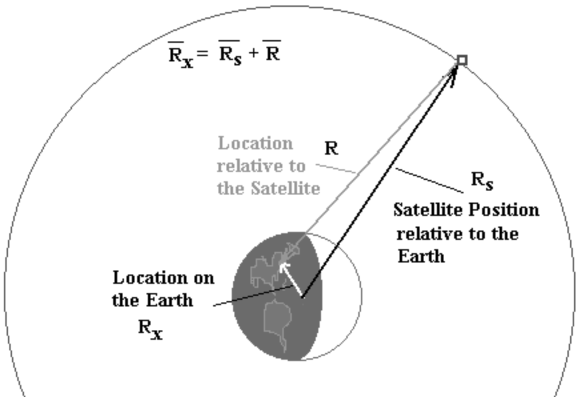
Use of Global Positioning Systems in Gliding ***by Larry Bogan***

How Does GPS Work?

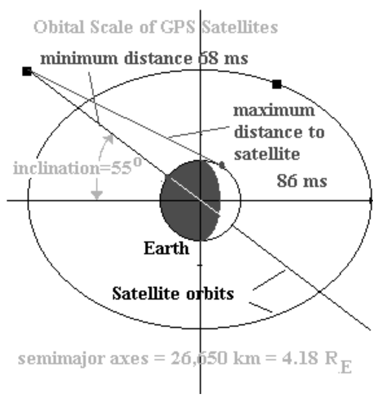


Satellite System and Position Determination:

R_S = The Satellite's position is determined relative to the Earth using accurate orbital path calculations.
R = Location on Earth relative to the satellite. The GPS receiver detects a radio signal from the satellite then the distance is determined by measuring the time of flight of that signal from the satellite. Speed = 300,000 km/s (typical time = 68 to 86 millisecond)
R_X = Position on the Earth is determined from the Vector sum of the other two positions. All measurements must are done to such a precision that the location on the Earth is known to within 15 m.

Origin -
The Global Positioning System is funded by and controlled by the U. S. Department of Defence (DOD). The system was designed for and is operated by the U. S. military. Costs of $12 billion with replacement satellites committed to 2006.

Maintenance -
The Master Control facility is located at Schriever Air Force Base in Colorado. A series of monitor stations around the world measure signals from the Satellite Vehicles (SVs) which are incorporated into orbital models for each satellites. The models compute precise orbital data (ephemeris) and SV clock corrections for each satellite. The Master Control station uploads ephemeris and clock data to the SVs. The SVs then send subsets of the orbital ephemeris data to GPS receivers over radio signals.



Satellite Orbits -
There are six orbital planes (with four SVs in each), equally spaced (60 degrees apart), and inclined at about fifty-five degrees with respect to the equatorial plane. This constellation guarantees the user of five to eight SVs visible from any point on the earth. The orbit altitude (22,000 km) is such that the satellites repeat the same track and configuration over any point approximately each 24 hours (4 mins earlier each day). Orbital period is 12 hours.

Satellite Broadcast Signals:
Frequencies: Microwave signals are sent with carrier wavelengths of 19 and 24.4 cm. These are modulated with synchronizing signals at 1 MHz or 10 MHz and with data signals at 50 Hz. Output power of a satellite is 50 Watts.
Coarse Acquisition (C/A) Codes: Each satellite has a unique code number (1-32) which is used to determine a 1023 bit random modulation code at 1 MHz. The code pulse is 1 millisecond long. The receiver knows the C/A codes for all the satellites and uses the correct one to get correlation with the signal to establish accurate timing to 1/15 microsecond.

A low frequency 50 Hz modulation carries the data from the satellite in a long series of numbers. Each data frame is transmitted every thirty seconds and a set of twenty-five frames makes up the complete navigation message that is sent over a 12.5 minute period. Signal acquisition time on receiver start-up can be significantly shortened by having current almanacs in the GPS receiver.

Receivers: The GPS receiver usually contains a computer with programming to do all the necessary calculations to reduce the signal timings to X, Y, Z positions and then convert these rectangular co-ordinates to latitude, longitude and universal time. This latter conversion depends on the Earth ellipsoid that is used as a reference system. In North America we use the WGS-84 datum. There are hundreds of different ones used through out the world and the GPS receiver is capable of calculating location relative on most of them.

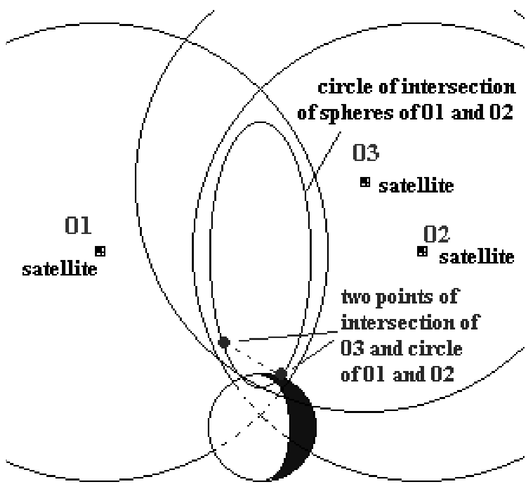
Many different types of receivers exist and have become less and less expensive in recent years. Initially the receivers sequentially sampled satellite signals but modern, faster receivers can simultaneously monitor up to 12 satellites. They are now portable enough to put in your pocket. Internal active antennas are sensitive enough to pick up satellites signals under tree cover. (Water is an absorber of GPS microwaves.) External antennas are available for some receivers and are necessary in some situations (e.g. use inside of metal aircraft)

Details of Position Determination:
How does the GPS know the location of the satellite?

The data frames from the satellites includes time corrections, updated satellite ephemerides, as well as status information. This data is stored in memory.

How is the Direction Determined?

Three satellites must be used to uniquely determine the GPS's location relative to the satellite. The intersection of three spheres representing the signals that were received at the same time from three different satellites. Two points are uniquely determined by the intersections.



Note: Only one of the two points is on the Earth

Time Synchronization and Four Satellite Required:

The satellites have highly accurate atomic clocks (1 part in one hundred trillion, 10^{14},per day) but the GPS has a much less expensive and less accurate clock. As a result the GPS will not have exactly the correct time interval for the radio waves to travel down from the satellites. As a result the wrong position will be determined. A fourth satellite signal is used to correct the time error. Additional satellite signals can be used to improve the accuracy of the position determination.

How Accurate Is It?
Sources of Errors:
- Clock errors: 1 meter (3 billionth of a second = 3 ns).
- Satellite ephemeris data errors: 1 meter
- Tropospheric delays: 1 meter. Complex models of tropospheric delay require estimates or measurements of these parameters.
- Unmodeled ionosphere delays: 10 meters. The transmitted model can only remove about half of the possible 70 ns of delay leaving a ten meter unmodeled residual.
- Multipath: 0.5 meters. Multipath is caused by reflected signals from surfaces near the receiver that can either interfere with or be mistaken for the signal that follows the straight line path from the satellite.

- *PPS Precision Positioning Service accuracy*
(Only for military use. This uses two frequencies to model the ionisphere and security coded signals not available to the domestic market)
22 meter Horizontal accuracy
27.7 meter vertical accuracy
100 nanosecond time accuracy

SPS Standard Positioning Service accuracy (Domestic using one frequency)
100 meter horizontal accuracy
156 meter vertical accuracy
340 nanoseconds time accuracy

Geometry of Satellites
The accuracy of the position determination depends on the relative position of the satellites used. An example of bad geometry which give very poor position accuracy would be if all four were in nearly the same place in the sky. The best geometry occurs when the satellites are space 90 degrees from each other in the sky (example: 45° altitude and 90° spacing around the horizon).

Selective Availability (SA) is the intentional degradation of the SPS signals by a time varying bias. SA is controlled by the DOD to limit accuracy for non-U. S. military and government users. The potential accuracy of the C/A code of around 30 meters is reduced to 100 meters. This bias is slowly varied randomly over hours of time and as a result, it is difficult to average out the changes. It is observable with a fixed GPS receiver tracking its location.

What is Available?
- *Aviation Navigation GPS ($?)*
Includes specific databases and navigation computers
- *Data Loggers - Computers* ($1000 up)
Includes computers, memory and barometric height measurement.
(e.g. GPS- IGC data logger - US$900-1000
Filser GPS-Vario-Datalogger-Computer US$3500-$4000)
- *Sports Handheld Receivers* ($200 up)

Handheld GPS Receivers
All have computer connection,
Over 1000 track points,
Waypoints, data bases
12 parallel channels
Magellan
-**315** - $250 Canadian Tire
-**320** - $360 Radio Shack
Garmin
- **12** - $250 Canadian Tire
- **II Plus** - $270 Walmart
detachable antenna,
world database
Lorance
Eagle

Features of a GPS Handheld Unit

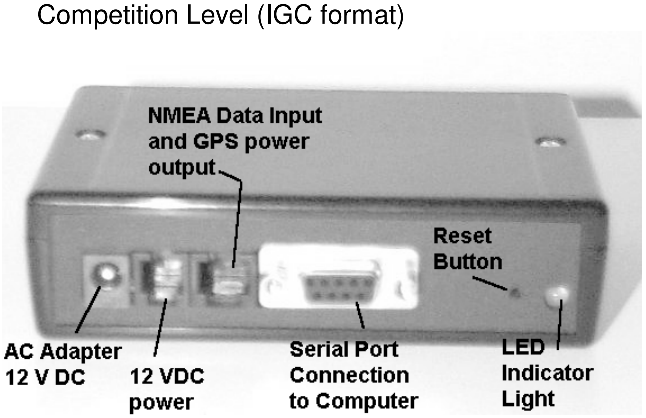
Basic Position
    Horizontal Position (Lat/Long)
    Height and Time (to 1 second)
    Velocity (may be limited in maximum value)
Databases
    Maps (not really useful aloft when VFR)
    Waypoints (Pre-Entry and MOB)
    Routes (Useful for tasks)
Recording Tracks (desired unless you have a recorder that can be interfaced to it .) This facility provides the fun of recording whole flights and transferring them to graphics on a computer for printing. Timing is variable with in the unit. Unfortunately, height is usually not recorded.
Calculations
    Distance and bearing between waypoints
    Alarms and TOA (Time Of Arrival)
    Track direction
    Wind Speed/Direction (using ground speed)
Digital Interface
    Protocols (proprietary and NMEA)
    (National Marine Electronics Association)
    Computer upload/Downloads
        Waypoints and Tracks
    Software and Database Upgrades
    Interface with computer mapping programs.

Operation of GPS

- See Garmin 12 Quick Reference (Appendix A)

Recorders

Competition Level (IGC format)



Canadian Advance Soaring (CAS)- Sporting
(built by Varicalc - Nick Bonniere ~ $150)
    up to 8 hours of distance, time and height
    IGC format and plotting

Real Time Use

Distance - Bearing to Airport
    Air Traffic Control (reporting location/track)
    Accurate glide distance to home or field
Ground Speed
    Wind Speed/Direction
    Real Glide Slope Determination
Height
    Altimeter is usually more accurate
Marking Positions (Mark or Man Overboard, MOB)
    Thermals and Fields

Examples of Recorded Track Plots

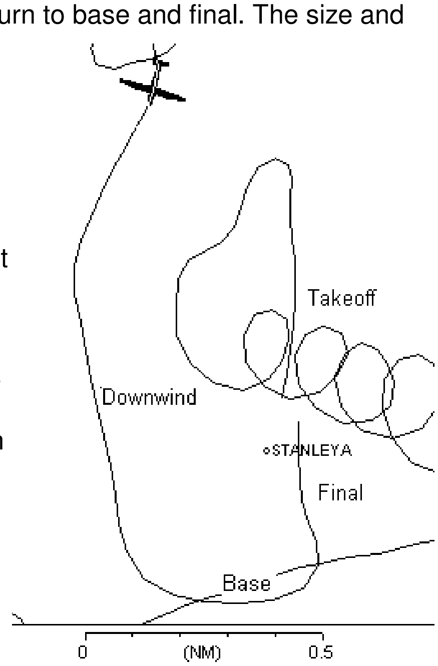
Basic Analysis of Flying
    Circuits (example - June 27)
    Thermalling Circles (August 31)
    Wind Drift (August 2)
Intermediate Analysis of Cross Country
    Position and Height Track - (June 20)
        Cross Country Thermalling (July 9)
        Cross Country Track (Sept 2, '98)
            Plot over a map possible
Statistics
    Record where Thermals Repeatedly occur.

Circuits - Landing 02 - June 27, 1999

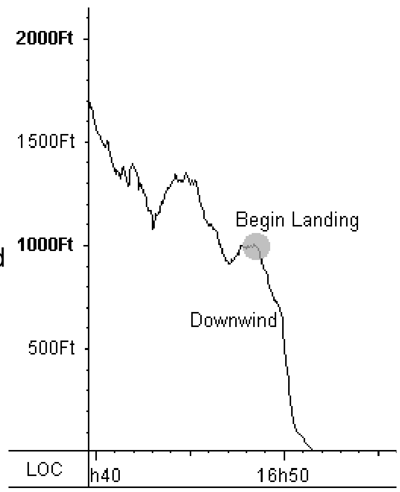
After an hours flight with marginal lift to 3000 feet. Note how quickly the flight drops on landing - It shows how effective spoilers are.

This path shows the shape of the downwind approach, the downwind, turn to base and final. The size and shape of the circuit is shown. StanleyA is the location of the clubhouse. The next image shows the change in height during this part of the flight.

This is the barograph trace of the last part of the June 27th flight. The grey dot is the location of the glider indicated in on the track. You can see

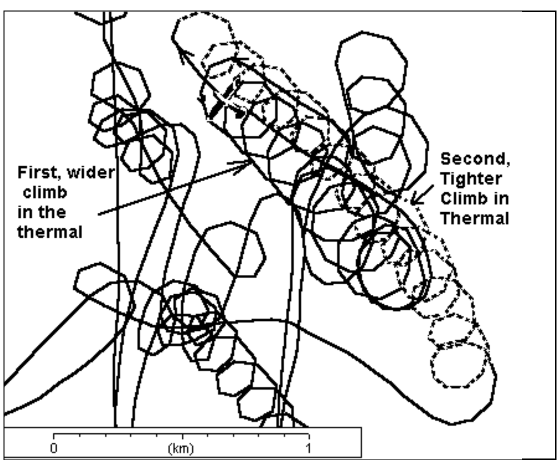


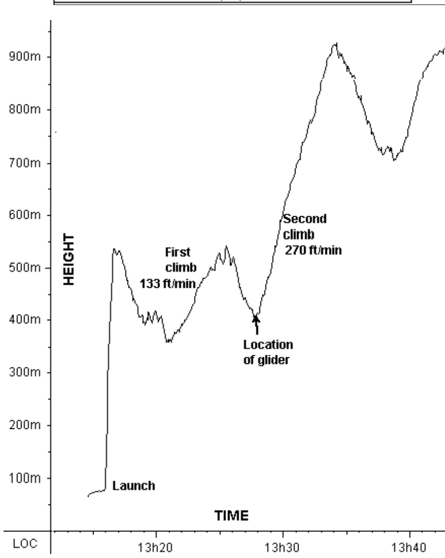
how quickly the glider loses altitude during landing. On base the sink is 900 ft/min. This and more can be derived from the GPS track. It is very useful for routine analysis of flights - especially good for students to practice improving their circuits,etc.



Thermally Circles

A GPS track is excellent in analyzing your thermalling. Below is an example of how changing your circling radius will increase your lift. Note that the initial thermalling with larger circles only gives a small increase in height. After I circled back upwind and hit the thermal again, I increased the bank and tightened the circle and climbed much better. The barographic trace illustrates the difference between the two climbs over the same area. Note, the data in the plots are four seconds apart. The tighter circles are 30s in duration

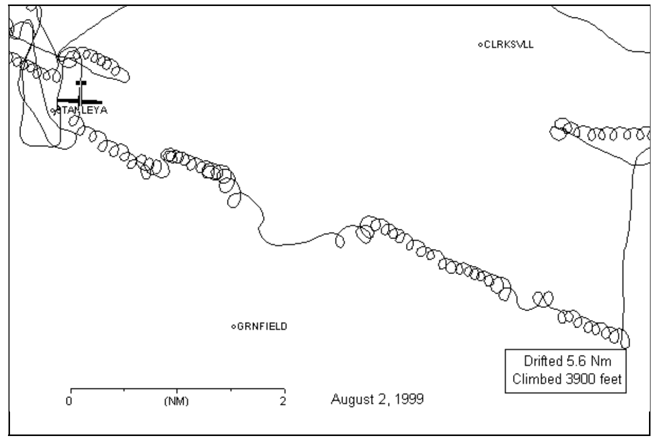




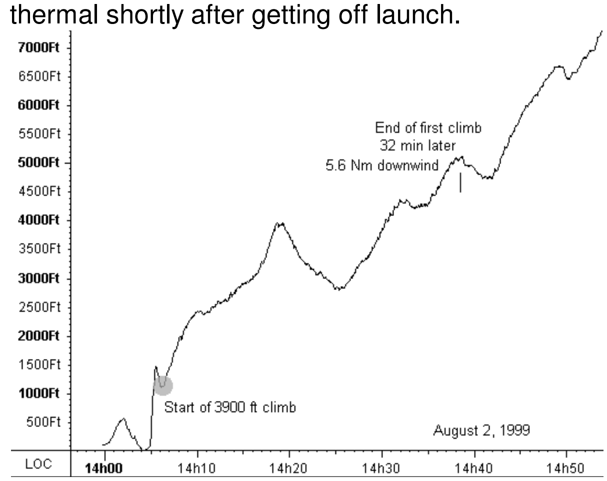
Wind Drift (August 2, 1999)

This flight (above) dramatically shows the amount of wind drift that can occur during thermalling. If I had not been climbing quickly, I could have ended downwind and not been able to get back.

However, the barographic trace below shows that it



was a great height day dispite the wind. The trace also shows the large sink rate in the region of flight between two downwind thermals. Luckily, I hit a thermal shortly after getting off launch.

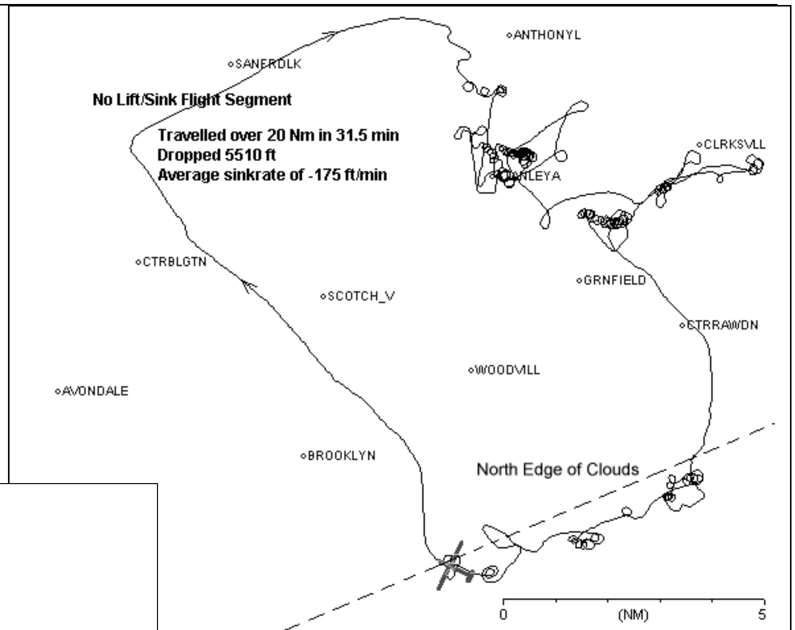


Cross Country Flying (June 20, 1999)

Cross country flying is the reason most glider pilots get a GPS. It is useful in flight and a record track is used for analyzing the flight afterwards. This particular flight (next page and clockwise around the track) was to a bank of clouds at 7000 south of the field. In order to get to that bank I was lucky to catch a thermals to 7000 feet that allowed a glide south until I got into the lift associated with the cloud bank. I stayed at 7000 while under the cloud. North of that bank was blue with very scattered lift. As you can see from the track, I was thermalling under that bank but when I left it south west of Stanley (location indicated by the glider symbol on the track and height indicated by the circle on the barographic trace), I found no thermal until nearly back to Stanley. That flight from the 7000 ft cloud bank in smooth zero sink air was perfect to observe the glide performance of my Ka6e (see comments on track to the right).

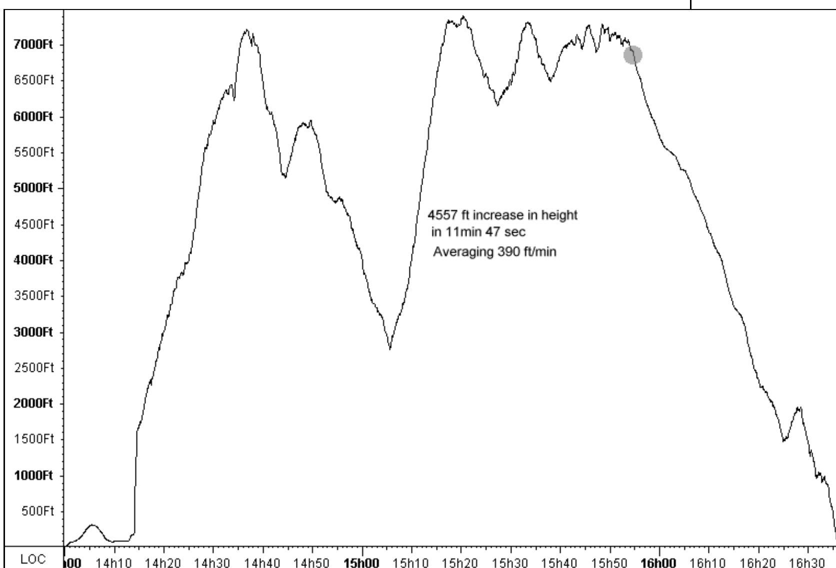
The barographic trace below shows the thermalling and long glide flight. It is amazing how little time is used in straight flight compared with circling. On this particular flight there was a combination of good lift and heavy sink in the blue while there was mostly good lift under the clouds. If I would have stayed in the blue it would have been up and dramatically down as indicated in the first half of the barograph trace below.

Note the analysis of the 4560 ft climb in the middle of the flight when the lift average almost 4 knots.



Cross Country Barograph Trace (July 9).

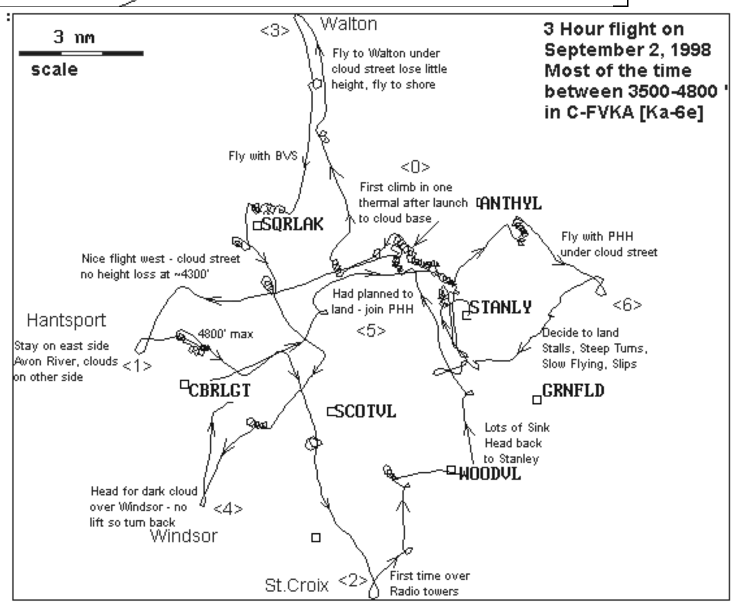
The altitude given by a GPS is not accurate enough to be used for badges but it is fine for diagnostics of cross country flights. The trace below shows how on a good day you can get high and stay high. Note: a GPS alone can not record height but it can send the height to a

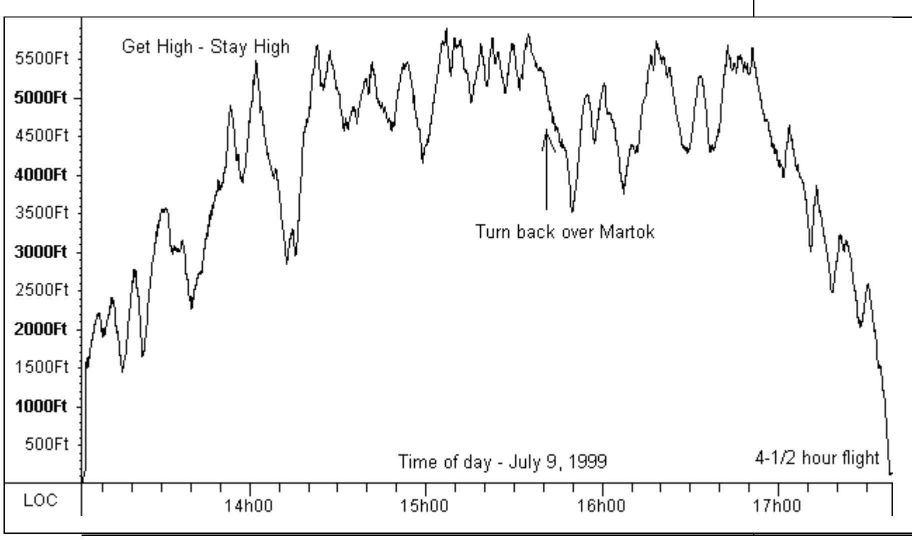


data logger; my traces used the CAS Visicalc recorder shown earlier.

Cross Country Traces for Fun (and competition)

As you can see from the tracks and barographic traces in this document, you can annote your records using computer graphics programs to add information to your traces. (Or just print them out to write and draw on them!) Above (September 1998) is one that I heavily commented on when I was first using a GPS. There are map and soaring analysis software that will plot your track on any map that can be scanned. The soaring analysis programs will dissect your flight, report the thermals and how well you used them. They can also plot soaring tasks (routes) to be compared with your actual flight.

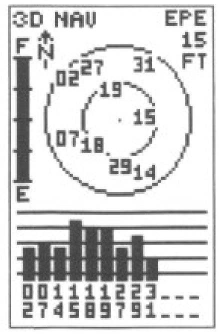




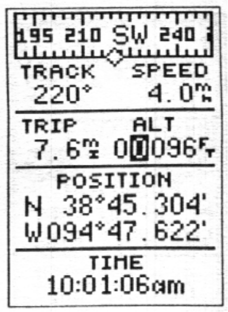
APPENDIX A

Garmin 12 Screens (Pages)

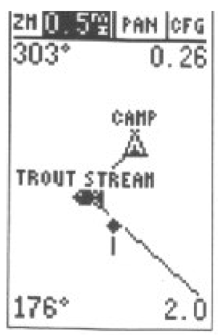
The first screen to popup after you turn it on is the satellite access screen. This shows the relative positions of the satellites that are visible and the strength of each signal. After four satellites are accessed, the GPS automatically changes to the second screen.



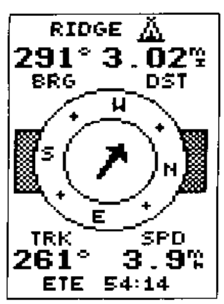
This page shows basic information At the bottom is the time (can be set for any time zone) and the latitude and longitude. The other information is only important if you are moving: speed, tack direction. Actually this screen can be changed so that elapsed time and average speed are calculated and shown.



This page is graphic and shows the track and/or route to scale, relative to the waypoints recorded in memory. Both the scale and centring of the plot is changeable. The CFG leads to another setup page to record of a track with adjustable time spacing and length.

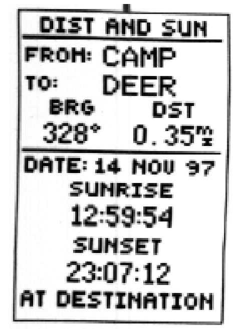


This is the page to keep up while flying. It is set up to show position relative to a selected waypoint (here called RIDGE). It displays the distance and bearing to the point (Stanley when flying near there). It also shows your ground speed and track direction as well as an estimated time to the point (at present speed and track)



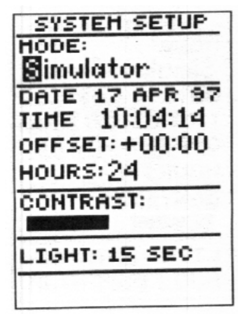
This is a major page for setting up the GPS. It is from here that there is access to many setup pages. You see and set waypoints with the first group of pages. Routes can be setup using waypoints. Examples of the last five pages are shown in the second column.

This DIST AND SUN page allows you to do calculation on different places that you have stored in your waypoint list. By selecting waypoints you can find distance and direction between them. This page will allow you to calculate bearing and distance from Halifax Airport to the glider when the TO: is left blank.

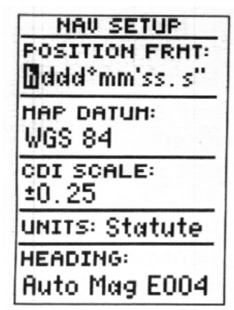


This is the MESSAGES page. You will get notices of events and to find out what they are, you go to this page to see the message. e.g. in this case is tell you are near the waypoint called CAMP. (proximity alarm was set)

The page to set various aspects of the GPS. Units, time zone, type of clock, contrast of the screen and light shut off time. The most important is the mode which allows you to practice the use in simulator mode.



Another setup page. This one sets the form of Latitude and Longitude, the map datum, scale, units (metric, English, or nautical).



The INTERFACE page allows you to program the data interface for several different protocol of transfer of data. For the Garmin there is GARMIN, NMEA, RTCM. Once the protocol is set you can upload and down load data. Messages tell you what is going on. The transfers can also be controlled by a program in an attached computer.

Note: There are many more pages but these give you an idea of the more important functions.