APPENDIX D

Sensitivity of GPS Coverage to Loss of One or More Satellites
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Navigation satellites have become an immensely important asset to the United States military. Not only do U.S. ships, aircraft, and land forces use them extensively to determine position, U.S. "smart bombs"-an increasingly important aspect of U.S. power projection policy-rely on them to precisely hit both strategic and tactical targets in urban centers. If a foreign power were to eliminate this space asset, it could cause significant problems for our forces. The GPS/NAVSTAR constellation is, however, very robust both because of the altitude (roughly 20,000 km, high enough that it takes twelve hours for each satellite to complete one orbit) and the large number of satellites used, a total of 24.

This is illustrated in the figure below, which shows a snapshot of the GPS/NAVSTAR coverage over Beijing, China. The second figure below shows how many navigation satellites are visible from Beijing during a 24 hour period-the time it takes both the satellite constellation and the Earth to return to the same alignment. It takes a minimum of four satellites in view of a GPS receiver, such as one in a JDAM[2] equipped bomb, to determine the user's position. Of course, the accuracy of the position-determination increases if more satellites can be used and the accuracy also depends on the geometry of the satellites at the time; the optimum geometry has at least three satellites spread evenly along the horizon and the fourth directly overhead. Nevertheless, as the figure shows, an adversary can destroy a significant number of satellites and the United States would still have full coverage for a significant fraction of the day. In fact, if six satellites are destroyed the coverage only drops below the minimum number of four visible for roughly two hours. (These six satellites were not chosen randomly but were, in fact, chosen because their elimination would be the most effective at removing GPS/NAVSTAR coverage over Beijing.) The final report will include an analysis of how much the system's accuracy is degraded over those periods when the number of satellites is four or more but less than the standard constellation.

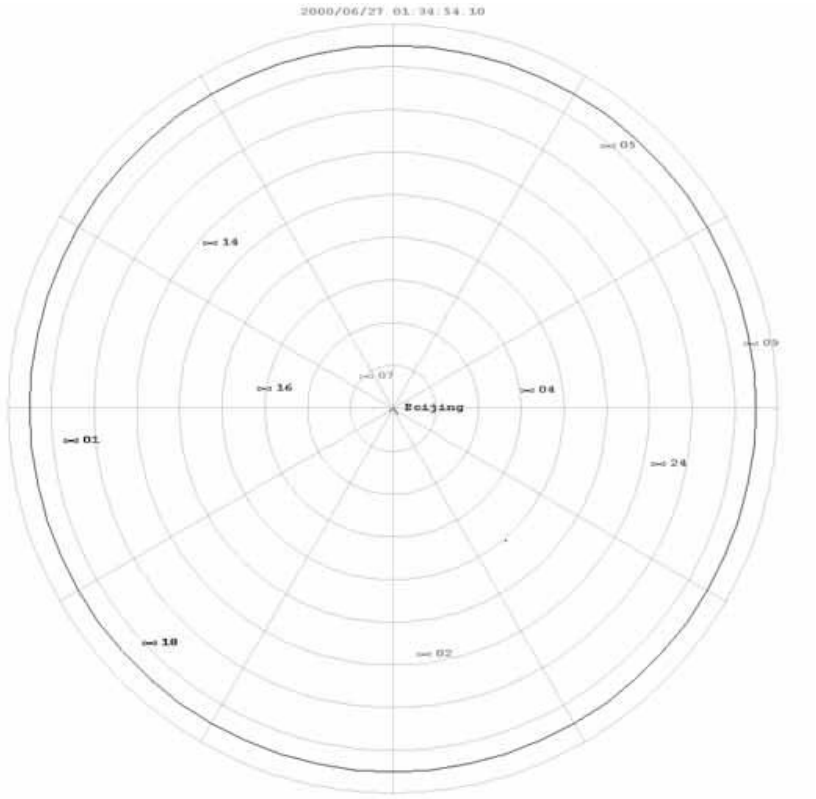

Fig. 6. View, looking up from the center of Beijing, of the GPS/NAVSTAR constellation of satellites. The rings represent elevation above the local horizon and the radial lines represent azimuth. The dark line near the outer radius is the 5 degree minimum elevation to be used in a position "fix."

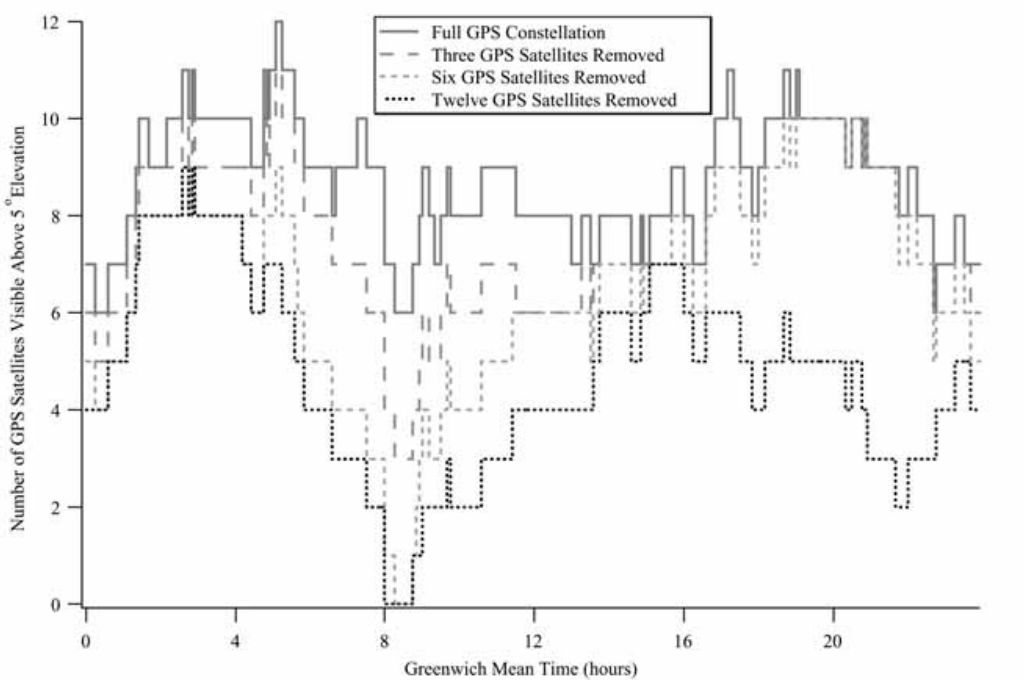

Fig. 7. GPS/NAVSTAR coverage over Beijing with the full constellation, three, six, and twelve satellites removed