Conference Program

Kyle T. Alfriend
Astrodynamics Symposium

17-19 May 2010

Monterey, California

Schedule of Events

Monday, 17 May

6pm	-	8pm	Welcome Reception

Tuesday, 18 May

7 am	-	8 am	Breakfast
8:30 am	-	12 pm	Technical Session 1
12 pm	-	1 pm	Lunch
1:15 pm	-	5 pm	Technical Session 2
6pm	-	8 pm	Reception at Alfriend Home

Wednesday, 19 May

7 am	-	8 am	Breakfast
8:15 am	-	12 pm	Technical Session 3
12 pm	-	1 pm	Lunch
1:15 pm	-	5 pm	Technical Session 4
6 pm	-	9 pm	Symposium Banquet

May 18, 2010

Session 1: Tuesday Morning

Chair: Dr. Shannon Coffey
Naval Research Laboratory

08:15 **Introductory Remarks**
Professor John Junkins, Texas A&M University

Professor John Junkins, Texas A&M University, will provide introductory remarks to start the symposium.

08:40 **AAS 10 - 301** **Resonances And The Stability Of Stationary Points Around A Non-Spherical Planet**
Antonio Elipe, University of Zaragoza, Spain; Victor Lanchares and Ana I. Pascual, University of La Rioja, Spain

The question of Lyapunov stability of stationary points around a non-spherical planet has been studied in previous works of the authors in the non resonant case, and also for resonances of 3rd and 4th order, by means of some results given by Arnold, Markeev, Beletesky, Alfriend and the authors, among others, in which the computation of the normal form up to the second order is required. However, some special degenerated cases are not yet covered, as it happens for resonances of order 5 and 6, when the free parameters of the problem are chosen properly. In this paper we deal with these resonances and apply appropriate results to establish the type of stability of the stationary points.

09:05 **AAS 10 - 302** **On Roto-Translatory Motion. Reductions And Radial Intermediaries**
Sebastián Ferrer, Universidad de Murcia, Spain; Martin Lara, Real Observatorio de la Armada, Spain

Due to the current technology which allows us to measure distances to the Moon with a very high precision, there is a renew interest in a significant improvement of the theoretical models of the orbital and rotational dynamics of the Earth-Moon system and satellites around them. This paper discusses some methods and problems in developing such mathematical models for the roto-translational dynamics of a rigid body, in a central gravitational field. A chain of canonical transformations is used to reduce the problem, reaching an 1-DOF radial intermediary which shows some main features connecting both dynamics.

09:30 **AAS 10 - 303** **An Investigation of the Effects of Nonlinearity of Algebraic Models**
Dr. Manoranjan Majji, Dr. John L. Junkins and Dr. James D. Turner, Texas A&M University

Effects of nonlinearity of algebraic systems is studied in this paper. Some prime examples are shown of nonlinear transformations in astrodynamics and classical measurement systems. The nonlinear transformations are shown to affect the uncertainty transformations even in static problems. Attempts are made to understand how classical algorithms provide solutions for such problems. Measures of nonlinearity are used to study the domain of attraction of the nonlinear root solvers and the associated uncertainty estimates provided by the Gauss-Newton type methods, especially in the presence of measurement uncertainty. It is noted that the fundamental understanding of this problem is pivotal in applications.

09:55 **Break**

10:20 **AAS 10 - 304** **Applications of Symplectic Topology to Orbit Uncertainty and Spacecraft Navigation**
D.J. Scheeres, University of Colorado; M.A. de Gosson, University of Wien

Gromov's symplectic non-squeezing theorem, a fundamental property from symplectic topology, is applied to the study of uncertainty analysis in Hamiltonian Dynamical systems. Previous results published in the literature are re-derived and shown to be similar to the uncertainty principle of quantum mechanics. Extensions of this result are made to the problem of orbit estimation.

10:45 **AAS 10 - 305** **Control of the Restricted Three-Body Problem**
Tamas Kalmar-Nagy and Daniele Mortari, Texas A&M University

The N=3 body problem is a 9-DOF Hamiltonian system, but using the first integrals it can be reduced to 4 degrees of freedom. A simpler, well-studied case is the circular restricted three-body problem (CRTBP). In this problem two bodies of a finite mass revolve around their center of mass and a third body of negligible mass moves in their gravitational field without exerting any influence on the motion of the two other bodies. Since the orbits of the two finite mass bodies conform to the known solution of the two-body case, the problem is reduced to the study of ...

11:10 **AAS 10 - 306** **GPS and GLONASS Orbit Evolution**
Bob Schutz, University of Texas at Austin

As of January, 2010, the GPS constellation consisted of 32 active satellites, and the GLONASS constellation consisted of 15 active satellites. The orbit evolution is influenced, in part, by the deep resonance of the GPS satellites with the Earth's gravitational field, whereas the GLONASS satellites are in shallow resonance. This paper will describe the orbit evolution of selected satellites in the respective constellations and contrast their evolution.

11:35 **AAS 10 - 307** **Estimating Density Using Precision Satellite Orbits from Multiple Satellites**
Craig A. McLaughlin, Travis Lechtenberg, and Eric Fattig, University of Kansas

This paper examines density estimated using precision orbit ephemerides (POE) from several satellites including CHAMP, GRACE, and TerraSAR-X. The results of the calibration of CHAMP and GRACE-A densities derived using POEs with those derived using accelerometers are compared for various levels of solar and geomagnetic activity to examine the consistency of the calibration between the two satellites. In addition, the densities derived simultaneously from multiple satellites are compared to the Jacchia 71 model densities to observe altitude effects and consistency of trends in the offsets from Jacchia 71 among all the satellites.

May 18, 2010

Session 2: Tuesday Afternoon

Chair: Dr. Chris Sabol
Air Force Research Laboratory

13:15 **AAS 10 - 308** **Earth-Impact Modeling and Analysis of a Near-Earth Object Fragmented and Dispersed by Nuclear Subsurface Explosions**
Bong Wie, Iowa State University, David Dearborn, Lawrence Livermore National Laboratory

This paper describes the orbital dispersion modeling, analysis and simulation of a near-Earth object (NEO) fragmented and dispersed by nuclear subsurface explosions. It is shown that various fundamental approaches of Keplerian orbital dynamics can be effectively used for the orbital dispersion analysis of fragmented NEOs. It is also shown that under certain conditions, proper disruption (i.e., fragmentation and large dispersion) using a nuclear subsurface explosion even with shallow burial (< 5 m) is a feasible strategy providing considerable mitigation if all other approaches failed.

13:40 **AAS 10 - 309** **Satellite Breakup Parameter Determination**
Felix R. Hoots and Marlon E. Sorge, Aerospace Corporation

A satellite break-up can cause collision risk to other resident satellites. If the time, location, and energy content of the breakup can be determined, Aerospace has models that can quickly estimate the risk to other resident satellites from the debris. We have developed a method that allows determination of all required breakup parameters within about 12 hours after the breakup event. If a large number of radar tracks are available, this timeline could be even quicker. The method then facilitates rapid determination of debris collision risk to resident satellites, providing satellite operators with timely space situational awareness.

14:05 **AAS 10 - 310** **Design of Satellite Formations in Orbits of High Eccentricity with Performance Constraints Specified over a Region of Interest**
Christopher Roscoe , Srinivas R Vadali, and Kyle T. Alfriend
Texas A&M University

An approach for determining the differential mean element initial conditions for formations in highly elleiptic orbits to maximize a Quality Factor(QF) is presented. The QF is defined only in a region of interest (ROI), not over the entire reference orbit. Previous works on the design of formations in high-eccentricity orbits have used numerical integration-based approaches for orbit propagation. We present a fast optimization scheme by using the Gim-Alfriend state transition matrix. A verification of our results via the software package GMAT is provided.

14:30 **AAS 10 - 311** **Geosynchronous Large Debris Reorbiter: Challenges and Prospects**
Hanspeter Schaub, University of Colorado; Daniel F. Moorer Jr., Wacari Group

An elegant solution is proposed to remove debris from the geosynchronous belt using a blend of electrostatic control and low-thrust propulsion to avoid any physical contact. The Geosynchronous Large Debris Reorbiter (GLiDeR) raises its own absolute potential to 10's of kilovolts and, in addition, directs a charge stream at the debris to increase its absolute potential. Next, fuel-efficient micro-thrusters are employed to gently tug the debris out of its geosynchronous ``slot'' and deposit it in a ``disposal'' orbit. The separation distance is held fixed even if the debris is tumbling. Numerical simulations are presented illustrating the expected performance.

14:55 **Break**

15:20 **AAS 10 - 312** **Feedback Control for Formation Flying Maintenance Using State Transition Matrix**
Hui Yan and Qi Gong, University of California at Santa Cruz

The Linear Quadratic Regulator (LQR) control design method has been widely used for satellite formation maintenance. The computational burden associated to the matrix differential Riccati equations imposes a challenge on the online implementation of LQR control, especially, when the linear, time-varying dynamics changes due to the change
of reference trajectories. In this paper a feedback control is proposed to solve LQR problems using state transition matrix. Such method has the potential to reduce the online computational burden. We apply the control law to formation flying maintenance under J2 perturbation using the Gim-Alfriend state transition matrix.

15:45 **AAS 10 - 313** **Optimal Control for Relative Motion in Arbitrary Fields**
Ryan P. Russell and Gregory Lantoine, Georgia Institute of Technology

We formulate a second-order, general dynamics, relative motion tool to solve for optimal finite burn relative motion transfers subject to gravity fields and chief orbits that are not amenable to analytic solutions. The control is chosen based on a robust, second order technique that is a variant of differential dynamic programming (DDP). In the paper, we examine a variety of perturbation models and compare solutions to conventional relative motion models. The resulting implementation is useful for Earth orbiters as well as missions to complex environments such as the Moon, asteroids, comets, or planetary satellites.

16:10 **AAS 10 - 314** **Elliptic Rendezvous in the Chaser Satellite Frame**
Prasenjit Sengupta, Optimal Synthesis Inc.

Analysis of rendezvous in planetery orbits typically derives control laws in a frame rotating with the target. However, since the control is ultimately required in the chaser satellite's frame, knowledge of the chaser's motion with respect to the planet may be required to correctly transform the control vector. This paper analyzes the rendezvous problem in the chaser satellite's frame directly. A nonlinear transformation between between the chaser and target frames, in terms of relative position and velocity variables is derived. This is used to formulate and solve the rendezvous problem using optimal power-limited propulsion analytically, that includes nonlinear effects. A framework is thus developed for the orbital transfer problem. An example is used to demonstrate the derived control.

16:35 **AAS 10 - 315** **Optimal Multiple-Impulse Time-Fixed Relative Orbit Transfer Using Nonlinear Relative Motion Dynamics**
Weijun Huang, University of Missouri

Satellite formation resizing and reconfiguration can be regarded as relative orbit transfer of several satellites. In this paper, an algorithm for solving optimal multiple-impulse time-fixed relative orbit transfer problem is provided. Because both the related initial value problems (IVP) and two-point boundary value problem (TPBVP) are solved by using second order analytic solutions of the relative motion, the algorithm is both efficient and accurate. With this algorithm, the patterns of the primer magnitude histories of the local optimal relative orbit-to-relative orbit impulsive transfers are qualitative investigated.

May 19, 2010

Session 3: Wednesday Morning

Chair: Dr. Paul Schumacher
Air Force Research Laboratory

08:15 **AAS 10 - 316** **Space Surveillance – U.S., Russia, and China**
P. K. Seidelmann, University of Virginia

With the launch of Sputnik the US and Russia began the process of tracking artificial satellites. This led to developments for observations, orbit determination, and catalog maintenance. The two countries followed somewhat different approaches to the same problem based on the available hardware and theoretical developments. As more sophisticated hardware and theories have been developed, progress has been made. However, new problems have developed due to debris, collision possibilities, and reentering objects. Also, the range of spacecraft has increase to include geosynchronous orbits. In more recent times the European Space Agency (ESA) and China have become involved in various aspects of Space Surveillance.

08:40 **AAS 10 - 317** **Sequential Probability Ratio Test for Collision Avoidance Maneuver Decisions**
J. Russell Carpenter and F. Landis Markley, NASA Goddard Space Flight Center

When faced with a potential conjunction between space objects, satellite operators' decision concerning a collision avoidance maneuver has four possible outcomes: (1) a correct decision to maneuver, (2) an incorrect decision to maneuver (false alarm), (3) a correct decision not to maneuver, or (4) an incorrect decision not to maneuver (missed detection). We suggest Wald's Sequential Probability Ratio Test as a means for applying missed detection and false alarm criteria to the decision. We suppose that basing the maneuver decision on a Wald test could give decision makers a better understanding of the tradeoff between false alarms and missed detections.

09:05 **AAS 10 - 318** **Comparison of Covariance Based Track Association Approaches with Simulated Radar Data**
Chris Sabol, AFRL-AMOS

Alfriend first applied the concept of covariance based track association to space surveillance in 1997. This paper describes the performance of covariance based track association algorithms using simulated radar observations of low Earth satellites. In particular, the percentage of false associations is compared using six dimensional equinoctial, 3+3 dimensional curvilinear, and 5.7 dimensional equinoctial coordinates, where the 5.7 dimensions refers to the practice of ignoring eccentricity-mean longitude cross correlation terms in the computation of the Mahalanobis distance. These results are compared to a traditional fixed gate association approach and show a dramatic improvement.

09:30 **AAS 10 - 319** **Correlation of Optical Observations of Earth-Orbiting Objects by Means of Probability Distributions**
Kohei Fujimoto and Daniel J. Scheeres, The University of Colorado-Boulder

Situational awareness of Earth-orbiting particles is highly important for future human activities in space. For optical observations of debris, multiple observations must be combined in order to determine the orbit of the observed object. It is generally uncertain, however, whether two arbitrary tracks are of the same object, and solving this problem can be computationally intensive. In this paper, we propose a technique of correlating multiple optical observations by means of probability distributions in Poincare orbit element space. These distributions are mapped linearly in order to reduce computational burden but without significantly losing accuracy.

09:55 **Break**

10:20 **AAS 10 - 320** **Comparison of Sigma-Point and Extended Kalman Filters on a Realistic Operational Scenario**
John Gaebler and Russell Carpenter, NASA Goddard Space Flight Center; Sun Hur-Diaz, Emergent Space Technologies, Inc.

Sigma-point filters have received a lot of attention in recent years as a better alternative to extended Kalman filters for highly nonlinear problems. In this paper, we compare the performance of the additive divided difference sigma-point filter to the extended Kalman filter when applied to orbit determination of a realistic operational scenario based on the Interstellar Boundary Explorer mission. For the scenario studied, both filters provided roughly equivalent results. The performance of each is discussed in detail.

10:45 **AAS 10 - 321** **Adaptive Gaussian Sum Filters for Space Surveillance Tracking**
Joshua T. Horwood, Numerica Corporation

While orbital propagators have been investigated extensively over the last fifty years, the consistent propagation of state covariances and more general (non-Gaussian) probability densities has received relatively little attention. The representation of state uncertainty by a Gaussian mixture is well-suited for problems in space situational awareness. Advantages of this approach include the potential for long-term propagation in data-starved environments, the capturing of higher-order statistics and more accurate representation of nonlinear dynamical models, the ability to make the filter adaptive using realtime metrics, and parallelizability. Case studies are presented establishing uncertainty consistency and the effectiveness of the proposed Gaussian sum filter.

11:10 **AAS 10 - 322** **Solving Boundary Value Problems Using Picard-Chebyshev Methods**
Xiaoli Bai and John L. Junkins, Texas A&M University

We present Picard-Chebyshev methods to solve boundary value problems. For initial value problems, a piecewise Picard-Chebyshev method is used to solve problems on a large domain. When used to solve two-body problems, the Picard-Chebyshev method presented achieves more than one magnitude speedup over ODE45 together with one order of magnitude better accuracy for ten orbit revolutions. When used to solve Lambert's problem, the Picard-Chebyshev method has 50 to 80 speedups over fsolve. Compared with Battin's approach, the Picard-Chebyshev method is faster when the time interval is less than 15% of the orbit while achieving the same accuracy.

11:35 **AAS 10 - 323** **Least Squares GEO Initial Orbit Determination**
James R Wright, Analytical Graphics, Inc.

A new fast-running algorithm was constructed and demonstrated to perform refined orbit determination for any spacecraft in GEO, for any measurement type, and without the requirement for an a priori orbit estimate. This is enabled by: (i) Use of equinoctial orbit elements, (ii) A one-dimensional search in the equinoctial orbit element mean argument of orbit longitude, (iii) The use of ground station locations to reduce the one-dimensional search, (iv) convergence boundaries of the nonlinear least squares algorithm. The user interface is in Kepler orbit elements, and LS differential corrections are performed in ECI position and velocity components.

May 19, 2010

Session 4: Wednesday Afternoon

Chair: Professor John Junkins
Texas A&M University

13:15 **AAS 10 - 324** **Further Studies On Singular Value Method For Star Pattern Recognition And Attitude Determination**
Jer-Nan Juang and Eileen Wang, National Cheng Kung University, Taiwan

The objective of this paper is to study the effectiveness of a star pattern recognition method using singular value decomposition (SVD) of a measured unit column vector matrix in a measurement frame and the corresponding catalog vector matrix in a reference frame. The approach is to use sensitivity analysis to define an effectiveness measure for comparison with other conventional methods via a pairing process for individual measured and cataloged stars. A new method is proposed to generate the mission catalog to improve the quality of pattern recognition in speed and accuracy and avoid the failure possibility of pattern recognition.

13:40 **AAS 10 - 325** **Covariance-based Scheduling of a Network of Optical Sensors**
Keric Hill, Paul Sydney, Kris Hamada, and Randy Cortez,
Defense Solutions; K. Kim Luu, Paul W. Schumacher, Jr., and Moriba Jah, Air Force Research Laboratory

A comprehensive high-fidelity simulation environment of networked optical sensors has been created under an effort called TASMAN (Tasking Autonomous Sensors in a Multiple Application Network). On a broad level, the objective of TASMAN is to research various dynamic mission planning algorithms to improve autonomy, timeliness, robustness, and improved performance for any distributed network of autonomous sensors. Initial studies have focused on a novel resource management approach, namely covariance-based tasking. Under this scheme, one observation effectiveness metric is tested under a fully distributed tasking scenario. Sensor outages are simulated so that complexities from real-time dynamic tasking are incorporated.

14:05 **AAS 10 - 327** **Two Impulse Reorientation of Spinning Axisymmetric body: Single axis thrust**
Neha Satak, Jeremy J. Davis, James Doebbler and John E. Hurtado, Texas A&M University

A sequence of two impulses can be used to redirect the spin axis of an axisymmetric rigid body. The first impulse initiates coning motion by imparting an angular velocity that is transverse to the spin axis. The second impulse halts the coning motion by zeroing the transverse angular velocity. When the thrust axis is fixed along one axis, it is found that a two-impulse maneuver can still be designed to achieve any reorientation. The penalty is that the body may need to initially coast so that the thrust axis points in a favorable direction prior to impulse. Further by appropriately choosing the time of second impulse, solution is found for bodies with thrust restricted to only one direction along that axis.

14:30 **AAS 10 - 328** **Nonlinear System Identification - A Continuous-Time Bilinear State Space Approach**
Cheh-Han Lee, National Central University, Taiwan; Jer-Nan Juang, National Cheng Kung University, Taiwan; Shyh-Biau Jiang, National Central University, Taiwan

A class of nonlinear systems can be approximated by a bilinear system to an arbitrary high order as needed. In this paper, we develop an improved SEMP (Single Experiment with Multiple Pulses) method for bilinear system identification. We then use this improved SEMP method to identify a nonlinear system. Several numerical examples such as the Euler's equation describing the rotation of a rigid body are given to demonstrate the power of the bilinear approach for nonlinear system identification.

14:55 **Break**

15:20 **AAS 10 - 330** **A Superstate Method for Discrete-Time Bilinear State-Space Model Identification**

Minh Q. Phan, Dartmouth College, Haris Celik, Royal Institute of Technology, Stockholm, SWEDEN

This paper presents several techniques to identify discrete-time bilinear state-space models from a single set of general input-output data. The initial state can be non-zero and unknown. Unlike other approaches, specialized inputs are not required, such as duration-varying unit pulses involving multiple experiments, sinusoidal, or white noise inputs. The formulation uses a superstate vector derived from a single set of sufficiently rich input-output measurements to identify the bilinear state-space model matrices. Several identification techniques will be presented with numerical illustrations. A companion paper deals with the identification of input-output models instead of state-space models for a bilinear system.

15:45 **AAS 10 - 331** **The Influence on Stability Robustness of Compromising on the Zero Tracking Error Requirement in Repetitive Control**

Yunde Shi and Richard W. Longman, Columbia University

Repetitive control (RC) can be used to design active vibration isolation mounts that aim to cancel the influence of spacecraft vibrations on fine pointing equipment. It can cancel the influence of slight imbalance in momentum wheels, reaction wheels, and CMGs. A series of publications have demonstrated a method of averaging over models to increase the robustness of RC designs to model error, but there is a hard limit on phase error. This paper considers compromising on the zero tracking error requirement as a way of extending this hard limit and allowing RC to tolerate larger model errors.

16:10 **AAS 10 - 332** **Generalized frequency domain State-Space Models for Analyzing Flexible Rotating Spacecraft**

James D. Turner, Texas A&M University

Flexible rotating space structures are mathematically described by coupled rigid and flexible body degrees-of-freedom, where the equations of motion are modeled by integro-partial differential equations. A closed-form Laplace transform model is developed for the governing integro-partial differential equations by introducing a generalized state space. The unforced part of the solution is described by a 6x6 s-domain matrix exponential. The forced part of the solution is described a 6x1 s-domain convolution integral. Scalar transfer functions are obtained for both the rotational and flexural deformation of the structure. Numerical results are presented that compare the classical series based approach with the generalized state space approach for computing representative spacecraft transfer function models.