TECHNICAL REPORT

Title: Managing Angular Momentum Accumulation by Visit Sequencing and Visit Roll Selection		Doc #:	JWST-STScI-000713, SM-12
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1.0 Abstract

Managing the angular momentum accumulation over the ~22-day interval between orbit station keeping maneuvers using visit sequencing and simple visit roll assignment algorithms was investigated by considering 22 day sequences of 1 day visits. In the unconstrained case where no visits have externally defined roll requirements, active optimization of the roll angle to reduce momentum buildup reduces momentum buildup by ~75% compared to the case where all visits are simply assigned nominal roll[1] at the midpoint of the visit. In the constrained case where all the visits were assigned a fixed orientation, reordering the visits allowed discovery of a visit sequence that also reduces the momentum buildup ~60% compared to the nominal roll case. Statistically, with most unconstrained, nominal roll assignment visit sequences, one momentum unload would be required per 22-day interval assuming a 40 N-m-s angular momentum limit. Given that an operational visit pool will be a mixture of unconstrained and constrained visits, a combination of visit sequencing and optimized visit roll assignment is a promising approach for limiting momentum accumulation on JWST

2.0 Introduction

The Observatory orbit about the sun-earth L2 point is unstable and requires periodic Station Keeping (SK) maneuvers to maintain the orbit. In addition, solar radiation pressure on the sunshield produces a torque on the observatory, which is balanced by changing the spin rate of the reaction wheels. The reaction wheel speeds are kept within operational limits by momentum unloads using thruster firings and by minimizing the stored angular momentum accumulation by management of the observatory attitude via judicious observation planning and scheduling.

The GSFC Flight Dynamics Facility (FDF) is responsible for determining the JWST orbit and generating the Maneuver Plan to maintain the orbit by using Tracking data obtained by the DSN during daily communication contacts. Tracking data collection must occur for at least 19 contacts (~ 19 days) after a SK maneuver in order for FDF to converge on an orbit solution that will support the next SK maneuver.

[1] Nominal roll is used here as the observatory roll where the sun is in the half plane defined by a line through the V1 vector and the –V3 vector.

Assuming the possibility of one missed contact, that the transfer of the last tracking data set and generating the Maneuver Plan takes about a day, and the transfer and processing of the directives for uplink will take an additional one day implies the SK maneuvers will be planned no closer than every 22 days. In addition, momentum unloads perturb the Observatory's orbit which impacts the ability of FDF to obtain an orbital solution. This causes the momentum unloads and the Station Keeping orbit maintenance activities to be coupled:

- At most, two momentum unload activities can occur in the interval between two SK maneuvers.
- If needed, a momentum unload activity will be planned within one day before a planned Station Keeping maneuver.
- If needed, a second a momentum unload activity will be planned. The S&OC shall ensure that the second momentum unload activity is scheduled no closer than four days (TBR) to the first momentum unload activity or previous SK maneuver.

In addition, to optimize the upcoming SK maneuver, FDF requires a predictive JWST attitude profile that extends at least to the next planned SK maneuver.

The requirement to provide FDF with a ~22-day attitude profile and the need to ensure the number of planned momentum unloads do not violate the constraints will nominally require the creation of a schedule that extends to the next SK maneuver or beyond. During the schedule construction, the S&OC will model the accumulation of the angular momentum in each reaction wheel and, as needed, will plan a momentum unload in the schedule to maintain the reaction wheels within their limits.

The current JWST Reaction Wheel Assembly (6 wheels) will support a stored angular momentum up to 40 N-m-s, Root Summed Square (RSS). If one Reaction Wheel has failed, only 4 wheels can be used which will support up to 24 N-m-s.

Earlier investigations have shown that that in the absence of any kind of momentum management, it is easy to saturate the momentum wheels and violated requirements to limit the number of momentum dumps (Kinzel 2004). Here, I carry out some preliminary studies to determine whether adjusting the rolls and/or the order of visits during a 22 day interval can significantly reduce momentum buildup.

To simulate the building of an operational 22-day timeline and statistically investigate the impact of visit ordering and visit orient assignment on momentum accumulation, multiple visit sets were created that each contained 22 daylong visits. For each visit set, multiple visit sequences were generated, and the visit orientation for each visit established by several different methods. Statistics of the accumulated angular momentum at the end of each 22-day visit sequence were collected to determine the impact of the different timeline construction methods. The following paragraphs describe the process in detail.

3.0 The Model

Statistics were collected from 511 visit sets and the various visit sequences and orient assignments.

Each visit set was created using 22 visits selected from a simplified visit pool:

- Each visit was one day long.
- Each visit was assigned a random pointing assuming a uniform target distribution over the JWST Field of Regard (FOR). The actual area used was slightly smaller than the 85° to 135° sun angle FOR annulus in that the assigned pointings were valid throughout a particular 22 day interval (days 2012.093 - 2012.116). This allowed maximum flexibility in creating the visit sequences.

Three methods of assigning the roll of the visits were used:

Nominal Roll: In this case, each visit in a sequence was assigned the nominal roll at the mid-time of the visit. This roll assignment tends to zero out the momentum gain about the roll axis for the visit and thus minimizes the individually accumulated RSS momentum for that visit at that time.

Minimize Accumulated Momentum Roll: In this case, the roll was assigned to minimize the accumulated momentum in the visit sequence. Specifically, for each visit sequence, starting with the first visit, a roll was assigned that was valid and minimized the total accumulated angular momentum up to the end time of that visit.

Fixed Roll: In this case, for each visit set, a visit sequence was created and the roll for each visit was fixed at the nominal roll at the mid-time of the visit. For subsequent visit sequences, each visit's roll remained fixed at the value it was assigned. This roll restriction limited where a particular visit could be rescheduled in the 22 day interval. Only sequences where all 22 visits were rescheduled were created.

A simple, brute force, scheduling algorithm was used. For each set of visits, and each position angle assignment method, the visits were randomly reordered 100 times. For each visit sequence, the position angle for each visit was assigned and the ending accumulated angular momentum was calculated assuming the starting angular momentum was zero. It was assumed the start of each visit contained a 30 minute slew where no momentum was accumulated. The momentum calculation used the NGST provided torque table from September 2004. For each of the orientation assignment methods and for each visit set, the multiple of the visit sequences produced varied final accumulated momentum whose statistics were then captured (mean, standard deviation, min, and max).

Histograms of the mean and minimum of the final accumulated momentum due to visit ordering for each of the visit sets and each of the roll assignment methods are presented in Figures 1 to 3 using a 1 N-m-s bin size. The blue bars show the distribution of the mean final accumulated angular momentum for each set of visits. The red bars show the distribution of the minimum of the final accumulated angular momentum for each set of visits.

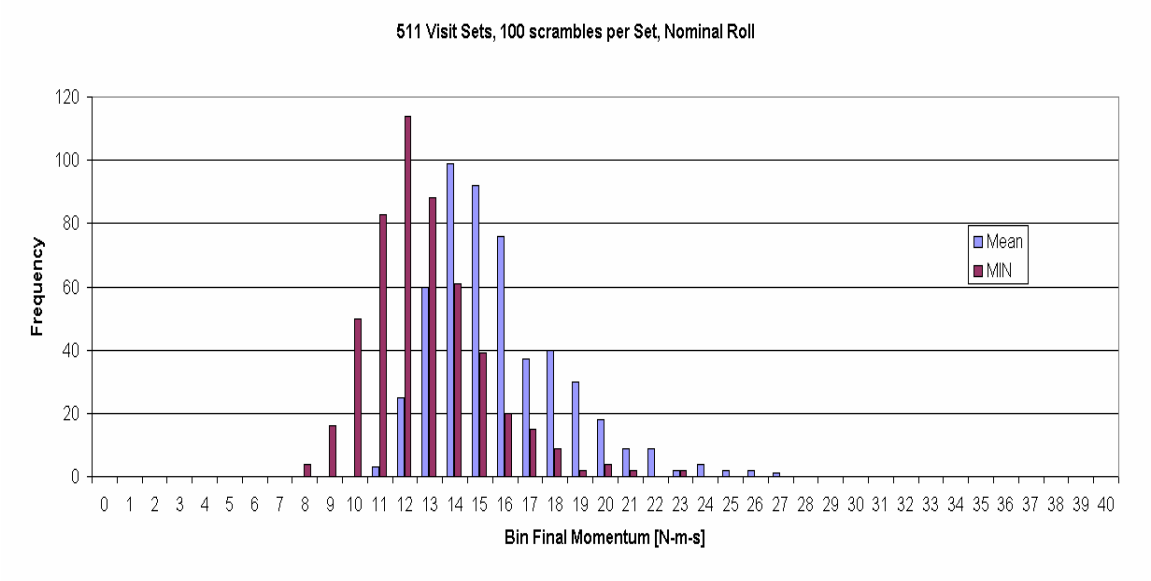

Figure 1: Nominal Roll

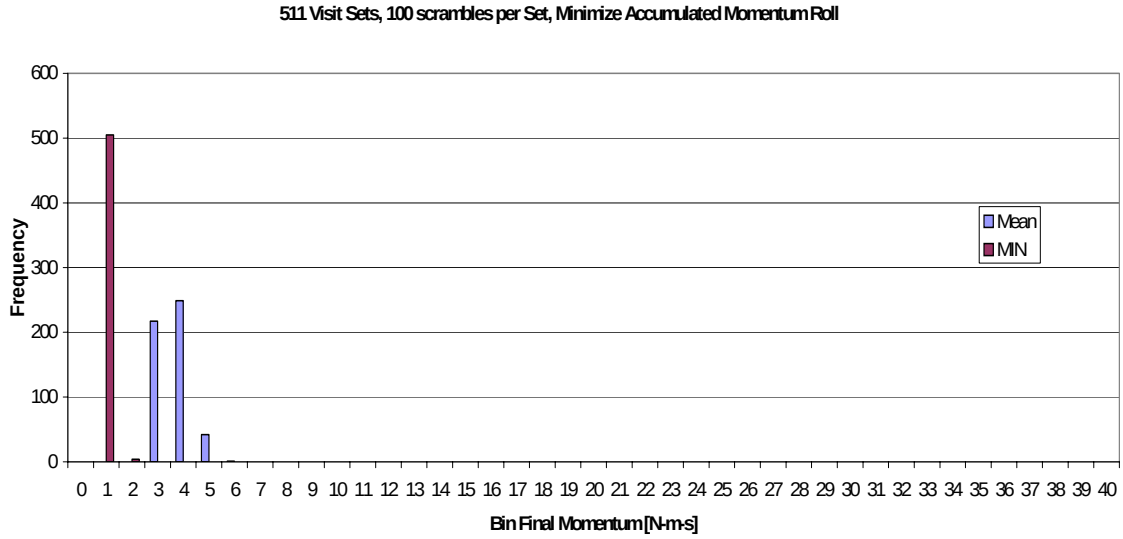

Figure 2: Minimize Accumulated Momentum Roll

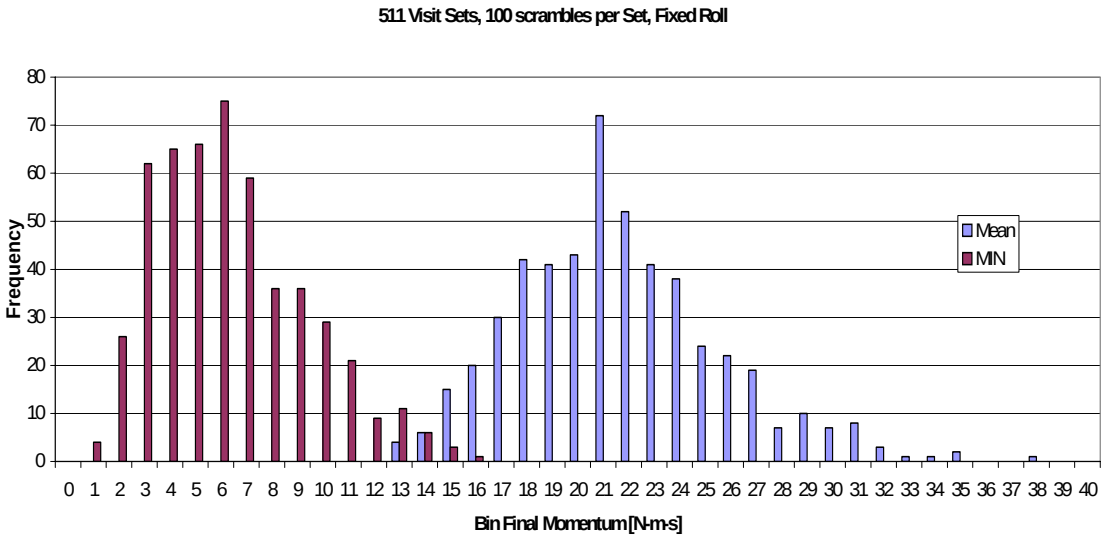

Figure 3: Fixed Roll

4.0 Discussion

The three cases examined are at two extremes of the expected visit pool. In two of the cases, Nominal Roll and Minimize Accumulated Momentum Roll, the visits are unconstrained; the visits' rolls were allowed to be adjusted and the visits could schedule anywhere in the 22 day interval. In the third case, all the visits were constrained in that the visits' rolls were set to a roughly arbitrary fixed position angle.

In the Nominal Roll method, there was a slight decrease (~20%) in the peak of the distribution of the minimum final momentum versus the mean momentum. This is caused by the fact that for each scrambling of the visit set, the momentum accumulation for each visit was minimized by selecting the nominal roll. In this case, the angular momentum gained during a visit is due mostly to contributions from the pitch torque component, which is a slowly varying function of time (relative to the roll torque). Thus reordering the visits has a smaller impact on the overall momentum accumulation compared to the other methods.

In the Minimize Accumulated Momentum Roll method, the peak of the mean ending momentum distribution was only ~25% of the peak of the Nominal Roll mean distribution. There was an addition ~75% reduction between the peaks of the mean and minimum angular momentum distributions, however, since this roll assignment method produced a substantial reduction of the final accumulated momentum, the additional reduction due to visit sequencing may not be of practical value.

In the Fixed Roll method, the peak of the minimum accumulated final angular momentum distribution was only ~25% of the peak of the mean distribution. In this case, since the visits' rolls were fixed, the placement of each visit in the schedule did directly affect the amount of momentum accumulation about the roll axis for the visit and thus the final accumulated momentum was strongly dependent upon the specific order of the visits.

5.0 Conclusions

Finding a particular order of the visits impacted the ending accumulated angular momentum most in the Fixed Roll case. Even when **all** the visits had a fixed orientation, it was still possible to find a particular visit order, selected from just 100 random orderings, that allowed a significant drop in the accumulated momentum (~75%). The largest reduction in the accumulated angular momentum occurred using just the assigned roll to minimize the momentum accumulation; even without the added benefit of including visit sequencing.

An operational set of observations will be a mixture of non-restricted visits and orient and time restricted visits. Based on this study and assuming that the visits are not overly time restricted and the assignment of orients for a substantial fraction of visits can be deferred to short term scheduling, a combination of visit ordering and optimum roll assignment is likely to be a good strategy for managing momentum accumulation on JWST

6.0 References

Kinzel, W. M., 2004, STScI-JWST-TM-2004-0006 A, “Initial JWST Momentum Management Analysis”