Validation of GTDS and DSST Standalone versions against precise orbit ephemerides

Paul J. Cefola*[1,3], Jacob Stratford†[2], Rosario López‡[3], and Juan Félix San-Juan§[3]

[1]Research Scientist, Department of Mechanical & Aerospace Engineering, University at Buffalo (SUNY), Amherst, NY. Also Consultant in Aerospace Systems, Spaceflight Mechanics, and Astrodynamics, Vineyard Haven, MA.
[2]Graduate student in Electrical Engineering at Brigham Young University, Provo, Utah.
[3]Scientific Computing & Technological Innovation, University of La Rioja, Logroño, La Rioja, Spain.

Abstract

GTDS [1, 2, 3, 4] has played a significant role in Space Research: as an orbit propagation (OP) and determination (OD) suite, as a prototype for subsequent operational systems, and as a platform for Astrodynamics education and research. This research includes enhancement of the physical models, development of the Draper Semi-analytical Satellite Theory (DSST) OP method [5, 6], development of DSST Weighted Least Squares and Kalman Filter OD methods [7, 9, 10], test of other analytical and semi-analytical propagators, and port to several operating systems. This effort has led to new operational orbit determination systems and standalone tools and libraries in classical programming languages such as Fortran, C/C++, and Java and interfaces with Python and Julia. Given these applications, it is essential to understand the accuracy of the GTDS physical models and the DSST algorithm in their different versions. The recent availability of independent, very precise orbit ephemerides offers new opportunities to evaluate the accuracy and the computational efficiency of the current version of GTDS and the Fortran, C/C++, and Java DSST Standalone implementations [11, 12, 13, 14]. We started the investigation by considering the Jason-2 and Lageos-2 orbits. The Jason-2 satellite is in a near circular orbit at 1330 km, and is perturbed by the geopotential, lunar-solar, and solar radiation pressure. The Lageos-2 is in a less circular orbit at 5780 km. Very precise ephemeris for both orbits is available from the NASA Crustal Dynamics Data Information System (CDDIS). Our general approach is to least-squares fit the GTDS Cowell and the GTDS DSST orbit propagators to the CDDIS orbits. For Jason-2, with a one minute spacing between the ECEF vectors and a one-day fit span, the GTDS Cowell orbit propagator fits the CDDIS data with a converged iteration position residual RMS of 1.5 meters (Figure 1). The ECEF x and y residuals (both the positions and velocities) exhibit a 12-hour signature envelop with multiple higher frequencies. The ECEF z residuals exhibit only the multiple higher frequencies. For the GTDS DSST fit, the converged iteration position residual RMS increases to 2.1 meters (Figure 2). Similar Cowell and DSST least-squares fits were conducted for the Lageos-2 case. The GTDS Cowell orbit propagator fits the CDDIS data for Lageos-2 with a converged iteration position residual RMS of 1.37 meters (Figure 3). Again, the ECEF x and y residuals exhibit a 12-hour envelop with multiple higher frequencies. The ECEF z residuals exhibit only the multiple higher frequencies. For the GTDS DSST fit, the converged iteration position residual RMS increases to 3.9 meters (Figure 4).

For the Jason-2 case, the envelops of the DSST residual plots follow the envelops for the respective Cowell residual plots. However, there are additional periodic terms in the DSST residual plots. These additional frequencies are intermediate between the high frequencies and the 12-hour terms in Figure 1.

The differences between the DSST and Cowell residuals are larger for the Lageos-2 case than for the Jason-2 case. Also, the 12-hour signature seems less obvious in some of the Lageos-2 DSST plots. This suggests that the increase in the Lageos-2 DSST residuals is connected to the treatment of the lunar-solar perturbations.

In the full paper, we plan a more detailed analysis of the differences between the DSST and Cowell residuals for each of the orbital cases.

---

*Email: paulcefo@buffalo.edu.
†Email: jacob.stratford00@gmail.com.
‡Email: rosario.lopez@unirioja.es.
§Email: juanfelix.sanjuan@unirioja.es.

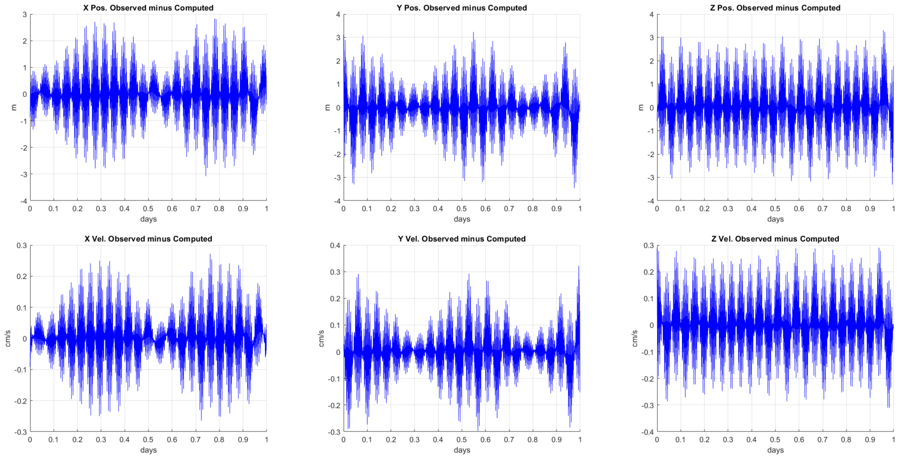

Figure 1: Jason-2 GTDS Cowell DC Converged Iteration ECEF Measurement Residuals (EGM96 50x50, Jacchia-Roberts, Lunar Solar Point Masses, SRP, SET, J2000 Integration Coordinate System) (position differences are in meters and velocity differences are in cm/sec).

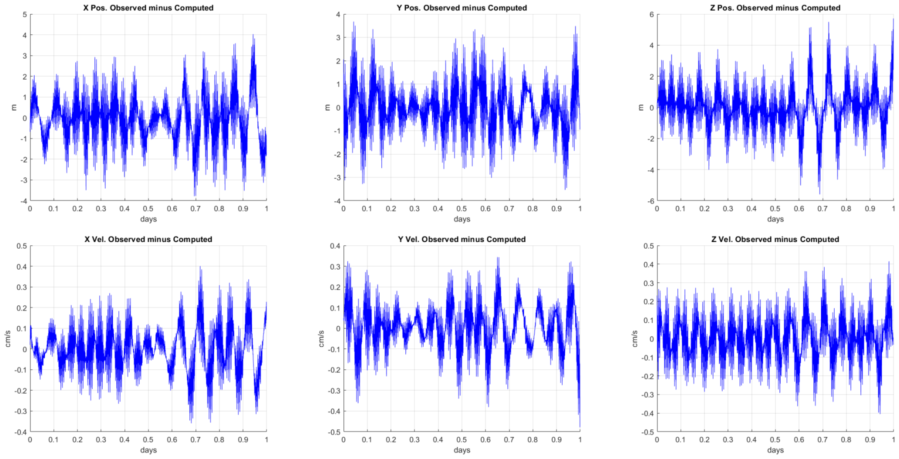

Figure 2: Jason-2 GTDS DSST DC Converged Iteration ECEF Measurement Residuals (GGM01S 50x50, Lunar Solar Point Masses, SRP, SET, J2000 Integration Coordinate System) (position differences are in meters and velocity differences are in cm/sec).

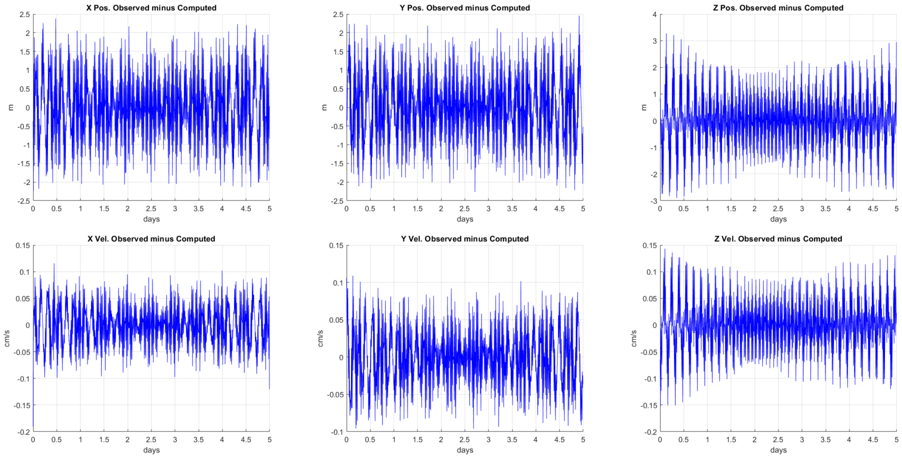

Figure 3: Lageos-2 Cowell DC Converged Iteration ECEF Measurement Residuals (EGM96 50x50, Jacchia-Roberts, Lunar Solar Point Masses, SRP, SET, J2000 Integration Coordinate System) (position differences are in meters and velocity differences are in cm/sec).

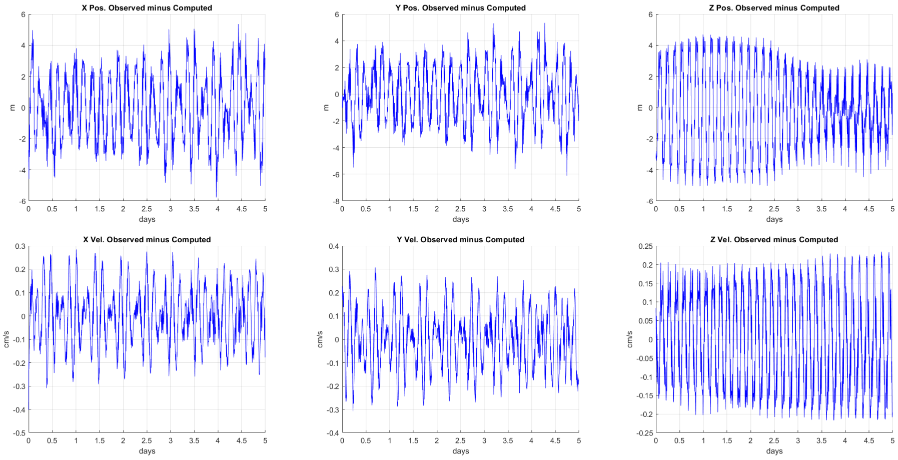

Figure 4: Lageos-2 GTDS DSST DC ECEF Measurement Residuals (GGM01S 50x50, Lunar Solar Point Masses, SRP, SET, J2000 Integration Coordinate System, DSST Short-period model: SPGRVFRC set to complete model, SRP short period motion, Short-Period J2 partials) (position differences are in meters and velocity differences are in cm/sec).

References

[1] J. O. Cappellari, A. C. Long, C. E. Velez, and A. J. Fuchs, "Goddard Trajectory Determination System (GTDS)," Goddard Space Flight Center, Tech. Rep. CSC/TR-89/6021, 1989.

[2] P. J. Cefola, "R&D GTDS semianalytical satellite theory input processor," Charles Stark Draper Laboratory, Cambridge, MA, USA, Intralab Memorandum ESD-92-582 (SGI GTDS-92-001), December 1992, (rev. 1, February 1993).

[3] J. R. Vetter, "Fifty years of orbit determination: Development of modern astrodynamics methods," *Johns Hopkins APL Technical Digest*, vol. 27, no. 3, pp. 239–252, 2007.

[4] T. Stengle and S. Hoge, "Evolution and reengineering of nasa's flight dynamics facility (fdf)," in *SpaceOps 2008 Conference*, 2008, p. 3276.

[5] J. G. Neelon, Jr., P. J. Cefola, and R. J. Proulx, "Current development of the Draper Semianalytical Satellite Theory standalone orbit propagator package," *Advances in the Astronautical Sciences*, vol. 97, pp. 2037–2052, 1998, paper AAS 97-731.

[6] Z. Folcik and P. Cefola, "Very long arc timing coefficient and solar lunar planetary ephemeris files and application," in *Proceedings 29th AAS/AIAA Space Flight Mechanics Meeting*, Ka'anapali, HI, USA, January 13-17 2019, paper AAS 19-401.

[7] Z. J. Folcik, "Orbit determination using modern filters/smoothers and continuous thrust modeling," Master's thesis, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, MA, USA, June 2008.

[8] P. Cefola, C. Sabol, K. Hill, and D. Nishimoto, "Demonstration of the dsst state transition matrix time-update properties using the linux gtds program," in *Advanced Maui Optical and Space Surveillance Technologies Conference*. Maui, HI, USA: Maui Economic Development Board, September 2011.

[9] S. Setty, P. J. Cefola, and J. F. San-Juan, "Space Situational Awareness capabilities of the Draper Semianalytical Satellite Theory," in *Proceedings 6th International Conference on Astrodynamics Tools and Techniques, ICATT 2016*. Darmstadt, Germany: European Space Agency (ESA), March 2016.

[10] S. J. Setty, P. J. Cefola, O. Montenbruck, and H. Fiedler, "Application of Semi-analytical Satellite Theory orbit propagator to orbit determination for space object catalog maintenance," *Advances in Space Research*, vol. 57, no. 10, pp. 2218–2233, May 2016.

[11] P. J. Cefola, J. F. San-Juan, L. Maisonobe, P. Parraud, and R. Di Constanzo, "Semi-analytical satellite theory for the OREKIT open-source space flight dynamics library," in *Proceedings 5th International Conference on Astrodynamics Tools and Techniques, ICATT 2012*. Noordwijk, The Netherlands: European Space Agency (ESA), May-June 2012.

[12] P. J. Cefola, B. Bentley, L. Maisonobe, P. Parraud, R. Di-Constanzo, and Z. Folcik, "Verification of the Orekit Java implementation of the Draper Semi-Analytical Satellite Theory," *Advances in the Astronautical Sciences*, vol. 148, pp. 3079–3110, 2013, paper AAS 13-398.

[13] P. J. Cefola, Z. Folcik, R. Di-Costanzo, N. Bernard, S. Setty, and J. F. San-Juan, "Revisiting the DSST standalone orbit propagator," *Advances in the Astronautical Sciences*, vol. 152, pp. 2891–2914, 2014, paper AAS 14-411.

[14] J. F. San-Juan, R. López, R. Suanes, I. Pérez, S. J. Setty, and P. J. Cefola, "Migration of the DSST Standalone to C/C++," *Advances in the Astronautical Sciences*, vol. 160, pp. 2419–2437, 2017, paper AAS 17-369.