IMPROVING FERMI ORBIT DETERMINATION AND PREDICTION IN AN UNCERTAIN ATMOSPHERIC DRAG ENVIRONMENT

Matthew A. Vavrina(1)**, Clark P. Newman**(2)**, Steven E. Slojkowski**(3)**, and J. Russell Carpenter**(4)

(1)(2)(3)*a.i. solutions, Inc., 10001 Derekwood Ln. Suite 215, Lanham, MD 20706, 301-286-5105, matthew.vavrina@ai-solutions.com,* (2)*clark.newman@ai-solutions.com,* (3)*steven.slojkowski@ai-solutions.com*

(3)*NASA Goddard Space Flight Center, 8800 Greenbelt Rd, MS 595.0, Greenbelt, MD 20771, 301-286-7526, Russell.carpenter@nasa.gov*

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ABSTRACT

Atmospheric drag uncertainty of Earth orbiting spacecraft at low altitudes poses significant challenges to accurate orbit determination and prediction. Such is the case for the Fermi spacecraft orbit, which at an operational altitude of roughly 535 m is strongly influenced by atmospheric drag. The drag force is difficult to estimate and predict due to atmospheric density variations caused by unpredictable space weather. Drag modeling inaccuracies are exacerbated by an uncertain spacecraft ballistic coefficient (BC).

For operational orbit determination (OD) of the Fermi spacecraft, point solutions from the GPS receiver are processed by the Fermi owner/operator (O/O) using an extended Kalman filter and backwards smoothing. Predictive ephemerides are also generated for conjunction assessment and frequently compared to solutions produced by the Joint Space Operations Center (JSpOC) when a close approach with a second object is anticipated. JSpOC predictions, however, are based on OD using radar measurements and are expected to be less accurate than predictions based on an orbit derived from GPS data. Significant differences between the predicted miss distance of Fermi with a second orbiting object from the O/O and the JSpOC solutions were regularly observed. The predicted miss distance six days ahead of the estimated time of closest approach (TCA) often varied by multiple kilometers between the two different solutions. Additionally, in several instances, the JSpOC prediction appears to predict a more consistent miss distance as the TCA nears. While the predictions eventually converge on a similar miss distance at the TCA, differences as high as 10 km at six days from TCA are observed. This disparity between the predictions leads to difficulty in selecting which solution to trust when making a decision on whether to execute a maneuver to mitigate a close approach, prompting this investigation.

A tuning analysis was conducted to characterize the observed issue, and then to refine and optimize the drag models and other parameters critical to the prediction process. The goal of the tuning analysis was to identify the best filter settings, models, and model parameters to improve prediction accuracy and consistency. Prediction accuracy is closely coupled with definitive OD accuracy, so the best tuning cases are expected to also be of reasonable definitive accuracy. That is, accurate forward predictions generally require a starting state that is close to the truth state as the errors will increase as the spacecraft state is propagated. Effectively, the tuning process is an

optimization problem where the filter and model parameters are the design variables and the prediction accuracy is the objective function to be maximized (i.e., minimize error between predictive and definitive states). Three days was selected as the prediction span to be "optimized" as that is roughly when the spacecraft operations team must determine whether or not to maneuver the spacecraft to avoid a potential collision with another object.

Initially, a broad search was conducted across the design space. Filter parameter settings and models were widely varied to identify the parameters that have the highest impact on performance and to detect any strong couplings between parameters. As expected, the key parameters were those related to drag modeling such as the nominal base atmospheric density model and the stochastic model parameters for the BC correction and the atmospheric density correction. Once the broad search produced potential leads in terms of improved prediction accuracy, those basins of attraction were investigated in closer detail with a more refined and strategic variation of the parameters. The tuning process included iterating with the following strategies: 1) thinning GPS measurements that are processed; 2) adjusting measurement noise in the filter; 3) varying the initial drag coefficient of the filter; 4) evaluating different BC stochastic models and parameters (Gauss-Markov, random walk, and Vasicek models); 5) modifying BC uncertainty; 6) inflating atmospheric density correction uncertainty; 7) investigating different atmospheric models; 8) and testing interpolated versus step-function produced geomagnetic indices.

It was apparent over the course of the tuning analysis that the propagation of Fermi is highly sensitive to drag modeling uncertainty due to Fermi's low altitude. Fermi experiences relatively large drag perturbations and any mis-modeling of the drag will strongly affect prediction accuracy. The focus of the tuning became determining BC and atmospheric density correction modeling parameters that would allow not only for accurate estimation, but would best balance definitive OD accuracy with the ability to appropriately maintain the estimated value through prediction. Determining the best balance is difficult given the manner in which the BC and atmospheric density correction states are modeled as stochastic processes. Significant performance improvements were obtained with appropriate tuning. A 45% improvement in the mean 3-day accuracy and a 26% reduction in the maximum error over the evaluation period were realized by thinning the measurements processed by the filter, setting a relatively short half life for a Gauss Markov stochastic process for the BC, setting a relatively long half life for the atmospheric density cor-rection stochastic model, and increasing the expected correction to the baseline atmospheric density in the filter. Additionally, the predictions were more consistent, where the standard deviation of the maximum 3-day prediction error decreased by 36%.