10 Orbit and Constellation Design—Selecting the Right Orbit

10.2.1 Evaluating Earth Coverage

10.2.1.6 Coverage Analysis Example

James R. Wertz, *Microcosm/USC*

The purpose of this section is to provide a detailed example of how we might go about analyzing a particular coverage problem. Our example problem is to provide observations of the island of Haiti in the Caribbean at an elevation angle greater than 25 deg, while simultaneously being in contact with a ground station located on Wallops Island, VA, at an elevation angle greater than 5 deg. We would like to do this with a satellite in a circular orbit at an altitude of 850 km and an inclination of 65 deg. The general objectives for the problem are shown in Fig. 10web-1. What we would like to find out is not only whether or not the problem can be done but how much coverage we will have, how sensitive that coverage is to the various orbit or ground station parameters, and how we might be able to redesign either the problem or the orbit in order to provide better coverage.

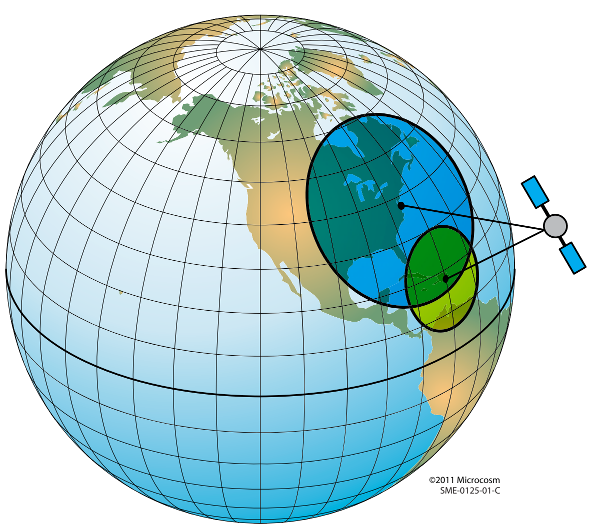

Fig. 10web-1. The Wallops/Haiti Coverage Example. We would like to determine how difficult it would be to photograph Haiti at an elevation angle greater than 25 deg while simultaneously communicating with Wallops Island at an elevation angle greater than 5 deg. See text for discussion.

We begin by computing the angular radius of the Earth and maximum Earth central angle from Table 8-11 as:

$$\rho = 61.93 \text{ deg} \tag{10web-1}$$

$$\lambda_0 = 28.07 \text{ deg} \tag{10web-2}$$

We then compute fundamental coverage parameters for Wallops Island (W), again using the equations from Table 8-11.

$$\varepsilon_{min,W} = 5 \text{ deg} \tag{10web-3}$$

$$\lambda_{max,W} = 24 \text{ deg} \tag{10web-4}$$

$$\eta_{max,W} = 61.62 \text{ deg} \tag{10web-5}$$

and for Haiti (H), the same set of equations yield:

$$\varepsilon_{min,H} = 25 \text{ deg} \tag{10web-6}$$

$$\lambda_{max,H} = 12 \text{ deg} \tag{10web-7}$$

$$\eta_{max,H} = 53.27 \text{ deg} \tag{10web-8}$$

We use the above data to construct Fig. 10web-2, which shows a representative coverage pass near the descending node, which sees both Wallops Island and Haiti. For several positions along the ground track we have drawn the coverage circles for both locations. The dashed outer circle is the maximum coverage area for communicating with Wallops, and the solid inner circle is the limit for observations of Haiti. Note that at the upper time step we have begun to communicate with Wallops Island, but are still well away from Haiti. At the middle time step, Haiti is beginning to come into view within the observation limit, and we can still communicate with Wallops, although it is behind us. In the third step, Haiti is leaving the observation region, though we lost contact with Wallops Island some time ago.

Fig. 10web-2. Motion of the Spacecraft Along the Orbit Showing Visibility Regions for Both Haiti (Solid Circle) and Wallops Island (Dashed Circle).

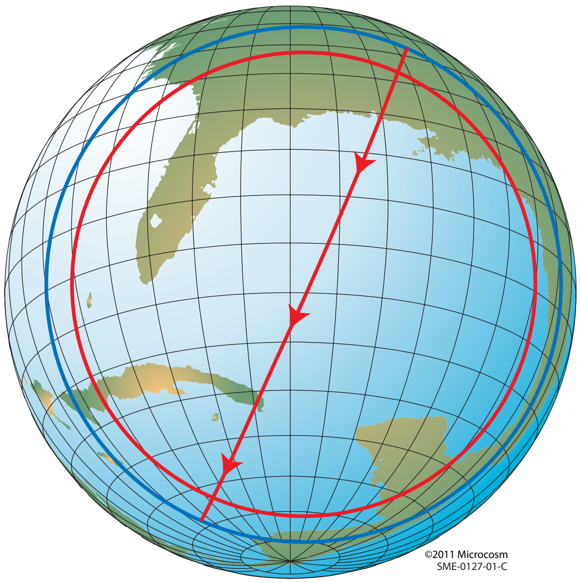

Fig. 10web-3. View from the Spacecraft at the Time of the Center Plot in Fig. 10web-2. Haiti is just coming into view on the forward horizon and Wallops is near the horizon, but still within communications range near the rearward horizon.

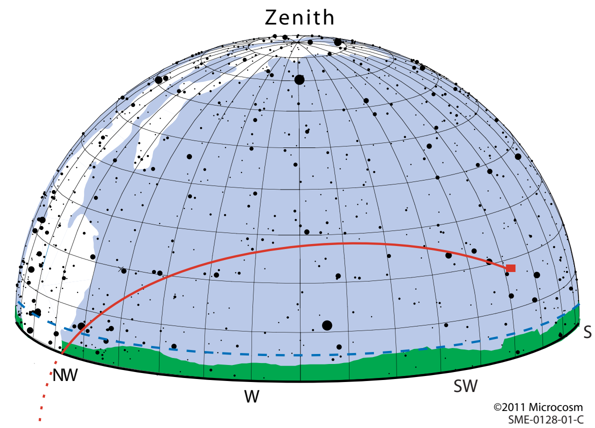

Fig. 10web-4. View from Wallops Island at the Time of Fig. 10web-3. The satellite has passed its highest point and is on the way down as it begins to see Haiti.

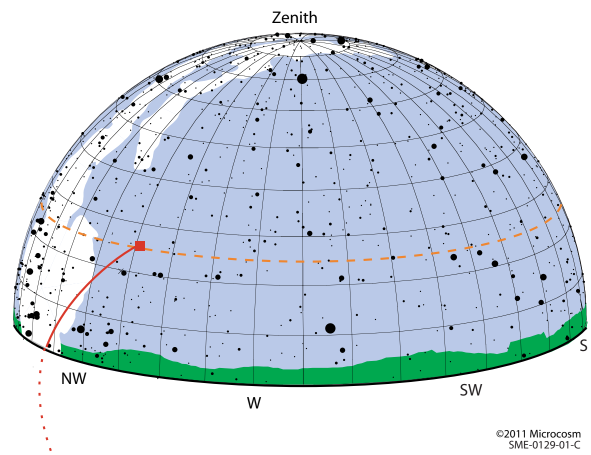

Fig. 10web-5. View from Haiti at the Time of Fig. 10web-3. Here the satellite is just rising over the 25 deg effective horizon. By the time the satellite reaches its highest point, Wallops Island will no longer be visible to the satellite.

Figure 10web-3 shows the mission geometry as seen from the spacecraft for the central time step in the previous figure. The spacecraft is now approximately midway between Florida and Cuba. The outer circle represents the angular radius of the Earth at 61.93 deg. Just inside of that is a circle almost touching it which shows the limit at which we can communicate with Wallops. Clearly observations at that distance where foreshortening is so dramatic would not be possible, but communications are acceptable. (See Sec. 8.6.2.) The inner circle is the 25 deg elevation angle curve at which we can begin observations. In this particular plot, Haiti is just coming into view within the observation limit. We could no longer observe Wallops but it is still well within our communications band for at least a brief period.

Figure 10web-4 shows the geometry at the same time as viewed from the Wallops Island ground station. Here the path of the satellite is plotted against the background of the stars in the Milky Way. Notice that the satellite has long since passed its peak elevation and is heading toward the horizon, although we're still well above the 5 deg elevation angle limit for communications. Figure 10web-5 shows the same information as viewed by an observer on Haiti. Here the satellite is just passing the 25 deg elevation angle limit for observations and will be above this limit for some time to come. We can make use of these plots to understand the observation and communications geometry as seen on the surface of the Earth, from the perspective of the satellite, and from the perspective of the communications station at Wallops Island, and the observation area in Haiti.

Figure 10web-6 provides a method of analyzing the orbit geometry and coverage characteristics for this problem. We have drawn a circle of 24 deg radius around Wallops Island representing all possible subsatellite points where we're in potential communication with Wallops. Similarly, we have drawn a circle of 12 deg radius about Haiti indicating the subsatellite points for which Haiti can be observed within the observation limits. The overlap between the two is the shaded region in which we can simultaneously observe Haiti at an elevation angle above 25 deg and communicate with Wallops at an elevation above 5 deg. We have also shown a representative orbit pass near the descending node for our satellite. At point A, Wallops comes into view for communications. At point B, Haiti comes into view for observation. At C, we lose the capacity to communicate with Wallops, and at point D, Haiti goes out of observation range.

Simulations can provide a detailed numerical assessment of how well our problem works. However, we can gain a high level of physical insight by simply examining the ground track plot in Fig. 10web-6. For the geometric

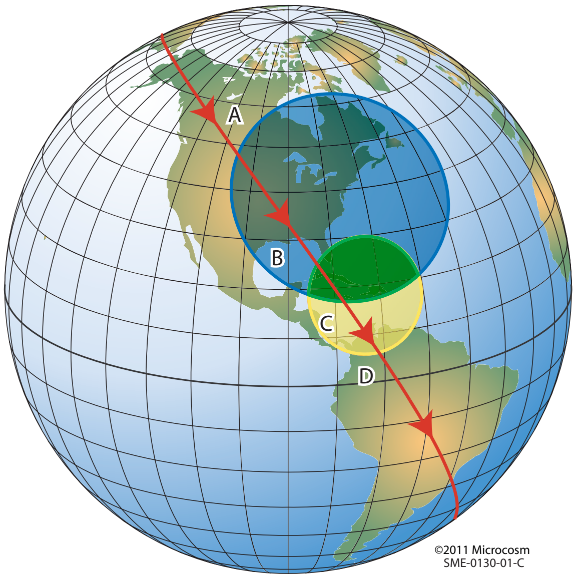

Fig. 10web-6. Coverage Analysis of the Wallops Island/Haiti Problem. See text for discussion. Plots of this type provide a very powerful analysis tool and are very easy to generate.

conditions shown, approximately 60% of the time that Haiti can be observed, we can also be in communication with Wallops Island. Irrespective of where the descending or ascending nodes occur, we will have somewhat more than half of the observation time available to us on any orbit for which observations can occur. Consequently, this appears to be a workable geometry for the problem that we have defined.

By examining Fig. 10web-6, we can determine not only the extent to which the problem can be done, but the impact of changing virtually any of the parameters. For example, if we increase the minimum elevation angle for observation, we will reduce the coverage circle centered around Haiti and will have less total observation time available. Nonetheless, we will continue to have the same or more percentage contact time with Wallops. As another example, if we move the ground station from Wallops Island to Chicago, we will significantly reduce the amount of overlap but we will still have some on most orbits. However, for some orbits in the vicinity of the ascending node the satellite would be able to slip past such that observations could be made but communications were not possible. If we move the ground station from Wallops to Los Angeles, then the two regions will not overlap and irrespective of the orbit there will be no position of the spacecraft for which we are able to both observe Haiti and communicate with Los Angeles simultaneously. By closely examining Fig. 10web-6, we can determine the impact of varying essentially any of the defining parameters of the problem. We can understand what makes the problem work and not work, and how to go about adjusting the parameters so as to provide better coverage or to cover other scenarios as well. This is indicative of the substantial power available from relatively straightforward analytic and plotting techniques.

Finally, Fig. 10web-7 shows the results of a coverage simulation run for our example. The two tombstone plots represent observations of Haiti and communication with Wallops, and, of course, the overlap region between them is where both are possible, simultaneously. This provides a good assessment of the timelines, and allows us to evaluate time intervals between coverage periods. It shows us how many observations we will have in the course of a day, and approximately how they will be distributed. It does not, however, provide the same level of insight as Fig. 10web-6 as to the impact of changing the defining parameters or varying any of the conditions of observation. Each type of analysis is useful, and together they can provide strong mechanisms for evaluating satellite coverage.

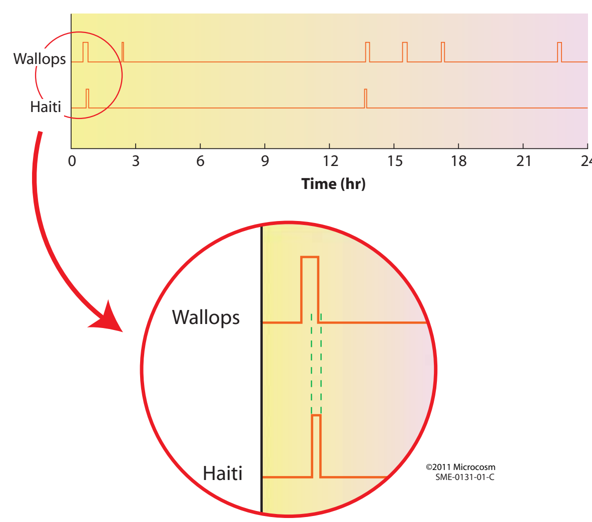

Fig. 10web-7. Results of a Coverage Simulation Run for the Example Problem.