ROCSAT-3 Constellation Mission

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Abstract

ROCSAT-3 mission is an international collaboration of Taiwan and the United States to deploy in 2005 a constellation of six microsatellites equipped with GPS occultation receivers in low Earth orbits to collect the GPS signal as passing through the atmosphere. The satellites would generate thousands of sounding data everyday uniformly distributed over the world. The satellites will then downlink the GPS occultation measurements to the ground receiving stations for processing and assimilated into the weather forecast model with minimal delay. The design of ROCSAT-3 constellation takes into consideration factors such as the capability of the available launch vehicle, the mass of the propellant, the locations of ground receiving stations, and the deployment period to achieve the final constellation.

The six ROCSAT-3 satellites will be delivered by a single Minotaur launch into the same orbit plane initially. The dispersion of the satellites into the target constellation utilizes the principle that satellites at different altitudes will precess into different orbits over the time. By adjusting the altitude profiles, the six ROCSAT-3 microsatellites would be placed into six orbit planes. Considering ionospheric research, the fuel constraint, and the launcher lifting capability, the mission orbit of 800 km is selected. The inclination angle of 72 degrees is selected as the results of the trade studies involving the location of receiving stations and the precession rate of the orbit. The dominant factor in the selection of the separation angle among orbit planes is the requirement of distribution of the sounding data uniformly. With the constraint of the deployment period, the separation angle is currently defined as 24 degrees. Furthermore, in order to minimize the downlink confliction among satellite passes at the ground stations, a true anomaly separation of 52.5 degrees between satellites in adjacent orbit planes is selected.

The mission life of ROCSAT-3 is 2 years. The constellation will be achieved 13 months after launch. An early phase mission plan has also been developed for the deployment period when the satellites are at lower altitudes. At altitude below 500 km, a pitch-biased attitude control can be used to point either the forward or aft occultation antenna at the desired angle for conducting the experiment.

Introduction

ROCSAT-3 mission, also known as COSMIC (Constellation Observing Systems for Meteorology, Ionosphere, and Climate), is the third project of ROCSAT series furbished by National Space Program Office at Taiwan, ROC. It is an international collaboration of Taiwan and the United States and will be launched in the second half of 2005. The goal of this mission is to deploy a constellation of six microsatellites to collect atmospheric remote sensing data for improvement on weather prediction, and for ionosphere, climate, and geodesy research. There are three payload instruments on-board of ROCSAT-3 spacecraft. The primary one is the GPS occultation experiment receiver (GOX); the tri-band beacon (TBB) and the tiny ionospheric photometer (TIP) are secondary payloads.

As GPS signal passing through the atmosphere, it is retarded and bent. The information of atmospheric pressure, temperature, and water vapor are then can be retrieved from the bending angle. Therefore, to ROCSAT-3 GOX measurements, one occultation event is corresponding to one profile of atmospheric sounding. ROCSAT-3 constellation would collect about 2500 sounding data everyday uniformly distributed over the world. The satellites will downlink the occultation measurements to the ground receiving stations every revolution for processing and to be assimilated into the weather forecast model with delay of 50 minutes.

The six spacecraft will be placed into the same initial orbit by a single Minotaur launch. With each satellite carrying propellant to raise itself to different altitude, a constellation with global coverage is expected be achieved 13 months after launch due to different orbital precession rates.

Trade Study on Final Constellation

The design of ROCSAT-3 constellation takes into consideration factors such as the capability of the available launch vehicle, the mass of the propellant, the locations of ground receiving stations, and the deployment period to achieve to the final constellation.

In order to have better data for ionospheric research, the altitude of orbit should be at 700~1000 km. The launcher lifting capability can inject the satellite suite to 500 km. The fuel loaded on satellite can support orbit raising of 300 km. The final orbit of 750~850 km is then selected.

In order to have polar cap coverage for ionospheric research, the inclination angle should be higher than 70 deg. Since Fairbanks (148 deg W, 65 deg N) and Kiruna (21 deg E, 68 deg N) have been chosen as the receiving stations, the inclination lower than 70 deg will cause the receiving station acquire less than 90% of orbit revolutions from the satellite.

However, higher inclination will make the project takes longer time for constellation deployment. Figure 1 shows the relationship of inclination with percentage of orbit coverage and with the duration of constellation deployment. Considering high inclination may cause (1) constellation drift duration longer and (2) the lift capability of launcher worse, inclination of 72 deg is chosen as the mission goal.

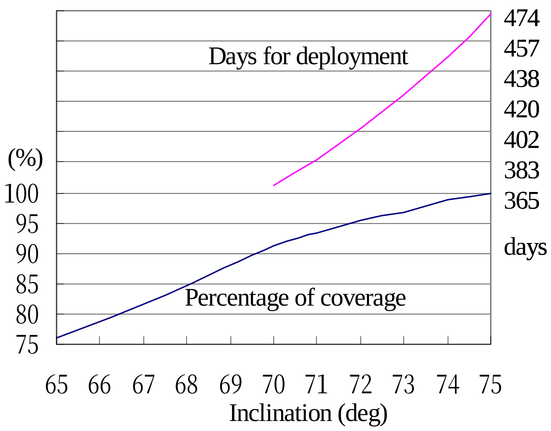
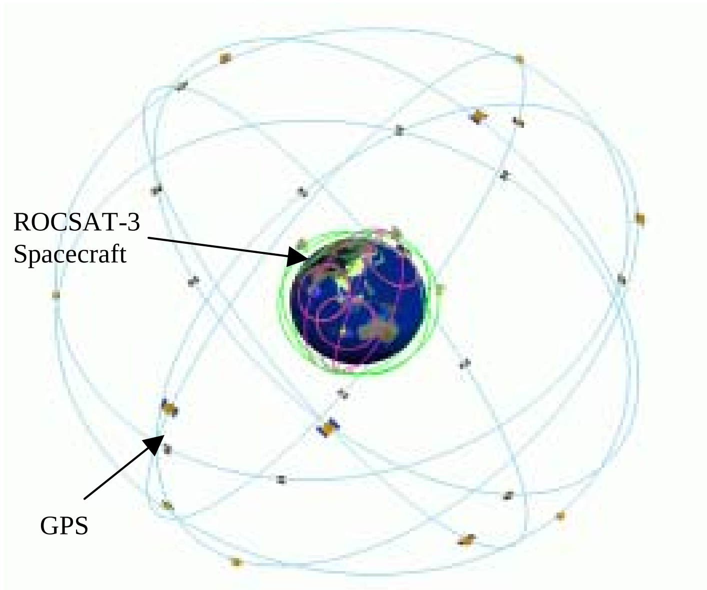


Figure 1. Inclination Trade

The dominant factor on the selection of the separation angle among orbit planes is the requirement for uniform distribution of the sounding data. With the constraint of the deployment period of 12 months and the propellant load with 300-km lifting capability, the first raised satellite and the last raised satellite can be separated by 120 deg in right ascension of ascending node (RAAN) at most. Therefore, the separation angle among orbit plane is currently defined as 24 deg.

Furthermore, in order to minimize the downlink confliction among satellite passes at the ground stations, the separation of argument of latitude between satellites in adjacent orbit planes is 52.5 degrees. Figure 2 shows a cartoon for ROCSAT-3 constellation mission.



ROCSAT-3 Final Constellation:
Altitude: 750 km ~850 km.
Inclination: 72 deg.
Orbit planes: 6 orbit planes, 24 deg separation.
Argument of latitude: 52.5 deg separation.

Figure 2. ROCSAT-3 Constellation

Constellation Deployment

The satellites will be separated one by one into same injection orbit. Then the satellites will perform orbit transfer to different altitudes in order to get into separate orbital planes through the nodal precession.

The nodal precession is a well-known gravity phenomenon that the orbital plane drifts (i.e. RAAN precesses) due to the Earth oblateness.

Assuming inclination angle of 72 deg and the eccentricity of 0, the constellation deployment ($\Delta\Omega$ in degree) can be expressed by

$$\Delta\Omega \cong -6.3804\times10^{13}\,\Delta(a^{-7/2})\cdot\Delta t$$

where a is semi-major of orbit altitude in km and Δt is deployment time period in day.

The strategy of deployment is to use the first raised spacecraft as the reference, the second spacecraft will be raised to its mission orbit when the difference of right ascension of ascending node between the first and the second spacecraft is 24 deg. The third spacecraft will be raised when the difference of right ascension of ascending node between the first and third spacecraft is 48 deg, and so forth. Figure 3 shows an example of constellation deployment timeline, assuming the injection orbit is 475 km.

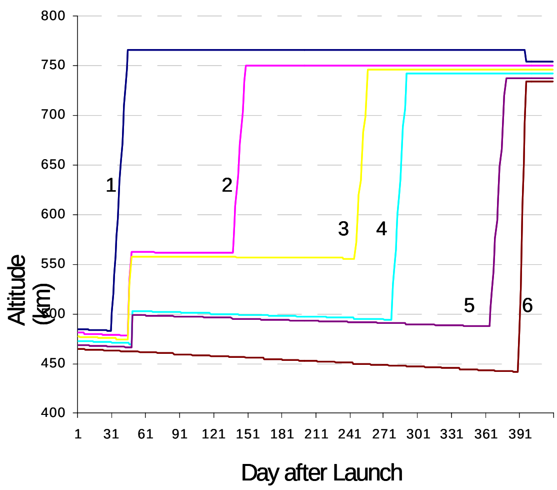


Figure 3. Constellation Deployment

One may notice that the first satellite is raised higher than final altitude then it would be lower down at the end of constellation deployment. The benefit for doing this is to accelerate the deployment and balance the fuel loading since the sixth would suffer a lot from air drag.

In order to accommodate the geodesy research on high order harmonics of the geopotential from the GPS data, two pairs of spacecraft at the same altitude are designed. The tandem of satellite is separated by 200~400 km. From the example shown above, the second & the third spacecraft have about 90 days and the fourth & the fifth spacecraft have about 230 days to perform the study.

Occultation

The number of occultation is heavily dependent on the antenna field of view (FOV) characteristics of the GPS instrument and altitude of the orbit.

A case study shows that the total occultation number is 2763 per day at altitude 750 km assuming six ROCSAT-3 spacecraft and twenty-eight GPS functioning. The distribution is shown in Figure 4.

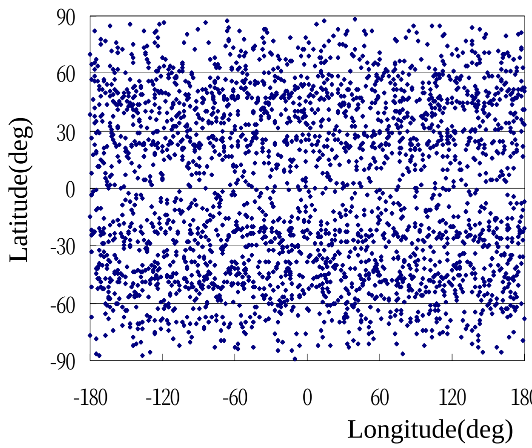
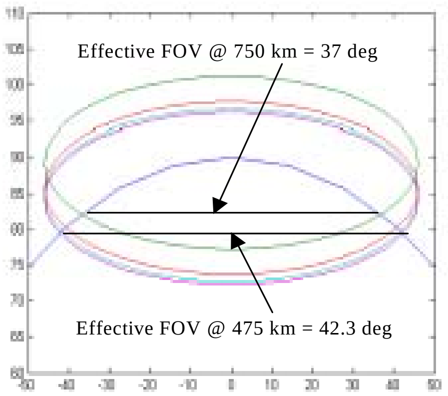


Figure 4. Occultation Distribution at Day 400

Thinking of a mission with life of two years with twelve months spending on constellation deployment, one may ask how is the occultation collection during the constellation deployment. A study is performed at day 100, day 200, day 300, day 400 corresponding to Figure 3. At day 100, there are two pairs of tandem; at day 200, there is one pair of tandem. At day 300, four satellites have reached final orbit and two satellites still stay at different parking orbits. Day 400 is a case for final constellation.

In order to simplify the study, the field of view of the GOX receiver is assumed as an eclipse. The effective FOV is different when spacecraft is at different altitudes. Figure 5 provides the illustration of effective FOV and a summary on FOV at parking orbits. At attitude of 475km, although the FOV is wider, it has 20% possibility to be blocked by the solid earth itself because the disturbance of low orbit makes attitude control harder.



Altitude (km)	Effective FOV (deg)
750	37
550	40.9
500	41.8
475	42.3

Figure 5. Effective FOV

Figure 6, 7, 8, 4 show the occultation distribution at day 100, day 200, day 300, day 400, respectively. The total number of occultation is about 2700~2800 per day. However, the patterns of occultation distribution look different. Thinking of spacecraft flying in tandem for geodesy research at the early stage of constellation of deployment, two ROCSAT-3 may observe the occultation with close location. Therefore, if one compares the occultation grid (which is a 2 deg latitude x 2 deg longitude), the number is increasing as the constellation approach their final constellation as shown in Table 1.

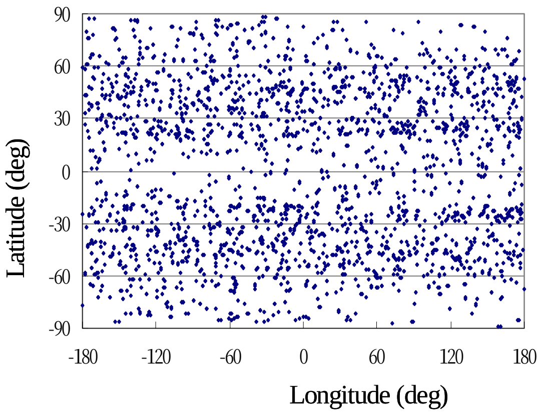


Figure 6. Occultation Distribution at Day 100

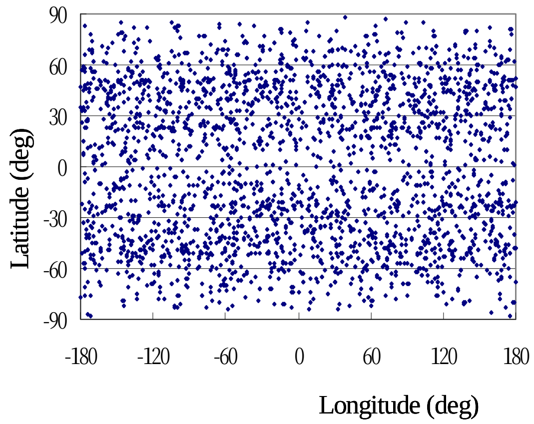


Figure 7. Occultation Distribution at Day 200

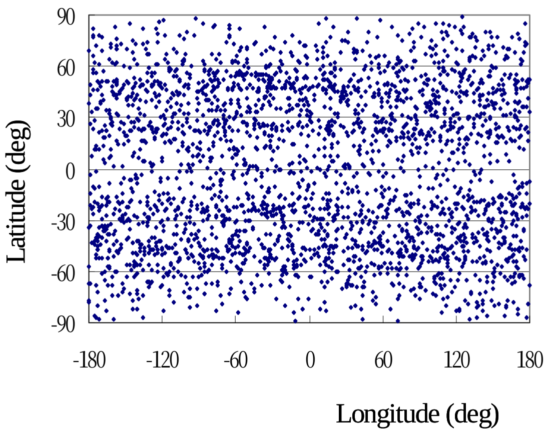


Figure 8. Occultation Distribution at Day 300

Table 1. Occultation Number and Sounding Grid

Days after launch	Total occultation number per day	Sounding grid per day
100	2871	1735
200	2755	2011
300	2729	2360
400	2762	2496

In Table 1, the occultation grid is calculated based upon 200 km of tandem separation. To have closer look on the impact of tandem separation to the number of sounding grid, Table 2 provides the summary.

Table 2. Sounding Grid per Day

Day after launch	Tandem separation by 0 km	Tandem separation by 200 km	Tandem separation by 400 km
100	1590	1735	1854
200	1943	2011	2067

The result is as expected, the furtherer the tandem separation is, the more the sounding grid is. In summary, taking consideration of sounding grid, the parking orbit can achieve more than 68% of final orbit mission. As time going by, the situation would be better off. In other words, valuable measurements are available for science community to study once the spacecraft have completed the checkout.

Conclusion

ROCSAT-3 is a constellation mission. The goal of the mission is to generate a "uniform" distribution of atmospheric sounding on daily basis to improve the accuracy of weather forecast. Constellation is the only solution to this mission. To achieve the goal of "uniform", six orbit planes with 30-deg separation in RAAN is best choice. However, under the constraint of limited resources, the most optimized constellation design is to phase the spacecraft in six orbit planes with 24 degree apart in RAAN. The configuration can generate 2500 sounding grids among 2700 occultation events per day. Time effectiveness is another important consideration for constellation design. The collected measurements on-board spacecraft need to be sent to the processing centers on the ground timely to fit into the weather prediction model. A 52.5-deg phasing on argument of latitude is applied to make sure one-orbit worth of measurements can be sent to the receiving stations.

The mission performance at parking orbit is also studied. The mission plan of ROCSAT-3 is to operate the payload even at constellation deployment phase as far as there is no orbit raising activities. The mission can be exercised 68% in terms of sounding grids at the beginning of constellation deployment. The number of sounding grids can also be improved if the separation of tandem is furtherer.

Finally, if one wants to enhance the mission at parking orbit, it is recommended to apply a pitch bias to satellite at low orbit. Since the occultation antennas are installed at fore and aft of satellite. If one needs to measure the high gain occultation, which is applicable to moister atmosphere, the disturbance of low orbit may make the measurement by chance. The biased pitch can guarantee one of them can take the observation. Therefore, the mission becomes more controllable.

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