GPS TRACKING FOR
SMALL SOUNDING ROCKETS

Darin K. Fowers

Department of Electrical Engineering
Utah State University, Logan, Utah 84341

ABSTRACT

Active areas of research often create the need for improved technology to make observations in a way that has not previously been utilized. Such is the case with middle atmospheric research. This 60 to 120 km region of the atmosphere is too low to be directly probed by satellites and too high to be probed by research airplanes or high altitude balloons. Sounding rockets are the only vehicle that can carry instruments for *in situ* measurements. Up until now only a few methods have been available to track the location of a sounding rocket - radar skin tracking, radio beacon tracking, and inertial reference platform tracking. In this paper a joint NASA - Utah State University (USU)/Space Dynamics Lab (SDL) project to develop a Global Positioning System (GPS) based solution for tracking small sounding rockets (10D DARTs to be specific) in the middle atmosphere is presented. The size of the DART casing and the g-force created by the booster present various obstacles in the implementation of a GPS receiver. Rockwell's Jupiter GPS receiver designer's kit has shown that it is capable of overcoming these obstacles. Research is continuing in the area of antenna development, but initial test results reveal the Toko DAK series dielectric patch antenna as a workable solution. Finally, plans for the hardware system integration have been made.

I. History

Interest in the middle atmosphere (consisting of the area between approximately 60 to 120 km) is increasing as various areas of research are demanding more information about the properties and processes that take place in this region. Weather prediction and Communications (which in and of itself encompasses many aspects of technology) are two of the most prominent areas of research currently pursuing ongoing research in the middle atmosphere.

There are various means of observing phenomena in this region, almost all of which are relatively expensive. In fact, most observations have been made from the ground or from some other vehicle observing below or above this region. Satellites cannot effectively orbit in this region because of the drag that terminates their missions within a few minutes. Balloons, research airplanes or other similar vehicles cannot attain this altitude and sustain themselves. Ground stations are limited in the types of observations they can make, and only produce long term trend data. One method has been devised using the GPS radio signals themselves as a way of measuring total electron content of the ionosphere over a broad region covering a good portion of the globe[1]. But for truly high resolution, *in situ*, measurements that can make measurements of whatever characteristics are desired, sounding rockets are the only option available[2].

The short flight duration of sounding rockets has made flights - in comparison to remote ground based observations - very expensive. Research has been done at USU/SDL and NASA Goddard Space Flight Center to simplify the traditional sounding rocket to be a very cost effective method of making measurements in the middle atmosphere[3]. Using a 10D DART rocket with smaller boosters, miniaturized electronics, and lighter payloads than have traditionally been employed, researchers can have more rocket observations for the same cost. The ultimate goal of the research team at USU/SDL and NASA is to make the rockets and basic systems a standard package that comes with all the necessary components for flight. Space for the science experiments would be fixed and easily adapted for a variety of instruments from one flight to the next.

The focus of this research is how to make small sounding rockets cheaper and more flexible to the scientist by examining tracking issues. Obviously the researcher wants to know where in the middle atmosphere his instruments are located when they take the data. Once again, traditional methods are fairly confining and expensive in one way or another. Two methods are typically used by NASA to track sounding rockets - radar skin tracking and radio beacon tracking. Both are costly in terms of ground station facilities. Radar skin tracking requires the use of a radar and the manpower to support the operation. This is an expensive proposition and limits the scientist to making observations where there is an established range. Also, the high velocity and small cross-sectional area of the sounding rockets in general make tracking them with radar a bit of a challenge in and of itself. The method of beacon tracking has its challenges as well. It also requires a tracking receiver system at an established launch range. Antennas are required on the vehicle and a transponder must be included in the payload, both of which are an issue for a small rocket.

The possibility of using GPS offers a much simpler alternative for determining the actual trajectory of a sounding rocket. With recent improvements in GPS receivers, miniaturized, inexpensive models are available that make this a contender for position determination. Integrating a self-contained receiver and antenna into a sounding rocket would theoretically enable the determination of position to be done in real-time without reliance on expensive radars or receivers. Thus, not only would researchers have a cheap, easy to build and highly portable rocket, but it could be flown basically anywhere that had enough area to support such a flight. The tradeoff in using GPS for position determination is accuracy. Using the civilian Course Acquisition (C/A) code without Selective Availability (S/A) turned on, errors are estimated to be a nominal value of 22 meters in a three dimensional sphere[4], but can get as high as 300 meters[5]. This performance can be improved to within 10 meters of error if Differential Global Position Systems (DGPS) are used. This could be accomplished with a base station receiver sitting on the launch pad with predetermined and constant latitude/longitude/altitude specifications set in the initialization process.

II. GPS Receiver

A. GPS Operation

Position of a receiver is determined by knowing ranges (officially termed psuedorange) to four GPS satellites, and each ones' corresponding ephemeris (or positional) data. The receiver then uses these range measurements to compute the latitude, longitude, altitude (and many other optional facts such as velocity, climb rate, etc.) by basically solving a four dimensional problem with x, y, z, and time being the variables. The term psuedorange comes about as absolute ranges to the satellites are not directly available - errors are introduced into the ranges by hardware offsets and atmospheric perturbations which make this a relative measurement. Export regulations require that GPS receivers have limitations built into the software such that they will not calculate valid solutions at altitudes greater than 30 km and velocities greater than 950 m/s in order to protect national security. These limitations can be turned off for U.S. Government applications.

The approach taken by USU/SDL and NASA in this project is to attempt to get the software locks turned off to allow for continuous positional solutions to be calculated for the entire flight. Otherwise, raw psuedorange measurements and ephemeris data would have to be used in post flight analysis to calculate the position. The method used to test this potential receiver candidates was to run tests on Goddard Space Flight Centers' Northern Telcom GPS Simulator. Expected flight trajectories and conditions were represented by the simulator and the responses of the receivers were recorded.

B. Selection of the Receiver

The market for GPS receivers is not a small one. Just browsing the Internet reveals over 20 companies that offer some sort of GPS package or product. The first and foremost concern for the receiver required for this project is size. The 10D DART has an inner diameter of less than 2-1/8 inches, which eliminates a good portion of the available receiver units. Of the products that appeared to meet the size criteria, four really showed potential of accomplishing the task at hand. Trimble, Rockwell, Garmin, and Magelllan claim to make units that are small enough to fit into the rocket shell and provide enough detailed information that could be extracted upon request from the receiver. Upon further investigation, it was discovered that the Magellan model wasn't available to the public at the time of the receiver procurement.

Beyond size, other desirable characteristics for the receiver include: low power consumption, active and passive antenna configurations, and ease of extracting pertinent positional information. The Garmin model was quickly eliminated because the software lock could not be turned off and it didn't provide raw psuedorange measurements.

The remaining two models had many of the same characteristics, such as similar power consumption (5 V @ approx 1.5 mA), and active and passive antenna modes. The Trimble SVeeSix appears to have several advantages over Rockwell's Jupiter. First of all, for an extra fee and cutting through some red tape, Trimble will provide a receiver without software locks in place. It provides ephemeris data directly upon request, and has more flexibility in the initialization options (i.e., it can accept much higher velocities than the Jupiter to help the re-acquisition process in the event of lock-drop).

The drawbacks of the Trimble model, however, were many. The cost of the unit (without software locks) is five times that of the Jupiter. The signal processing chip at the heart of the receiver is limited to tracking six satellite signals in parallel, and the method of tracking these satellites leaves ambiguities in the code phase. Under these circumstances, the user has to figure out the integer number of C/A code cycles and apply this factor into the psuedorange calculation. Measurements following this format are clustered within a 1 ms time frame, but are not simultaneous. Testing has shown that the SVeeSix is slower to acquire and needs stronger signals than the Jupiter.

NASA flew a rocket (much bigger than the proposed DART) that contained the two GPS receivers under consideration. The Jupiter never lost lock (surviving 18 g's) and tracked accurately for the entire flight. The SVeeSix, on the other hand, never acquired during the flight. NASA personnel have admitted this result may not totally be attributed to the performance of the receiver, but the doubts about the receiver cannot be ignored.

The information that the receiver sends to the end user is put into "packets". Different packets can be requested providing details ranging from latitude, longitude and altitude, to receiver communication line status (i.e., serial port comport, etc). The information in these packets for the SveeSix does not follow the standard IEEE binary floating point format, thus making user manipulation of individual packets much more complicated.

The Rockwell unit, although incapable of providing ephemeris data directly upon request, does provide the user with the raw 50 bps GPS data messages, and by manipulating the correct information packets, this data can be obtained. Also, the Jupiters' packet format does adhere to the IEEE binary floating point format (with inherent scaling factor), making this manipulation more straightforward. Rockwell, however, was not flexible in turning off the software locks. The architecture of the Jupiter allows for 12 channels to simultaneously track satellites - thus enabling an overdetermined solution without psuedorange and carrier phase ambiguities.

One last inconvenience that has been found with the Jupiter is the fact that it will only accept an initialization velocity of up to 300 m/s. This has proven to slow the re-acquisition process for the receiver after losing lock due to launch conditions.

Time proved to be the ultimate factor in deciding which receiver was used in testing to see if the GPS concept would work. The Jupiter unit arrived months ahead of the SVeeSix, and when it did arrive, all efforts were focused on this model.

C. Testing the Rockwell Receiver

Roger Hart, an aerospace engineer at Goddard, orchestrated the testing scenarios and facilities. Scenarios range from stationary to rapid motion, and surface to orbital altitudes. After altering the representative trajectory given in the NASA Review Package for the DART 94.1 Plasma Dynamics Payload[6] to meet the scenario format criteria for the simulator, the receiver was tested for its ability to stay locked for the entire trajectory. In altering the scenario, the g-force represented by the simulation was less than a realistic force by a factor of about 4.

Of course the receiver lost 'lock' very close to take off, as both the velocity and g-force limit were surpassed. By the time the rocket had slowed enough to be below the velocity limit, it had surpassed the altitude limit. Soon after losing lock (right after, as far as the precision of our simulation could ascertain) new lat/lon/alt/vel measurements were placed in the re-initialization packets and downloaded to the receiver. It would re-acquire and track the satellites, outputting psuedorange measurements, but not outputting valid position and velocity solutions. Extracting the information packets from the receiver and comparing it to trajectory data used in the simulation confirmed that indeed the raw measurements were valid. Plot #1 shows the trajectory calculated from the simulation psuedorange data and also displays when valid lat/lon/vel calculations no longer are output. The circles show the true trajectory of the rocket, the solid line

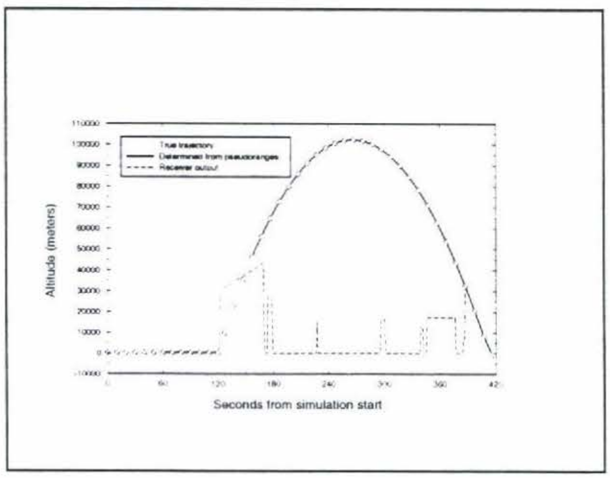

Figure 1

represents actual lat/lon/vel calculations using psuedorange data, and the dashed line shows the output reported by the receiver. After repeated tests with varying signal strengths and various lat/lon locations, the Jupiter receiver continued to produce reliable psuedorange measurements.

III. The Antenna

A. Selection of the Antenna

As the search for a suitable antenna progressed, two passive antenna options materialized as potential solutions. A passive antenna system decreases the signal strength, but lessens the power requirements of the battery packs for the rockets. Several companies claimed to have the capabilities to make a circular microstrip antenna that would wrap around the skin of the rocket. This would allow for continuous reception of satellite signals through the entire spin cycle of the body of the dart. After pursuing project details with all of the available contacts, none committed to actually building the microstrip - some due to quantity considerations, others to lack of technology, and still others to lack of time. In the event of poor results from the current tests with the patch antennas, the next course of action is to try for a microstrip antenna in an 'educated-trial-and-error' method.

The only other option was to use a small enough antenna (and maybe several in some sort of configuration) to fit inside the skin of the rocket. The specifications for the DAK Series dielectric patch antennas made by Toko meet this size requirement, as well as the center frequency and temperature stability. The antenna is 25 mm^2 and 4 mm thick. Other specifications include a center frequency of 1580.5 MHz, bandwidth of 9 MHz min all based on a 70 mm^2 ground plane. The ground plane requirement limits the number of antennas to two, as the 2-1/8 inch diameter rocket body barely provides a 70 mm cross sectional area when two antennas are used. Thus a back to back configuration, according to antenna pattern specifications, would give the receiver full sky coverage of the satellite signals (with some attenuation at the plane connecting the two patterns).

B. Testing of the Patch Antenna

A series of tests have been conducted which have determined the initial feasibility of using these patch antennas under less than ideal conditions. All data collection took place over at least a 12 hour period (generally the same time frame each test) in order to allow each satellite in the same subset of visible satellites to complete one entire arc across the sky. To establish a baseline from which to work, the original active antenna that came with the GPS development kit was used to record data. The series of tests that followed the baseline are: A single antenna with a flat 70 mm^2 ground plane; a single antenna with a cylindrical section of ground plane (representative of the body of the rocket) that has a flat square cut out just big enough for the antenna; two antennas connected back to back on the cylindrical section of ground plane; two antennas connected back to back on flat 70 mm^2 ground planes; two antennas back to back on the tubular section of ground plane with 70 mm of flat ground plane cut into the section (possible only in the axial coordinate); and finally, all of these tests are repeated with radome material (a product of Corning, called MACOR) covering the antennas, in this order.

Other factors regarding the testing environment of the antennas are: each test is performed with the antenna in a fixed position and a 90° rotation with respect to that fixed position; GC conductive grease was placed between the ground plane and the antenna; all tests took place from on top of the engineering building at Utah State University, allowing for maximal sky coverage; data points were recorded for each visible satellite every four minutes (theoretically allowing one data point per every degree change in elevation); and a 3-4 ft coaxial cable connecting the antenna to the receiver.

The topic of connecting the two antennas together has not been addressed fully, because at this point no efforts to match impedances have taken place. These first few tests are merely tests to 'feel out the situation'. As the testing procedure progresses, an effort to do so will take place in the form of stub tuning.

C. Test Results

The data that has been compiled thus far has been processed using MATLAB, in the which scatter plots have been created displaying the Carrier to Noise (C/N0) ratio versus elevation. Every satellite data point is plotted, creating an antenna pattern of sorts for the patch antenna under the various conditions imposed upon it. In the event that a given satellite data point is invalid, the C/N0 is assigned a value of zero. Figures 2 through 6 represent the results from the testing as such: Figure 2 - single, active antenna; Figure 3 - single antenna on 70 mm^2 ground plane; Figure 4 - single antenna on cylindrical ground plane; Figure 5 - two antennas on cylindrical ground plane; Figure 6 - two antennas on flat, back to back 70 mm^2 ground planes.

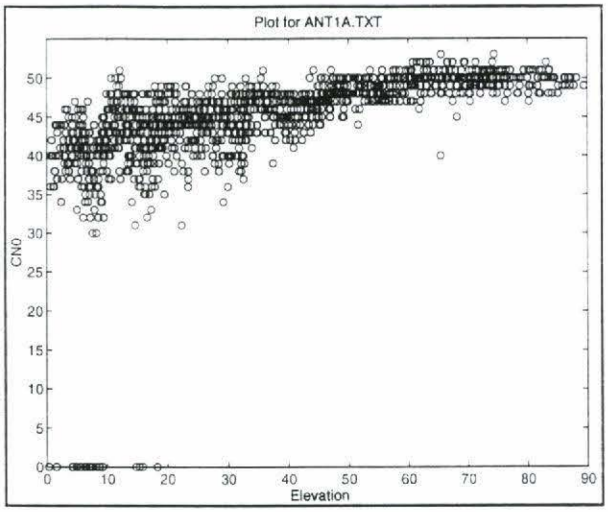

Figure 2

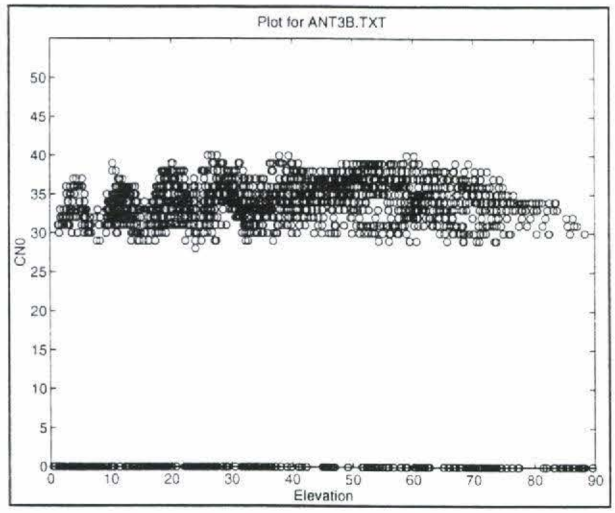

Figure 4

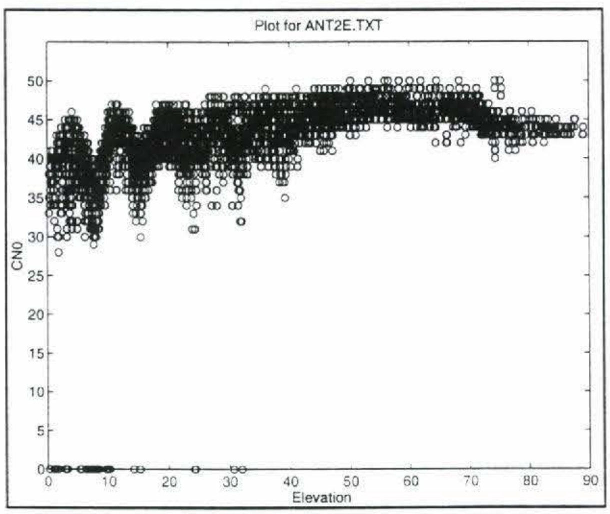

Figure 3

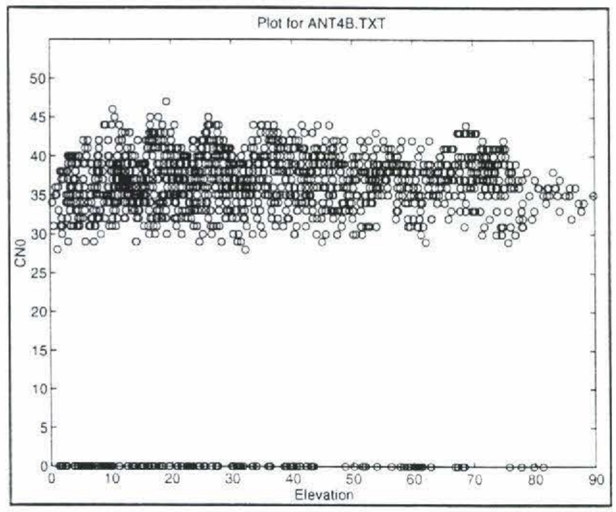

Figure 5

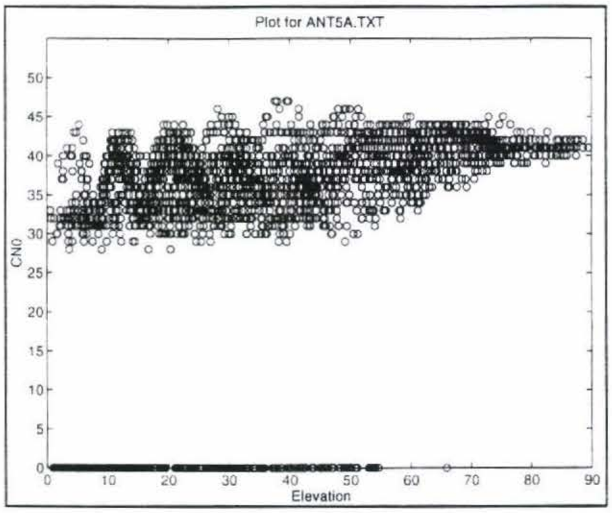

Figure 6

By studying these plots, it is obvious that the passive antennas drop the average signal strength by about 8 dB compared to the active antenna. All in all, it appears that the cylindrical antenna configuration without the radome material does provide adequate signal strength and adequate sky coverage to allow the receiver to function properly. The specifications for the antenna state that a decrease of about 5 dB in signal strength can be expected when radome material is used, which, according to the plots would still provide enough power to allow for proper operation.

IV. System Integration

The experience and expertise of SDL are being utilized in putting the rocket together. Engineer Peter Mace is spearheading the project and is accounting for the majority of the hardware specifications, power consumption concerns, and system interconnections. The current phase of the design allows for the GPS unit to be an entity almost entirely separate from the rest of the system. In order to extract the necessary data from the receiver and include it in the downlink from the rocket, a FIFO buffer will store the packets of information until the system PCM polls it. A certain amount of effort will need to be put into coordinating this buffer, as it will also be storing other inputs such as accelerometer data. The information in the buffer will then become part of the telemetry matrix that is downlinked via the S-band transmitter.

The details of this matrix have not been finalized, but the output rate of the GPS information is once per second, and the amount of information that will be requested will be on the order of hundreds of bytes. The transmitter operates at 2.28 GHz with a data rate of 800 kbit/s, so even with all of the other onboard instruments feeding data into the transmitter, the GPS data is a very insignificant portion (less than 2%) of the entire telemetry matrix.

Various information packets are proposed to be extracted during flight. At this stage, the more information the better. The psuedorange measurements will be taken, as well as the satellite ephemeris (for post-processing a calculated solution), receiver health and status, serial line status, and more. Once the design has been proven through several flights, the amount of information can be reduced to as little as the psuedorange and ephemeris data.

The initialization process for the receiver to 'lock' and update all of the almanac data for all of the satellites takes no more than 12.5 minutes. Thus the plan for launch includes an umbilical cord that will allow direct communication with the GPS receiver. Appropriate ground parameters will be fed into the receiver and at least a half hour will be allowed for complete lock to be acquired. Data will also be programmed into a memory storage location that will contain re-capture lat/lon/alt/vel initialization parameters. The receiver will then be put in 'frozen' state, which will keep the current configuration in memory, yet not process valid solutions and go into a lower power consumption mode so the umbilical can be removed and power demand on the battery pack will not be as great as if it were in full operation. After launch and the receiver has lost lock, the PCM will send the re-initialization packets containing the information programmed at launch to help the receiver re-acquire lock.

V. Conclusion

The anticipated launch date for this rocket is August 11, 1997, and will be flown from Wallops Island with radar skin tracking available. Thus the two methods will be compared to verify the correct operation of the GPS unit. As a note of interest, a real-time DGPS solution will be implemented from the ground, which will enable radar tracking enhancement. All of the tests that have been run demonstrate that this flight will be a highly successful mission, thus affording researchers greater flexibility in their science experiments.

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