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RECONSTRUCTION OF EARTH FLYBY BY THE JUNO SPACECRAFT*

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The Juno spacecraft conducted a successful gravity-assist flyby of the Earth on 09 October 2013, putting the spacecraft on a trajectory to reach Jupiter in July 2016. The DSN tracking was supplemented by tracking from two ESA stations, giving us an unprecedented, near continuous level of tracking for an interplanetary spacecraft flyby of Earth. We discuss the process of reconstructing that trajectory, the challenges encountered in that effort, and the results. In particular, no anomalous velocity change was observed at or near perigee as has been observed in some of the previous Earth gravity assist flybys by other spacecraft[1].

INTRODUCTION

The successful Earth gravity-assist (EGA) flyby on 09 October 2013 by the Juno spacecraft was a necessary step in reaching Jupiter. Herein, we will discuss some of the preparation by the orbit determination (OD) team for the flyby, the reconstruction of that trajectory, and the challenges encountered in that effort. The tracking schedule for range, Doppler, and delta-DOR measurements allowed precise targeting and reconstruction of the flyby. No delta-DOR measurements were included in our trajectory reconstruction of the flyby trajectory; however, they were necessary component of improving the OD accuracy leading into maneuvers targeting the Earth flyby. As the Deep Space Network did not have the necessary geometry in order to track the spacecraft during the period around closest approach, the coverage was supplemented by tracking from the European Space Agency (ESA) stations at Malargüe, Argentina, and Perth, Australia. While not needed in order to meet the targeting or reconstruction requirements of the EGA, they gave us an unprecedented level of tracking for an interplanetary spacecraft flyby of Earth.

Of particular interest is if a delta-V or acceleration at or near periapse, and not accounted for by other sources, is required to fit the tracking data. This has been observed in other Earth flybys[1], though the results are not always consistent. For example, a relatively large delta-V of was

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observed in the NEAR spacecraft flyby, while for the Galileo spacecraft an anomalous delta-V was readily observed in the first Earth gravity assist but not the second[2]. In preparation for the Juno EGA flyby, a trajectory sensitivity study was performed. This was done to help us identify any anomalies or unmodeled forces immediately after the flyby via the effect that could be observed in real-time in the Doppler residuals. These residuals were calculated based on a pre-flyby OD solution. The most significant sensitivity that we identified in simulations was due to truncation of the gravity field used in the trajectory propagation. Other reasonable perturbations were negligible. It also illustrated that an anomalous change in alongtrack velocity larger than several millimeters per second could be readily resolved, if present. No such velocity anomaly was detected in the flyby. While the unplanned thrusting events soon after periapse complicated this analysis, the dominant contribution was: (1) off the Earth-line, (2) not consistent with an alongtrack velocity perturbation, and (3) resolved with an uncertainty of less than 1 mm/s.

The initial step in using tracking data for Juno trajectory reconstruction is pre-processing the data to remove the sinusoidal signature and Doppler bias introduced by the spinning spacecraft. This procedure and analysis was significantly complicated by the response of the spacecraft upon entering safe mode soon after perigee. This event commanded a small turn to sun-point and resulted in small velocity perturbation as well as an unplanned change in spacecraft attitude. Unfortunately, this new attitude resulted in a significant amount of multi-path errors in the tracking data that persisted for several days immediately after the flyby, reducing the amount of usable tracking data. The situation improved after the recovery from safe mode was complete and the spacecraft was commanded back to the nominal planned attitude. The remaining useable tracking data still allowed us to successfully reconstruct the trajectory, but with a small corresponding increase in the precision of the reconstruction.

Juno Cruise Overview

Launched on 05 August 2011, the Juno spacecraft travelled within the inner solar system on a heliocentric orbit for approximately two years. It flew past the Earth on 09 October 2013 with a geodetic altitude of approx. 561 km for the gravity assist necessary to boost the trajectory to Jupiter. This particular EGA opportunity repeats every 13 months, hence the nearly two year journey. It required a large deep space maneuver (DSM), split into two parts DSM-1 & DSM-2, about one year after launch combined with the EGA 26 months after launch. The large DSM was executed near aphelion and was split into two smaller maneuvers in order to avoid having to qualify the main engine for a long burn that would be required by a single DSM.

The DSMs targeted an aimpoint that was biased away from the Earth flyby aimpoint to minimize the likelihood of the spacecraft being on an Earth impacting trajectory for a long period of time following the DSMs. This bias in the trajectory was first removed with a trajectory correction maneuver (TCM) at approximately 60 days prior to the Earth flyby (EFB-60 days), referred to as TCM-6 (see Table 1). During this phase of the mission, the only deterministic maneuvers were the DSMs and TCM-6. The remaining TCMs, TCM-7 and TCM-8, were statistical and opportunities to remove trajectory errors due to errors in the OD predictions and execution errors in the previous maneuvers. There was also a collision avoidance maneuver (CAM) scheduled at EFB - 12 hours in order to allow for deflection from possible orbiting debris. On approach to the flyby, only TCM-6 and TCM-7 were needed to target the Earth flyby aimpoint to within the requirements. TCM-8 was cancelled and the CAM was also found to be unnecessary.

Table 1. Selected Navigation Events Relevant to Flyby Reconstruction.

Mission Event	Event Time (UTC)	Antenna Active
TCM-6	01-May-2013 16:00	Torroidal low gain (TLGA)
TCM-7	09-Sep-2013 21:00	Aft low gain (ALGA)
TCM-8*	29-Sep-2013 16:00	
Precession Turn	05-Oct-2013 04:10:25	
Data Arc Start	05-Oct 2013 13:00	
CAM*	09-Oct-2013 07:30	
Earth shadow entry	09-Oct-2013 19:20	
Closest Approach	09- Oct-2013 19:21:24.8530	Forward low gain (FLGA)
Earth shadow exit	09-Oct-2013 19:39	
Safe Mode Turn	09-Oct-2013 19:47:36	
Precession Turn	13- Oct-2013 07:21:54	
Data Arc End	14-Oct-2013 02:50	
Safe Mode Turn	14- Oct-2013 02:56:57	
**cancelled activity*		

Nominally, the final thrusting event prior to the EGA would have been the precession turn on 05 October 2013. The reconstruction of this flyby trajectory was chosen to start soon after this turn in order to minimize the number of events needed to be modelled in the filter process. Unfortunately, a safe-mode entry complicated this plan. The safe mode entry occurred ~10 min after closest approach, followed by an approximately 4-deg turn to sun-point 26 min after closest approach. This introduced a small delta-V soon after periapse, while the spacecraft was not being tracked by the DSN or ESA.

Safe mode was exited with a relatively large 24-deg turn and the spacecraft returned to nominal operations on 13 October 2013. This placed it back on the nominal attitude plan and helped to alleviate the issues from muti-pathing adversely affecting the tracking data after the flyby. Due to the unbalanced nature of the thrusters, this introduced a larger delta-V; however, it occurred far from flyby and with tracking immediately before and after the turn. Safe mode was triggered again soon after on 14 October 2013. Since this introduced a small delta-V as well as an off-nominal attitude change, we decided to make that the end of the data arc used to reconstruct the flyby trajectory. This left only two delta-V events to model during the reconstruction trajectory span.

TRAJECTORY SENSITIVITY SIMULATIONS

Prior to the flyby, simulations where conducted to identify sensitivities in the force modelling that might be observed in the real-time Doppler residuals immediately after the flyby. By using reasonable – and sometimes unreasonable – perturbations in the known forces the goal was to allow for a means to quickly identify any anomalies that might be observed in tracking data immediately after the flyby. Since tracking data from the ESA stations was not available in real-time, only the two DSN tracks of data immediately before and after the flyby were simulated. Realistic levels of random noise and a spin signature were added to the simulated Doppler and range data.

The simulation process consisted of first calculating a nominal trajectory using baseline values for planetary GMs, solar radiation pressure, atmospheric drag, and Earth's geopotential field.

The nominal values were not as important as was selecting appropriate perturbations based on estimates of the errors in the nominal force models. Multiple types of perturbations were used to integrate individual perturbed trajectories. These trajectories were then used as “truth” to generate simulated tracking data. Residuals were computed from this simulated tracking data relative to the nominal trajectory, thereby helping to show the effect that may be visible in near real-time as DSN tracking data was delivered to the Juno navigation team. Immediately, it was evident that no reasonable level of error or minor anomaly would be detectable in the real-time monitoring of tracking data still containing the spin signature. This data would have to be “despun” before an assessment could be made. This step is normally left to the reconstruction and not part of the real-time monitoring. Details of this process will be discussed in the trajectory reconstruction section.

Of particular interest was the possible detection of an Earth flyby anomaly in velocity as has been observed in other Earth flybys. For example, during the NEAR flyby a relatively large 13 mm/s velocity change was observed in the Doppler and range data[2]. From the historical set of velocity anomalies observed during Earth flybys, an empirical model is discussed in Reference 1 that could be used to help predict the expected anomalous velocity changes. For the Juno EGA flyby, this was predicted to be on the order of 7 mm/s in the alongtrack direction relative to Earth at the time of periapse[3].

Figure 1 shows the effect of this level of anomalous delta-V on simulated observations. The left side of the figure is with the spin signature and the right after the spin signature has been removed. Note the order of magnitude differences in scale. The jump is 3.2 mm/s (0.18 Hz for X-band two-way Doppler) in the Earth line and is obvious in the despun data, but insignificant relative to the amplitude of the spin signature. While the Earth-line component of the trajectory change was 3.2 mm/s for a 7 mm/s velocity perturbation at periapse, the total persistent trajectory change observed after the EGA was 11 mm/s. The flyby magnifies the effect of the perturbation, with only 3.2 mm/s of the total 11 mm/s immediately visible in the Earth-line direction for this particular case.

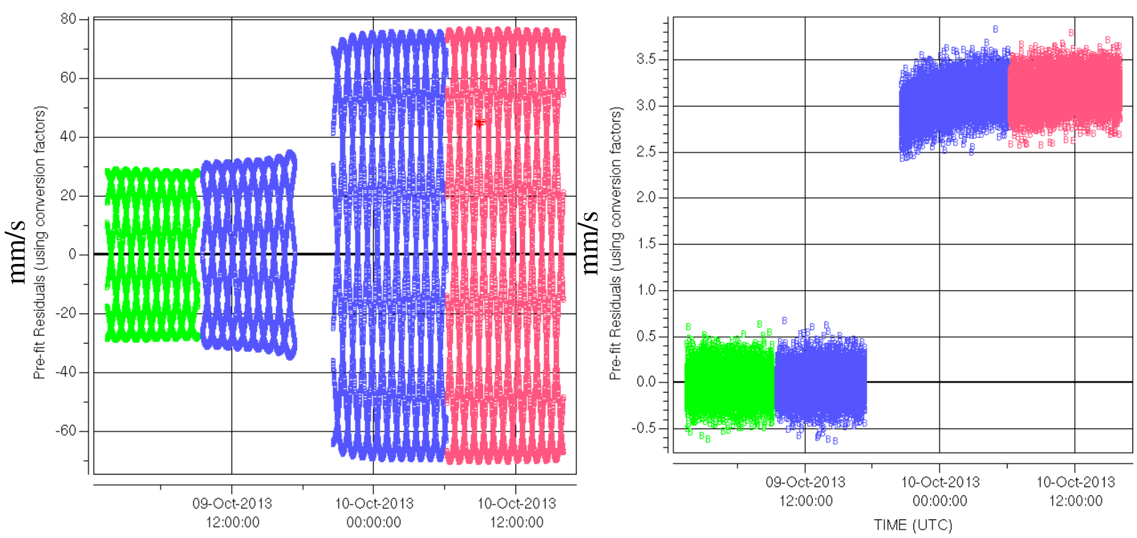

Figure 1. Simulated, Doppler residuals due to a 7mm/s delta-V perturbation: with (left) and without (right) the spin signature.

We examined a number of possible perturbations, but for one exception none of them reached a level of perturbation that would be easily detected in real-time monitoring. Turning atmospheric drag off produced a perturbation of only 0.1 mm/s, while increasing the drag scale coefficient by a factor of 10 was still only capable of producing a perturbation of 0.7 mm/s. The perturbation due to a three-sigma error in Earth's GM was also at this small level of 0.1 mm/s. And the difference between using the nominal Earth gravity model of GGM02C[4] and replacing it with GGM03C[5] was negligible – approximately 1 micron/s velocity difference in the trajectory.

We also considered variations in J2 that would not necessarily be known well in a predictive sense, but would be available later for reconstruction. These are geophysically significant variations in J2; for example, the secular variation due to post glacial rebound, seasonal variations in global hydrology, and tides. Monthly and seasonal variations are difficult to predict and need to be reconstructed by dedicated temporal gravity efforts. We found that these variations could only produce velocity perturbations in the trajectory of a few microns per second, which is well below the level of detectability. The conclusion being that this flyby is really a poor measurement of J2 as it is not sensitive to the expected variations or uncertainties in J2.

The only perturbation that we examined that was found to be capable of producing something detectable in real-time and comparable to the predicted flyby velocity anomaly was truncation in the Earth's geopotential model. Previously, we had found a 10x10 degree/order field sufficient for supporting launch operations. The uncertainties in the trajectory during that phase were large enough as to not require a higher fidelity model. However, for the EGA flyby we found that the perturbation caused by including the additional effect of the higher degree and order terms was as large as 4.5 mm/s when using a 50x50 field. Shown in Figure 2 is this effect for 20x20, 50x50, and 100x100 degree/order truncations all relative to using the 10x10 as nominal. For comparison purposes, also shown in the figure is the effect of removing the relativistic correction for the acceleration due to the geopotential (labeled "grav_newton"). It was later found that the data very near to closest approach, i.e., the ESA tracking data, was even sensitive to truncations higher than 100x100.

Would we be able to differentiate between a gravity error and a delta-V? The answer is possibly not in the real-time monitoring effort as that is sensitive to the Earth-line component and cannot differentiate between these types of perturbation sources. However, the comparison in Figure 3 does suggest that in trajectory reconstruction the differentiation is possible. An along track velocity change gives no change in the position component normal to the Earth-spacecraft orbit plane, while gravity errors show little to no change in the radial component. They are distinctly different sorts of perturbations.

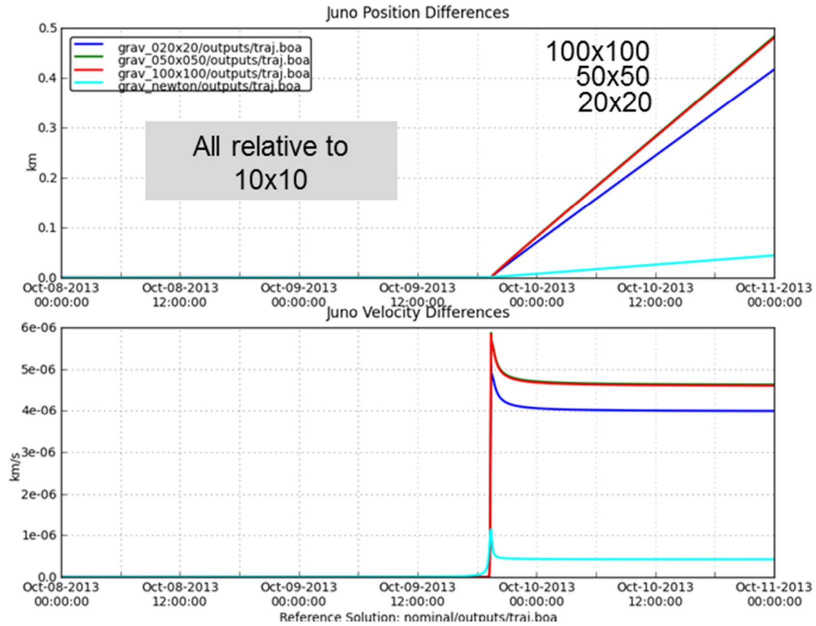

Figure 2. Perturbation in position (top) and velocity (bottom) in a trajectory perturbed by different geopotential fields. All relative to a 10x10 field.

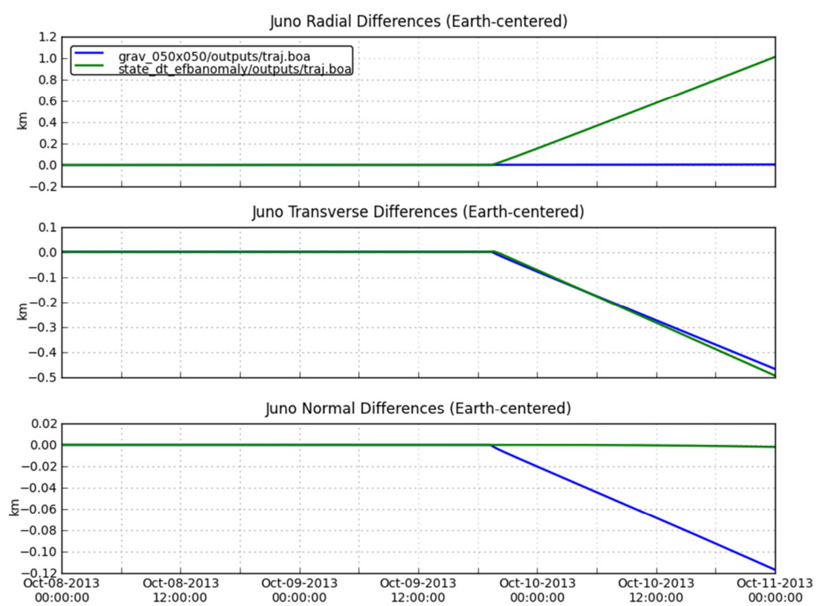

Figure 3. Trajectory changes relative to the nominal due to a higher fidelity gravity field (blue lines) and an alongtrack delta-V (green lines).

TRAJECTORY RECONSTRUCTION

Measurement Modeling and Dynamics

The Juno spacecraft is a spin-stabilized spacecraft. During the time period of this reconstruction, the spin period was approximately two revolutions per minute. The process of removing the spin signature for Juno is comparable to the procedures and scripts used for the Mars Science Laboratory (MSL) as documented in Reference 6. In fact, the first operational use of those procedures used by MSL took place during Juno's launch and initial cruise (the launch of MSL occurred in November 2011, several months after Juno's launch). The primary difference between the MSL process and Juno's being that the mass properties and antenna locations (phase centers) needed to be defined specifically for Juno.

Nominally, the pre-processing steps of removing the spin signature due to the aft low-gain antenna (ALGA) and forward low-gain antenna (FLGA) are fairly straight forward. What complicated this procedure significantly were the unexpected attitude changes introduced by the two safing events (see Table 1). This first safing just after periapse introduced two issues because of the attitude differences, as shown in Figure 4. The left plot shows the off-Earth angle of the antennae, which in the case of the ALGA is the -Z-axis and the FLGA the +Z-axis relative to Earth. Another effect is shown in the right plot of Figure 4, where the off-Sun angle made a sudden jump due to the safe mode attitude change. While it didn't fundamentally change the solar radiation pressure acceleration, the subtle difference was enough to show a small trend in the trajectory normal to the Earth line and warranted breaking up the scale factor estimate into two separate parameters separated by the turn.

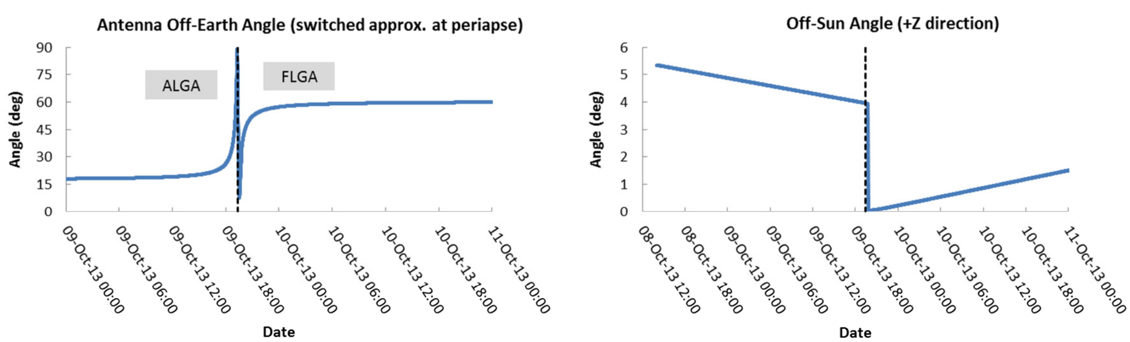

Figure 4. Off-Earth angle for the antennas (left) and off Sun angle of the solar panel normal (right)

While only differing initially by 4 deg from the nominal attitude, this attitude was off the nominal attitude enough to introduce significant multi-path errors in the data for the FLGA. We were unable to remove this multi-path error during the despin process. The end result is that we deleted selected portions of the tracking data for the few days immediately after the flyby. Shown in Figure 5 is an example with particularly bad multi-path errors that was deleted from the reconstruction. These are residuals after the spin signature has been removed. There is clearly structure evident in the residuals that does not look like random noise. The nature of this error is seen in Figure 6 when the residuals are plotted vs. spin phase. There is a pattern, correlated with the rotation, due to interference of the FLGA signal with the high-gain antenna and/or the solar panels. While easy enough to detect, there is no simple model that can be used to remove this. Because of the large biases in the data, the data is highly questionable as is any spin state derived from it. This type of residual vs. phase plot was used to identify other problem tracking passes removed from the reconstruction.

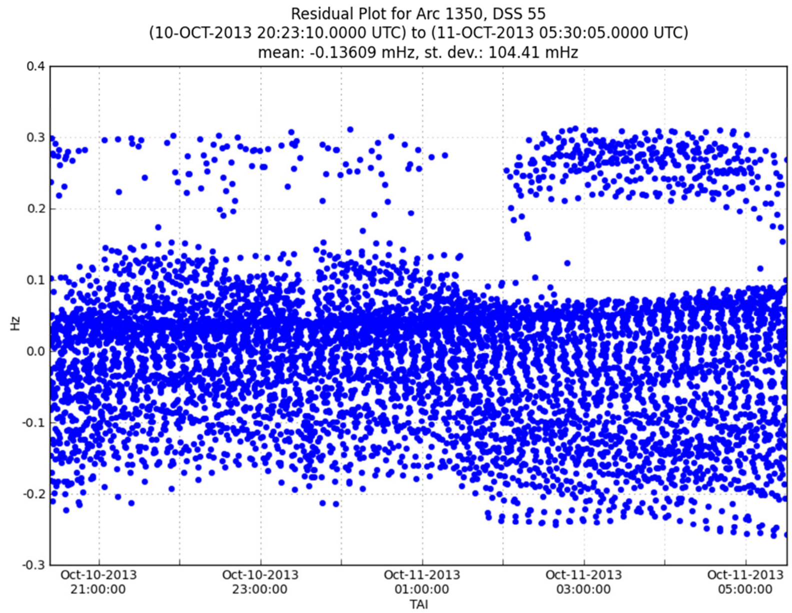

Figure 5. Example of multi-pathing: Two-way Doppler residuals (Hz) vs. time

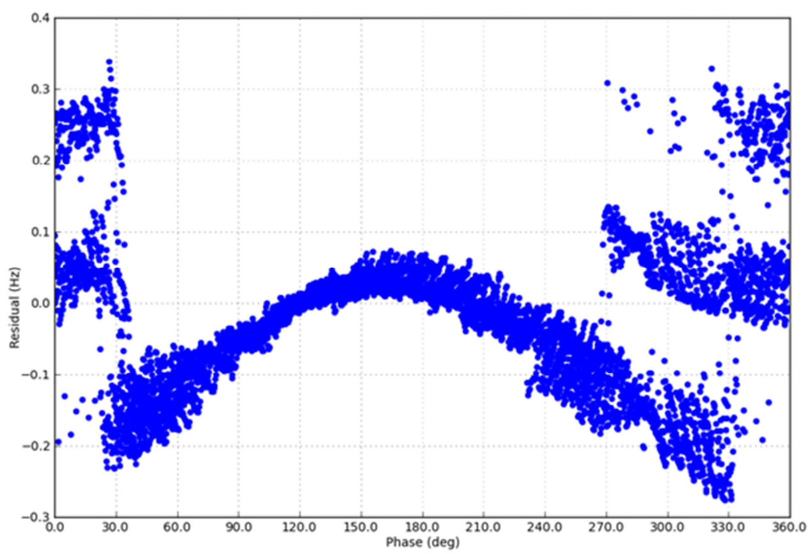

Figure 6. Example of multi-pathing: Two-way Doppler residuals (Hz) vs. spin phase

Once the spin signature had been successfully removed, we used the Mission analysis and Operation Navigation Toolkit Environment (MONTE) program[7] developed at JPL for the OD. We assumed a per-pass data weight based on the post-fit RMS of each tracking pass, data elevation cutoff of 10 deg, corrections for tropospheric and ionospheric media, and included all valid range and Doppler not adversely affected by multi-path errors.

The tracking data was compressed to 300-s count time from start of the data arc until end of DSS-55 track at 09 October 2013 16:52 UTC. The Malargüe data and Perth data beginning around closest approach was provided to the Juno navigation team with a 1-s count time, while the DSN data after periapse was provided at a 5-s count time. Rather than complicate the bookkeeping, we decided not to compress this data. Overly aggressive compression could mask some of the errors being introduced by the multi-pathing as well as hide any short-time scale perturbations or interesting dynamics.

The data arc from 05 October 2013 through 14 October 2013 was selected such that it minimized the number of delta-V events and significant changes in spacecraft solar panel usage. This helped us simplify the force modelling as the reconstruction was affected by our ability to resolve delta-V as well as to resolve the response of the solar pressure model to changes in attitude and power utilization.

The solar radiation pressure (SRP) model used a geometric model of the spacecraft with surface optical properties assigned to key components, e.g., the large solar panels. These properties (specular and diffuse coefficients) had been calibrated based on flight experience during cruise. The effect due to shadowing of the spacecraft when it was eclipsed by Earth was included. The only parameter of the SRP model estimated during the reconstruction was the SRP scale factor. There were two scale factors estimated: one for pre-flyby and one post-flyby, the dividing line in behavior being the turn on 09 October 2013. This is when the attitude and power utilization properties both changed – two things which both act to change SRP and other thermal accelerations acting on the spacecraft.

Other estimated parameters and associated error estimates were those included in turn delta-V and the initial state of the trajectory. Consider parameters in the reconstruction included media calibrations (troposphere & ionosphere), Earth orientation parameters (rotation and polar motion), DSN station locations, ephemeris of Earth/Moon barycenter, and GM of Earth & Moon. These types of error sources do not have parameters which are improved by the reconstruction but contribute error to the precision of the estimated parameters. The planetary ephemeris used was DE425[8]. The spherical harmonic expansion of the Earth gravity field was taken from GGM02C[4] and truncated to degree and order 180. For additional background on the fundamentals of statistical orbit determination (e.g., linearization, measurement processing, covariance propagation, and consider parameters to name a few topics), please see Reference 9.

As discussed earlier, at nearly 60-deg off Earth the FLGA was susceptible to multi-path errors. The turn due to the safe mode entry, while relatively small, exacerbated the issue and this 4-deg difference between the planned attitude and the actual attitude was enough to significantly corrupt the data. In Figure 7, postfit residuals are shown for the entire data arc used in the reconstruction. Also shown is the deleted data from the tracks heavily affected by multi-path; these deleted points are highlighted by the black boxes. The biases in the data can be readily seen in the detail of selected tracks. The data used was weighted on a per-pass basis, with minimum weights applied of 0.05 mm/s for Doppler (for 60-s count time) and 3 m for range.

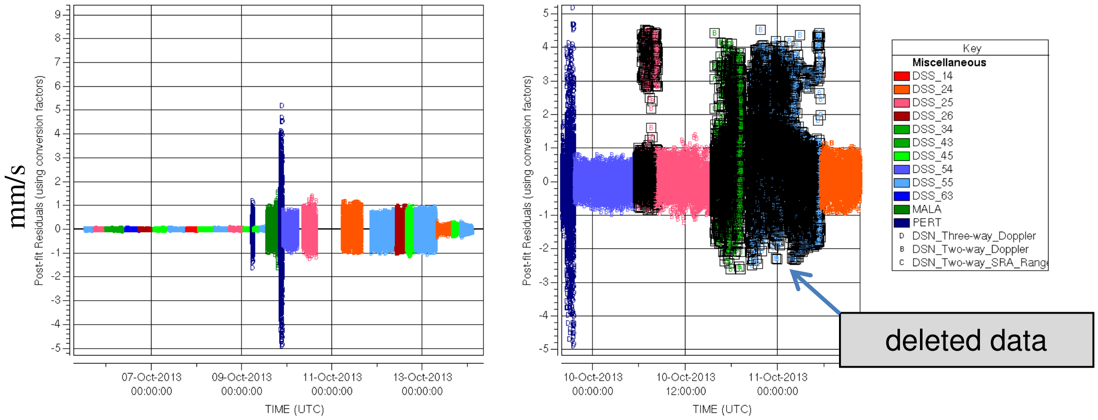

Figure 7. Doppler data postfit residuals. Data used in the reconstruction (left) and a close-up of selected post-flyby tracks (right) also showing deleted data (highlighted with squares).

Since it was the look angle from the spacecraft to the station that was important, and not the Earth-angle per-se, there were some instances where the data was usable due to the particular geometry. We were right on the edge of usefulness and a small angular change made a significant impact. Since the spacecraft was spin stabilized and does not have wheels, the attitude was allowed to evolve naturally relative to Sun and Earth while remaining relatively fixed in inertial space; the primary force changing the attitude being solar torque. Through a combination of exiting safe-mode to return it to the nominal attitude and the geometry change simply due to movement of the spacecraft relative to the Earth, the multi-path issue was eventually resolved.

Reconstruction results

In Table 2 and Figure 8 are shown the TCM-7 target and the reconstructed trajectory in the Earth B-plane, along with their associated uncertainties. The error ellipse for the TCM-7 target is due to the a priori execution error assumed for the TCM. For a detailed discussion of the definition of the B-plane and its application to spacecraft navigation, see Reference 10. It wasn't a specific altitude that was targeted, but a target in B.R, B.T, and time of closest approach (TCA) that was selected based on minimizing propellant usage to reach Jupiter. When looking at the differences between the TCM-7 target and the trajectory reconstruction, keep in mind that the final approach maneuver (TCM-8) was cancelled and that TCM-7 occurred at EFB-30 days. In terms of geodetic coordinates, this reconstructed flyby corresponds to an altitude of 561.112 km over the latitude and longitude point of -34.3098 deg and 33.91158 deg, respectively – a point off the southwest coast of South Africa.

Table 2. B-plane: TCM-7 target vs. reconstructed flyby trajectory

				Error ellipse, 1-sigma		
Label	**B.R (km)**	**B.T (km)**	**TCA**	**Semi-major**	**Semi-minor**	**TCA**
TCM-7 Target	7098.013	6988.020	19:22:31.8605 ET	64.1 km	12.3 km	3.3 s
Reconstruction	7095.6731	6993.8464	19:22:32.0353 ET	1.4 m	1.4 m	26 ms

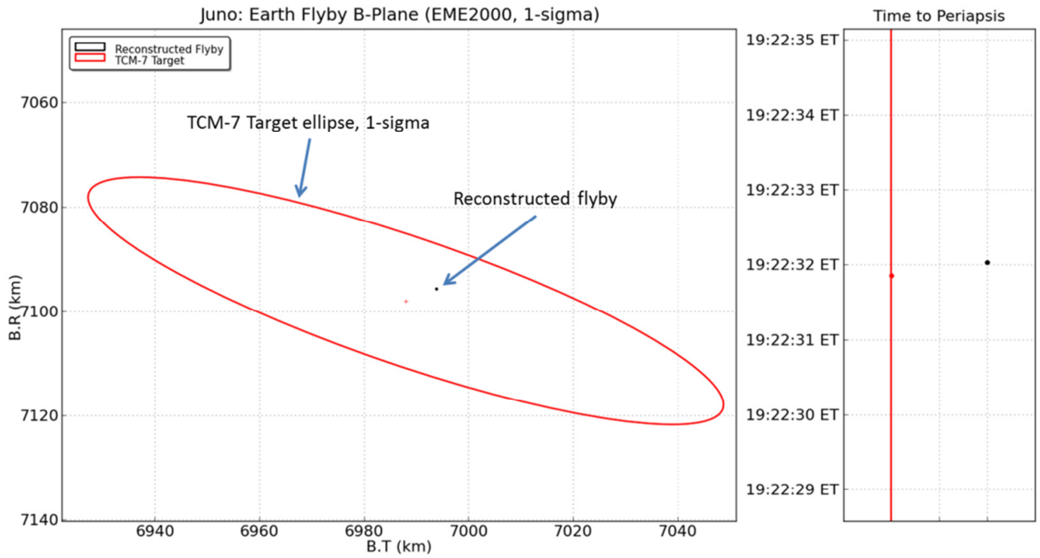

Figure 8. Earth flyby B-plane and 1-sigma error ellipses for TCM-7 target and reconstructed trajectory. Error ellipse for reconstruction does not show at this scale.

The SRP scale factor was estimated in two batches, with the dividing line being the turn after the safe mode near periapse. The estimates for the scale factor for those two batches were found to be 1.000 pre-flyby and 0.998 post-flyby, with a one-sigma uncertainty of 0.006 and 0.007 respectively. This is a relatively small difference between the two regimes, and they are effectively the same scale factor within the formal uncertainty calculated for each.

The impulsive velocity changes found for the turns within the arc were relatively small, although they have a somewhat high level of uncertainty in the normal direction (perpendicular to the Earth-line). Because of this, the estimates are not that different from their nominal values of zero delta-V in a one-sigma sense. The size and uncertainty have been shown previously in cruise to be strongly correlated with the size of the turn, so the safe mode turn near periapse and the precession turn later to exit safe mode differ in size accordingly and the estimated values are consistent with our flight experience (Table 3).

Table 3. Turn delta-V.

Event	Event Time (UTC)	Magnitude (mm/s)	Sigma (mm/s)	Turn size (deg)
Safe Mode Turn	09-OCT-2013 19:47:36	1.7	1.1	3.9
Precession Turn	13-OCT-2013 07:21:54	3.7	3.8	24.4

Non-detection of anomalous velocity

Was a previously unmodeled (i.e., anomalous) delta-V or acceleration at or near periapse required for the reconstruction? This has been noted as necessary in other Earth flybys, though the behavior is not always consistent. For example, it was readily observed for the Galileo spacecraft in the first Earth gravity assist but not the second (e.g., see Reference 2). Based on the collection of anomalous velocity perturbations observed at prior Earth flybys, it was predicted that an anomalous delta-V on the order of 7 mm/s in the alongtrack direction might be observed at periapse for the Juno EGA[3].

We didn't find a velocity perturbation to be necessary to fit the data or explain anything observed in the reconstruction. While the safe mode entry does complicate the analysis somewhat, it was at a magnitude and in a direction that would be inconsistent with the predicted anomaly of 7 mm/s in the alongtrack direction, or any anomaly in the alongtrack direction larger than ~1 mm/s. Due to the unbalanced thrusting during the turn, the delta-V was predominantly a direction normal to the spin axis and little perturbation was placed in the alongtrack direction due the safe mode near periapse. The estimated delta-V due to the turn is largely orthogonal to the alongtrack directions. The primary effect of the safe mode turn was to reduce the precision of the dynamics occurring near periapse to approximately the 1 mm/s level.

Where this lack of an anomaly is especially evident is when using a pre-flyby trajectory to calculate residuals for the Doppler data post-flyby. We used all available data prior to periapse to calculate a nominal trajectory. This includes the Malargüe data just prior to losing contact near periapse. This nominal trajectory was then used to calculate residuals for the remaining tracking data after periapse, after the spin signature had been removed. This type of residual is referred to as a "passthru", as this data is not used to adjust the trajectory in order to minimize these residuals. This highlights any dynamics not captured in the nominal trajectory that was based on only pre-periapse tracking. The result is shown in Figure 9, with the post flyby data highlighted by black boxes. Recall in the trajectory sensitivity studies, an alongtrack velocity perturbation was readily visible in the tracking data (Figure 1). In the Earth-line direction, not even the safe mode turn is evident as the majority of that delta-V was in a direction normal to the Earth-line. The only structures evident are the large levels of noise in the multi-path data and the delta-V due to the larger 24-deg precession turn on 13 October 2013.

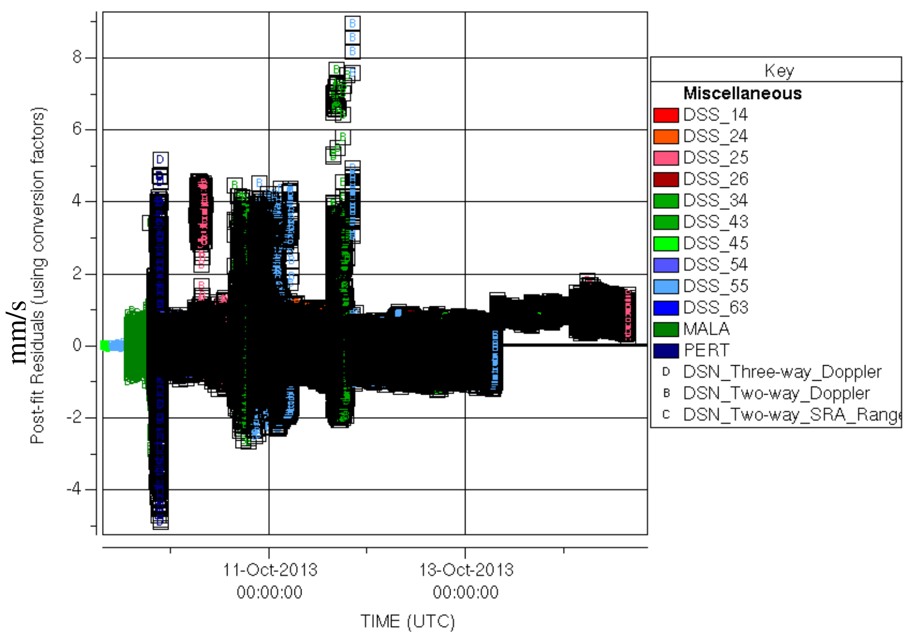

Figure 9. Passthru of Doppler data (black boxes) based on a trajectory reconstruction prior to periapse.

SUMMARY

This was a very successful Earth gravity assist flyby by the Juno spacecraft. It flew over a point off the coast of South Africa at a geodetic altitude of 561.112 km. We were able to reconstruct the flyby with a precision of 1.4 m, 1.4 m, and 29 ms in B.R, B.T, and time of closest approach, respectively. Multi-path issues degraded the reconstruction to a small level, but there was more than enough data post-flyby in order to adequately reconstruct the trajectory and to isolate the velocity changes introduced by the turns.

There was no detection of a velocity anomaly in the alongtrack direction; any anomalous perturbation would have to have been less than 1 mm/s and partially nullified by events later in the trajectory as there was no persistent perturbation observed in the trajectory. In particular, the addition of the ESA data near closest approach was instrumental in resolving any dynamics around periapse, particularly in light of the unintentional velocity change introduced by the safe mode entry so soon after periapse.

This reconstructed trajectory was delivered to the Juno Science Team for the purposes of conducting analysis with their science observations during the Earth flyby. It will also become part of the spacecraft ephemeris archive available on the JPL HORIZONS system.

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