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# Link Analysis Methodology for Secondary Payloads

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## Abstract

Commercial launch vehicles frequently have excess payload capacity, enabling them to provide launch opportunities to additional spacecraft at a greatly reduced cost. These opportunities are attractive to universities and many other groups who wish to launch small spacecraft, but taking advantage of this secondary payload status requires flexibility in orbit destination, as the launch provider is often not identified until the spacecraft integration and testing phase. Performing link analysis across a broad range of potential orbit parameters can prove difficult with traditional methods. This article addresses the challenge by proposing a methodology to design a system and select equipment robust enough to support a wide range of orbits, maximizing potential launch opportunities. The effects of variations in orbit altitude, eccentricity and inclination on downlink data throughput are parameterized, yielding a direct evaluation of orbit suitability for meeting data volume requirements. Applications to both variable and fixed data rate protocols are discussed, and sample results for a small satellite mission are provided to demonstrate how the methodology can be used to drive component selection and provide mission designers with relevant mission planning data.

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## 1. Introduction

Launch opportunities for small satellites are increasingly available, as new and existing launch vehicles offer launch services for secondary payloads (Werner, 2012; Thakker, 2010). Missions designed to be launched as secondary payloads must be robust enough to support a wide range of orbit geometries, as the launch provider is often not identified until late in the spacecraft integration and testing phase. The sec-

ondary payload is typically injected into an orbit defined by the launch profile of the primary payload, so it must therefore be robust to a range of orbits to ensure that a suitable launch opportunity can be identified. This initial orbit uncertainty results in a dilemma for mission designers because orbit parameters feed into the design and component selection of key subsystems. In particular, the link budget depends on the spacecraft's elevation angle and range, parameters that vary not only with every overpass of a ground station, but

also with orbit geometry (Krikorian et al., 2005).

The uncertainty within link budget calculations affects multiple areas of the flight project: mission design, spacecraft component selection, and ground system design. Mission designers require knowledge of the system's data throughput capability for use in mission operations planning.

Mission designers of an imaging satellite, for example, would want to know the number of images that can be downlinked during each overflight, on average, in order to establish post-processing procedures and estimate the science data return. Orbit geometry uncertainty also affects component selection, primarily within the telecommunication and command and data handling subsystems. Telecommunication components (transmitters, receivers, and antennas, both onboard the satellite and at the ground station) are differentiated by factors such as operational frequency, RF transmit power, and directionality, which drive the equipment type, mass, power, and cost. Designers must select these features based on the communications link budget, which is dependent upon orbit geometry. Command and data handling equipment is also affected in terms of required storage capacity, since low data throughput to the ground could result in an accumulation of mission data onboard the satellite. Finally, the ground system must be capable of spacecraft tracking, data acquisition and storage (Wheaton, 2006). Therefore, it is important to develop a realistic link budget during the preliminary design phase before procuring or fabricating equipment.

The methodology discussed below addresses these challenges to mission planning and component selection by evaluating a baseline telecommunication subsystem design against a range of orbit geometries. This approach can be used to determine whether or not the required data throughput can be achieved for each of the potential destination orbits using the baselined components. If a system cannot close the satellite-to-ground communication link with sufficient data throughput to meet mission requirements for every potential orbit geometry, the range of acceptable injection orbit geometries is reduced for the baselined telecommunications system design. The resulting decrease in launch opportunities may spur mission designers to

reevaluate the data throughput requirement, or redesign the telecommunications system to achieve greater performance.

The proposed approach for link budget analysis for secondary payloads addresses the issue of an uncertain orbit geometry in two ways. First, it provides data throughput statistics and compares them to the spacecraft's data production in order to quantify the mission data downlink capability for each potential orbit scenario. Second, it provides risk analyzers with an evaluation of data throughput for the full range of possible orbits, ultimately allowing mission designers and subsystem engineers to make design trades, select communication and computing equipment, and develop a mission operations strategy.

## 2. Solution Methodology

Calculating achievable data throughput for a given orbit geometry requires the combination of an orbit propagation program and an algorithm to automate multi-orbit link budget calculations. For this discussion, Satellite Tool Kit by Analytical Graphics, Inc. (AGI STK, 2009) and MATLAB (MathWorks, 2007) were used to develop a working example of the methodology. The MATLAB wrapper script allows for consecutive link evaluation of many orbit geometries, resulting in a full-factorial design space exploration over user-defined ranges of orbital elements. For each combination of orbital elements, the wrapper script accesses STK to obtain ground station overpass data – specifically, elevation angle and range versus time – over a user-defined time period. The wrapper script then passes that data, along with user-defined ground station and spacecraft telecommunication system specifications, to a link budget algorithm to calculate the achievable data throughput for that time period.

Orbit geometries are defined by the following orbital elements: periapsis altitude, eccentricity, inclination, argument of periapsis, right ascension of the ascending node, and mean anomaly. Periapsis altitude is defined by STK as the difference between the radius of periapsis and Earth's equatorial radius. The first four elements may be varied over ranges based on potential launch vehicle and launch site combinations. Right as-

cension of the ascending node and mean anomaly are nominally set to zero and vary as the orbit is propagated.

For each orbit geometry, the link analysis uses the overpass data (elevation angle and range versus time) to determine the time-varying data rate required to close the spacecraft-to-ground link with a certain link strength (indicated by bit energy to noise spectral density ratio margin). This desired margin is user-defined and is held constant throughout the simulation. A middle Riemann sum is then used to approximate the area under the data rate versus time curve (Salas et al., 2007); the area under this curve is the data throughput over the user-defined time period. In this way, data throughput for a representative period of time in each possible orbit can be determined and compared. This portion of the analysis concludes with the tabulation of data throughput sample statistics (minimum, maximum, mean, and standard deviation) across all orbits.

Although the spacecraft's elevation angle and range change continuously during an overpass, in practice, the data rate cannot be continuously optimized for each instantaneous geometry. Thus, two methods for data rate modification are proposed and applied within the methodology: a mid-pass discretely variable data rate scheme similar to other complex link analyses (Ryan et al., 1997, Krikorian et al., 2006), and a scheme that identifies and operates at a single optimum data rate for each overpass. For the first case, the data rate is assumed to be tunable during each overpass at user-defined intervals between 0 and 60 seconds via on-board software or ground command. The operating data rate is therefore updated once per interval based on the current elevation angle data. This method allows for more data throughput overall, but it has a greater risk of losing the communication link during an overpass due to errors in orbit prediction, especially if an aggressive value is chosen for acceptable link margin. The second case assumes the spacecraft maintains a constant data rate for the duration of each overpass, but the data rate is allowed to change from pass to pass. The data rate for a particular overpass is calculated to maximize data throughput for that overpass, which can be accomplished by determining and selecting the acquisition angle (the elevation angle at which the spacecraft ac-

quires a link and begins transmitting data) corresponding to maximum data transfer. Beginning transmission at a lower acquisition angle (i.e., earlier in the overpass) results in a longer transmit time, implying a higher data throughput during the pass. However, the corresponding longer range associated with a low acquisition angle means the equipment must operate at a lower data rate for the entire pass duration. The combined effect of transmit time and data rate on data throughput is evaluated for a range of acquisition angles, and the acquisition angle/data rate combination that maximizes throughput for a given overpass is automatically selected for that pass, as illustrated in Figure 1.

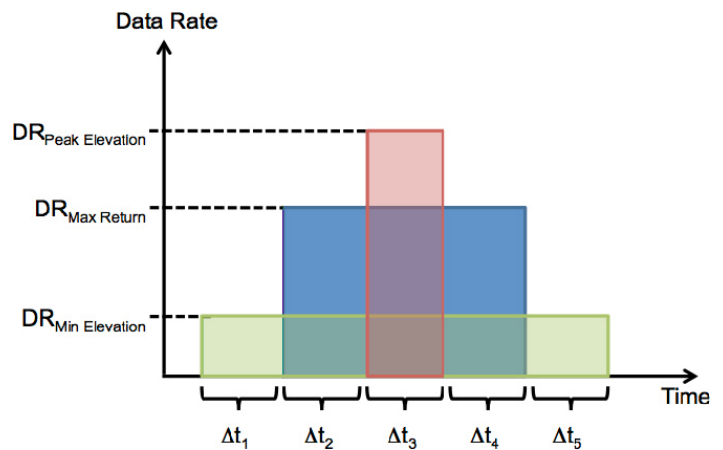


Figure 1. Data rate modification scheme: constant data rate optimized for each pass. During a single overpass, the spacecraft can begin transmission at a lower elevation angle (and lower data rate) and operate for a longer time (green box), or it can begin transmission at a higher elevation angle (and higher data rate) and operate for a shorter time (red box). Data volume is maximized at some elevation angle between these two cases (blue box).

While this scheme will result in lower data throughput compared to the mid-pass variable data rate approach, it is a simple, robust approach with a lower risk of losing the telecommunications link during the pass. Note that for either method to be applicable, the selected communication equipment must be capable of on-orbit data rate modification.

Based on long-term orbit propagations and the link calculation methodology described above, data throughput for various orbit geometries can be assessed against the mission requirements. This approach

allows an evaluation of the capability of the flight and ground system to meet data throughput requirements across the full range of potential orbits. Failure to meet throughput requirements may result in a decision to narrow the potential range of orbit geometries, relax the data throughput requirements, or select alternative telecommunications hardware to increase performance. The data throughput assessment may also drive requirement updates for on-board data storage and data latency.

### 3. Application to Rapid Reconnaissance and Response Mission

The methodology and link analysis described above were developed specifically for the Rapid Reconnaissance and Response (R<sup>3</sup>) mission at the Georgia Institute for Technology. The following sections describe the R<sup>3</sup> mission objectives and inputs to the link analysis, including the potential orbit geometries the satellite may be launched into as a secondary payload and the baseline hardware selected for the communication subsystem. A description of the data throughput calculations is provided for both data rate modification schemes discussed above (mid-pass variable data rate and constant data rate optimized for each pass). The discussion includes an evaluation of the data throughput requirements and a summary of the decisions made by the design team to improve the link performance and reduce risk to the mission.

#### 3.1 Mission Objectives and Relevant Hardware Drivers

The R<sup>3</sup> satellite was developed for the sixth round of the University Nanosat Program (UNP-6). This two-year concept-to-flight-ready design competition is a collaboration between AFRL, AFOSR, and AIAA that provides seed funding to selected teams to design, build, and test a small satellite. The winner of the competition is provided a launch opportunity as a secondary payload, hence the application of this methodology to R<sup>3</sup>.

The R<sup>3</sup> mission objectives were to characterize the radiation environment effects on an uncooled mi-

crobolometer thermal imager, perform thermal and visible imaging from low Earth orbit, and demonstrate the autonomous detection and geolocation of warm-water ocean currents using onboard image processing algorithms (Walker, 2010). To achieve these objectives, the R<sup>3</sup> satellite would acquire thermal images of specified regions on the surface of Earth using an uncooled microbolometer. The coordinates (latitude and longitude) of the thermal features would be computed on-board and downlinked to the R<sup>3</sup> team. The R<sup>3</sup> satellite would also use a visible camera to acquire visible context images and a radiation dosimeter to measure the on-orbit radiation environment. Radiation total dose and single event data would be used to assess the effect of radiation on the performance of the uncooled microbolometer.

Because the mission objectives involved analysis and downlink of thermal and visible images, both the onboard data storage and satellite-to-ground data throughput required were substantial. The data throughput requirement for the mission was to return, at minimum, one thermal and one visible image per orbit in addition to sufficient telemetry and radiation data. Additionally, since the ocean current data was intended for use by the maritime community, it was time-sensitive and could not be stored for a prolonged period of time between acquisition and downlink. Furthermore, since the R<sup>3</sup> satellite would launch as a secondary payload, a broad range of orbit geometries were considered. Therefore, the methodology discussed in this paper was of particular interest in evaluating the large amount of data produced by the satellite and selecting the data storage and communication equipment necessary for adequate robustness to support many potential orbit geometries.

#### 3.2 Link Analysis Inputs

A total of 96 orbits were considered, with orbital elements selected from the ranges presented in Table 1. The periapsis altitude range was selected based upon orbit lifetime considerations: a minimum altitude of 300 km was required to ensure a mission duration of at least 6 months, and a maximum altitude of 600 km was determined to ensure drag-induced deorbit within 25

years (Opiela, 2012). The orbit eccentricity was allowed to range from zero (circular) to 0.3. Orbital inclination was required to be greater than 34 degrees to ensure that the Georgia Tech tracking station could be used to support flight operations. Retrograde orbits were not considered. The argument of periapsis was allowed to vary from 0 to 360 degrees.

Table 1. Ranges of orbital elements considered.

Orbital Element	Range
Periapsis Altitude	300 – 600 km
Eccentricity	0.0 – 0.3
Inclination	34° – 90°
Argument of Periapsis	0° – 360°

The time period of interest for data throughput calculations was selected as two weeks. This value was chosen to reflect the mission planning cycle (the length of time over which the orbit would be propagated for scheduling of imaging and communications passes) and was considered to be representative of the full six-month mission. The data throughput requirement was defined to encompass the data volume associated with all spacecraft engineering telemetry and radiation data produced within this two-week time period, along with at least one image pair (i.e., one thermal image and one visible image) per orbit.

The baseline communication architecture consists of a UHF uplink system for commands and an S-band downlink system for telemetry and mission data. Specifically, the Georgia Tech ground system uses a UHF transmitter and Yagi antenna to transmit data to the satellite and an S-band receiver and 3 m parabolic dish to receive downlinked data. In anticipation of collaboration with institute partnerships, a second tracking station of similar architecture is baselined to increase downlink capabilities. The R<sup>3</sup> satellite uses a UHF receiver and monopole antenna for uplink and an S-band transmitter and circular antenna for downlink. A block diagram illustrating the baseline communication system architecture, including hardware specifications, is provided by Figure 2.

### 3.3 Link Analysis, Data Throughput Calculation, and Requirement Verification

Since the R<sup>3</sup> mission objectives emphasized image capture and downlink, data throughput requirements for downlink were significantly greater than those for uplink. Thus, the data throughput calculations and requirement verification were conducted with this methodology for downlink only. The R<sup>3</sup> team initially considered data rate modification using the mid-pass variable data rate scheme, and the results of the data throughput calculations using this scheme revealed a need for a communication system hardware update to meet the data throughput requirement. A low-noise amplifier was added to the ground system, resulting in a 16 dB gain to the received signal. With the addition of the low-noise amplifier to the design, the link analysis and data throughput evaluation showed significant margin relative to the throughput requirement. While the incorporation of a low-noise amplifier in the ground receiving equipment is nearly universal in practice, the comparison of results before and after its addition is significant for the purpose of verifying and demonstrating the utility of this methodology to make trades within the system. The team then considered implementing the lower-throughput data rate modification scheme (constant data rate optimized for each pass) to reduce the risk of losing the communication link during an overpass. Data throughput calculations and results for each of these steps are discussed and compared in the following sections.

#### 3.3.1. Mid-Pass Variable Data Rate Scheme

The mid-pass discretely variable data rate scheme was implemented using a 60-second step size for evaluation and modification of the data rate. A 3 dB link margin was maintained for each link established between the satellite and the ground station. Data throughput was calculated for each pass over a two-week period, and the total was compared to the amount of science and telemetry data produced onboard the satellite over the same two weeks. The data production analysis was

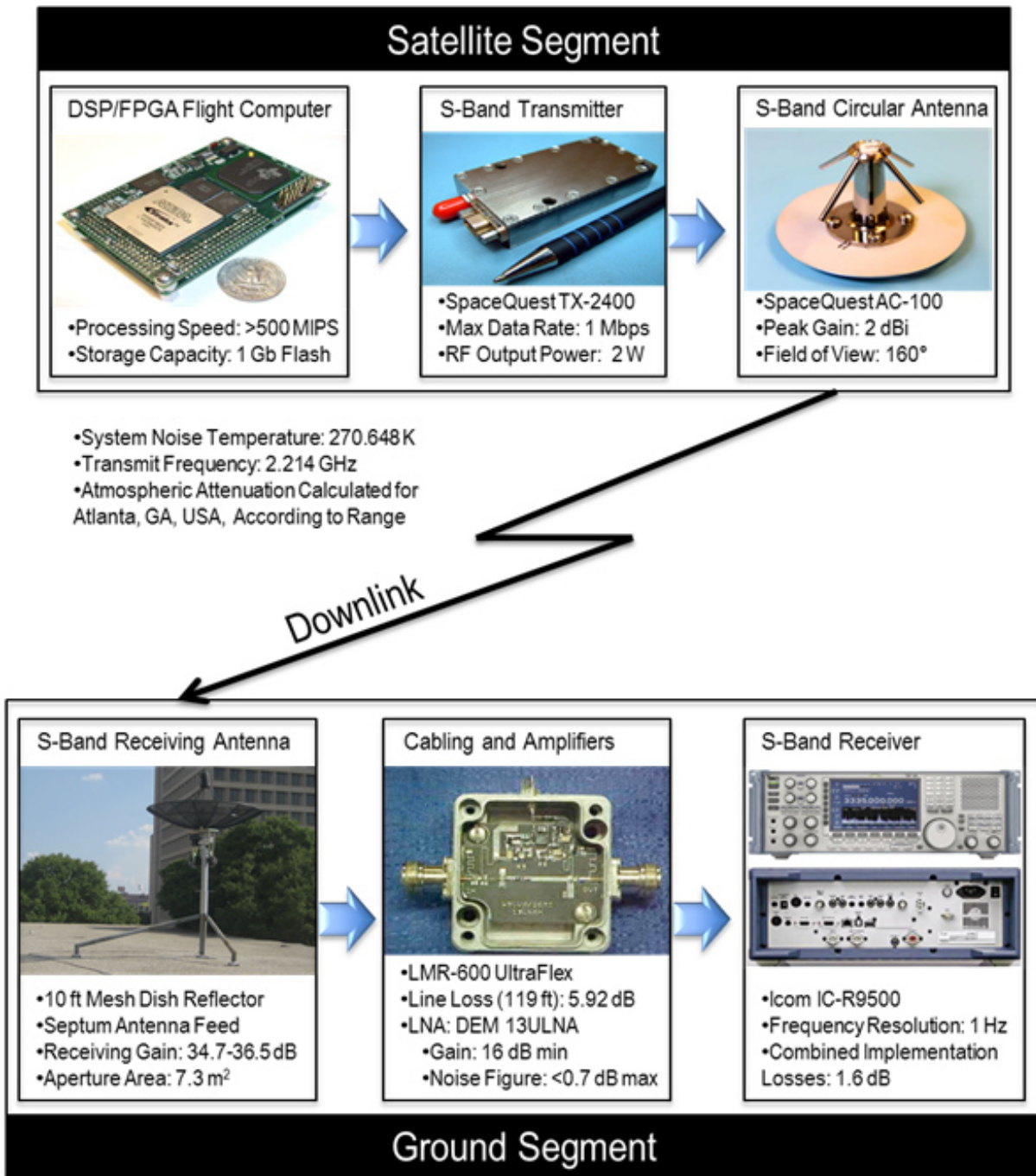


Figure 2. R<sup>3</sup> equipment specifications for link analysis.

performed by first identifying all data-producing entities onboard the satellite. For each data source, the volume of data (bits) was multiplied by the frequency of data production (per unit time), resulting in a data production rate. These rates were then multiplied by the two-week time period to obtain the total data production over the time period of interest. The achievable

data throughput and actual data production were then compared and framed in terms of the data throughput requirement to produce information meaningful to the mission planning team. Specifically, the R<sup>3</sup> team calculated the number of image pairs that can be down-linked over two weeks after all telemetry and radiation data produced in that time period has been transmit-

ted to the ground. That data was tabulated for each analyzed orbit geometry and is shown graphically in Figure 3 (recall the requirement that at least one image pair be downlinked per orbit). For reference, an image pair, compressed, corresponds to approximately 15 Mb of data.

As Figure 3 shows, with the original design for the flight and ground telecommunications systems, R<sup>3</sup> could successfully downlink telemetry for all orbits considered, but the data throughput requirement

could not be met for any orbit. Even the most favorable orbit (circular, 300 km altitude, 34 deg inclination, 0 deg argument of periapsis) could only downlink telemetry plus 66 image pairs over a two-week period, while the requirement for that orbit was 222 image pairs over two weeks. This result drove the R<sup>3</sup> team to consider the three options discussed in Section 2: further restrict the range of acceptable orbit geometries, change mission operations protocols to allow for delayed downlink of mission data, or enhance the link

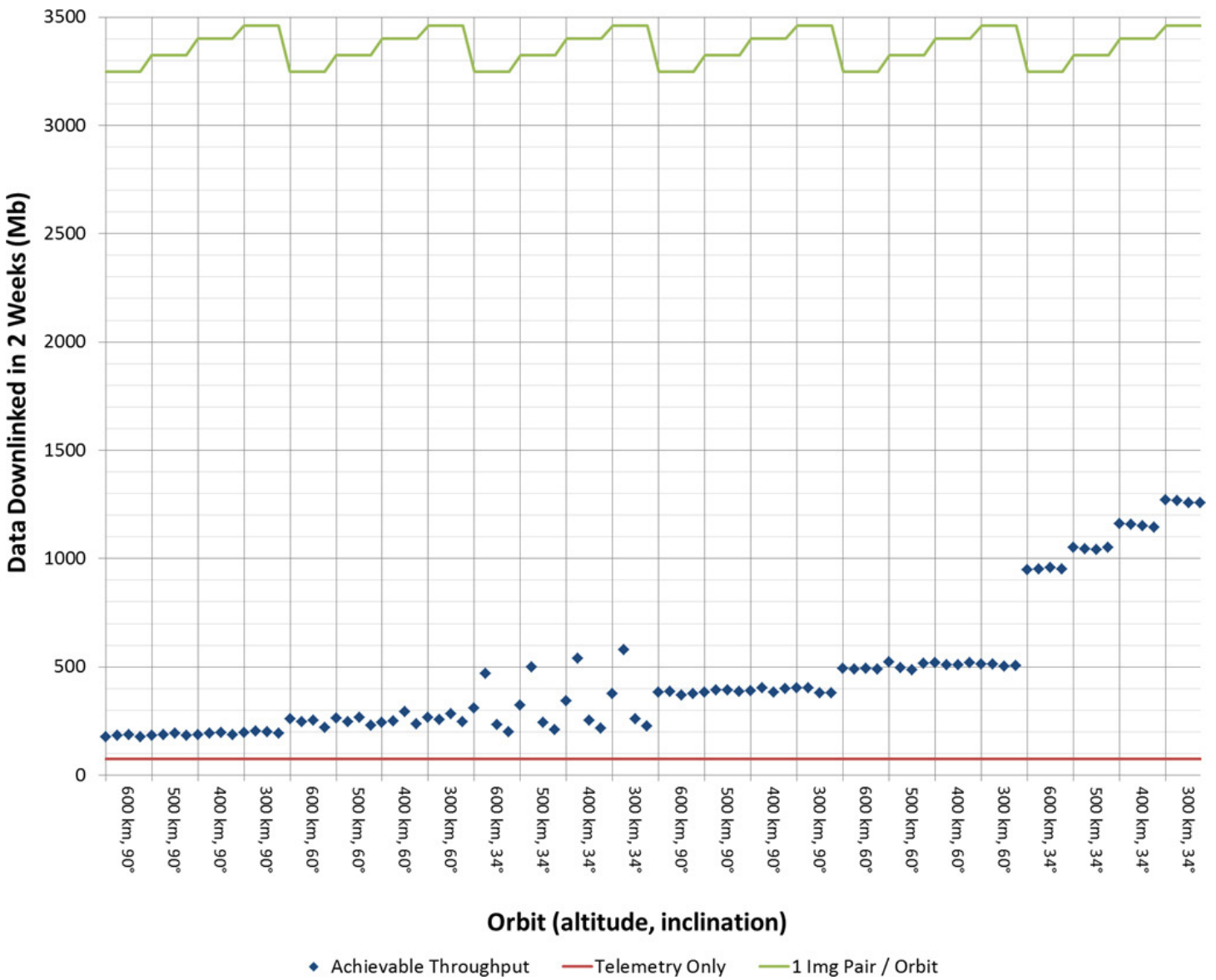


Figure 3. First evaluation of data throughput performance. Data downlinked in two weeks over a range of potential orbit geometries, using the mid-pass data rate modification approach. Orbit geometries are identified in terms of eccentricity, periapsis altitude, and inclination. Each orbit label corresponds to four data points on the plot, which represent the four arguments of periapsis considered: 0°, 90°, 180°, and 270°.

performance by modifying the communications equipment. In this case, restricting the range of acceptable orbit geometries would be ineffective, since there was no subset of orbit geometries that could achieve adequate data throughput. Additionally, onboard storage for delayed downlink of mission data was infeasible, since the end-users of the mission data required near-real-time knowledge of warm-water current locations. Therefore, the R<sup>3</sup> team chose to alter the communication system hardware to improve the link performance

and increase data throughput for all orbit geometries under consideration.

### 3.3.2 Hardware Update

To strengthen the link without affecting the spacecraft mass, volume, or power, the R<sup>3</sup> team added a low noise amplifier to the planned ground station receiving equipment. The simulation was re-run to reflect this change, and the updated results are displayed in

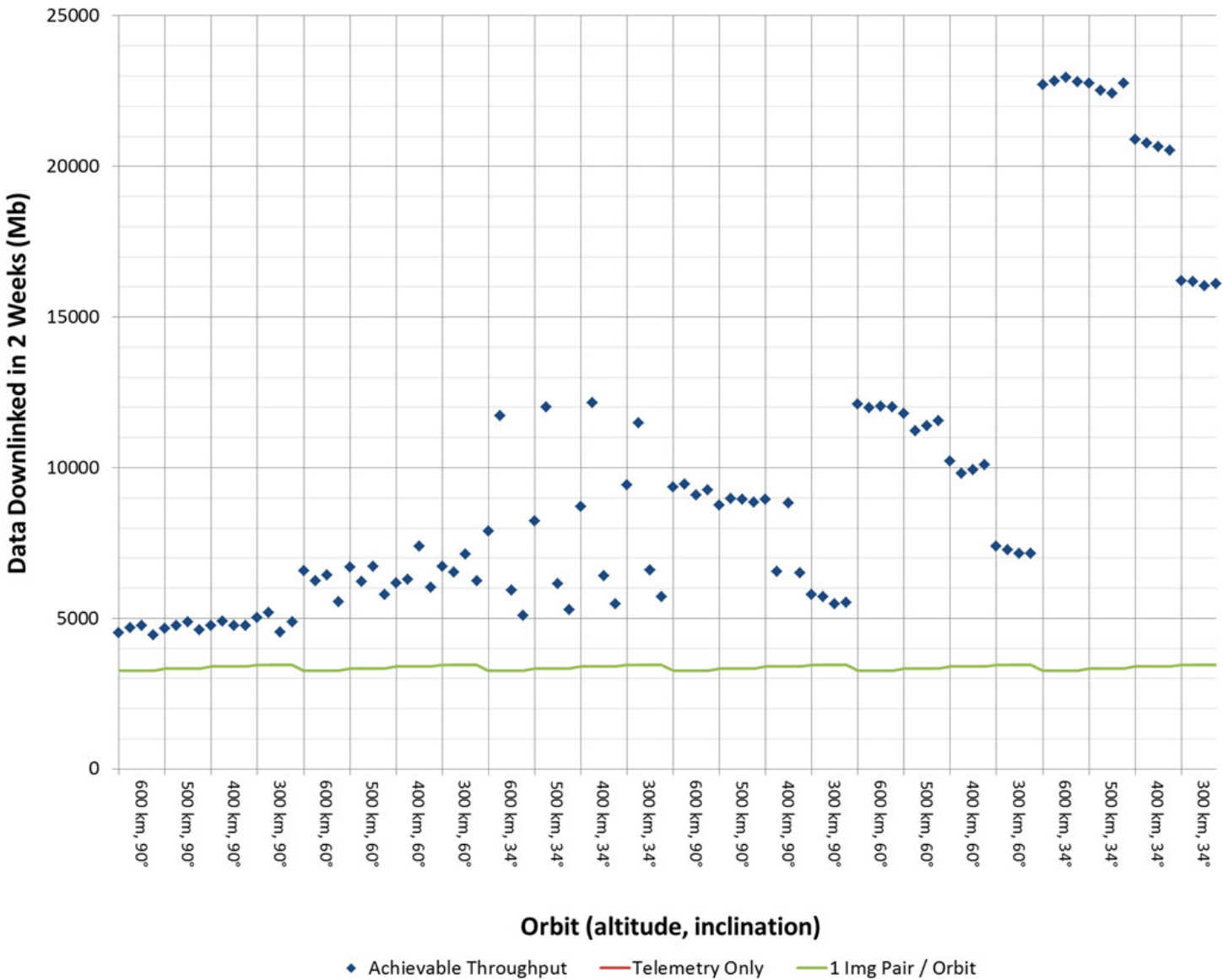


Figure 4. Second evaluation of data throughput performance. Data downlinked in two weeks over a range of potential orbit geometries, using the approach of a constant data rate optimized for each pass with an added groundside LNA. Orbit geometries are identified in terms of eccentricity, periapsis altitude, and inclination. Each orbit label corresponds to four data points on the plot, which represent the four arguments of periapsis considered: 0°, 90°, 180°, and 270°.

Figure 4. These results indicate that the data throughput requirement can be met for each potential orbit geometry, since at least one image pair per orbit can be downlinked during the two-week period.

Thus, this link analysis methodology enabled the R<sup>3</sup> team to recognize the need for a stronger link than that achievable with the baseline equipment and to quickly reassess the new communication architecture with the additional groundside receiving LNA. This reassessment resulted in assurance of meeting the data throughput requirement for all orbit geometries con-

sidered to be potential launch opportunities for the R<sup>3</sup> spacecraft.

### 3.3.3 Constant Data Rate Optimized for Each Pass

Since data throughput was improved significantly after the hardware update, the R<sup>3</sup> team investigated implementing the alternate data rate modification scheme (identifying and operating at a single optimum data rate for each overpass) to determine whether the data throughput requirement could still be met for all

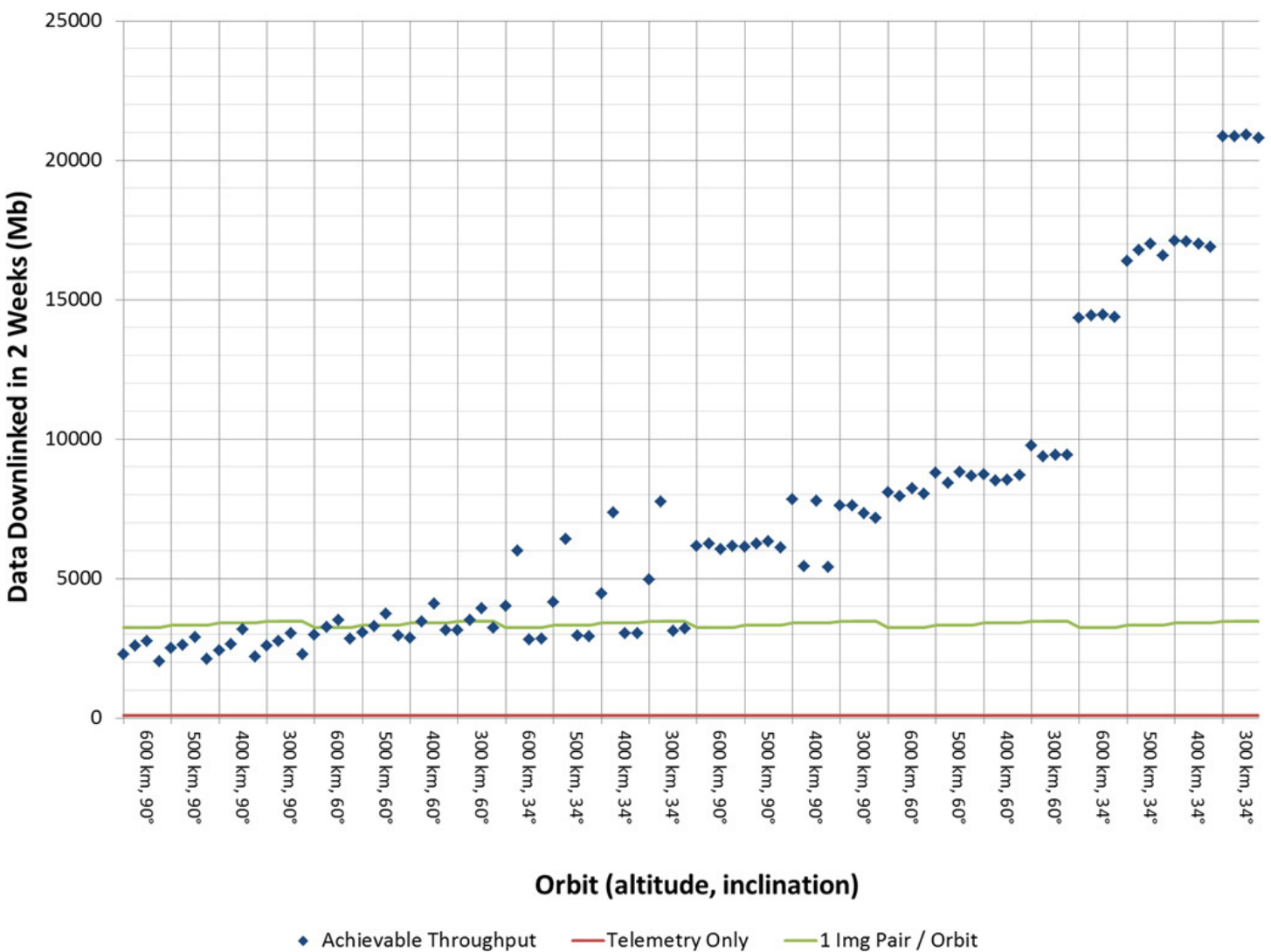


Figure 5. Third evaluation of data throughput performance. Data downlinked in two weeks over a range of potential orbit geometries, using the lower-throughput data rate modification approach (constant data rate optimized for each pass). Orbit geometries are identified in terms of eccentricity, periapsis altitude, and inclination. Each orbit label corresponds to four data points on the plot, which represent the four arguments of periapsis considered: 0°, 90°, 180°, and 270°.

potential orbit geometries. Although this modification scheme would result in a lower data throughput overall, it would be favored from a mission operations perspective due to the reduced risk of losing the communication link during an overpass. As shown in Figure 5, the throughput was indeed less than that of the mid-pass data rate modification scheme, resulting in the data throughput requirement being met for only 65% of orbit scenarios considered. However, the requirement was successfully met for 100% of circular orbits (see the

right half of Figure 5). Consulting with the University Nanosat Program revealed that the majority of primary payloads on the Air Force manifest target circular or low-eccentricity orbits. Thus, the R<sup>3</sup> team was satisfied with the alternative data rate protocol and decided to request circular launch opportunities.

For this method, two additional data sets were calculated within the link analysis script and displayed graphically. The first data set depicts the process of selecting an optimum acquisition (elevation) angle for

Acquisition Angle vs. Throughput (Data Volume) For Each Pass in Orbit

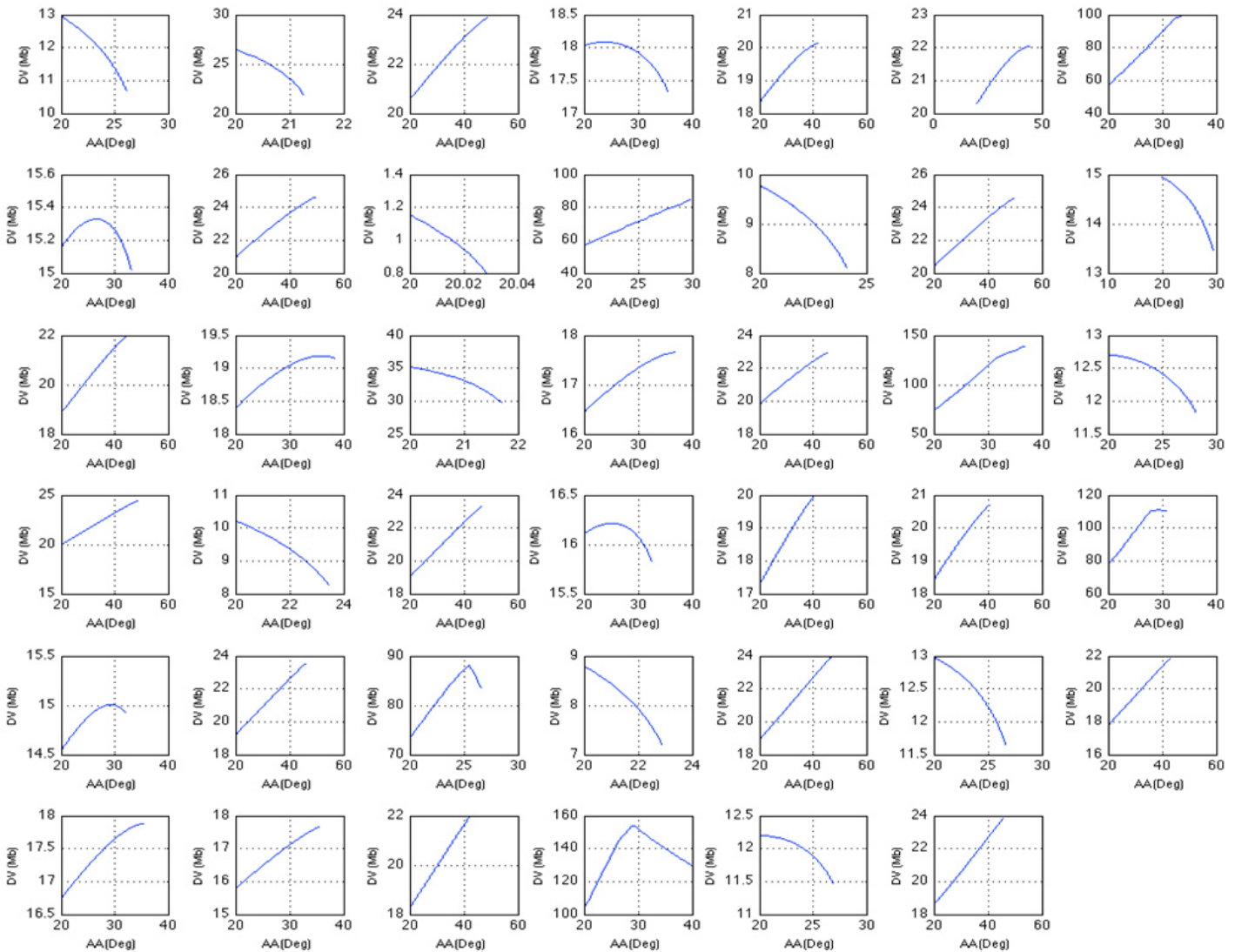


Figure 6. Achievable throughput data volume (DV) vs. acquisition angle (AA) for each pass of the following orbit geometry: eccentricity = 0.3, periapsis altitude = 600 km, inclination = 90°, argument of periapsis = 0°.

each overpass of a single orbit. An example data set is shown in Figure 6, where each consecutive overpass during a two-week period is represented by a subplot. For each overpass, all of the acquisition angles evaluated for that pass are shown, as long as they resulted in a closed link. Note that Earth noise was considered too great for reasonable communication below 20 degrees in elevation; thus, acquisition angles below 20 degrees were not considered. The acquisition angles are plotted against the data throughput achievable for that pass if data were transmitted for the entire duration of the pass at the data rate corresponding to that acquisition angle.

In other words, data rate increases as acquisition angle increases for all acquisition angles considered (both are allowed to vary continuously), but the highest data rate achievable (corresponding to the highest acquisition angle) does not necessarily result in maximum data throughput if the link can only be maintained for a short period of time. Each point on the graph defines the total data that could be transmitted (y-axis) during that pass if the maximum data rate achievable at a given acquisition angle (x-axis) were used for the time period over which a closed link is achievable for that data rate. The peak of each curve represents the maxi-

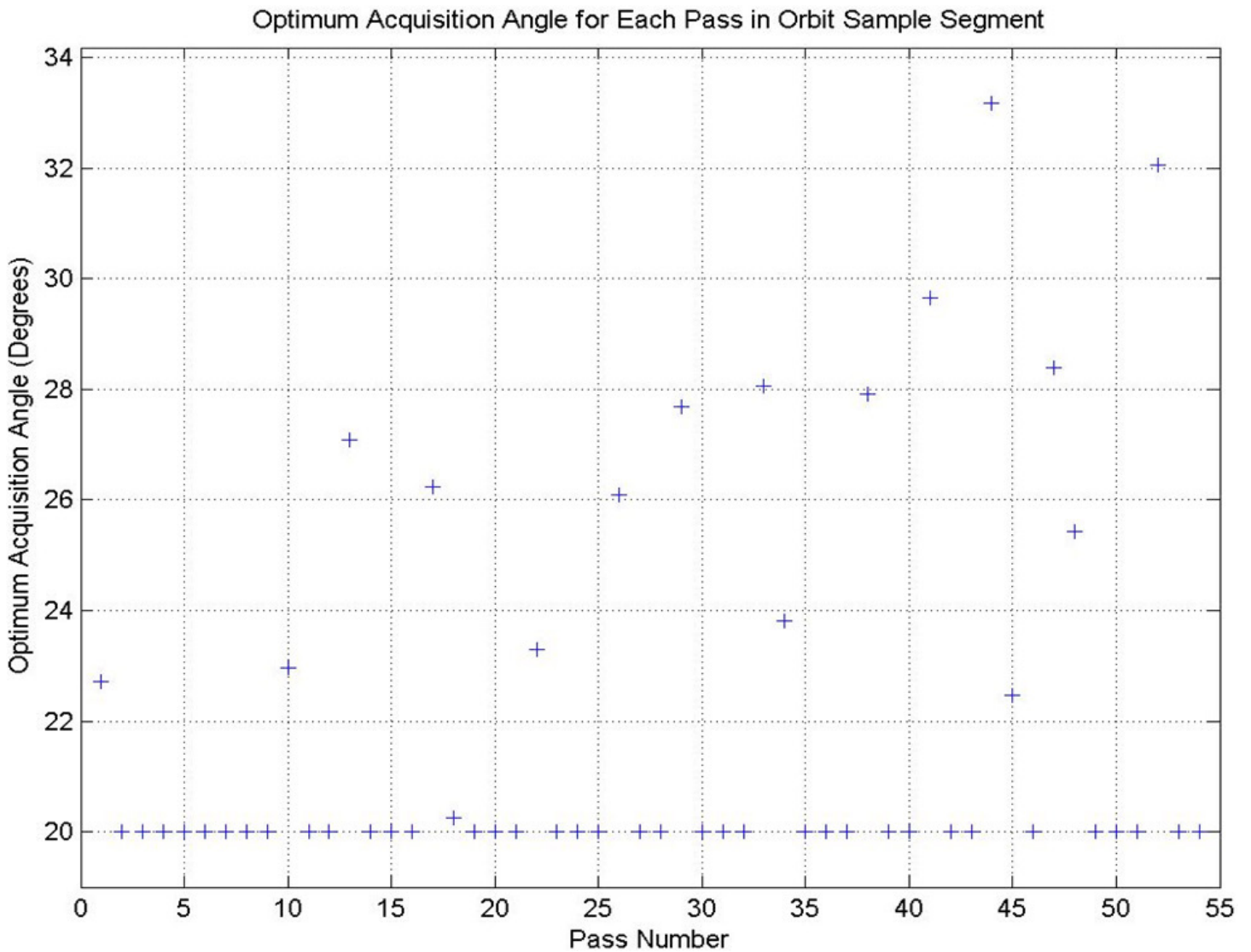


Figure 7. Optimum acquisition angle for each pass of the following orbit geometry: eccentricity = 0.3, periapsis altitude = 300 km, inclination = 34°, argument of periapsis = 0°.

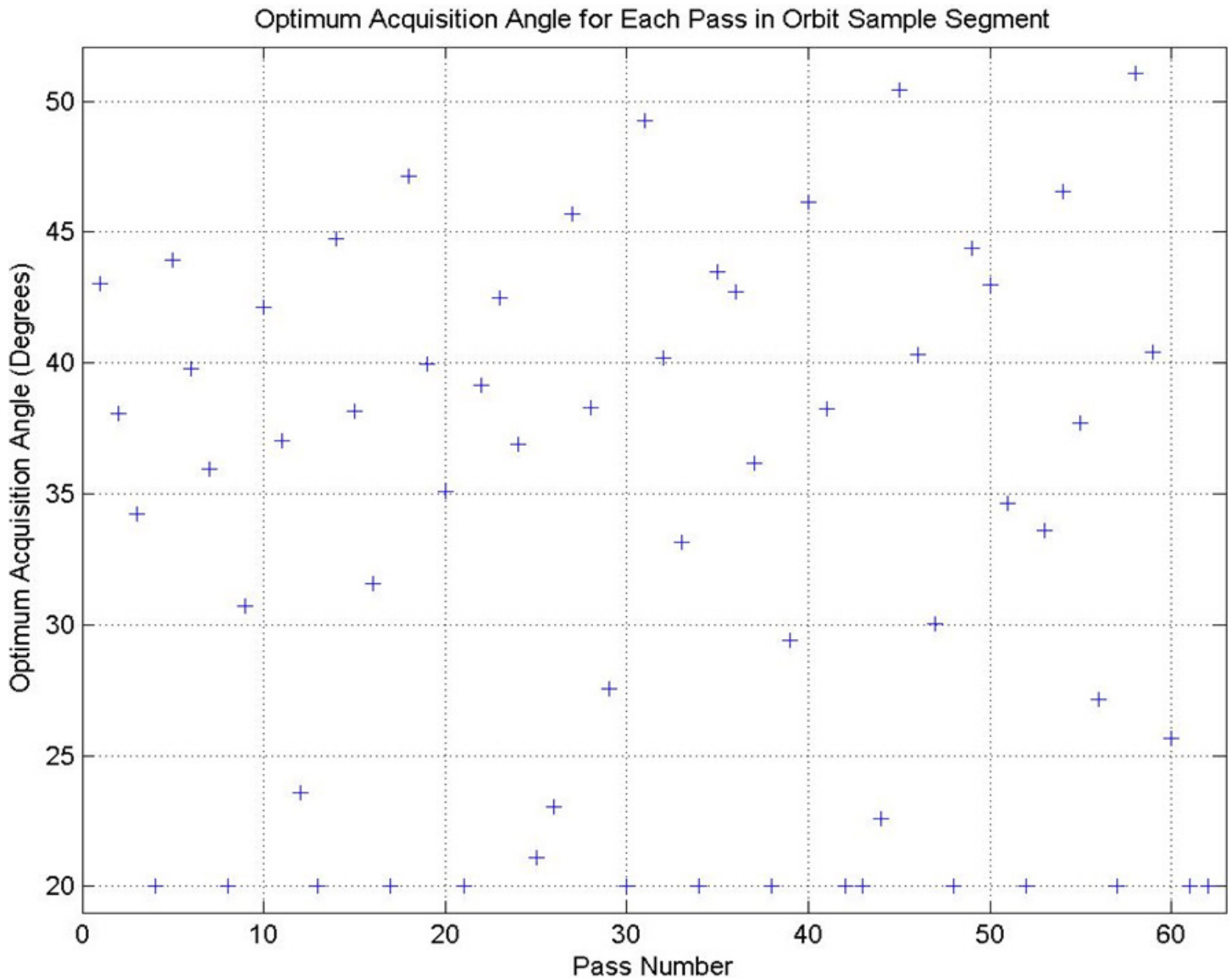


Figure 8. Optimum acquisition angle for each pass of the following orbit geometry: eccentricity = 0.3, periapsis altitude = 300 km, inclination = 34°, argument of periapsis = 180°.

imum achievable data throughput for that pass, and thus marks the optimum acquisition angle (and therefore data rate) selected for that pass in the link analysis. The data in Figure 6 confirm that the optimum acquisition angle changes significantly between passes of a single orbit geometry. In addition, within a single pass, selection of acquisition angle can affect achievable throughput by more than 40 Mb, or in the case of R<sup>3</sup>, 6 images. Thus, use of a data rate modification scheme is important to maximize the data throughput achievable by the selected communication equipment, emphasizing

the utility of this methodology.

The second data set produced condenses these subplots to a chart of the optimum acquisition angle for each pass in a single orbit; examples for two different orbit geometries are given in Figures 7 and 8. As shown by the figures, the optimum angle changes as a result of both orbit geometry (marked by the differences between Figure 7 and Figure 8) and the nature of each pass within that orbit (marked by the range of y-axis values on each plot). For the orbit geometry in Figure 7, the optimal strategy for the majority of the

passes is to maximize the downlink time through establishing a 20 degree acquisition angle. For a subset of the passes, there is a benefit to reducing the pass duration in favor of selecting a higher downlink data rate (for example, the acquisition angle for pass 44 is set to 33 degrees). With a different argument of periapsis, as seen in Figure 8, the overflight geometry is changed such that there is frequently a benefit to reducing pass duration in favor of greater downlink data rates. As seen in Figure 8, some cases have optimal acquisition angles of 50 degrees or greater.

These findings reinforce the utility of this automated full-factorial link analysis methodology by demonstrating that multiple inter-related dynamics govern which acquisition angle results in the maximum data throughput. The full-factorial strategy allows mission designers to select equipment and develop mission operations protocols that will be effective regardless of orbit geometry. Using knowledge of the optimum elevation angle at which a link with the satellite should be established, designers can refine the mission operations protocol to better match the expected operational conditions, thereby maximizing data throughput. This process provides designers with the ability to select equipment that meets the data throughput requirement while eliminating the added mass, power, and cost resulting from overdesign that would occur if the link were to be acquired as soon as possible for each overpass.

#### **4. Conclusion**

Missions designed to be launched as secondary payloads face a dilemma during the design, fabrication, and testing phases: the link budget, which affects mission design and component selection for key subsystems, depends on the spacecraft's orbit, which is unknown until late in the integration and testing phase when a launch opportunity is confirmed. Thus, to maximize the number of potential launch opportunities, a secondary payload must be robust enough to support a wide range of orbit geometries. The methodology discussed in this paper addresses this issue by evaluating a baseline telecommunication subsystem design consecutively against a range of orbit geometries cor-

responding to potential launch opportunities. Within the methodology discussed, data throughput statistics are calculated and compared to the spacecraft's data production in order to quantify the mission data downlink capability for each potential orbit scenario. It then quantifies the ability of the baseline system to meet the data throughput requirement for the full range of possible orbits. If a system cannot close the satellite-to-ground communication link with sufficient data throughput to meet the requirement for every potential orbit geometry, mission designers can decide to either accept the risk of a missed launch opportunity, adjust the mission operations strategy to decrease the required data return, or modify component selection to accommodate a higher percentage of potential orbit scenarios. In the latter case, this methodology enables rapid design iteration until sufficient robustness to an uncertain orbit scenario is attained.

The iterative nature of link design for secondary payloads necessitates advances in the automation of the link analysis, hardware decision, and mission planning processes. By integrating these three steps into a largely end-to-end methodology as discussed in this paper, significant design schedule improvements can be made. This methodology begins with the input of a baseline hardware configuration, evaluates the achievable link for any number of possible orbit scenarios and two common data rate modification schemes, compiles throughput statistics for the baseline design operating in each orbit, and relates these throughput statistics to relevant metrics for mission planning. In this way, design changes can be evaluated rapidly even for a scenario in which there is great uncertainty in key variables. Finally, the criticality of moving link analysis for secondary payloads toward a methodology such as this one is demonstrated in practical terms by displaying the wide variability of throughput capability between orbit geometries, and more importantly, between subsequent passes of a single orbit geometry. This approach incorporates all of these factors into a simultaneous link analysis of multiple orbit geometries for maximum practicality in mission protocol implementation during early design stages of secondary payloads.

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