Partial List of Orbit Propagators

B. Neta
Naval Postgraduate School
Dept. of Mathematics
Code MA/Nd
Monterey, CA 93943

1 Analytic

PPT2 (**P**osition and **P**artials as functions of **T**ime)
Brouwer [4, 5, 6], Lyddane [39]

SGP (**S**implified **G**eneral **P**erturbations)
Kozai [29, 28].

SGP4 (**S**implified **G**eneral **P**erturbations)
Lane [32] and Lane and Crawford [33]. Based on an early work of Brouwer and Hori [5, 6] to include drag effects.

SDP4 (**S**implified **D**eep-space **P**erturbations)
Hujsak [25]. Includes some deep-space perturbations.

SGP8 (**S**implified **G**eneral **P**erturbations)

SDP8 (**S**implified **D**eep-space **P**erturbations)

ANODE (**AN**alytic **O**rbit **DE**termination)
Sridharan and Seniw [49] MIT, Lincoln laboratory.

HANDE
Hoots [22] and Hoots and France [24, 23]. Hoots applied the method of averaging to Brouwer's theory. Hande computes atmospheric density from the Jacchia 1970 model.

ASOP (**A**nalytic **S**atellite **O**rbit **P**redictor)
Mueller, et al [42]. Poincaré-similar elements in conjunction with Von Zeipel's [41] solution method.

AOPP (**A**nalytic **O**rbit **P**rediction **P**rogram)

Russian

Danielson et al [14]

Coffey et al [11, 12]

2 Semi - Analytic

SALT (**S**emi - **A**nalytic **L**iu **T**heory)
Liu and Alford [35, 36] and Liu [37].

DSST
Direct descendent of the Goddard trajectory determination system (GTDS) averaged orbit generator [21].
Early [17]. Equinoctial elements Cefola et al [8, 9]. The mean equations are integrated using a Runge - Kutta method. Three point Hermite (5^{th} order) interpolator.
Fourier series for the short periodic Cefola and McClain [10]. See also Danielson et al [15, 16] and Neta et al [44].

Kaufman
Kaufman [26]. Includes secular, long and medium periodic terms due to third body perturbations. The resulting equations of motion are numerically integrated to obtain a "mean" ephemeris of the satellite. Perturbation theory is used to recover the short period terms due to the Sun, Moon and zonals of the Earth.

STOAG for LEO Long-term evolution of satellites in low earth orbits. see
$http://sirrah.troja.mff.cuni.cz/~ales/density_therm/pohtd/index.php$
Online calculation of long-term changes in the orbital elements of LEO satellites over extended time periods using the STOAG theory of motion based on atmospheric drag with the TD88 model density, the zonal geopotential coefficients up to J9 and lunisolar perturbations. The code is free to download.

The STOAG theory of motion for LEO satellites
The detailed information about the theory and examples of its application to the real world satellites can be found in [1, 2].

3 Numerical (Special Perturbations)

SPEPH (**S**pecial **P**erturbation **EPH**emeris)
Code used by NAVSPACECOM and AFSPACECOM.

POD (**P**recision **O**rbit **D**etermination)
Klosko [27]. Developed for geodetic applications and uses 10^{th} order Cowell integrator.

TRAJ1 & TRAJ2
Lear [34] use Nystrom - Lear integrators of orders four and five.

Pt. Mugu
Crawford [13]. Adams - Moulton 8^{th} order predictor corrector with Runge Kutta to start the integration.

TMPEST (**T**he **M**illston **P**recision Orbit **EST**imator)
MIT Lincoln Lab.

GEODYN II
McCarthy et al [40]. Evolved from GEODYN, originally written for NASA/Goddard space Flight Center by EG&G Washington Analytical Services Center, Inc.

TRACE66
Buechler and Walker [7]. Cowell's method (eighth - order predictor - corrector Gauss - Jackson scheme) with a fourth order Runge Kutta method for the integrator starting and for halving.

ASAP (**A**rtificial **S**atellite **A**nalysis **P**rogram)
Kwok [30]. JPL. Cowell's method (Runge Kutta 8^{th} order and compares to 7^{th} order to estimate the truncation error).

LOP (**L**ong-term **O**rbit **P**ropagator)
Kwok [31]. Analysis tool for life - time studies of orbiting spacecrafts.

Picard-Chebyshev
Fukushima [18, 19, 20].

4 Web resources

---

1. SSCWeb Graphics Are Operational

From: Bob McGuire ¡Robert.E.McGuire.1@gsfc.nasa.gov¿
Just in time for your last minute 1997 Fall AGU or other meeting preparations, and although we're still tidying things up just a bit, online orbital graphics from the Satellite Situation Center (SSCWeb) are now fully up and running. With a database of some 45 geocentric missions with extensive and the latest predictive as well as definitive orbit information, please select the "Locator Graphics" option under $http://sscweb.gsfc.nasa.gov/$ and take a look at what SSCWeb can now do to plot

- Spacecraft orbits, including multiple spacecraft in a number of different coordinate systems and with your choice of automatic or user-specified scales;

- Spacecraft orbits tracked on the Earth's surface, either radially or field-line traced, including the ability to show multiple spacecraft, a choice of projection perspectives, ground station location overlays and the ability to "zoom" for detailed views of specific geographic regions.

The SSCWeb interface operates in two modes (standard and advanced) to support both new or occasional users along with users needing to tap more complex capabilities of the codes. The Web interface features an innovative use of "hidden fields" to allow users to save and restore query specifications on their local machines without the need for the server to track their individual "sessions." Missions supported include both older operating missions (e.g. IMP8, SAMPEX, Yohkoh), the current missions of ISTP (e.g. Wind, Geotail, Polar, SOHO), the Interball program and ACE, plus upcoming missions such as Equator-S.

And if you've forgotten, also please note that SSCWeb remains a publicly-available tool at your disposal to produce list (ASCII) output of

- Spacecraft locations in many different coordinate systems with various field parameters and geophysical regions available to output as desired, and

- A sophisticated query engine to identify conjunction times and conjunction conditions, including region co-occupancy and radial or magnetic alignments of spacecraft or spacecraft with ground stations.

The SSC and SSCWeb are a joint effort of NASA's GSFC Space Physics Data Facility (system definition, development and direction), the National

Space Science Data Center (SSC operations staff) and the ISTP Science Planning and Operations Facility. Your ongoing comments (good or bad) and suggestions to this service are welcomed.

5 Parallel Versions

PPT2 (**P**osition and **P**artials as functions of **T**ime)
Phipps [47], and Phipps et al [48] parallelized the code on a hypercube.
Stone [50] used PVM.

SGP (**S**implified **G**eneral **P**erturbations)
Ostrom [46] parallelized the code on a hypercube.
Brewer [3] used PVM.

SGP4 (**S**implified **G**eneral **P**erturbations)
Ostrom [46] parallelized the code on a hypercube.
Brewer [3] used PVM.

SDP4 (**S**implified **D**eep-space **P**erturbations)
Ostrom [46] parallelized the code on a hypercube.
Brewer [3] used PVM.

DSST
Wallace [51]

SP
Lustman, Neta and Gragg [38], Neal and Coffey [45] and Fukushima [19, 20].

References

[1] Bezdek, A., Vokrouhlicky, D., 2004. Semianalytic theory of motion for close-Earth spherical satellites including drag and gravitational perturbations. Planet. Space Sci. 52(14), 1233-1249. DOI (full pdf): http://dx.doi.org/10.1016/j.pss.2004.08.004

[2] Bezdek, A., 2004. Semianalytic theory of motion for LEO satellites under air drag. In Proceedings of the 18th International Symposium on Space Flight Dynamics, Munich, Germany, Oct. 1115, ESA SP-548, in print.

[3] S.K. Brewer, Air Force Space Command Satellite Orbit Predictor Using Parallel Virtual Machines, M. Sc. Thesis, Naval Postgraduate School, Department of Mathematics, Monterey, CA, 1993.

[4] D. Brouwer, Solution of the problem of artificial satellite theory without drag, Astron. J., **64** (1959), 378 - 397. Errata published in Vol. 65, p. 108.

[5] D. Brouwer, and G.-I. Hori, Theoretical evaluation of atmospheric drag effects in the motion of an artificial satellite, Astron. J., **66** (1961), 193-225.

[6] D. Brouwer, and G.-I. Hori, Appendix to theoretical evaluation of atmospheric drag effects in the motion of an artificial satellite, Astron. J., **66** (1961), 264-265.

[7] G. Buechler, and D. C. Walker, TRACE66 orbit determination program, Vol. III: trajectory generation equations and methods, Aerospace Report No. TOR-0066 (9320) - 2, Vol. III, Aerospace Corp., El Segundo, CA, 1970.

[8] P. Cefola, A. Long, and G. Holloway, The long-term prediction of artificial satellite orbits, AIAA preprint 74-170, presented at AIAA 12^{th} Aerospace Sci. Meeting, Wash., DC, Feb. 1974.

[9] P. Cefola, and R. Broucke, On the formulation of the gravitational potential in terms of equinoctial variables, AIAA preprint 75-8, presented at AIAA 13^{th} Aerospace Sci. Meeting, Pasadena, CA, Jan. 1975.

[10] P. Cefola, and W. D. McClain, A recursive formulation of the short-periodic perturbations in equinoctial variables, AIAA/AAS Astrodyn. Conf., Palo Alto, CA, 7-9 Aug. 1978.

[11] S. L. Coffey, and K. T. Alfriend, An analytic orbit prediction program generator, J. Guidance, Control and Dynamics, **7** (1984), 575-581.

[12] S. Coffey, and A. Deprit, Third order solution to the main problem in satellite theory, J. Guidance, Control and Dynamics, **5** (1982), 366-371.

[13] M. Crawford, NSOC precise orbits and atmospheric effects, Astrodynamics Conference, Dahlgren, VA, Jan. 91.

[14] D. A. Danielson, C. P. Sagovac and J. R. Snider, Satellite motion around an oblate planet: a perturbation solution for all orbital parameters. Part II - orbits for all inclinations, AIAA paper # 90-2885, Aug. 1990.

[15] D. A. Danielson, B. Neta, and L. W. Early, *Semianalytic Satellite Theory (SST): Mathematical Algorithms,* NPS–MA–94-001, Technical Report Naval Postgraduate School, Monterey, CA (1994).

[16] D. A. Danielson, C. P. Sagovac, B. Neta, and L. W. Early, *Semianalytic Satellite Theory (SST): Mathematical Algorithms,* NPS–MA–95-002, Technical Report Naval Postgraduate School, Monterey, CA (1995).

[17] L. W. Early, A portable orbit generator using semianalytic satellite theory, AIAA/AAS Astrodyn. Conf., paper # 86-2164-CP, 18-20 Aug. 1986.

[18] T. Fukushima, Reduction of round-off errors in the extrapolation methods and its application to the integration of orbital motion, Astron. J., **112**, (1996), 1298-1301.

[19] T. Fukushima, Picard iteration, Chebyshev approximation, parallel quadrature, and global numerical solution of perturbed dynamics, Astron. J., **113**, (1997).

[20] T. Fukushima, Vector integration of dynamical motions by Picard-Chebyshev method, Astron. J., **113**, (1997).

[21] Goddard Trajectory Determination System (GTDS) Mathematical Theory, NASA's Operational GTDS Mathematical Specification, Revision 1, Edited by Computer Science Corporation and NASA Goddard Space Flight Center, Contract NAS 5-31500, Task 213, July 1989.

[22] F. R. Hoots, An analytical satellite theory using gravity and a dynamic atmosphere, AIAA paper # 82-1409, 9 Aug. 1982.

[23] F. R. Hoots, and R. G. France, An analytic satellite theory using gravity and a dynamic atmosphere, Celes. Mech., **40** (1987), 1-18.

[24] F. R. Hoots, and R. G. France, Performance of an analytic satellite theory in a real world environment, AAS Paper 83-395, Aug. 1983.

[25] R. S. Hujsak, A restricted four body solution for resonating satellites with an oblate earth, AIAA paper # 79-136, June 1979.

[26] B. Kaufman, First order semianalytic satellite theory with recovery of the short period terms due to third body and zonal perturbations, Acta Astron., **8** (1981), 611-623.

[27] S. M. Klosko, Precision orbit determination (POD) for geodetic applications, presented at NSC Astrodyn. Conf., Dahlgren, VA, Jan. 91.

[28] Y. Kozai, Mean values of cosine functions in elliptic motion, Astron. J., **67** (1962), 311-312.

[29] Y. Kozai, The motion of a close earth satellite, Astron. J., **64** (1959), 367-377.

[30] J. H. Kwok, The Artificial Satellite Analysis Program (ASAP), JPL Tech. Report EM 312/87-153, 1987.

[31] J. H. Kwok, The Long-Term Orbit Prediction (LOP), JPL Technical Report EM 312/86-151, 1986.

[32] M. H. Lane, The development of an artificial satellite theory using a power law atmospheric density representation, AIAA paper # 65-35, 25 Jan. 1965.

[33] M. H. Lane, and K. H. Crawford, An improved analytical drag theory for the artificial satellite problem, AIAA paper # 69-925, 20 Aug. 1969.

[34] W. M. Lear, The programs TRAJ1 and TRAJ2, Technical Note 87-FM-4, NASA Johnson Space Center, Houston, TX, 1987.

[35] J. J. F. Liu, and R. L. Alford, A semi-analytic theory for the motion of a close-earth artificial satellite with drag, AIAA paper No. 79-0123, 15 Jan. 1979.

[36] J. J. F. Liu, and R. L. Alford, Semianalytic theory for a close-earth analytic satellite, J. Guidance and Control, **3** (1980), 304-311.

[37] J. J. F. Liu, Satellite motion about an oblate earth, AIAA J. **12** (1974), 1511-1516.

[38] L. Lustman, B. Neta, and W. Gragg, Solution of ordinary differential initial value problems on an INTEL hypercube, International J. Computers and Mathematics with Applications, **23** (1992), 65-72.

[39] R. H. Lyddane, Small eccentricities or inclinations in the Brouwer theory, Astron. J., **68** (1963), 555-558.

[40] J. J. McCarthy, D. E. Pavlis, J. A. Marshall, S. B. Luthcke, L. S. Tsaoussi, S. Rowton, and D. A. Williams, GEODYN II System description, STX Systems Corporation, Lanham, MD, 1991.

[41] Morrison, J.A., Generalized method of averaging and the von Zeipel method, Bell Telephone Lab. Inc., Murray Hill, NJ. Presented as reprint 65-687 at the AIAA/ION Astrodynamics Specialist Conference, Monterey, CA, September 1965.

[42] A. Mueller, G. Scheifele, and S. Starke, An analytic orbit predictor for near-earth satellites, AIAA paper # A79-19547, Jan. 1979.

[43] H. Neal, and S. Coffey, Maintaining the space catalog with special perturbations, *Proc. AAS/AIAA Astrodynamics Conference*, Sun Valley, Idaho, August 4-7, 1997, Paper Number 97-687.

[44] B. Neta, and D. A. Danielson, *R & D GTDS SST: Code Flowcharts and Input,* NPS–MA–95-009, Technical Report , 1995.

[45] H. Neal, and S. Coffey, Maintaining the space catalog with special perturbations, *Proc. AAS/AIAA Astrodynamics Conference*, Sun Valley, Idaho, August 4-7, 1997, Paper Number 97-687.

[46] Ostrom, S.R., Parallelization of the Air Force Space Command Satellite Motion Models, MS thesis, Naval Postgraduate School, 1993.

[47] Phipps, W. E., Parallelization of the Naval Space Surveillance Center (NAVSPASUR) Satellite Motion Model, M.S. thesis, Naval Postgraduate School, Monterey, CA, 1992.

[48] Phipps, W.E., Neta, B. and Danielson, D.A., Parallelization of the Naval Space Surveillance Satellite Motion Model, Journal Astronautical Sciences, **41**, (1993), 207-216.

[49] R. Sridharan, W. P. Seniw, ANODE: an analytic orbit determination system, Technical Note 1980-1, MIT Lincoln Lab, Lexington, MA, 1980.

[50] Stone, L.C., Parallel Processing of Navy Specific Applications Using a Workstation Cluster, MS Thesis, Naval Postgraduate School, Department of Electrical and Computer Engineering, Monterey, CA, December 1993.

[51] S. T. Wallace, Parallel Orbit Propagation and the Analysis of Satellite Constellations, Master of Sciences Thesis, Massachusetts Institute of Technology, Draper Laboratory Technical Report, CSDL-T-1245, Cambridge ,MA, June 1995.