedicated aviation market with a very elegant and feature-rich product, the TNL-2000 and -3000 series. These are complete nav management systems, occupying 2 inches of standard radio stack space and incorporating either U. S. or worldwide Jeppesen database coverage via the now-familiar user-replaceable "credit card size" data cartridge. Capabilities include the usual navigation outputs, flight planning, minimum safe altitude within 30 miles, emergency airport search, and all the other bells and whistles we've come to expect from top-line LORANs; the only difference between the -2000 and -3000 is that the former is strictly a GPS system, while the latter also incorporates a multichain LORAN. For those planning to fly in the clag, IFR certification is contemplated for both units; the -2000 goes for about $6600, the -3000 for about $1000 more.

Magellan Systems

If Trimble was the first to go after the portable GPS market overall, Magellan Systems was the first to aim specifically at the low-price



Arnav Systems' GPS - 506

recreational end. The various models of the Magellan Navigator are all the same physical size and shape - like a rather plump handheld radio - and include a stubby quadrifilar antenna on a swivel mount. Aimed primarily at the boating market, the Magellan is not only waterproof, but even floats; their later 1000+ models have improved software to track at high aircraft speeds and offer outputs more suitable to aircraft use. Once again, there's no database; while an external antenna (mounted in a radome that looks like the top of a "L'Eggs" stocking container) and mounting rack are available, the unit's form factor doesn't really lend itself that well to panel mounting. Still, at $1400 for the unit and only $300 for the external antenna and mounting bracket, it's among the lowest-priced GPS systems available.

II Morrow

LORAN giant and pioneer II Morrow has recently jumped onto the GPS bandwagon with a couple of products at opposite ends of the price and performance spectrum. At the upper end, their NMS 2001 nav management system combines the usual range of database goodies and nav functions with either a LORAN sensor for $2500, a GPS sensor for $3200, or both for $4200 (making a system so configured the lowest-price hybrid "LORSAT" currently available). The system can be combined with II Morrow's air data sensor package for even more versatility including actual VNAV, automatic true airspeed inputs, etc.

At the same time, the tremendous boom in low-end GPS has prompted II Morrow to package a GPS receiver in the same physical configuration, and with the same operating modes and capabilities, as their very popular "Flybuddy" LORAN. In fact, as far as the pilot is concerned, there's no difference in operating the system; it just gets its basic information from different sources. II Morrow has gone so far as to call the new system the "Flybuddy GPS"; at $2200 for the basic unit, running up to $2600 with full continental or foreign database cards, these are the currently the lowest-price permanently panel-mounted GPS systems.

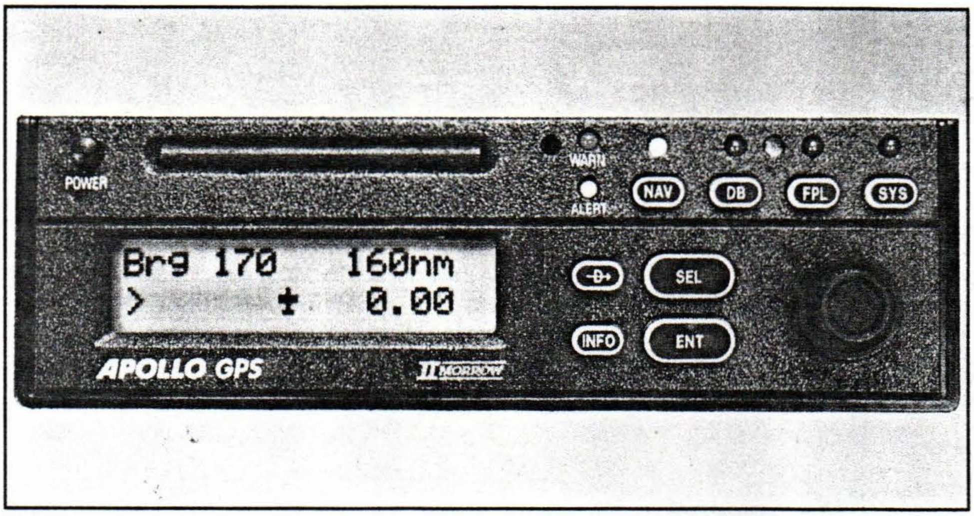
Garmin/Pronav

As far as I'm concerned, GARMIN (formerly ProNav - they changed the name because they worried people might think their products were only for pros!) is deservedly the "500-pound gorilla" of the lightplane GPS market - a fact reflected by the availability of their fabulous GPS 100 system on just about every page of Trade-A-Plane. Currently their primary product, the GPS 100 works great as a general-purpose GPS for applications ranging from pedestrians to boats (it's splashproof), and weighs only 28 ounces including its built-in quadrifilar antenna and rechargeable NiCad batteries; however, it's obvious from the start that this is the only general-purpose unit aimed from the outset at the aviation market. (This may have something to do with the fact that GARMIN is located in Lenexa, Kansas, only a few miles from Olathe - and many of its key personnel came right from avionics giant King, right up the road.)

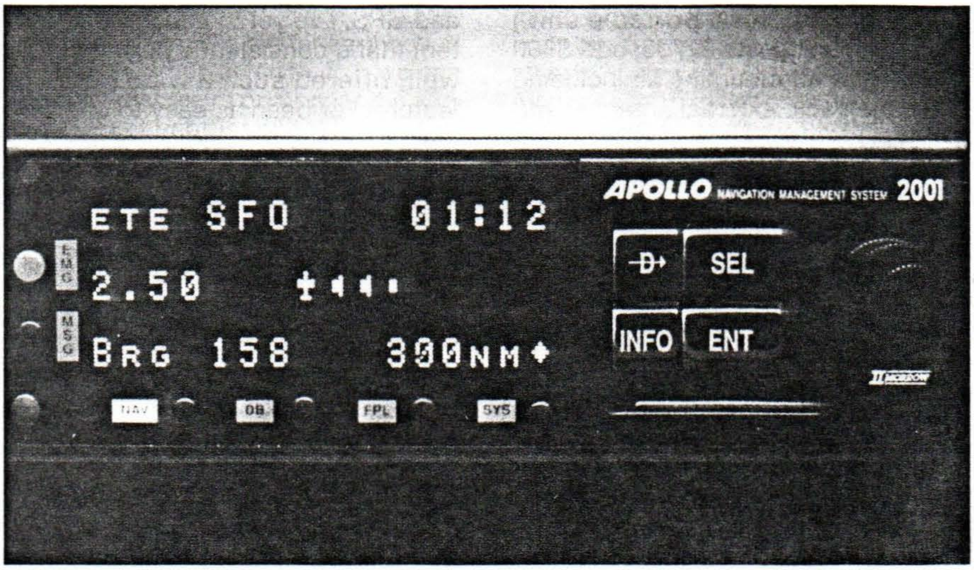
The system's aviation aim starts with the form factor: the case is 2" tall, about 4" deep, and 6-1/4" wide - exactly the right size for the standard radio stack. The keyboard and 66-character display are all on the front panel, and both display and keyboard have variable backlighting.

Where the system really shows its aviation thinking is in its operating modes and capabilities - in its navigation mode, its user-configurable display can show such things like range and bearing to waypoint or destination, groundspeed, ETE or ETA, and a left-right CDI, all at the same time. Other features not normally used by boaters, four-wheelers, or hikers are such things as true airspeed, actual winds aloft, and density altitude. Warnings can be programmed in for given distances around selected waypoints (such as the center of a TCA or the boundary of restricted airspace), and vertical navigation guidance can be provided to cross waypoints at desired altitudes. Flight and fuel planning are also available from submenus. Everything is very logically thought out; I'll have to confess that I used the unit for weeks on ferry flights, guided almost entirely by prompts from the display, before I got around to really reading the excellent and well illustrated manual.

Another real plus for aviation users is GARMIN's aircraft mounting kit. It



II Morrow's "Flybuddy" GPS . . .



. . . and Apollo NMS 2001

Magellan Systems' NAV 5000 GPS receiver

includes an external blade antenna about four inches tall and a slide-in radio stack mounting rack; what's nifty about the rack is that it includes converter circuitry to provide standard DC left-right signals to interface with aircraft nav indicators and/or autopilots. (While these are standard on panel-mounted GPS's, the GARMIN is the only one that offers this capability for a portable unit.) The basic unit costs $1700; add $800 for the aircraft mounting kit including the panel rack, external antenna, and cabling.

To add even more capability, an additional $500 gets you the GPS 100 AVD version, which includes all the capabilities of the basic system plus a built-in Jeppesen database. You get your choice of U.S. coverage including all airports, VORs, NDBs, and enroute airway intersections by name, or an international version that sacrifices the multitudinous U.S. intersections in favor of worldwide airports, VORs, and NDBs, and still has enough room for all the intersections that are outer markers or named as approach fixes. In either case, you can also plug in user waypoints as required, either in terms of latitude/longitude or as distance and bearing from an existing waypoint.

If I sound wildly enthusiastic about this unit, it's because I am; having flown over quite a bit of the world in light aircraft with navigation systems ranging from none at all through LORANs and OMEGAs to inertial nav and GPS, I've yet to encounter a system that's consistently performed as well, offered such a wide range of features, or been as easy to operate. The fact that even with every possible option it costs just $3000, and can be slipped out of the instrument panel and into my jacket pocket to use for relocating my favorite fishing hole, is just icing on the cake. In fact, for the price of some of the permanently-mounted nav systems, I could have TWO fully-optioned GPS-100s for redundancy and even more versatility.

LORAN Add-Ons

Several major LORAN manufacturers have addressed their already large customer bases by offering basic GPS "sensor" receivers that can be integrated with already-installed top-end LORANs for "transparent" operation. ARNAV Systems' $4200 GPS-506 receiver is designed to play through any R-50i LORAN (earlier R50s can be updated), as well as through ARNAVs lap-mounted nav management and moving map display system. Similarly, NorthStar offers a $4000 GPS receiver to interconnect with M2 or M1a LORANs (again, earlier M1s can be updated). Such systems offer capabilities essentially identical to those of hybrid "LORSAT" systems like Trimble's TNL-3000 or II Morrow's NMS 2001.

LAST, BUT NOT LEAST

The next big step will probably be toward very inexpensive and very basic GPS "sensor" systems. Some of the drive toward lower price will come from high volume production by industry giants; Sony, for example, just announced their "Pyxis" GPS system for a list price of $1400 (which means that you'll soon find it for about $850 at places like Crazy Eddie's or 47th Street Photo). More to the point, Peacock Systems (makers of the well-known "LapMap" moving map display software for owners of laptop computers) is just starting to release their version of the basic Sony receiver, minus its display and navigation calculation functions, as a position sensor for the LapMap - for under $1000! This means that with nothing more than a receiver about the size of a couple of packs of cigarettes and a laptop or pocket computer, you'll have complete database and moving map capabilities unheard of even for airliners just a couple of years ago; for permanent aircraft installations, the only sign of Peacock's little receiver will be a tiny instrument panel jack to connect to your laptop computer.

Sometimes it's almost frightening; I'm reminded of the conjecture that the cockpit of the future will contain only a pilot, a computer, and a Rottweiler. The pilot's job will be to feed the Rottweiler, the Rottweiler's job will be to bite the pilot if he tries to touch the computer.

Actually, of course, these developments are nothing if not heartening; I'd hope that the availability of GPS for virtually any aircraft (I've even had my GARMIN up in gliders, balloons, and ultralights!) will make everyone's flying easier, safer and more accurate. The reduced workload can even free up some attention for looking down at towns, lakes, rivers, and roads!

Just fine . . .

AW, C'MON, THAT WASN'T EVEN FUNNY LAST TIME! NO, REALLY . . .

GPS uses many of the same basic principles as "classical" celestial navigation, and, as in celestial navigation, those basics are pretty simple. It's the mechanization of those principles that required not only years of research, but the development of whole new areas of electronic and signal-processing technology.

KEEP YOUR DISTANCE

GPS is a distance-based navigation system; if you want to be fancy and use mathematician's Greek letters, it uses "rho-rho" coordinates (perhaps the Greeks developed it for use on their war galleys!). We'll look at an analogy: let's say you have some way of knowing that you're 500 miles from Pittsburgh, PA. Now, all alone, this doesn't do you much good; all you know is you're somewhere on the periphery of a 1000 mile circle with Pittsburgh in the middle, anywhere from Montreal to Charleston, SC to somewhere out in the Atlantic.

Still, it's a start. Now, let's determine another distance - say, 750 miles from Oklahoma City. This puts you on another circle; plot the two circles out on the map, and you'll see that they intersect at two points. Obviously, you must be at one or the other of those intersections; measure a third distance - say, 150 miles from Chicago - and you'll resolve the ambiguity, ruling out the intersection near Atlanta and defining your position as some little town in Wisconsin where they have a fly-in every year . . .

THIS IS OF THE ESSENCE

As simple as it seems, that's the principle that underlies GPS navigation: the user terminal (that's your trusty GPS receiver) determines its distance from various satellites at known positions, "plots the circles" mathematically, and arrives at a position. HOW it does this, of course, is a bit more complicated, but not all that difficult to understand:

We'll return to our crude analogy, and for the purposes of explanation we'll temporarily repeal a few physical laws. In particular, let's slow the speed of light down to a mere 1 mile per second - about like a well-tuned SR-71. We'll also assume we have an accurate clock in our airplane, and that GPS satellites are passing over Pittsburgh, Oke City, and Chicago. Each satellite plays a recorded message something like "Hello, this is satellite #14. At exactly 2:00, I was right over Pittsburgh . . ." Our receiver, of course, "knows" that the signal takes 1 second per mile to arrive; thus, again using our crude analogy, we'd actually receive the signal at Oshkosh at 2:08:20, 500 seconds later.

We'd have processed similar messages from the other satellites, of course; to agree with the one from Pittsburgh in our analogy, at the same time we'd have to get a message that had been transmitted from the Oklahoma City satellite at 1:55:50, and one transmitted from Chicago at 2:05:50.

Now let's see how it works with the satellites. When the GPS system is fully implemented sometime next year, there'll be 24 of them in orbit - 21 working, and 3 "on-orbit spares." They all fly in high earth orbit, about 12,000 miles out; thus, they appear to move relatively slowly, remaining above the local horizon for 6 hours or more. Each satellite transmits a data stream containing its position and a very accurate time signal derived from onboard atomic clocks. By measuring the difference between actual arrival time of the signal and the "timestamp" from the satellite, we can arrive at a distance; since the satellites move in space, that distance puts us somewhere on the surface of a sphere with the satellite at the center. Measure the distance from a second satellite, and you get another sphere; this puts us somewhere on the circle where the two spheres intersect. A third satellite measurement produces another "circle of intersection", narrowing down our position to one of two points, just like on the map, while a fourth measurement from yet another satellite resolves the ambiguity and pinpoints our exact position.

Actually, it's not quite that simple: for it to work exactly as I've described, each receiver would need an atomic clock as accurate as the million-dollar instruments in the satellites. Instead, we use one additional satellite: If three pure distance signals would provide an accurate fix if we knew an accurate time, a fourth signal can be used to provide accurate time as well - there's only one combination of time and distances that works for any given situation. We can, however, "cheat" a bit: for earthbound and low-altitude aviation use, we can assume that we're on or near the surface of yet another sphere of known position, one with a radius of about 4000 miles - the earth itself! Thus, if our system can receive three satellites, it'll give us an accurate two-dimensional position; add another satellite, and it'll give us altitude (or, strictly speaking, distance from the center of the earth) as well. In either case, the system will also give us an accurate time check - so accurate, in fact, that the master and slave stations of LORAN chains now use GPS signals to synchronize themselves!

LISTEN UP!

The one additional advance that had to be made was a way for simple receivers with small nondirectional antennas to receive the signals from the satellites. Bear in mind that these satellites are at least 12,000 miles away, and radiate at pretty low power. True, sensitive receivers exist - after all, TV satellites are twice as far away and their signal digital data stream from a GPS satellite. On the other hand, my satellite TV receiver needs a 12 foot dish antenna that must be very accurately aimed - and that can point at only one satellite at a time!

The secret, known as "spread spectrum technology", is that very weak signals - signals so weak, in fact, that they're much weaker than the background electrical "noise" overlying them - can be detected quite easily over time if you know what you're looking for. To draw another crude analogy, take a typical EAAer at a crowded party. He might not take in a word of the general babble of conversation - but let someone clear over at the other end of the room say the word "homebuilt" and he'll be over there like a shot. Why? Because he's "sensitized" to that word - unconsciously, he's listening for it all the time.

Similarly, the GPS satellites transmit their data in a string of pulses so similar to random noise that it's called "pseudorandom code." The difference is that the receiver is preprogrammed to recognize that code, which is repeated over and over. If a code pulse coincides with a positive pulse of random noise, the net result is positive - call it a mathematical "1" - while the coincidence of a code pulse with a negative noise pulse produces a mathematical "0". The receiver generates an identical code string and "slides" it along the time base of the received signal; at some point, it will coincide with the satellite pulse buried in the noise, and the number of "1's" will start to increase above the statistical 50% average. Every time the pattern is repeated, the average improves a bit more; if the receiver can "keep in step" with the transmitter for 1000 pulse strings, it's the same effect as increasing its sensitivity a thousandfold. A dividend of this technique is that measuring how far the receiver has to "slide" its timebase also indicates the transmission delay - and hence distance - from the satellite to the receiver. Another benefit is that a signal that's already weaker than ambient noise is virtually "jamproof." Moreover, the GPS system transmits several different sets of code, some of which are encrypted for military use only. Thus, in the event of actual or impending hostilities, the civilian code can be either degraded in accuracy or shut down altogether to prevent some miscreant from sending off a homebuilt cruise missile equipped with a GPS from Trade-A-Place.