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EVALUATION OF GPS COVERAGE FOR THE X-33 MICHAEL-6 TRAJECTORY

Prepared By:	**John B. Lundberg, Ph.D.**
Academic Rank:	**Assistant Professor**
Institution and Department:	**Auburn University** **Department of Aerospace Engineering**
NASA/MSFC:	
Branch:	**Flight Mechanics, Guidance, Navigation, & Control Systems**
Division:	**Guidance & Control Systems**
Laboratory:	**Structures & Dynamics**
MSFC Colleagues:	**John M. Hanson, Ph.d.**

Introduction

The onboard navigational system for the X-33 test flights will be based on the use of measurements collected from the Embedded Global Positioning System (GPS)/INS system. Some of the factors which will affect the quality of the GPS contribution to the navigational solution will be the number of pseudorange measurements collected at any instant in time, the distribution of the GPS satellites within the field of view, and the inherent noise level of the GPS receiver. The distribution of GPS satellites within the field of view of the receiver's antenna will depend on the receiver's position, the time of day, pointing direction of the antenna, and the effective cone angle of the antenna. The number of pseudorange measurements collected will depend upon these factors as well as the time required to lock onto a GPS satellite signal once the GPS satellite comes into the field of view of the antenna and the number of available receiver channels. The objective of this study is to evaluate the GPS coverage resulting from the proposed antenna pointing directions, the proposed antenna cone angles, and the effects due to the time of day for the X-33 Michael-6 trajectory from launch at Edwards AFB, California, to the start of the Terminal Area Energy Management (TAEM) phase on approach to Michael AAF, Utah.

Procedure

To evaluate the GPS coverage, the parameters of interest are assumed to be the minimum possible (optimal) GDOP (Geometric Dilution of Precision) and the number of satellites that the receiver locks onto at any particular point in the trajectory. Using the current baseline Michael-6 trajectory, these parameters are computed at equally spaced intervals in time. Parameter permutations include four antenna positions, two cones angles, and 24 launch times. The time of day is varied to generate 24 profiles for each antenna and cone angle combination. The results are summarized by computing the percentage of time during this trajectory that each of the two parameters fall within a specified range of values.

Assumptions

1) The Michael-6 trajectory has the following time characteristics: main engine cut-off (MECO) at 200 seconds after launch and TAEM entry at 476 seconds after launch. The trajectory has bounded attitude rates, and the vehicle is assumed to have a perfect response to guidance command inputs. Periods of significant maneuvering for energy management occur near 260 seconds after launch and from 300 to 380 seconds after launch.

2) The GPS receiver has 5 tracking channels; 4 of these channels are used to lock onto the "primary" GPS satellites and the remaining channel is to lock onto another GPS satellite whose data will be used in the event that signal lock to one of the primary satellites is lost. There is assumed to be a 6 second delay between the time that a GPS satellite comes into the field of view and the time when the receiver is able to lock on to the signal and generate valid measurements. The receivers are assumed to record measurements at intervals of one second.

3) There are 4 possible antenna positions on the current X-33 vehicle configuration. All 4 are located on the forward part of the vehicle in a symmetrical arrangement about the center line

(2 to port and 2 to starboard). Since only the pointing directions of the antennas affect the results, the actual positions of the antennas are immaterial. The body-fixed pointing directions of the antennas are assumed to be:

Antenna Position	ID	Pointing Direction		Body-fixed Unit Vector		
		zenith	azimuth	x	y	z
Front/Port	1	11.8°	-30°	0.1771	-0.1022	-0.9789
Front/Starboard	2	11.8°	30°	0.1771	0.1022	-0.9789
Back/Port	3	9.5°	-30°	0.1429	-0.0825	-0.9863
Back/Starboard	4	9.5°	30°	0.1429	0.0825	-0.9863

Note: the x direction is forward, the y direction is to starboard, and the z direction is down.
Note: antenna 2 is currently reserved for the JPL GPS experiments while antennas 1, 3, and 4 will feed the three GPS/INS units.

4) The antennas are assumed to have two possible cone angles: 120° and 150°. There is assumed to be no masking of the antenna field of view by the body of the vehicle or any other object other than the Earth's disk.

5) The orbital parameters for the GPS constellation are those from the Yuma almanac for week 784. During the 476 second flight, the actual positions of the GPS satellites in an Earth-fixed system change very little although there will be significant changes from one hour to the next.

6) To consider the effect of the time of day, 24 scenarios were considered with launch occurring at the beginning of every hour (0000 to 2300).

Software Tools

The truth trajectory for the X-33 was generated using MAVERIC in 3 DOF mode. A file of time, position, velocity, acceleration, and attitude was generated at one second intervals from 1 second after launch to 476 seconds after launch.

The parameters associated with the coverage analysis were computed using GPS-RCM (GPS Digital Statistical Receiver and Constellation Model) which simulates GPS measurements along a user specified trajectory and using user specified information about receiver characteristics, environmental parameters, and antenna characteristics. Currently, GPS-RCM is capable of simulating two receivers each on separate trajectories with up to 12 channels and 4 antennas per receiver. Options in GPS-RCM include the capability to compute navigational solutions using a Kalman filter or using a static positioning approach.

Results

Since the receiver under consideration has only five channels and exports data from only four of these channels, the optimal (minimum possible) GDOP is selected from the set of all possible GDOP values computed using permutations of four GPS satellites selected from the set of all GPS satellites within the field of view of the antenna. No assumption is made as to whether or not the receiver has locked onto the satellites which produce the optimal value. The GDOP corresponding to the measurements exported by the receiver will depend on which satellites the receiver is actually locked onto as opposed to which satellites are in the field of view. The satellite selection algorithm employed by the receiver and the time required to lock onto a satellite once it comes into the field of view (lock delay interval) will result in some degradation of the GDOP of the exported data when compared to the optimal GDOP.

A profile of optimal GDOP values was generated for each combination of time of launch, antenna position, and cone angle. For each profile, the number of optimal GDOP values in the following groups were counted: (0-5), (5-10), (10-20), (> 20), and (no GDOP available: < 4 GPS satellites in the field of view). It is noted that when only 4 GPS satellites are considered, the minimum possible value of GDOP is approximately 1.57; thus the lower limit of the first group in Tables 1 and 2 should read 1.57 rather than 0. Tables 1 and 2 show the distribution of GDOP values for antenna 1 using cones angles of 120° and 150°, respectively.

For a maneuvering vehicle that is carrying a GPS receiver, the number of satellites that the receiver is able to lock onto at any time is a critical parameter in evaluating the effect of the satellite cone angle and the lock delay interval on the overall navigational performance. The actual satellites that are locked onto will depend on the particular satellite selection algorithm. For the following results, the receiver is initialized by locking onto all satellites within the field of view at the start of the trajectory. If more than five satellites are visible at the start of the trajectory, the satellites are selected in terms of their usefulness in reducing the value of the GDOP. After initialization, the receiver locks an open channel onto the next GPS satellite that has been in the field of view beyond the lock delay interval. Once a channel has been locked onto a particular GPS satellite, it remains locked on that satellite until the GPS satellite is no longer in the field of view. This approach tends to maximize the number of locked channels rather than minimizing the GDOP of the primary GPS satellites. From this information, two parameters which measure the quality of GPS coverage are the total time during which fewer than four channels are locked on GPS satellites and the maximum duration during which there are fewer than four locked channels. Figures 1 and 2 show these two parameters for antenna 1 using cone angles of 120° and 150° respectively.

Conclusion

Despite the general improvement in reducing the optimal GDOP values with a cone angle of 150° over the corresponding cases for a cone angle of 120°, there are still some periods during the day in which the GPS coverage is significantly degraded with high GDOP values and/or less than 4 GPS satellites visible. Also, despite the general improvement in increasing the number of locked channels with a cone angle of 150° over the corresponding cases for a cone angle of 120°, there are still some significant periods during which the number of locked channels is 3 or less. Even with a cone angle of 150°, these periods range from 1 second to as much as 51 seconds and generally occur around the times of maneuvers when the GPS satellites can quickly disappear from the field of view and before other GPS satellites can be acquired. However, some of these instances are also due to launch or near launch conditions when the antennas are pointing toward the horizon.

Table 1
Percentage of epochs for the minimum possible GDOP:
Antenna 1 with a 120° Cone Angle

Launch Time (hour)	GDOP Range 0-5	5-10	10-20	> 20	< 4 sat
00	4.2	32.4	24.4	3.6	35.5
01	6.7	32.6	28.2	4.8	27.7
02	9.2	45.5	17.9	2.7	25.2
03	0.2	76.3	0.0	4.4	19.1
04	0.8	36.8	0.0	17.6	44.7
05	17.6	39.1	4.8	0.0	38.4
06	4.4	64.9	0.0	1.1	29.6
07	1.1	62.2	11.6	2.7	22.5
08	15.1	23.1	20.4	3.6	37.8
09	2.3	51.9	3.4	3.6	38.9
10	1.1	38.2	17.2	9.2	34.2
11	5.9	65.8	2.9	0.8	24.6
12	5.5	29.4	23.9	2.7	38.4
13	9.9	42.6	23.9	0.1	17.4
14	10.5	43.7	17.9	2.3	25.6
15	0.0	74.6	0.0	4.8	20.6
16	0.6	34.7	0.0	17.9	46.8
17	19.3	30.7	12.4	0.0	37.6
18	5.0	61.8	0.0	0.0	33.2
19	1.1	72.7	8.0	1.5	16.8
20	11.8	21.8	23.1	4.2	39.1
21	1.7	49.4	6.3	3.6	39.1
22	1.5	36.6	17.0	10.3	34.7
23	5.9	63.9	2.7	0.6	26.9

Table 2
Percentage of epochs for the minimum possible GDOP:
Antenna 1 with a 150° Cone Angle

Launch Time (hour)	GDOP Range 0-5	5-10	10-20	> 20	< 4 sat
00	81.9	12.2	5.9	0.0	0.0
01	73.9	10.7	15.3	0.0	0.0
02	55.7	26.1	8.2	0.0	10.1
03	61.1	38.9	0.0	0.0	0.0
04	32.1	46.8	0.0	0.0	21.0
05	69.3	23.5	0.0	0.0	7.1
06	58.6	31.1	0.0	0.0	10.3
07	51.9	36.6	11.6	0.0	0.0
08	67.4	23.3	6.7	2.5	0.0
09	39.7	34.5	13.4	0.0	12.4
10	60.9	17.4	15.8	0.0	5.9
11	65.1	25.6	0.0	0.0	9.2
12	81.3	11.6	7.1	0.0	0.0
13	88.4	5.7	5.9	0.0	0.0
14	55.9	25.6	8.2	0.0	10.3
15	59.9	40.1	0.0	0.0	0.0
16	39.5	40.8	0.0	0.0	19.7
17	64.1	28.2	1.7	0.0	6.1
18	55.9	33.4	0.0	0.0	10.7
19	56.1	41.6	2.3	0.0	0.0
20	69.1	20.6	6.3	4.0	0.0
21	38.4	35.1	14.3	0.0	12.2
22	65.3	13.0	14.3	0.0	7.4
23	63.0	27.7	0.0	0.0	9.2

Figure 1
Antenna 1 with a 120 degree cone angle

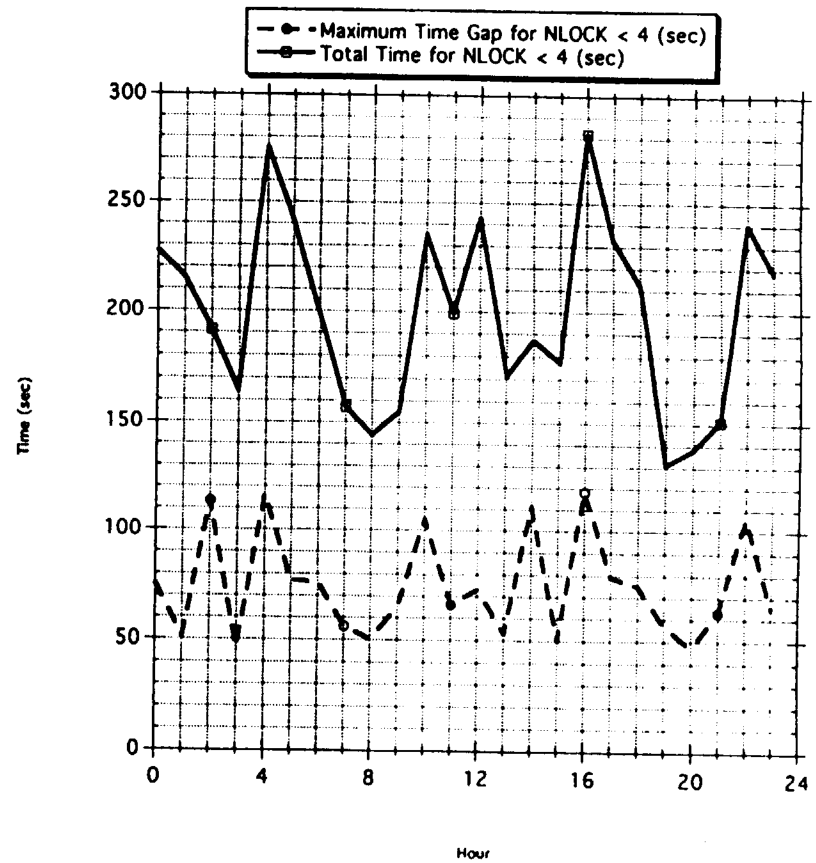

Figure 2
Antenna 1 with a 150 degree cone angle