TIME CRITICAL TARGETING USING RESPONSIVE TACTICAL SATELLITES

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A key enabler for responsive space is the capability to respond to unanticipated needs in any geographical theater in a timely fashion. The CONOPS and utility for Unmanned Aerial Vehicles (UAVs) have become critical assets in addressing tactical military targets in a responsive manner. In current military operations, UAVs are deployed to specific theaters of ongoing operations. However, when an unexpected national security event of interest occurs, UAVs can not provide the same capability to any location on the globe within hours. Additionally, UAVs may have further restrictions for airspace overflight of certain areas of interest. However, the migration of UAV CONOPS to space could "re-locate" an asset to any geographical theater within hours. This paper will discuss the utility and technical feasibility of pre-deployed tactical satellites to achieve responsive space missions and needs.

Scenario

A high value target on the ground is identified via intelligence sources. A military plan is required to respond appropriately to the target. The tactical plan requires time critical targeting information for pre-mission operations which include imagery and other intelligence data. There are no airborne sensors in-theater to support the mission within the desired timeline.

The theater commander requests a capability to employ an imagery sensor to provide mission support to a forward unit, within 4-8 hours.

Concept

A concept of operations for this solution utilizes knowledge and information about the orbit of a rapid response satellite. An in-theater soldier utilizes an existing chat tool (e.g. Instant Messenger in the commercial world) for computing the window of opportunity for the in-theater soldier to know precisely when an overhead responsive satellite would available to image an area of interest. The same device used to request the overhead satellite could also receive the imagery or other data via e-mail from the satellite as it passes overhead. Data is downloaded from responsive space satellite to handheld device with Time Critical Targeting information (e.g. imagery, lat/long coordinates, etc). Alternatively, the device could be outfitted to upload tasking commands of known targets for imagery collection. The collection tool computes the precise time of collection opportunity and this start/stop time is uploaded in the tasking plan. This concept combines disparate existing technologies. This also requires appropriate and adequately precise modeling of the satellite orbit and management of the maneuvering plan to achieve the desired mission.

Summary
The technology to plan, compute, and execute precise collection opportunities utilizing responsive tactical satellites can be achieved with satellite orbits and maneuvers that optimize overflights of desired targets. Optimized overflights increase the Time Over Target and provide the target collection with an increased response time. Responsive space concepts can be achieved prior to launching new systems. By implementing unique modeling, simulation & analysis techniques with existing space platforms and within existing satellite systems – tactical data from space platforms can be delivered in a responsive timeframe. Responsive space concepts can have civil and military utility and can be enhanced with dedicated responsive space platforms.

Repeating ground-track orbits have been proposed in support of responsive space. One type of repeating ground track orbit is an elliptical orbit with a period of about 2.66 hours, such that the spacecraft passes over 9 different longitudes on the Earth, each twice a day, once at perigee, and once at apogee. These orbits are shown in Figures 1 and 2, in the Earth-Inertial coordinate frame, and in the Earth-Fixed coordinate frame, respectively.

With this type of orbit, relatively small maneuvers at perigee can change the orbit period sufficiently that in only a few days any location on Earth can be overflown. For this study we allocated 3 days from the maneuver to the overflight.

By adjusting the perigee maneuver, the overflight time can be changed to arrive early or arrive late. This has several advantages. It allows a collection to be taken at a desired elevation angle and allows the time of day to be changed to alter the shadow or to surprise the target of interest which negates the ability to hide or conceal activities or events from satellite collection – also known as denial & deception. Figure 3 shows a nominal overflight orbit over Baghdad, as well as an orbit that arrives 2 hours early. Notice that the early orbit will perform it's collection at an oblique angle compared to the 90 degree elevation angle for the nominal overflight. The tick marks on the orbits are at 5 minute intervals.

The orbit we used had the following orbit elements:

Semimajor axis	9751 km
Eccentricity	0.276
Inclination	85 degrees
Argument of Periapsis	0 degrees

The Right Ascension of the Ascending Node and the True Anomaly are somewhat arbitrary in this case, although the selection of the node will govern the nominal Δ-V needed to perform an overflight. For this orbit, nine longitudes will require no Δ-V for the desired overflight.

We performed a parametric study of the maneuvers needed to change the overflight time, as well as the restoration maneuver needed to return the orbit back to it's original repeating ground-track (to support subsequent operations.) These trajectories were numerically integrated with a full force model using the

STK/Astrogator module. The maneuvers were modeled as impulses so that there is no dependence on spacecraft size. The ΔV's were calculated using a differential corrector to achieve the desired overflight epoch. These data are shown in Table 1.

Because the maneuver targeting method achieved the desired epoch at the target's latitude, the epoch of the maximum elevation angle is slightly different, especially as the time moves away from the direct overflight time, which in this study occurred at: 21 April 2010 18:47.

These data are plotted graphically in Figures 4, 5, and 6. The fact that the minimum ΔV does not occur at the maximum elevation angle overflight is due to the selection of the initial Right Ascension of the Ascending Node.

Because this orbit has a period of about 160 minutes, the ΔV can be improved by using the previous or the next orbit if more than about 80 minutes from the minimum Δ-V. This is shown in Figure 7, which shows the same data as Figure4, with the addition of data from adding an extra orbit. This essentially uses less Δ-V because an additional nominal orbit is used to phase the orbit overflight. Because the orbit is smaller, the range to the target at the time of collection is also less, as shown in Figure 8. Even the magnitude of the Δ-Vis larger in some of the cases; the direction of the Δ-V for some of the maneuvers is retrograde, causing the orbit to be smaller for the additional orbit case. For instance, for the maximum elevation angle, the initial study had a maneuver of about 16 meters/second applied in the direction of the velocity at perigee. With the additional orbit, the same elevation angle and epoch require a retrograde maneuver of about 40 meters/second.

These data can be used by the commander of the spacecraft to determine the tradeoff between spacecraft lifetime (Δ-V), the image angle (if an imaging satellite), and the range from the spacecraft to the target at the time of collection. These parameters are all important to a collection mission, but vary in weight depending on the tactical and strategic objectives for a particular mission.

A critical aspect of satellite collection is precise information on the location of the satellite along the orbit trajectory. The precise location within a few meters directly affects the following aspects of a satellite mission

- Accurate pointing of the satellite's sensor
- Pointing of the ground station antenna to uplink/downlink commands
- Antennae pointing for a remote user on the ground up to the satellite
- Communication links for users on the ground

The responsive satellite will utilize various orbital maneuvers to provide the desired overflight opportunities. The orbital maneuvers can last in duration from seconds to minutes. The amount of thrust provided during any particular maneuver is typically a percentage of the desired thrust. Thus an engine that fires at 110% efficiency is considered a "hot" burn. An engine that fires at 80% efficiency is considered a "cold" burn. The ability to calibrate each burn and then determine the precise location of the satellite within it's orbit trajectory is Orbit Determination (OD).

These responsive satellite runs utilized the Orbit Determination Tool Kit (ODTK) system to model the precise locations before, during, and after maneuvers. The ODTK system provides the ability to solve the OD problem throughout a maneuver. This capability is especially critical for responsive missions. Historically, OD systems require several observations or satellite orbits after a maneuver before an OD solution is achieved.
Additionally, ODTK utilizes a filter and smoother in determining a solution. By using the filter and the smoother, ODTK can calibrate the engine based on the planned and the observed maneuver. That way, the next time the satellite's engine fires, compensation can be made if the engine burned hot or cold during the previous maneuver.

Utilizing this advanced system is well suited for the responsive overflight mission. This permits planning for the next maneuver to occur quickly which keeps the mission moving. This enables timely, relevant, and actionable information.

Conclusion

The migration of UAV CONOPS to space can provide increased overflight opportunities and provide a level of responsiveness unachieved from space. Utilizing existing satellite systems in dual-use roles or the development of dedicated tactical satellites could decrease the amount of time to perform a mission in an area where time is short and assets are few. In civil and military applications, executing a mission and delivering information downstream is critical to the outcome of a mission.

Utilizing technology and business models in the commercial world with civil and military systems can be shown to have utility in the scenario outlined in this paper. Figure 9 highlights the ability to utilize Instant Messenger™ as a type of application that permits timely, responsive satellite data information on-demand. This information could be utilized by in-theater regional commands to plan the use of tactical satellites.

Once the desired mission and satellite is determined, the use of a tactical satellite system can be executed by implementing well planned trajectory design, maneuvering planning sequences, and accurate orbit determination operations. Consequently, existing satellite missions and future dedicated missions will be more responsive to civil and military needs.

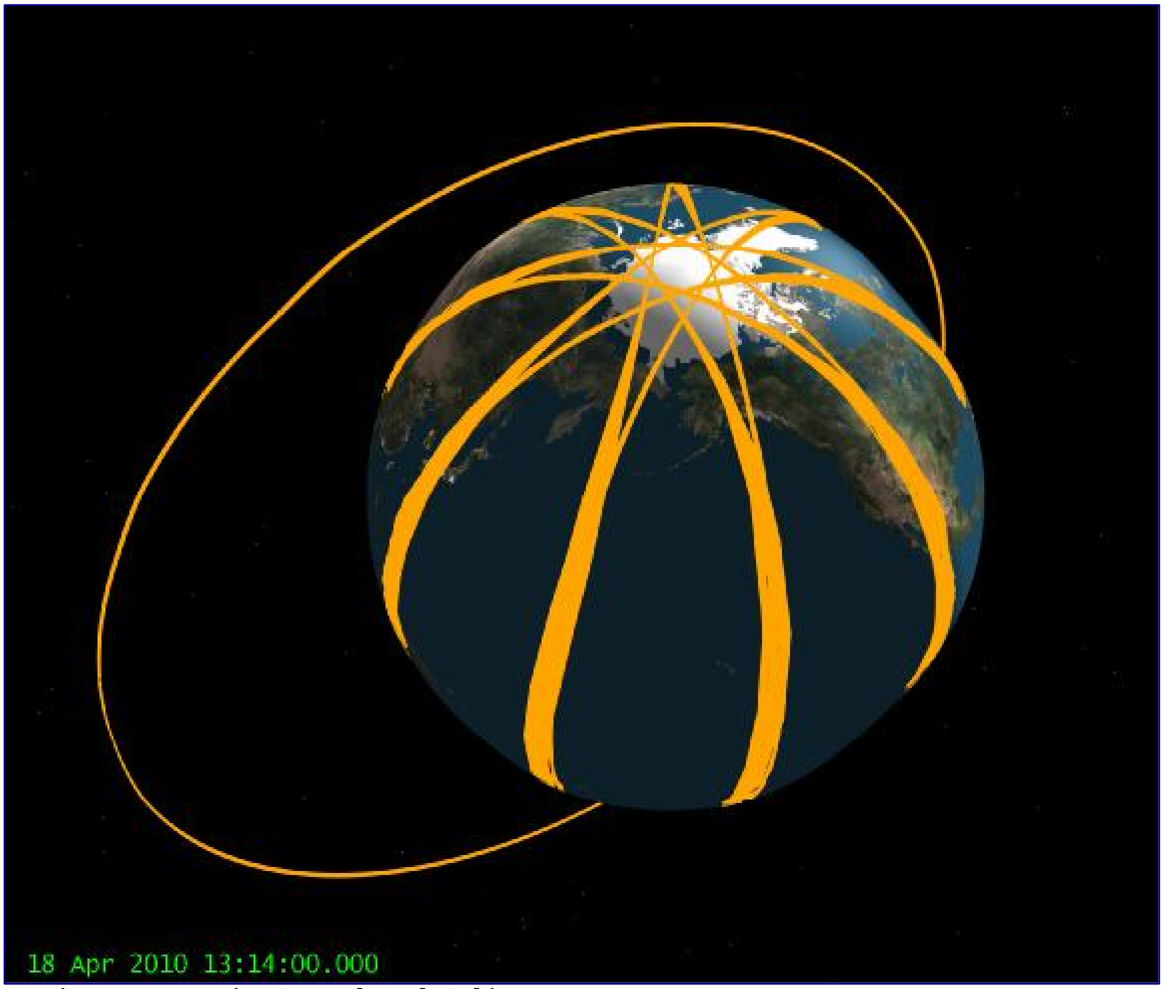

Figure 1 Repeating Ground-track Orbit inertial Frame

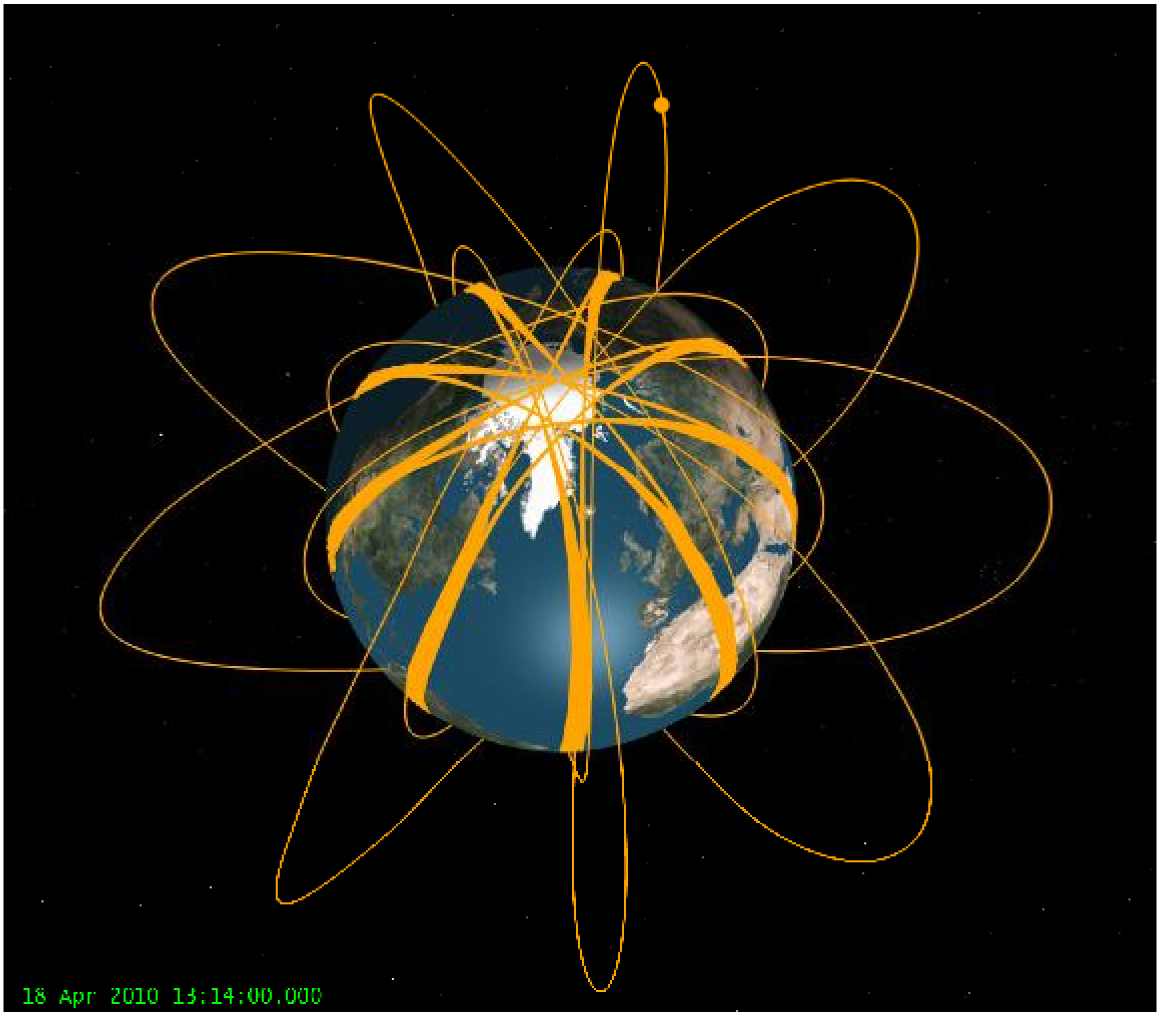

Figure 2 Repeating Ground-track Orbit in Earth-Fixed Frame

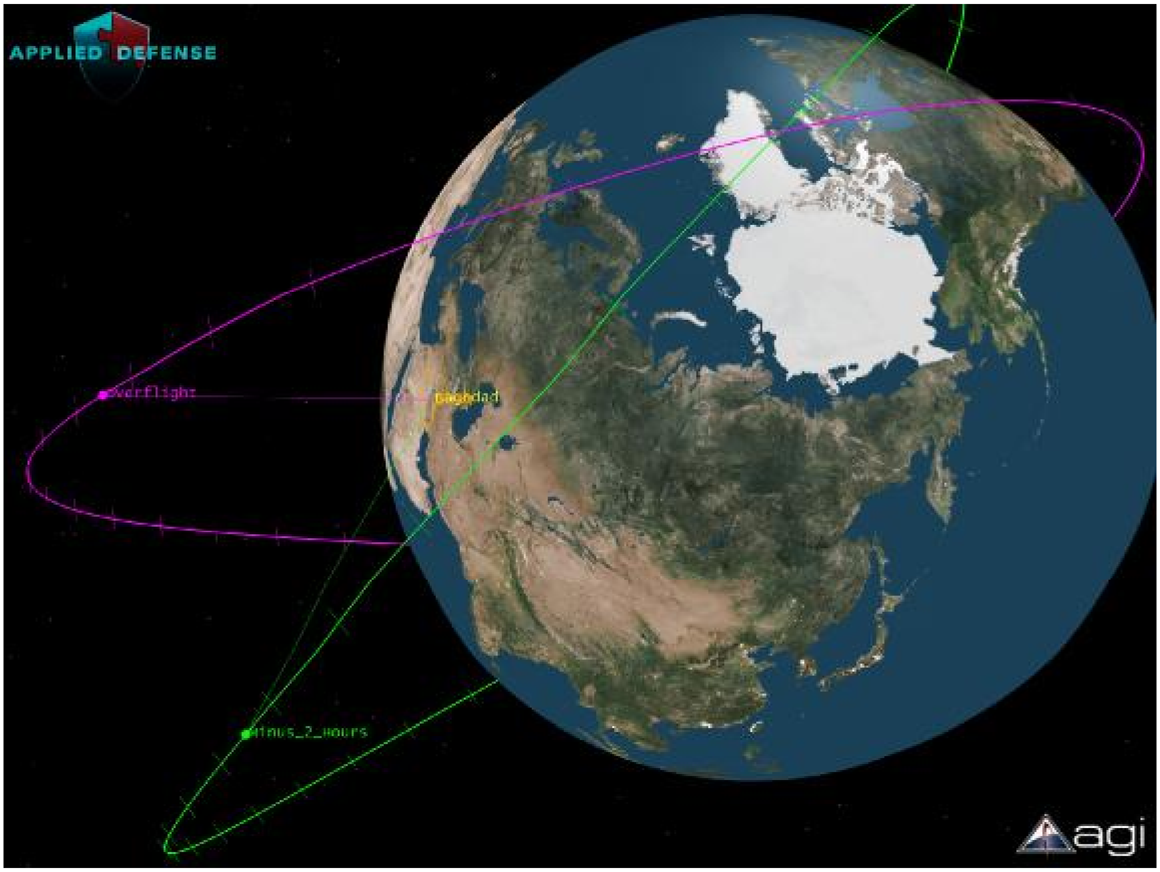

Figure 3 Overflight and 2-Hour-Early Orbits

Overflight Epoch (UTC)	Time Difference (min)	Δ-V(m/s)	Restore Δ-V(m/s)	Maximum Elevation Epoch	Elevation Angle (deg)	Range (km)
21 Apr 2010 16:47:19	-120.00	27.0	27.3	21 Apr 2010 16:46:41	40.37	6444.9514
21 Apr 2010 17:07:19	-100.00	19.7	20.0	21 Apr 2010 17:07:03	47.57	6179.24918
21 Apr 2010 17:27:19	-80.00	12.4	12.7	21 Apr 2010 17:27:17	55.30	5949.51725
21 Apr 2010 17:47:19	-60.00	5.2	05.5	21 Apr 2010 17:47:24	63.52	5766.64057
21 Apr 2010 18:07:19	-40.00	2.0	01.7	21 Apr 2010 18:07:26	72.14	5640.49281
21 Apr 2010 18:27:19	-20.00	9.1	08.8	21 Apr 2010 18:27:25	81.02	5578.80402
21 Apr 2010 18:47:19	**0.00**	**16.1**	**15.8**	**21 Apr 2010 18:47:19**	**90.00**	**5585.84311**
21 Apr 2010 19:07:19	20.00	23.1	22.8	21 Apr 2010 19:07:10	81.11	5662.20265
21 Apr 2010 19:27:19	40.00	30.0	29.7	21 Apr 2010 19:26:58	72.48	5804.79305
21 Apr 2010 19:47:19	60.00	36.9	36.6	21 Apr 2010 19:46:42	64.24	6007.49211
21 Apr 2010 20:07:19	80.00	43.7	43.4	21 Apr 2010 20:06:23	56.49	6261.98051
21 Apr 2010 20:27:19	100.00	50.4	50.2	21 Apr 2010 20:25:58	49.26	6557.32969
21 Apr 2010 20:47:20	120.01	57.1	56.9	21 Apr 2010 20:45:29	42.55	6884.81049

Table 1 Variable Overflight Epoch

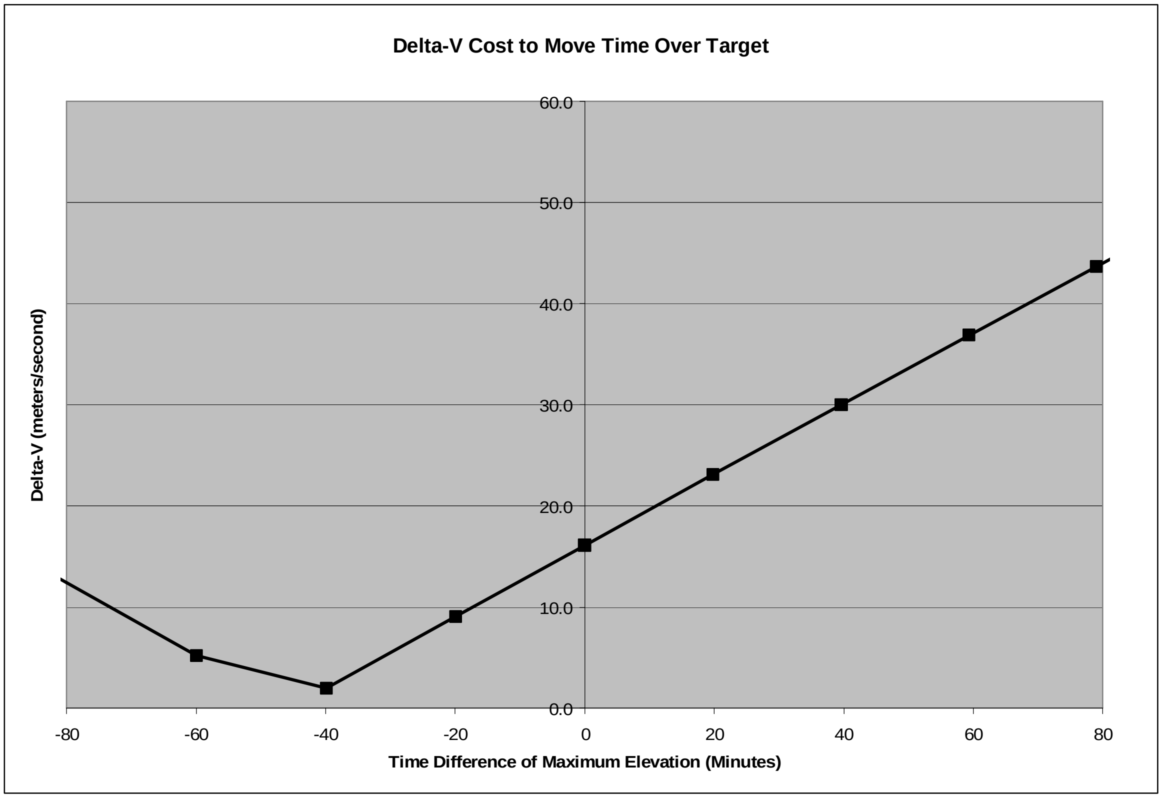

Figure 1 Delta-V

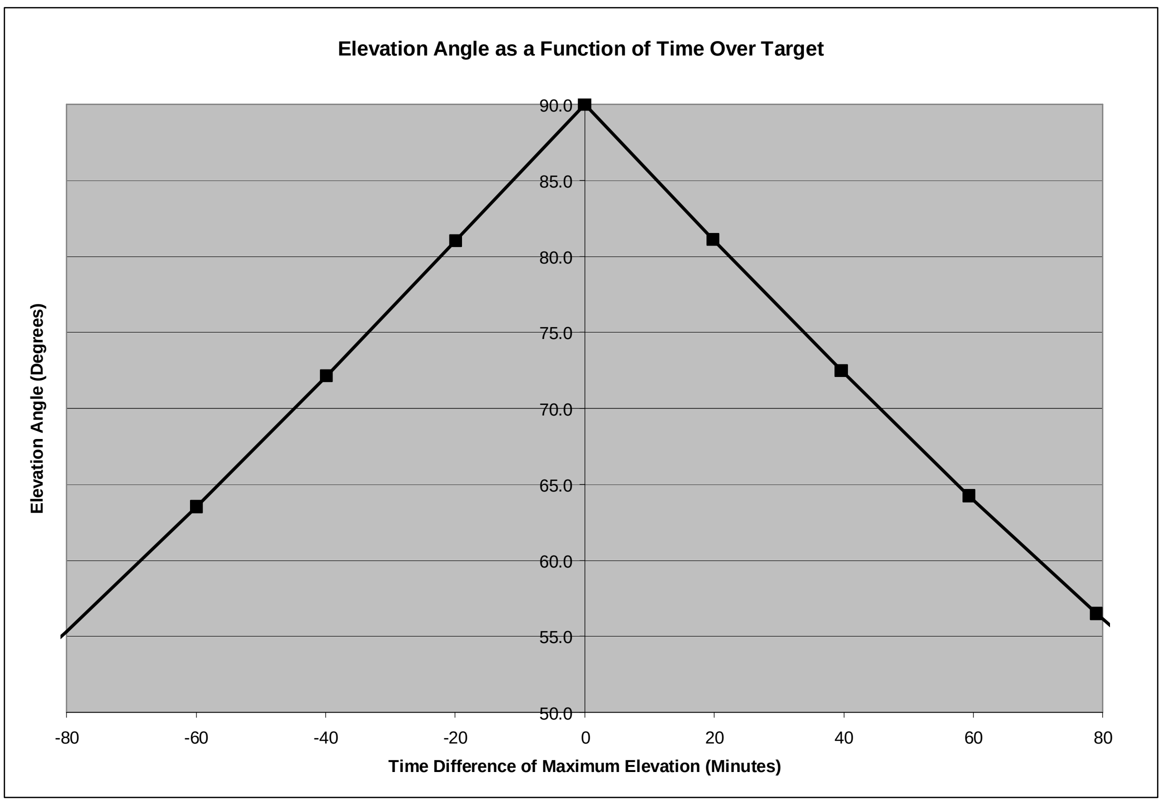

Figure 2 Elevation Angle

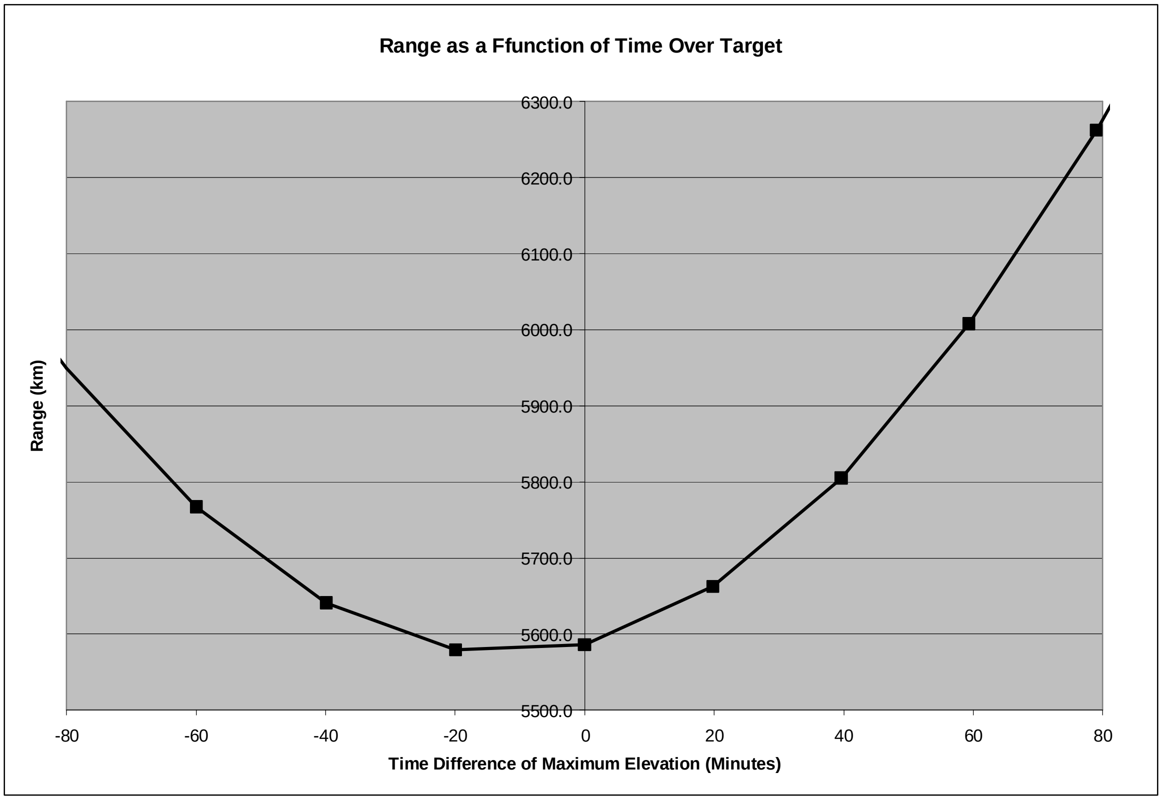

Figure 3 Range to Target

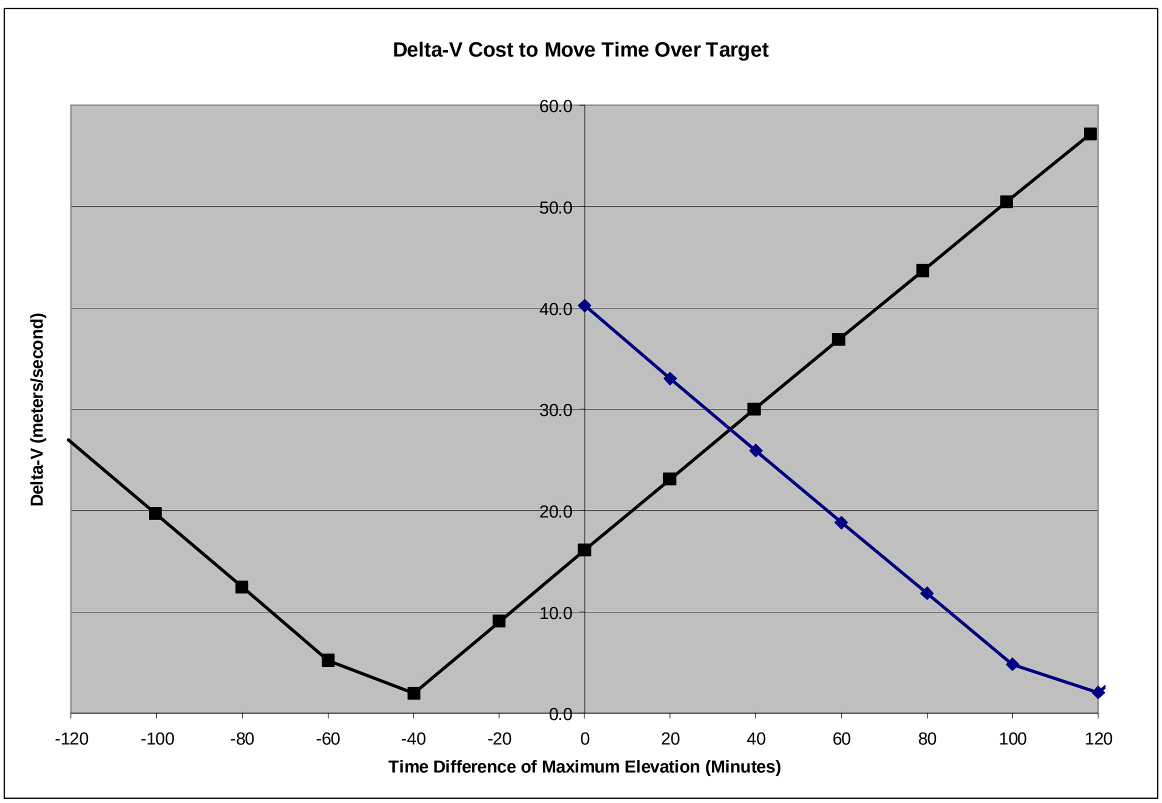

Figure 4 Delta-V with an Additional Orbit

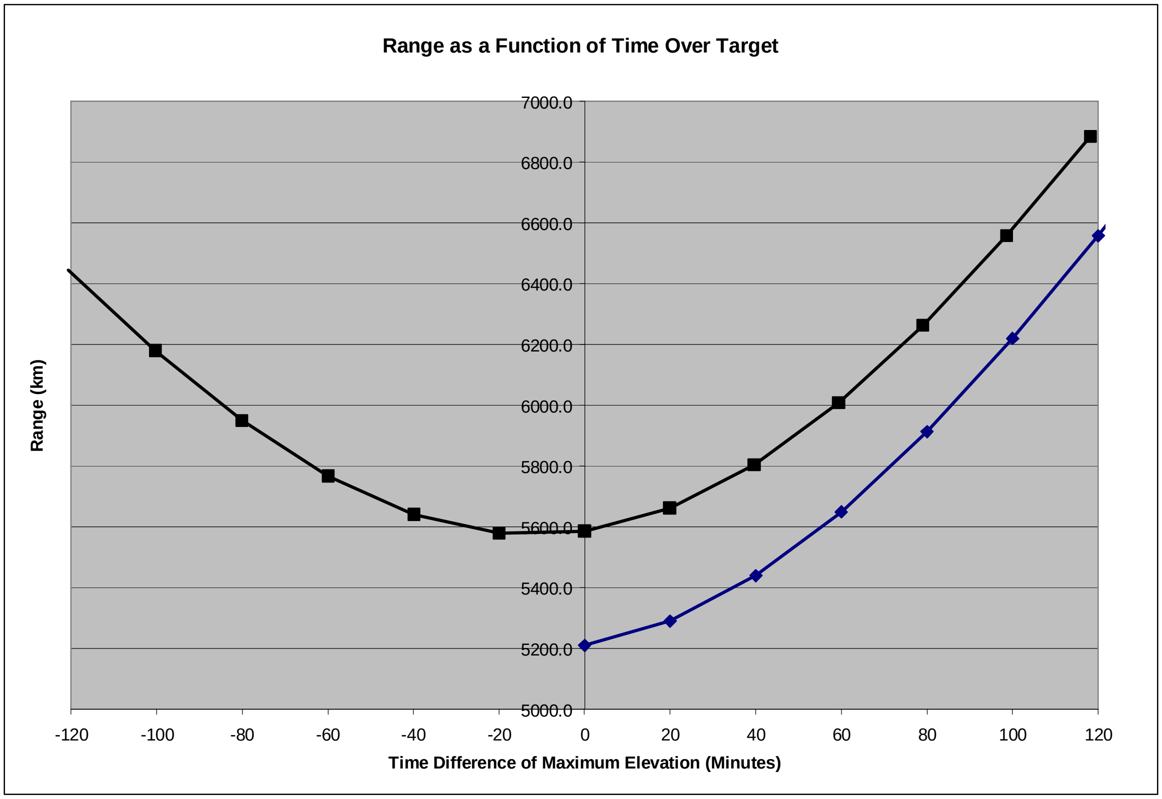

Figure 5 Decreased Range with an Additional Orbit

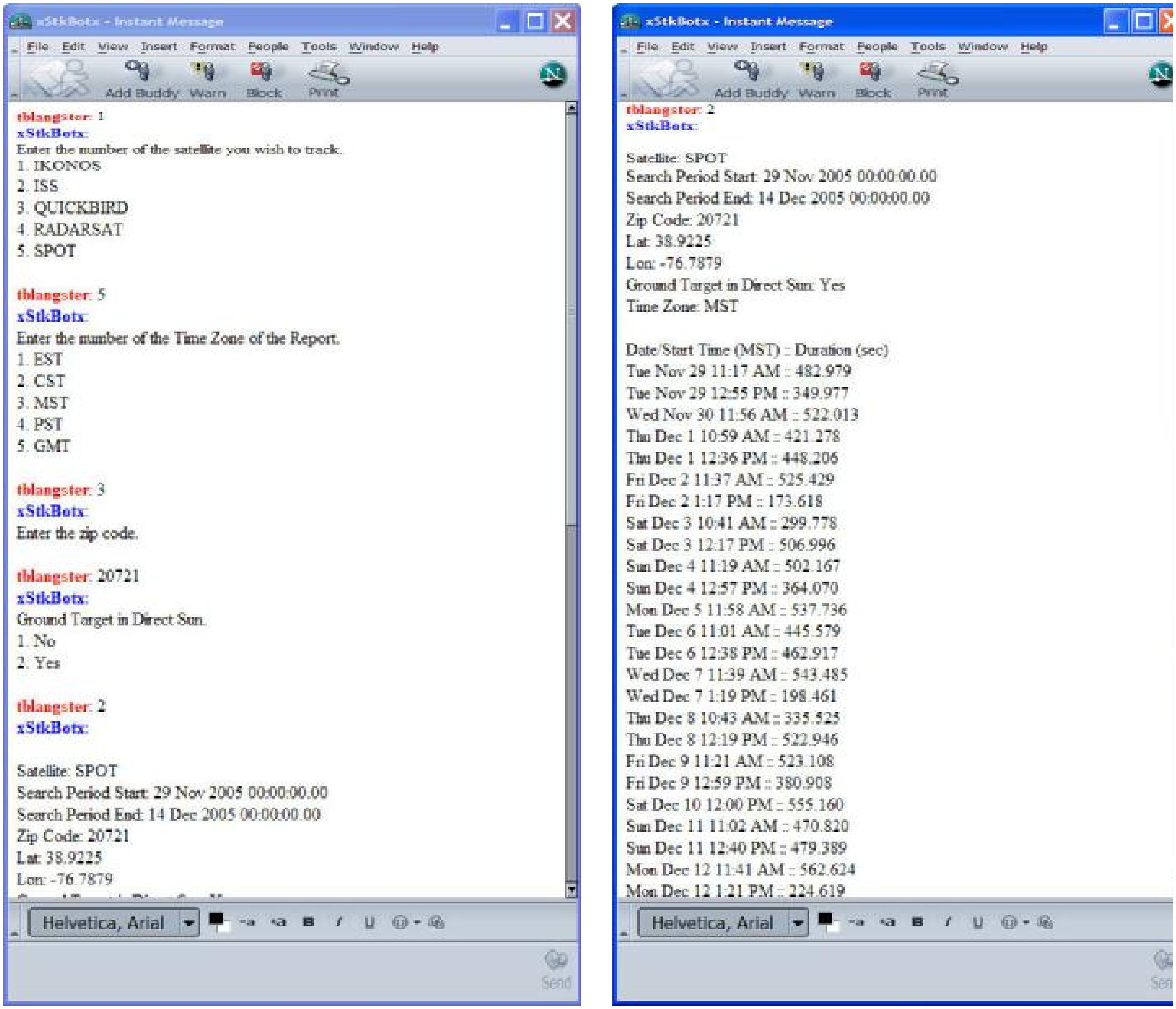

Figure 9 Instant Messaging of Satellite Overflight