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Meeting Information

REGISTRATION

The following registration fees will be in effect for this conference:

AAS or AIAA Members	$210
Nonmembers (includes 1 year membership in AAS)	$295
Students	$20

We ***cannot*** accept credit cards for payment toward registration. Please pay cash or make checks payable to *American Astronautical Society*.

The registration desk will be open in the Preconvening Area on the 3rd Floor at the following times

Sunday evening	4:00pm – 7:00pm,
Monday and Tuesday	7:00am – 4:00pm
Wednesday	7:00am – 11:00am.

CONFERENCE PROCEEDINGS

Advance purchase of the conference proceedings will be available at the registration desk. The cost is $150.

SOCIAL EVENTS

Sunday: For early registrants, there is an Early Bird Reception, a Desserts Extravaganza, in Texas Ballroom C on the 2nd Floor from 6:00 – 9:00pm.

Monday: For all attendees, there is a reception in the Executive Salon 5 from 5:00 – 7:00pm.
An optional event is a guided tour followed by a dinner at The Alamo from 6:00 – 9:00pm. The price for this event is $25 per person.

Tuesday: This evening is left free for enjoying the excellent regional cuisine and attractions of San Antonio.

Please address questions or comments to one of the General Chairs:

AAS General Chair

Dr. Kim Luu
Det 15 AFRL
535 Lipoa Pkwy Ste 200
Kihei, HI 96753

(808) 874-1608 (voice)
(808) 874-1640 (fax)
kim.luu@eagle.mhpcc.af.mil

AIAA General Chair

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(303) 343-2596 (voice)
(303) 360-4460 (fax)
Cheryl.walker@trw.com

Technical Program

Technical Sessions

There are 18 technical sessions scheduled over a 3-day period with a total of 156 papers on the agenda. The technical sessions will run in parallel with 3 morning sessions and 3 afternoon sessions. All technical sessions will be held in Executive Salons 2, 3, and 4. Morning and afternoon coffee breaks will be held mid-way through each technical session.

Speakers' Briefings

Authors who are making presentations and session chairs will meet for a short briefing on the morning of their sessions at 7:00am in Executive Salon 1. A continental breakfast will be served.

Paper Presentations

Technical sessions will start at 8:00am and in the afternoons at 1:30pm every day. All papers are scheduled for 25 minutes. Authors should allow 20 minutes for the presentation and 5 minutes for questions. This schedule will be strictly enforced so that attendees may schedule their time between parallel sessions. Please note that a strict **NO PAPER/NO PODIUM** rule will be enforced, i.e., speakers will not be allowed to present their work if they have not provided 50 copies of the written paper. Papers will also be automatically withdrawn from the conference and will not be eligible for inclusion in the proceedings if none of the affiliated authors are in attendance to present the paper.

Paper Sales

Authors are required to bring 50 copies of their paper to the conference. The preprints will be on sale for $1.00 per paper in a designated room adjacent to the meeting rooms. Bound copies of the proceedings may be ordered at the registration desk.

Committee Meetings

Committee meetings will be held in Executive Salon 5 according to the following schedule:

AIAA Astrodynamics Technical Committee	Monday	11:30am – 1:00pm
AAS Space Flight Mechanics Technical Committee	Tuesday	11:30am – 1:00pm
AIAA Astrodynamics Standards Committee	Wednesday	11:00am – 2:00pm

Please address questions on the Technical Program to one of the Technical Chairs:

AAS Technical Chair

Dr. Terry Alfriend
Texas A&M University
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3141 TAMU
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AIAA Technical Chair

Dr. Beny Neta
Naval Postgraduate School
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(831) 656-2235 (voice)
(831) 656-2355 (fax)
bneta@nps.navy.mil

San Antonio Information

Conference Location

Adam’s Mark San Antonio-Riverwalk
111 Pecan Street East
San Antonio, Texas 78205
1-800-444-2326 or (210) 354-2800 voice
(210) 354-2700 fax

The Adam’s Mark Hotel is located on the beautiful Riverwalk (Paseo del Rio) in the heart of downtown San Antonio, just a 10 minute drive from the international airport. Within walking distance along the Riverwalk, a cobblestone and flagstone path bordering the San Antonio River, are quiet park-like stretches as well as areas full of activity with European-style sidewalk cafes, specialty boutiques, and nightclubs. Also within walking distance are attractions such as The Alamo, Children’s Museum, Rivercenter Mall, Market Square (El Mercado), the theatre/cultural district, and the Alamodome (professional sports facility).

SAN ANTONIO

The history of San Antonio at: http://www.sanantoniocvb.com/history.htm
Now the eighth largest city in the United States, the city has retained its sense of history and tradition, while carefully blending in cosmopolitan progress. The city has always been a crossroads and a meeting place. Sounds and flavors of Native Americans, Old Mexico, Germans, the Wild West, African-Americans and the Deep South mingle and merge. Close to seven million visitors a year delight in the discovery of San Antonio's charms.

For history buffs, San Antonio is a mecca. Native Americans first lived along the San Antonio River, calling the area "Yanaguana," which means "refreshing waters," or "clear waters." A band of Spanish explorers and missionaries came upon the river in 1691, and because it was the feast day of St. Anthony, they named the river "San Antonio."The actual founding of the city came in 1718 by Father Antonio Olivares, when he established Mission San Antonio de Valero, which became permanently etched in the annals of history in 1836 as The Alamo, where 189 defenders held the old mission against some 4,000 Mexican troops for 13 days. The cry "Remember the Alamo" became the rallying point of the Texan revolution against Mexico. Located in the heart of downtown, today The Alamo is a shrine and museum.

A tour of downtown San Antonio will uncover centuries of history, including:
La Villita, one of the original settlements was comprised of Spanish soldiers and their families. The Spanish Governor's Palace, which was the seat of government, when San Antonio was the capital of the Spanish Province of Texas. The San Fernando Cathedral, whose construction was started in 1731 by Canary Islanders. The Jose Antonio Navarro State Historical Park, home of Navarro, a central figure in the formation of Texas. Market Square, the largest Mexican marketplace outside of Mexico and the Steves Homestead, a mansion open to the public in the King William Historic District.

Just northeast of downtown lies Fort Sam Houston, another "must-see" for history buffs. Military greats like Pershing, Stilwell, Krueger and Eisenhower all served at Fort Sam. San Antonio was also a training site of the Buffalo Soldiers, famed African-American cavalry fighters, who helped bring peace to the Western Frontier a century ago. Today, Fort Sam is headquarters for the Fifth U.S. Army and the Health Services Command and home of the Fort Sam Houston Museum and the U.S. Army Medical Department Museum.

Amidst the daily hubbub of the busy metropolitan downtown, sequestered 20 feet below street level, lies one of San Antonio's jewels - the Paseo del Rio. Better known as the "River Walk," these cobblestone and flagstone paths border both sides of the San Antonio River as it winds its way through the middle of the business district.

The River Walk has multiple personalities - quiet and park-like in some stretches, while other areas are full of activity with European-style sidewalk cafes, specialty boutiques, nightclubs and gleaming high-rise hotels. The River Walk stretches for approximately two-and-a-half miles from the Municipal Auditorium and Conference Center on the north end to the King William Historic District on the south. Yanaguana Cruises, the river's floating transportation system, provides a novel method of sightseeing and people-watching in downtown San Antonio. Groups can also dine aboard open-air, candle-lit cruisers as they wind their way along the scenic waterway. River taxis deliver visitors to Rivercenter, a dazzling three-level glass shopping, dining and entertainment complex, and to the Henry B. Gonzalez Convention Center.

San Antonio has two impressive art museums.The McNay Art Museum is set in a Mediterranean-style mansion and has wide-ranging collections, including post-impressionist and modern art, theater art, Medieval art, Native American art and more. The San Antonio Museum of Art (SAMA) is housed in the castle-like former headquarters of the Lone Star Brewery. This museum is noted for its antiquities collections, Mexican folk art, modern art, pre-Columbian art and Spanish colonial art. Hotbeds of contemporary artistic expression include the Blue Star Art Space in Southtown, ArtPlace on Main Avenue and the Southwest School of Art and Craft, a lovely complex built by French nuns in 1848 which served as the first girls' school in the city. Galleries abound and offer the serious collector a wide range of styles and topics from Texas landscapes to Latin American folk art to western and Native American to contemporary.

With over 300 days of sunshine annually and an average temperature of 68.8 degrees Fahrenheit, visitors to San Antonio will find an abundance of outdoor sports and recreation to challenge them.

Dining options in San Antonio run the gamut from fine French cuisine to Chinese to Soul food and Cajun, but the one not to miss is Tex-Mex. Tex-Mex is a passion with local residents of all ethnic backgrounds, and numerous restaurants are open 24 hours.

Transportation

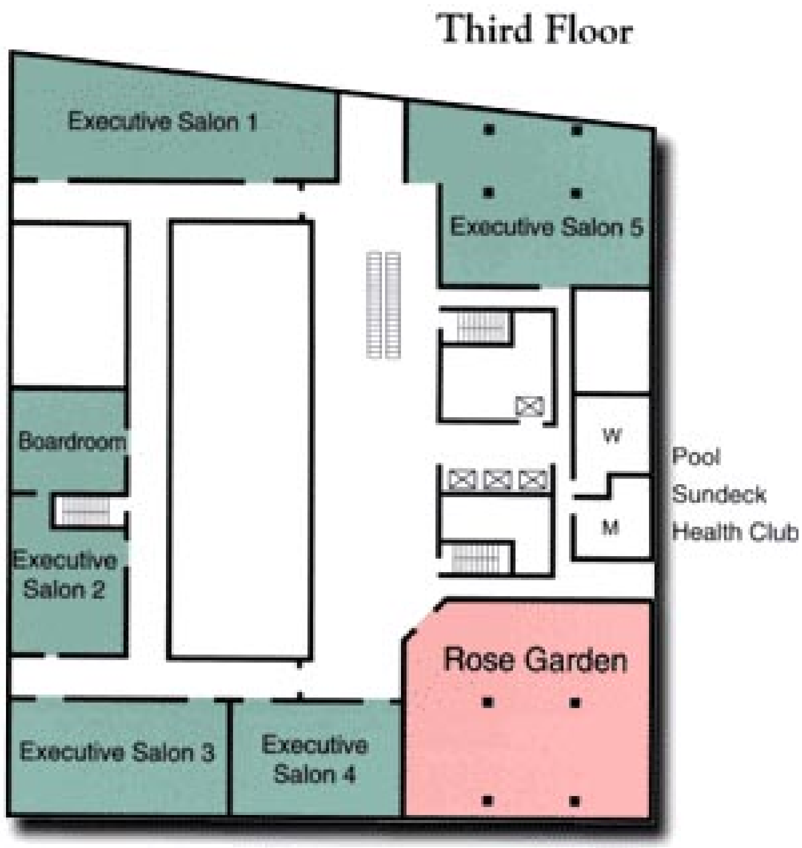
San Antonio International Airport (SAT) is served by all major US airlines. The Adam's Mark Hotel is less than 10 miles from the airport by expressway.

TO BE SUPPLIED IN PROGRAM AT CONFERENCE

HOTEL AREA

TO BE SUPPLIED IN PROGRAM AT CONFERENCE

HOTEL FLOOR PLAN



PROGRAM SUMMARY

Date/Time	Event	Location
Sunday, 27 January		
1600-1900	Conference Registration	3rd Floor
1800-2100	Early Bird Reception	Texas Ballroom C – 2nd Floor
Monday, 28 January		
0700-1600	Conference Registration	3rd Floor
0700-0800	Speaker's Breakfast	Salon 1
0800-1700	Paper Sales	Boardroom
0800-1115	Sessions 1,2,3	Salon 2,3,4
1130-1330	Lunch	
1130-1330	AIAA Astrodynamics TC Meeting	Salon 5
1330-1645	Sessions 4,5,6	Salon 2,3,4
1700-1900	Reception	Salon 5
1800-2100	Dinner at The Alamo	Alamo Complex
Tuesday, 29 January		
0700-1600	Conference Registration	3rd Floor
0700-0800	Speaker's Breakfast	Salon 1
0800-1700	Paper Sales	Boardroom
0800-1115	Sessions 7,8,9	Salon 2,3,4
1130-1330	Lunch	
1130-1330	AAS SFM Committee Meeting	Salon 5
1330-1645	Sessions 10,11,12	Salon 2,3,4
Wednesday, 30 January		
0700-1600	Conference Registration	3rd Floor
0700-0800	Speaker's Breakfast	Salon 1
0800-1700	Paper Sales	Boardroom
0800-1115	Sessions 13,14,15	Salon 2,3,4
1130-1330	Lunch	
1130-1330	AIAA Astrodynamics Standards	Salon 5
1330-1645	Sessions 16,17,18	Salon 2,3,4

Session 1: Attitude Determination & Sensors

Chair: Dr. Christopher D. Hall
Va. Tech

0800 AAS 02 -100

Attitude Determination for KOMPSAT-2 Using Star Identification Technique

G. Ju and S.K. Lee, Chosun University

Korea Aerospace Research Institute (KARI) is developing a Korea Multi-Purpose Satellite-2 (KOMPSAT-2), which accommodates Multi-Spectral Camera (MSC) with the realization of 1 m panchromatic and 4 m multi-spectral high-resolution images. Upgraded mission requirements for pointing accuracies of AOCS will be supported by designing the flight software including a new attitude determination algorithm associated with newly adopted star trackers. This paper describes the application of star identification technique based upon those proposed by G. Ju et. al to both AOCS and ground system of KOMPSAT-2 for attitude determination. Detailed algorithms for precise attitude determination are suggested including star catalog design, star pattern identification, attitude estimation with the filtering technique such as Kalman filter. The algorithms proposed will be tested using the Monte Carlo method to validate their reliability and to cover full sky tests. Effects of increasing attitude error and simulated observed star position error will be also discussed.

0825 AAS 02 -101

Determination and Autonomous On-orbit Calibration of Star Tracker For the GIFTS Mission

P. Singla, D.T. Griffith and J.L. Junkins, Texas A&M University

A novel dual view star tracker is being developed for the EO-3 GIFTS mission (2003). The camera is designed to be autonomously self-calibrating, and capable of reliable solution of the lost in space problem. Two efficient Kalman Filter algorithms for attitude, boresight error, and focal length estimation have been developed. The relative merits of the two algorithms are studied for a simulated spacecraft motion. Simulation results indicate that both the algorithm produce precise attitude estimates by determining boresight error, focal length and rate bias or spacecraft angular velocity in case of gyro failure; reliability and robustness characteristics favor the second algorithm.

0850 AAS 02 -102

Autonomous On-orbit Calibration Approaches for Star Tracker Cameras
T.D. Griffith, P. Singla, and J.L. Junkins, Texas A&M University

We present several approaches for on-orbit calibration of a star tracker camera for the EO-3 GIFTS mission (2003). For this mission a well-calibrated star camera will be required in order to estimate attitude to within design requirements. We detail development and testing of recursive and batch algorithms which are used to solve two calibration problems: 1) determination of the principal point offsets (xo, yo) and best effective focal length (f), and 2) estimation of higher order focal plane distorting effects. We present algorithmic numerical stability and convergence, and detail health monitoring features required for an autonomous system.

0915 AAS 02 -103

Predictive Centroiding for Single and Multiple FOVs Star Trackers
M.A. Samaan, D. Mortari and J. Junkins, Texas A&M University

The image centroiding is a fundamental process to increase the attitude data set accuracy provided by the Star Tracker. Recently, with the introduction of multiple field of view star trackers (which output non-circular images to identify the associated field of view), the centroiding algorithms have new challenges to meet. The speed and accuracy to accomplish the centroiding process represent, therefore, the units of measure to compare the existing different approaches. In this paper, the locations of the stars in the successive image frames are predicted using the angular velocity as provided by the rate gyro. When the rate gyros data are not available, then the angular velocity is estimated using kinematics equation and successive results from the Lost-In-Space Algorithm.

Break 0940 – 1000

1000 AAS 02 -104

Pyroelectric Earth Sensor For Geostationary Satellites
A.S. Laxmiprasad, K.V.S. Bhaskar, J.A. Kamalakar and G. Anandchandran, ISRO

The Geostationary Satellite-1 (GSAT-1) was launched during the later half of April 2001 by Indian Space Research Organization (ISRO) in its indigenously developed launch vehicle GSLV-1. The Laboratory for Electro-Optics Systems (LEOS) developed an earth sensor using pyroelectric detector for this satellite as a technological opportunity payload. This newly designed attitude sensor incorporates dual telescopes. The processing logic is realized in an Application

Specific Integrated Circuit (ASIC). This paper describes the design features, experiences encountered in the development of Pyroelectric based earth sensor (PES) and on-orbit flight performance.

1025 AAS 02 -105

Rate Estimator For Windowed Quaternion Estimator

I. Kim, INHA University and J. Kim, Swales Aerospace

Single point attitude determination has no unique solution for the insufficient number of measurement vectors. For this case, some sequential methods (such as Filter QUEST, REQUEST and windowed quaternion estimator) using the past measurement vectors are useful. However, the angular rate information is required to transform the past vectors into the current ones. This paper proposes the rate observer based on the linearized attitude dynamics. It is assumed that the control activity achieves the desired angular rate perfectly. Then this angular rate estimation is fed back to the windowed quaternion estimator. The application example for two star trackers is given for verification.

1050 AAS 02 -106

Development of Inertial Measurement Sensor Using Magnetic Levitation

K.R. Cho, P.M. Bainum, Y.D. Kim and Z. Tan, Howard University

A new concept of an inertial sensor system using magnetic levitation is proposed. The proposed system is expected to replace one single-axis rate or position gyroscope, and one single-axis accelerometer concurrently with a relatively simple structure. Based on specific parametric values, the system is modeled mathematically and the controller designed based on state feedback and model-based compensator techniques. For the desired system, the state equations of this system were separated into two modes; the translation mode of the X-axis and remaining motion modes. The LQG/LTR method was introduced to reach zero steady state error for the disturbances. Stability and robustness as well as the disturbance rejection were also considered.

Session 2: Orbital Mechanics I

Chair: Dr. David Vallado
Raytheon

0800 AAS 02 -107

The Second Order Theory of Perturbation Due to Geopotential and Luni-Solar Attraction

Y.A. Abdel-Aziz, Adam Mickiewicz University

We propose an analytical solution of some problems of Earth's artificial satellite moving on high orbits (at altitude above 20000 km). Perturbations due to combined effects of the geopotential (zonal and tesseral harmonics) and Luni-Solar attraction are considered. We include also resonance due to commensurability of satellite with the Earth's motion in the case of geosynchronous orbit. In particular, we discuss examples of the 1-1 and 1-2 resonance orbits. The solution will avoid the singularities from small eccentricities and small inclinations. We derive the theory of perturbation applying the Hori-Lie algorithm. Periodic and secular terms of this analytical solution are retained up to the order second and third, respectively.

0825 AAS 02 -108

Stability Bounds for Three Dimensional Motion Close to Asteroids

M. Lara, Real Observatorio de la Armada and D. J. Scheeres, University of Michigan

Asteroids belong to a class of celestial bodies which are clearly distinct from oblate bodies. In terms of specific perturbations, the ellipticity coefficient of asteroids often have the same order as the oblateness coefficient, meaning that classical theories for motion close to spheroidal bodies cannot be applied. In this paper we use numerically determined periodic orbits to explore stability of motion over the three dimensional space. Once a periodic orbit is computed, the stability of that orbit can also be computed, which sheds light on the character of phase space in the vicinity of the orbit.

0850 AAS 02 -109

The Generalized Sundman Transformation For Propagation of High Eccentricity Elliptical Orbits
M. Berry and L. Healy, Naval Research Laboratory

A generalized Sundman transformation dt = c r^n ds for exponent n at least 1 may be used to accelerate the numerical computation of high-eccentricity orbits, by transforming time t to a new independent variable s. Once transformed, the integration in uniform steps of s effectively gives analytic step variation in t with larger time steps at apogee than at perigee, making errors at each point roughly comparable. In this paper, we develop techniques for assessing accuracy of s integration in the presence of perturbations, and analyze the effectiveness of regularizing the transformed equations. A computational speed comparison is provided.

0915 AAS 02 -110

Almost Periodic Orbits Around The Geostationary Points
M. Lara, Real Instituto y Observatorio de la Armada and A. Elipe and F. Blesa, Universidad de Zaragoza

It is well known that under the action of a truncated geo-potential that takes into account the effect of the second order harmonics (the zonal $J2 and the tesserals C22 and S22, the motion of a satellite around the Earth has four equilibria (two stable and two unstable) and that it is possible to find families of periodic orbits around the equilibria. Unfortunately, the short- period orbits around the unstable points are unstable too. Here we find a family of long-period orbits around the stable points, but that spend a long interval of time in the vicinity of the unstable point, which may be of interest for mission designers.

Break 0940 – 1000

1000 AAS 02 -111

Analytical Formulation of Fast Flyby Trajectories Around a Triaxial Body
S. Casotto and M. Bardella, Universita di Padova

Using the Born approximation as the unperturbed solution, the relative trajectory of the Two-Body problem is obtained by a straightforward application of the variation of parameters technique. This is done both for the case of two point-masses and the case in which the primary is a finite rigid body, whose potential can be described by the McCullagh's approximation. In both instances the resulting analytical formulation is expressed directly in terms of simple functions of the time, without recourse to the use of Kepler's equation. Although valid as an approximation for all three types of Keplerian motion, this solution is particularly useful in modeling high speed flyby trajectories. An evaluation of the closeness of the present approximate analytical formulation to the exact solution is given. For the two point-masses case the true trajectory is obtained from hyperbolic motion, for the case of an extended primary, the solution is obtained from numerical integration.

1025 AAS 02 -112

Variations, Potentials and Numerical Integration

D. G. Hull, University of Texas at Austin

By taking variations, Taylor series expansions can be developed on a term by term basis. A variation behaves like a differential; variations of independent variations are zero, and each term of a Taylor series expansion is the variation of the previous term. Two examples of developing Taylor series by taking variations are presented. First, the potential of an oblate spheroid is expressed in terms of the eccentricity of the ellipse of revolution. Second, the equations of condition for a Runge-Kutta integrator are derived by taking variations. Taking variations is sometimes simpler than taking a standard expansion and sometimes not, but it provides the means for making an independent check of the results.

1050 AAS 02 -113

Aeroassisted Orbit Transfers For Altitude Lowering Missions

B. Woo, and V.L. Coverstone, University of Illinois

A strategy to obtain low altitude orbits (150 ~ 200 km periapse) from a nominal higher altitude circular orbit while minimizing propellant consumption is developed. In order to minimize the propellant consumption, an aeroassisted orbit transfer was considered. The results show that the total cost is minimized in the case, the orbital velocity when the satellite first reaches the desired periapse of the transfer orbit, matches the periapse velocity of lower altitude orbit. Finally, the general relation between transfer angle and the minimizing was formed from numerical simulations. The developed minimizing strategy was employed for a test case of a LEO remote sensing satellite.

Session 3: Collision Avoidance and Debris

Chair: Dr. Felix Hoots
GRC, International

0800 AAS 02 -114

A Preview on the ESA-MASTER 2001 Space Debris Model
H. Krag, J.Bendisch, K. Bunte, H. Klinkrad, C. Martin, H. Sdunnus, R. Walker, P. Wegener, C. Wiedemann, ESA

MASTER (Meteoroid and Space Debris Terrestrial Reference model) is the European particulate environment and risk assessment model. It is based on quasi-deterministic principles, using comprehensive orbit propagation theories and volume discretisation techniques, to derive spatial density and velocity distributions in a three-dimensional control volume ranging from LEO to GEO altitudes. The new release, MASTER 2001, will cover a time frame that reaches from the very beginnings of spaceflight out to the year 2050, using detailed simulation results. This paper focuses on the development of the MASTER 2001 model, concentrating on the related scientific aspects. The historical and future evolution of the space debris environment in terms of spatial density as given by MASTER 2001 is presented.

0825 AAS 02 -115

Close Geostationary Satellite Encounter Analysis: 1997-2001
R. Abbot, R. Clouser, E. Evans and J. Sharma, MIT/Lincoln Laboratory

The 1997 failure of Telstar 401 in the populous geopotential well 97-113 West longitude has led to approximately 100 encounters with active satellites at distances as close as 2 km. This has called attention to the general drifting geosynchronous satellite population that poses an ongoing threat to the active population. An automated system has been developed to monitor this threat and to make this information available to the commercial owners/operators. Research addresses orbit modeling and tracking issues pertaining to improvement of encounter estimation accuracy. Examples are shown illustrating encounters being monitored in real time with radars to validate predictions.

0850 AAS 02 -116

Analytic Solution to COLA Maneuver Optimization for Near Circular Orbits
G. Peterson, The Aerospace Corporation

When a dangerous "Class Red" conjunction between primary and secondary objects is identified as part of the collision avoidance (COLA) process, a maneuver might be warranted. Efficient numerical solutions to the maneuver problem have been implemented in the program DVOPT.BVOPT is accurate and produces solutions quickly for 1- and 2-dimensional burns. However, DVOPT is based upon a numerical quasi-brute force search algorithm; therefore achieving a full 3-dimensional solution (and even a 2-d solution under certain circumstances) can become time-inefficient in an operational environment. As a consequence, an analytical solution has been developed that can be examined directly.

0915 AAS 02 -117

Satellite Collision Analysis Using Genetic Algorithms as a Filter
A.L. Faulds and D.B. Spencer, Pennsylvania State University

When doing collision analysis, it is important to compare close approaches between all active satellites in space with all tracked objects in space. All possible combination of object pairs must be analyzed. An algorithm for finding object pairs that have a low probability of collision has been developed. To allow for quick computation so that all collision possibilities do not need to be analyzed using a high-order propagator, a low-order propagator that is easily parallelizable incorporates a Genetic Algorithm to find closest approach. The result is a parallel algorithm that filters out low probability collision pairs thus reducing the computation time necessary to evaluate the overall close-approach risk for all of the object pairs.

Break 0940 – 1000

1000 AAS 02 -118

The Effect of the Periodic Covariance Variations on the Probability of Collision
K.T. Alfriend, J-H. Yang and D.J. Lee, Texas A&M University, J.H. Frisbee, United Space Alliance

With no atmospheric drag the uncertainty volume (6D) defined by the covariance is constant with time. However, the volume of the position covariance increases slowly and has significant periodic variations. Since the probability of collision (Pc) is dependent on the position covariance these periodic variations have a significant effect on Pc. The timing of the last observation relative to the conjunction time can be critical in determining Pc. In this paper we investigate these effects as well as patterns in the covariance relative to the last observation.

1025 AAS 02 -119

Least Squares Estimate Covariance Behavior for a Moving, Fixed Length Fit Span and Fixed Epoch

J.H. Frisbee, United Space Alliance

A preliminary investigation has been conducted into the evolving behavior of the state error covariance matrix associated with the least squares differential correction algorithm. The specific problem of interest is that associated with satellite orbit determination and how the covariance changes, with respect to a fixed epoch time, as the orbit determination fit interval moves in time. The periodic variation in the covariance associated with both the satellite orbital period and the daily rotation of the Earth is shown as well as is the sensitivity to the number of observations, or sample size, in any particular fit interval. By considering the behavior of the covariance matrix in the random vector space associated with the population of observations rather than the vector space of the mean vector, it is possible to reduce or eliminate the effect of sample size. The interpretation of this population space view of the state uncertainty is also addressed.

1050 AAS 02 -120

Close Encounters With Multiple Satellites

K. Chan, The Aerospace Corporation

This paper is concerned with a detailed calculation of the collision probability between the primary spacecraft and numerous secondary orbiting objects over a period of time. These secondary objects are grouped into different classes specified by their altitude and inclination. All the secondary objects in this class have ascending nodes uniformly distributed around the equator, and have phase angles uniformly distributed within an orbital plane. The analytical expressions for close multiple encounters yield numerical results in agreement with those obtained using time-consuming Monte Carlo simulations.

Session 4: Attitude Control & Determination

Chair: Dr. Lester L. Sackett
Charles Stark Draper Lab

1330 AAS 02 -121

Design of the Reaction Wheel Attitude Control System for the Cassini Spacecraft

G. A. Macala, Jet Propulsion Laboratory

The Cassini spacecraft uses two types of control actuators to perform attitude control during different portions of its mission: a set of reaction control thrusters and a set of reaction wheels. In Reaction Wheel Attitude Command mode, the S/C uses the wheels to control S/C attitude and rate: attitude must be kept inertially fixed for some science observations but also must be able to turn and track moving targets (target motion compensation). This paper describes the requirements, design and analysis of Cassini's Reaction Wheel Attitude Controller. In addition, preliminary performance results from in-flight use of the controller will be presented.

1420 AAS 02 -122

Use of Guidance and Control Test Cases to Verify Spacecraft Attitude Control System Design

L. Chang, J. Brown, K.J. Barltrop and A. Y. Lee, Jet Propulsion Laboratory

A simulation and analysis approach is introduced for verification of attitude control flight software performance in a deep space mission. The Cassini Guidance and Control test cases simulate typical and mission-critical spacecraft scenarios under nominal and stress conditions. Plots compare simulation results against "pass/fail" curves traced back to functional requirements. The analysis also provides useful insight into performance margin. Comparisons of test results with flight telemetry provide an assessment of simulation fidelity. The method demonstrates the value of software simulation in qualifying an attitude control system to perform in the expected environment.

1445 AAS 02 -123

Attitude Control of Earth-Pointing Spacecraft Using the Reaction Jets and Magnetic Torquers

F.Wang, B.D. Tapley and S.V. Bettadpur, University of Texas at Austin

For low Earth orbit satellites, attitude control by a cold gas propulsion system and magnetic torquers becomes a practical means. On-off control by the cold gas propulsion system can be used to control the pitch set while on-off control can drive the controlled states in the roll/yaw set almost to zero except that the chatter occurs. Based on the state feedback control, the roll/yaw set can be controlled to be desired values using the magnetic torquer. Linear-Quadratic-Regulator (LQR) synthesis may be used to design the strategy presented in this paper.

1445 AAS 02 -124

Semi-Global Adaptive Feedback Stabilization of Spacecraft Attitdue Dynamics

H. Miwa and M.R. Akella, University of Texas at Austin

In this paper, we revisit the classical problem of adaptive attitude tracking for a rigid spacecraft. The interesting difference in the formulation is the assumption that, only attitude measurements are available for the purpose of feedback control. We proceed to construct semi-globally stabilizing control laws that enable the spacecraft to track any specified trajectory in the presence of inertia parameter uncertainty without requiring the body angular velocity measurements. Our formulations do not make any assumptions on prior knowledge and availability of bounds on desired trajectories or the unknown parameters and they complement and extend some recent developments in this field that are based on high-gain observers. A numerical simulation will be included to illustrate the performance of the proposed adaptive control scheme.

Break 1510 - 1530

1530 AAS 02 -126

ICESAT/GLAS Laser Pointing Determination

S. Bae and B.E. Schutz, University of Texas at Austin and J.M. Sirota, Sirota Research and Engineering

The Geoscience Laser Altimeter System (GLAS), which will be carried by the Ice, Cloud and land Elevation Satellite in 2001, needs to determine the attitude/pointing direction with 1.5 arcsecond (1 sigma) accuracy in post-processing. The attitude/pointing determination will be made by a CCD star tracker, Hemispherical Resonator Gyros, and the Stellar Reference System (SRS), which is specially designed by the GLAS instrument team. This paper presents algorithms utilizing the given instruments in the precise attitude/pointing determination and shows extensive simulation results.

1555 AAS 02 -127

Identification and Adaptive Control of a Satellite Flight Control System

D.L. Mackison, University of Colorado

Systems failures have seriously degraded many satellite missions. With the advent of extensive on-board computing capability, it is now possible to include as part of the satellite attitude control and determination system a system identification program, which may provide continuous monitoring of the attitude dynamics, and to identify a new dynamic model for use in the ADAC, compute new control and filter gains, and render the ADAC system robust against many types of system hardware and software failure. We examine system identification models, and include them in a extensive simulation of an attitude control system to determine appropriate identification methods, and indicate the way they may be implemented in flight computers.

Session 5: Orbital Mechanics II

Chair: Dr. Daniel J. Scheeres
University of Michigan

1330 AAS 02 -128

Progress Report on U.S. Space Command Astrodynamics Standards
M.J. Gabor, USSPACECOM

Current progress on the U.S. Space Command Astrodynamics Standards effort within the Joint Astrodynamics Working Group (JAWG) is summarized. By creating these standards, accuracy and interoperability will be encouraged throughout the U.S. military's operational space surveillance community. Previously this has not been possible because of the stove-piped development of the Air Force and Navy space control centers. A definition and roadmap for the standards process are presented and progress along the roadmap is summarized. Finally, a way ahead is charted for the standards development process.

1355 AAS 02 -129

The Atmospheric Neutral Density Experiment
A.C. Nicholas and S.E. Thonnard, Naval Research Laboratory

The Atmospheric Neutral Density Experiment (ANDE) is a mission proposed by the Naval Research Laboratory to monitor the thermospheric neutral density at an altitude of 400km. The mission objectives are to provide total neutral density along the orbit for improved orbit determination of resident space objects. The mission consists of two spherical satellites fitted with retro-reflectors for satellite laser ranging (SLR). One satellite is completely passive, the other carries active instrumentation to measure the partial pressure of atmospheric constituents, GPS positioning, 3-axis acceleration, and surface temperature. The active satellite will be fitted with modulating retro-reflectors. The spacecraft telemetry will be transferred to the ground by modulating and reflecting the SLR laser interrogation beam.

1420 AAS 02 -131

Recent Developments Of the Raven Small Telescope Program

C.Sabol, K. Luu and P. Kervin, Air Force Research Laboratory, D. Nishimoto, Oceanit Laboratories, K. Hamada and P. Sydney, Boeing

Raven is a class of small telescopes which combine inexpensive commercial hardware with state of the art astrometric image reduction techniques to produce high accuracy angular observations of satellites. Since the last publications at the Space Flight Mechanics and Astrodynamics conferences, the Raven system has continued to evolve and garner attention from the Air Force for a variety of applications. This paper highlights the improvements made to the Raven system, outlines some of its performance characteristics including calibration results and reliability of the automated systems, and discusses how this sensor impacts some very important and topical areas of astrodynamics research.

1445 AAS 02 -132

Astrodynamics Research With the Air Force Maui Optical and Supercomputing Site

C.Sabol, K. Luu and P. Kervin, Air Force Research Laboratory

Air Force Research Laboratory has made a commitment to develop in-house R&D capabilities within the Air Force Maui Optical and Supercomputing (AMOS) branch. Coupling newly-arrived astrodynamics specialists with the unique resources of AMOS provides incredible capability to pursue a variety of topics in space surveillance, space situational awareness, ballistic missile defense, and satellite mission support. Resources on Maui encompass a suite of telescopes including AEOS and Ravens, infrared sensors, the Hi-CLASS laser radar, Maui High Performance Computing Center, and support from Kaena Point radar. This paper provides an overview of these research areas and the supporting role of AMOS.

Break 1510 – 1530

1530 AAS 02 -133

Hybrid Ephemeris Compression

F. Hoots and A. Segerman, GRC, International

A new approach has been taken to developing an ephemeris compression model. The model uses the two body plus seculars and J2 short-period periodic solution as a basis and overlays Fourier series to model the small differences between this analytic model and the more accurate numerical reference. The ephemeris compression model runs with a speed comparable to currently used GP models, accurately imitates the SP reference within a hundred meters for a day, is valid for all eccentricities and inclinations, and requires transmission of less than three hundred coefficients.

1555 AAS 02 -134

Precise Onboard Ephemeris Propagation Method Using CW Frame and Multiple Compression

D.-J. Lee and K.T. Alfriend, Texas A&M University, T.S. No, J.-B. Baek, S.R. Lee and H.J. Kim, Korea Aerospace Research Institute

The purpose of this paper is to develop a precise onboard ephemeris propagator using multiple compression method. The overall procedures can be divided into two categories; one is data compression module (DCM) and the other is data reconstruction module (DRM). The basis model with two-body plus secular variations is used to define a reference orbit and the residuals between the reference and the true orbit from numerical technique are compressed in a form of multiple base functions. An accurate estimate of the ephemeris is generated within a few hundred meters for several days by reconstructing the residuals with the coefficients obtained from DCM and adding them into the reference orbit.

Session 6: Interplanetary Missions I

Chair: Dr. James McAdams
Applied Physics Laboratory

1330 AAS 02 -135

A Low-Cost and Low-Technology Mission and System Design Concept For Mars Entry, Descent and Landing

M.I. Cruz and M.I. Cruz, Aerocat Engineering, C. Chadwick

This paper addresses a low-cost and low-technology mission and system design concept for Mars Entry, Descent and Landing (EDL). It utilizes two techniques to deliver substantial payloads into Mars orbit and onto the surface of Mars in a ballistic low-cost and low-technology technique. The first technique is a ballistic and lifting Aerocapture into Mars orbit without the use of Aeromaneuvering technology. The second technique is a ballistic Aerobrake-Sail EDL without the need for Aeromaneuvering or Hypersonic Parachutes. These techniques do rely on propulsion to clean up the orbit insertion, and later commit to a precise landing out of Mars orbit of landed payloads.

1355 AAS 02 -136

Celestial Navigation on the Surface of Mars

B. Malay, University of Texas at Austin, R. Fahey, NASA Goddard Space Flight Center and D. Boden, U.S. Naval Academy

The goal of this project is to develop a celestial navigation process that will fix a position on Mars with 100-meter accuracy. This method requires knowing the position of the stars and planets referenced to the Martian surface with one arcsecond accuracy. This information is contained in an ephemeris known as the Arenautical Almanac. The theoretical accuracy of the almanac is determined mathematically and compared with the Astronomical Almanac. A preliminary design of an autonomous celestial navigation system is also presented.

1420 AAS 02 -137

Optical Navigation For the Mars Premier 2007 Orbiter Approach Phase
S. Delavault and J. Foliard - CNES

One of the most challenging techniques to be tested in the 2007 MARS PREMIER mission is aerocapture. In a navigation point of view, this kind of insertion implies a stringent accuracy level for the trajectory entry difficult to obtain with only radio data. The approach navigation accuracy can be improved with optical data, using celestial bodies pictures against a star background. This paper presents some studies used to specify the on-board camera. First the star background has been analyzed to infer the camera maximal detectable magnitude and field of view. Then a covariance analysis has been performed to determine the picture frequency and camera resolution allowing to respect aerocapture entry accuracy.

1445 AAS 02 -138

The Effect of USO Stability on One-Way Doppler Navigation of the Mars Reconnaissance Orbiter
D.E. Highsmith, Jet Propulsion Laboratory

This paper provides a summary of a study to assess the effect of the stability of the ultra-stable oscillator (USO) on board MRO (Mars ’05) on navigation accuracy when using one-way Doppler to the Deep Space Network. Subject to the assumptions of the covariance analysis, the results indicate that an oscillator with 10-12 short-term stability would provide navigation performance sufficient to meet the ephemeris requirements, but a 10-13 oscillator would ensure minimal loss of performance versus the nominal two-way Doppler.

Break 1510 – 1530

1530 AAS 02 -139

Low-Thrust Orbit Transfer Around Minor Planets
J.A. Sims, G.J. Whiffen, P.A. Finlayson and A.E. Petropoulos, Jet Propulsion Laboratory

Several methods for determining the characteristics of low-thrust transfers around minor planets are examined and compared. The methods range from simple analytic approximations to sophisticated optimization. The DV required for a given transfer generally decreases with increasing flight time. Allowing a relatively short coasting period can significantly decrease the required DV over a minimum time (continuous thrust) transfer. A simple analytic approximation provides a good estimate of the DV, and a Hohmann-type transfer, which can be achieved in a reasonable time, establishes a lower bound.

1555 AAS 02 -140

A Gravity Model For Navigation Close To Asteroids And Comets
C.J. Weeks, Loyola University

The gravity model used for planetary navigation is an expansion of Legendre polynomials and associated functions. The inverse r relationship causes divergence when the orbital radius is less than that of the Brillouin sphere. An alternative method for computing gravitational acceleration is described, and the shape model from the NEAR mission is used as an example. Computation is reduced to a surface integral by first analytically integrating with respect to r. The result is evaluated far more rapidly. A surface layer is added to accommodate internal density variations. The gravitational acceleration is compared to a polyhedral model.

1620 AAS 02 -141

Navigation of Aerial Platforms on Titan
R.D. Lorenz, University of Arizona

Future missions to Saturn's giant atmosphere-shrouded moon Titan may involve aerial platforms such as airships or helicopters. A significant challenge is the navigation of such vehicles, both in terms of global position determination and path planning in the zonal wind field, and for local stationkeeping. This paper overviews the Titan environment and the likely science goals and mission scenarios for post-Cassini missions, and examines the various methods (astronavigation, complicated by the hazy atmosphere, but possible at selected wavelengths; dead-reckoning, doppler navigation using an orbiter, expendable beacons, etc.)

Session 7: Formation Flying I

Chair: Dr. David B. Spencer
Pennsylvania State University

0800 AAS 02 -142

Models of Motion in a Central Field With Quadratic Drag
M. Humi, Worcester Polytechnic Institute and T. Carter, Eastern Connecticut State Universityt

In this paper we first derive the general properties and first integrals for the motion of a particle in a central force field with a general power law drag. Under this setting exact and approximate solutions of the equations of motion are found in various cases. Emphasis is placed on inverse square gravitation and quadratic drag. In one model the altitude of a circular orbit is found to decay exponentially under quadratic drag. Linearization of the equations of motion for orbits in which ether the tangential or radial speeds are relatively small leads to closed-form solutions for certain cases.

0825 AAS 02 -143

The Characterization of Formation Flying Satellite Relative Motion Orbits
K.T. Alfriend, D-W. Gim and S.R. Vadali, Texas A&M University

In this paper relative motion orbits in which the primary disturbance is the differential gravitational perturbation are classified or categorized. Four classes and several sub-classes of orbits are identified. The basis for the classification is the number of constraints on the orbit and these constraints define the drift rate between the satellites. There are no restrictions on the chief satellite eccentricity. Orbit maintenance Dv requirements are determined for each class of orbit.

0850 AAS 02 -144

A Solution of the Elliptic Rendezvous Problem With the Time As Independent Variable
R. A. Broucke, University of Texas at Austin

We give an explicit solution for the linearized motion of a chaser in a close neighborhood of a target in an elliptic orbit. Our solution is a direct generalization of the Clohessy-Wiltshire equations that are widely used for circular orbits. In other words, when the eccentricity is set equal to zero in our new formulas, we obtain the well-known Clohessy-Wiltshire formulas. Our solution is completely explicit in the time. As a starting point we find a closed-form solution of the "de Vries" equations of 1963, the linearized equations of elliptic motion in a rotating coordinate system, rotating with a variable angular velocity. We show that this solution is obtained by taking the partial derivatives, with respect to the orbit elements, of the elliptic orbit of the target.

0915 AAS 02 -145

Modelling and Simulation of Power Sail
M.P. Wilkins, K. Subbarao, K.T. Alfriend and S.R. Vadali, Texas A&M University

The objective of this work is to accurately model and simulate the behavior of a new type of satellite system called the Power Sail. The Power Sail concept is such that a large solar array, measuring 400 m2, is flown separately from the host satellite but connected via rigid links which also act as power conduits. Currently, the concept calls for two rigid links connected by a joint. This 6-DOF joint is modeled as either an uncontrolled joint or with a spring-damper system in place. The orbit of the Power Sail system is controlled via thrusters located on the Power Sail itself, at the joint, and on the host. The natural motion of this system is studied and found to be unstable in the desired nominal configuration. Suitable control laws are developed and their fuel requirements are studied.

Break 0940 – 1000

1000 AAS 02 -146

Modeling and Control of a Power Sail
K. Naik, M.P. Wilkins, S.R. Vadali and K.T. Alfriend, Texas A&M University

The Power Sail is a large solar ‘Sail’ connected to a host satellite with a pair of hollow links housing an electrical conductor. This paper will address the modeling of the system dynamics and the control design. The control objective is to point the sail toward the sun while minimizing the reaction transmitted onto the host. The dynamics are solved for in the presence of solar radiation and gravity gradient torque. Assuming that the host attitude is perfectly controlled or its attitude behavior is specified, the dynamics and the control action at the sail and link joints are determined so that the sail is always sun pointing. Finally a control strategy is developed.

1025 AAS 02 -147

A Third Order Analytical Solution for Relative Motion with a Circular Reference Orbit

J.W. Mitchell, AFRL and D.L. Richardson, University of Cincinnati

With a convenient Lagrangian formulation of the relative motion dynamics in the vicinity of a circular reference orbit, it is shown that the influence of a spherical primary mass takes the form of a third-body disturbing function with respect to the fixed point in Hill's frame. The resulting Lagrangian and equations of motion are very compact and provide an easily obtainable description of the nonlinear contributions to the motion to an arbitrary order using well-known recursion relations. Using this compact Lagrangian, a third-order analytical solution for the periodic motion in Hill's frame is investigated.

1050 AAS 02 -148

The Clohessy-Wiltshire Equations Can Be Modified to Include Quadratic Drag

T. Carter, Eastern Connecticut State University and M. Humi, Worcester Polytechnic Institute

The relative-motion equations of a spacecraft in the vicinity of a satellite in an orbit that is not highly eccentric but decays as a result of quadratic drag, are investigated. If the initial orbit is not highly eccentric the equations of motion of both the satellite and the spacecraft can be linearized, even in the presence of quadratic drag. Some transformations are then applied to simplify the equations of relative motion. If the drag is quadratic in the magnitude of the velocity and varies inversely with the distance from the center of attraction, the equations simplify further. If the two objects in orbit have the same drag acceleration and the initial orbit is circular, the equations reduce to an extension of the Clohessy-Wiltshire equations, modified to include quadratic drag.

Session 8: Orbital Mechanics III

Chair: Dr. Michael Gabor
USSPACECOM

0800 AAS 02 -149

Orbit Design and Station Keeping Strategy of the Co-located Geostationary Satellites

F.Wang, B.D. Tapley and S.V. Bettadpur, University of Texas at Austin

Geo-stationary co-location can effectively solve the resource problem caused by the rapid growing rate of geo-stationary satellites. Those clusters need an efficient separation method to provide safe co-location. This paper investigates a co-location strategy for three geo-stationary satellites and presents one separation strategy, combined longitude and eccentricity and inclination vector separation strategy . Furthermore, the station keeping strategy is investigated. The simulation shows that minimum separation is not less than 10 km.

0825 AAS 02 -150

An Algorithm for Autonomous Longitude and Eccentricity Control for Geostationary Spacecraft

B. Emma, San Jose State University and H.J. Pernicka, University, University of Missouri-Rolla

In order to lower the cost of maintaining satellites in orbit, spacecraft designers are seeking flight software that provides more autonomy. Longitude station-keeping and eccentricity are good candidates for autonomous control. The algorithm presented in this paper couples longitude control with eccentricity control. After the basic longitude control algorithm was written, a differential correction scheme was added resulting in an improved longitude error of +/-0.015 degrees longitude. Finally, longitude control and two-part maneuvers for eccentricity control were implemented. The result is good longitude control and eccentricity control to the desired mission constraints.

0850 AAS 02 -151

Collocation Analysis Of Three Geo-Stationary Satellites By Using a Boundary Occurrence Staggering Strategy
B. Srinivasan, ISRO

Amidst the existing strategies of collocation of geo-stationary satellites, a new strategy to collocate three satellites by means of staggering the boundary occurrence time has been analysed and presented. Instead of staggering the eccentricity and inclination vectors at a particular time-instant, the satellites are supposed to follow near identical cycles in inclination and identical cycles in eccentricity but with the times of occurrence of the boundaries (0.1∞ in inclination and 0.0002 in eccentricity). It results in a convoy type situation. The inter-satellite distance profiles generated for a period of one north-south station-keeping cycle – initially tried for multiple satellite systems – shows feasibility prima facie. It was done for 74∞ east longitude and a threshold of 5 km for the inter-satellite distance. The generation of the cycle start parameters must be done for each station-keeping cycle afresh. The east-west station-keeping cycles are sought to be synchronised for the satellites in order to maximise the minimum inter-satellite distances.

0915 AAS 02 -152

Autonomous Landing Manoeuvre by Landmark Tracking Technique
M. Vasili and M. Lavagna, Politecnico di Milano

Autonomy is becoming a driver for near future projects. Next generation landers, destined to interplanetary exploration, are excellent examples for which autonomy is a mandatory capability. In this paper an approach to autonomous landing manoeuvres based on optical measurements is proposed. The idea is to reconstruct the relative velocity vector and the time to impact from images of the landing scene during descent. Due to the short time available for image processing a novel strategy has been implemented which tries to identify useful landmarks in the scene and then reconstructs the relative motion from the motion of the landmarks on the image plane. The algorithm has been tested on simulated and real images of close approach to objects or irregular surfaces.

Break 0940 – 1000

1000 AAS 02 -153

An Efficient Searching Strategy Based On the Capabilities Of a Single Ground Station

M. Parisse, F. Curti and F. Longo, Universita di Roma

The study evidences the capabilities of a ground station which, by combining in an interactive way its own hardware resources together with suitable algorithms based on orbital dynamics, can autonomously provide support for orbital determination and tracking of satellites and space vehicles. The idea is to verify if and when it is possible "to absorb" the errors associated with the orbital parameters assessment by means of a suitable search strategy of the space vehicle around the nominal waiting point. The aim is the definition of operating criteria, functions of the error range width and antenna characteristics, based on the most suitable choice of parameters under the direct control of the antenna operator.

1025 AAS 02 -154

Vehicle's Non-Jet Propulsion Due To Internal Coupled Waves Interacting Speed-Dependently With Crossing Gravity And Magnetic External Fields

A. Chigirev, CRO SNA Space Communications

The general aim of this work was to find a technically feasible solution to implement the weak non-jet propulsion effect inherent extended or spinning satellites with internal coupled waves into trial space propulsion practice. It is found that there exist a promising as well as simple conceptual solution for non-jet propulsion arising both in gravity and in magnetic field. The solutions could increase cardinally (by four orders of magnitude) the weak propulsion effect inherent the non-jet conceptual designs earlier proposed.

1050 AAS 02 -155

Optimal Transfer Between Circular And Hyperbolic Orbits Using Analytical Maximum Thrust Arcs

D.M. Azimov and R.H. Bishop, University of Texas at Austin

Mayer's variational problem of determining optimal trajectories of a rocket moving with constant relative exhaust velocity and limited mass-flow rate is considered. An approximation of the Newtonian gravitational field by linear central field allows us to develop analytical solutions for maximum thrust arcs. The problem of optimal transfer between given circular and hyperbolic orbits via the maximum thrust arc is discussed. It is shown that the coordinates of junctions on the trajectory and Lawden's integration constants can be expressed in terms of terminal conditions and on the characteristics of the engine system, thereby avoiding iterations to find initial control vector. A numerical example is analyzed.

Session 9: Interplanetary Missions II

Chair: Dr. Lincoln Wood
JPL

0800 AAS 02 -156

Cassini Orbit Reconstruction From Earth to Jupiter

D.C. Roth, M.D. Guman, and R. Ionasescu, Jet Propulsion Laboratory

Cassini completed its fourth and final planetary gravity assist with closest approach to Jupiter occurring on 30 December 2000. Flying past Jupiter at a periapsis altitude of 9,722,965 km, a DV of 2.2 km/s was imparted to Cassini while bending its trajectory by 12.2∞. A detailed construction of Cassini's trajectory from Earth flyby will be described in this paper. The spacecraft trajectory will be characterized first, followed by a description of the data and a priori models. Reconstructed values will then be presented, accompanied with the resulting tracking data residual plots.

0825 AAS 02 -157

Pioneer and Voyager Jupiter Encounter Orbit Reconstruction in the ICRF System

R. A. Jacobson, Jet Propulsion Laboratory

Exploration of the Jovian system with spacecraft began when Pioneer~10 reached Jupiter in 1973; Pioneer~11 followed a year later. Subsequent visitors to the system include: the twin Voyager spacecraft, the Ulysses spacecraft, the Cassini spacecraft, and the Galileo spacecraft which is in orbit about Jupiter. We have been using data acquired by these spacecraft together with Earth based observations to determine the gravity field of the Jovian system and to improve the ephemerides of Jupiter and its satellites. A necessary byproduct of the work is the reconstruction of the spacecraft trajectories. This paper reports on our reconstruction of the Pioneer and Voyager trajectories.

0850 AAS 02 -158

Ballistic Jupiter Gravity-Assist, Perihelion-DV Trajectories for a Realistic Interstellar Explorer

J.V. McAdams and R.L. McNutt, Applied Physics Laboratory

This proposed interstellar precursor mission will penetrate into the nearby interstellar medium by achieving 1000 Astronomical Units from the Sun within the working lifetime (about 50 years) of the mission initiators. A variety of science goals and orbital mechanics constraints contribute to the formulation of a list of candidate stars for targeting the solar system escape trajectory direction. An approach is developed for minimizing both launch energy to Jupiter and a subsequent near-Sun, high-ISP, high-thrust maneuver in order to attain a high-speed escape from the solar system towards a target star. Detailed performance characteristics are given for selected reference trajectories.

0915 AAS 02 -159

Precise Determination of Accelerometer Proof Mass
F.Wang, B.D. Tapley and S.V. Bettadpur, University of Texas at Austin

The accelerometer is of high potential to be widely used in the gravity field modeling application. It can measure all non-gravitational accelerations, and also the disturbance accelerations. In most application cases, the accelerometer's proof mass needs to be known during the in flight phase in order to keep the disturbance accelerations as small as possible. By superimposing torque with short period upon the spacecraft, the accelerometer's proof mass position can be determined by the algorithms presented in this paper. A complete simulation shows that the accuracy of proof mass could be determined better than 0.1mm along each axis.

Break 0940 – 1000

1000 AAS 02 -160

Solar Sail Orbit Operations at Asteroids, Part 2: Exploring the Coupled Effect of an Imperfectly Reflecting Sail and a Nonspherical Asteroid
E. Morrow and D. Lubin, Scripps Institute and D. J. Scheeres, University of Michigan

The effect of an imperfectly reflecting sail on the spacecraft dynamics is evaluated and the effect of a non-spherical asteroid is explored. The effect of the imperfect sail is seen to be a decreased area about the asteroid where equilibrium points are possible and a diminished SRP force along the sun line. The effect of a non-spherical asteroid is modeled by using the J2 Gravity field contribution. Although a special class of stable orbits for solar sails are generally stable under the J2 perturbation, we find certain parameter combinations that lead to secular instabilities in the sail orbit.

1025 AAS 02 -161

Earth-Capture Trajectories Using Solar Electric Propulsion
C.A. Kluever and Y. Gao, University of Missouri-Columbia

This paper presents a new approach for computing minimum-propellant, Earth-capture trajectories using solar electric propulsion. The return leg of a Mars sample return mission provides the initial state vector and low-Earth orbit (LEO) is the terminal target. The initial phase of the capture is numerically computed using the combined gravity fields of the Earth, sun, and moon. Our solution method eliminates the computational burden of simulating the hundreds of near-circular revolutions of the inward spiral to LEO by utilizing curve-fits of universal low-thrust solutions. In addition, we present a feasible onboard guidance strategy for performing the capture maneuver.

1050 AAS 02 -162

Hyperbolic Rendezvous For Earth-Mars Cycler Missions
P.A. Penzo and K.T. Nock, Global Aerospace Corporation

A cycler is a free return trajectory which encounters Earth and Mars on each revolution about the sun, and may be used as the trajectory of a habitat for the several month transfer from one planet to the other. Close encounters with Earth and Mars would require hyperbolic rendezvous to transport humans from a departure orbital station to the cycler. This paper develops a program which computes.multiple impulse optimal trajectories for the transfer from various orbits in the Earth and Mars systems to the cycler, and will compare, with other considerations, the results for the most favorable locations for an orbital station.

Session 10: Attitude Dynamics & Control

Chair: Dr. Donald Mackison
University of Colorado

1330 AAS 02 -163

Adaptive Modeling of the Geomagnetic Field Based On Multiple Segmentation For Highly Accurate Attitude Determination
G.Michalareas, S.Gabriel, University of Southhampton

This paper presents the completed work on the development of a new method of modeling the geomagnetic field. The main contribution of this work is the development of a model which offers attitude determination accuracy of 0.15º rms in comparison to the 1º rms offered by the IGRF, used mostly to date. Beyond that the model incorporates an adaptive mechanism which compensates for unmodeled shifts in the field. The modeling is based on segmenting the field and using a sub model for each segment.

1355 AAS 02 -164

Using Inertial Measurements For the Reconstruction Of 6-DOF Entry, Descent, and Landing Trajectory and Attitude Profiles
G.G. Wawrzyniak and M.E. Lisano, Jet Propulsion Laboratory

A method was sought for estimating the "Stroke" distance between a Mars Exploration Rover (MER) test lander (protected by airbags) and a surface during impact. The authors at JPL have developed a suite of software known as REDLand (for Reconstruction of Entry, Descent and Landing) to accomplish this. REDLand uses data from accelerometers and gyroscopes on board the lander test body as measurements in an extended Kalman filter, in addition to geometric and dynamical constraints, and other data, where available. This paper is a discussion of the formulation of the REDLand filter algorithms and presents results from actual airbag-and-lander impact tests made in 2001.

1420 AAS 02 -165

Effect of Coriolis Terms in Thrust Equations for Misaligned Strap-On Solid Rocket Motors
A. P. Mazzoleni and W. E. Williamson, Texas Christian University

A solid rocket motor system can be modeled as a variable mass system whose mass is constantly changing due to the burning and ejection of propellant. Most dynamic simulations of rocket dynamics lump the variable mass terms together

under the heading of "thrust terms" and use data obtained from firings of the motors on test-stands. Because these tests are conducted with the motors attached to a fixed test-stand, Coriolis accelerations of the ejected propellant do not occur during the tests and hence are not reflected in the data. In this paper, we present a derivation of the proper equations of motion for such a system, and show by way of dynamic simulations that neglecting the Coriolis terms may give erroneous results in certain situations of interest to rocket-system designers.

1445 AAS 02 -166

On-Orbit Dynamics Of Space Station and Solar Arrays
R.B. Malla and C. Lin, University of Connecticut

This paper investigates the orbital motion and structural response of space station and solar arrays moving in an earth orbit. The coupled orbital-structural equations of motion of the structural system are developed using Lagrange's principle. A finite element (FE) formulation based on the nonlinear equations of motion is developed. The three-dimensional response of the structure in a planar orbit is obtained using the FE methodology developed herein. The orbital effects on the structural elastic deformation are analyzed. The dynamic behavior of the system under some special loading, including the flow field of a hypersonic jet from space shuttle, is also investigated and results reported.

Break 1510 – 1530

1530 AAS 02 -167

Observability in Attitude-Independent Magnetometer-Bias Determination
M.A. Shuster, Acme Space Group and Roberto Alonso, Texas A&M University

The TWOSTEP algorithm is examined for the case where the centered portion of the negative-log likelihood function provides incomplete observability of the magnetic-bias vector. In those cases where the full negative-log-likelihood function provides a complete estimate, the TWOSTEP algorithm can be modified to provide an estimate of all three components of the magnetometer-bias vector. However, the procedure leads to a discrete degeneracy of the estimate, which can be resolved only by explicit evaluation of the negative-log-likelihood.

1555 AAS 02 -168

Analysis Of Variable Speed Control Moment Gyroscopes For Reorientation Maneuvers Of Rigid Spacecraft

G. Avanzini, Polytechnic of Turin and G. de Matteis, University of Rome

A command generation technique, based on a local optimization approach, is proposed for attitude control of rigid spacecraft featuring variable speed control moment gyroscopes (VSCMG) as internal torque actuators. The combined use of RW and SGCMG control modes in VSCMGs is an effective means for dealing with SGCMG singularities, inasmuch as the higher degree of redundancy allows for a more general distribution of the angular momentum vector. In this study the capabilities of an inverse simulation algorithm for off--line command generation are demonstrated. The control profile is determined by minimizing a performance index expressed as a weighted combination of pointing error, control effort and proximity to singularities, enforcing suitable constraints to take into account limits on satellite motion and command input.

1620 AAS 02 -169

Equilibria of n-Link Chain in a Circular Orbit

A.D. Guerman, University of Beira Interior

We consider equilibria of a system of (n+1) material points connected by n light rods into an n-link chain. The junctions are spherical hinges. The gravitational field of the Earth is supposed to be central Newtonian. The center of mass of the system moves along a circular orbit. We study equilibrium configurations of this system in an orbital reference frame. We find all the equilibria of an n-link chain in the orbit plane and show also that its number does not exceed 22n.

Session 11: Orbital Mechanics IV

Chair: Dr. Robert Bishop
University of Texas

1330 AAS 02 -170

Design of Earth Return Orbits for the Wind Mission
H. Franz, Computer Sciences Corp.

Since its launch on November 1, 1994, NASA's Interplanetary Physics Laboratory, or Wind spacecraft, has exploited the potential of lunar gravity assist flybys to drastically alter the spacecraft's trajectory. Over the last seven years, Wind's dynamic trajectory has included multiple cycles of double lunar swingby orbits, high Earth orbits, two lunar backflip transfer trajectories, and Distant Prograde Orbits. In December 2003, Wind's 36th lunar flyby will propel the spacecraft into a nightside Earth Return Orbit (ERO), which represents a periodic solution to Hill's formulation of the restricted three-body problem. Wind will be the first spacecraft to utilize the ERO orbit concept.

1355 AAS 02 -172

A Comparison of the MAP Trajectory Flight Results with the Nominal Pre-launch Trajectory Design
O. O. Cuevas, L.K. Newman, M.A. Mesarch and M.A. Woodard, NASA Goddard Space Flight Center

The main science objective of the Microwave Anisotropy Probe (MAP) mission is to produce an accurate full-sky map of the cosmic microwave background temperature fluctuations - anisotropy. The MAP mission orbit is a lissajous orbit about the L2 Sun-Earth Lagrange Point. The mission duration is approximately 27 months with 3 to 4 months of transfer time to the final mission orbit about L2. The NASA Goddard Space Flight Center (GSFC) Flight Dynamics Analysis Branch provided mission analysis, maneuver planning and calibration for the MAP spacecraft. This paper outlines the premission analyses performed to design the nominal trajectory to meet MAP mission requirements, including strategies developed to handle possible contingencies. In addition, the paper presents the actual flight trajectory and describes how it differed from the planned mission.

1420 AAS 02 -173

The Orbital Perturbation Environment For the COBRA and COBRA Teardrop Elliptical Constellation
P. Cefola, MIT Lincoln Laboratory and J.E. Draim and R. Inciardi, Space Resource America

Elliptical, non-geostationary satellite orbit (NGSO) constellations have been proposed to address the shortage of GEO slots for new communications satellites. The new constellations greatly multiply the available space real estate without interfering with existing GEO satellites. These constellations employ eight-hour “leaning” elliptical orbits, operating at the critical inclination. The active arcs have a ground trace that resembles a coiled cobra, hence the name COBRA. Due to the exact repeat ground-track, the COBRA orbits experience deep tesseral resonance perturbations. These orbits also experience strong perturbations due to the lunar-solar point masses. The semi-analytical satellite theory DSST is used to explore the orbital perturbation environment.

1445 AAS 02 -174

The Probability of A Laser Beam Illuminating a Space Object
R. Patera, The Aerospace Corporation

The possibility of a laser beam accidentally impinging an operational satellite or space debris must be addressed with the development of space based laser systems. The use of laser beams for satellite-to-satellite and satellite-to-ground communication requires planning to ensure beam reception and to avoid interference from other space objects. A method to calculate the probability of a laser beam illuminating a space object was developed. Laser source and space object data including space object state vector error covariance, laser beam divergence and pointing uncertainty were included in the formulation. The associated transformation equations used for algorithm implementation are presented. A computer simulation using the methodology was developed and exercised with synthetic data.

Break 1510 – 1530

1530 AAS 02 -175

Assessing the Instantaneous Risk of Direct Laser Impingement
S. Alfano, Aerospace Corporation

Several methods are presented for assessing the instantaneous risk of direct laser impingement given uncertainties in object and emitter positions. These methods are constructed to identify those occurrences when the probability of laser impingement exceeds a user-defined threshold. These formulations enhance computational efficiency through use of analytically determined scale factors.

1555 AAS 02 -176

Orbit and Attitude Maneuvers Using Single Offset Axial Thruster
S. Tanygin, Analytical Graphics, Inc.

The use of a single thruster for both orbit and attitude maneuvers is investigated. The thruster is located along the spin axis of a spin stabilized spacecraft and is offset such that it can apply both force and torque to the spacecraft. Different thruster pulsing strategies are proposed for orbit and attitude maneuvers. The strategies can be utilized either in contingency modes, when other thrusters and actuators fail, or as primary means for orbit and attitude maneuvering for experimental spacecraft (e.g. NASA ST-5 spacecraft).

Session 12: Tensegrity Structures

Chair: Dr. Robert Skelton
University of California, San Diego

1330 AAS 02 -177

Equilibria of Tensegrity Structures
Darrell Williamson, ANU

The class I tensegrity structures are reduced to linear algebra problems, after first characterizing the problem in a vector space where direction cosines are not needed. While our approach enlarges(by a factor of 3) the vector space required to describe the problem, the advantage is that enlarging the vector space makes the mathematical structure of the problem amenable to linear algebra treatment. This paper characterizes the static equilibria of class I tensegrity structures. Our results characterize the equilibria conditions of class I tensegrity structures in terms of a very small number of variables since the necessary and sufficient conditions of the linear algebra treatment has eliminated several of the original variables.

1355 AAS 02 -178

Optimization of Tensegrity Structures
Bram de Jager, Eindhoven University of Technology

We discuss the effect of the choice of topology (or connectivity) and geometry on the stiffness of controllable tensegrity systems. These are systems built up from compressive member (bars) and tensile members (tendons). Stability is improved by pre-stressing the system. These systems can change shape by controlling the tendon or bar lengths. Class 1 tensegrity connect bars to tendons, and Class 2 tensegrity allow bar-to-bar connections via ball joints. Here we discuss how to choose topology and material to improve the stiffness and stiffness-to-mass properties of tensegrity systems. We also incorporate controllability requirements, by constraining the tendon length, that should either be zero (so a tendon can be eliminated) or it should exceed a certain minimum length, so there is room for the joint structures and for installation of a mechanism used to change the tendon length in the case closed loop tendon length control is applied.

1420 AAS 02 -179

Decentralized Control of Stable-Element Tensegrity Plates
Milenko Masic and Robert Skelton, UCSD

A new type of Tensegrity structure is shown here. It is a plate whose individual elements are controlled independently. The structure will deploy from a small stowed configuration to a large plate shape. Furthermore the stiffness of the deployed plate is easily controlled.

1445 AAS 02 -180

Equilibria and Stiffness of Planar Tensegrity Structures
Waileung Chan and Robert E Skelton, UCSD

In the traditional definition of tensegrity structures, compressive members are disconnected. However, if stiff tendons connecting two nodes are very short, then for all practical purposes, the nodes behave as though they are connected. It is therefore very practical to introduce a new definition of tensegrity that allows ball joints to connect compressive members. "Class k tensegrity" will describe a network of axially loaded members in which the ends of the compressive members are connected (by ball joints of course since torques are not permitted) at some node of the network. In this paper, the static mechanical properties of the C4T1 structure will be explored. The objective is to minimize the mass of the structure while preserving certain properties like strength and stiffness.

Break 1510 – 1530

Session 13: Formation Flying II

Chair: Dr. Robert Melton
Pennsylvania State University

0800 AAS 02 -184

Approximate Models for Spacecraft Relative Motion Analysis
S.S. Vaddi, S.R. Vadali and K.T. Alfriend, Texas A&M University

The problem of relative orbit mechanics is of interest for the formation flying problem. The objective is to study the dynamics of a satellite w.r.t. another satellite in its close vicinity. The most comprehensive model consists of a set of twelve first-order nonlinear differential equations that is not amenable to control law design. The simplest model is a set of linear ODE's called Hill's equations but their utility breaks down in the presence of eccentricity of the reference satellite orbit and J2 perturbations. The objective of this work is to obtain reduced order linear models that include the effects of eccentricity in the reference satellite orbit and the J2 perturbation.

0825 AAS 02 -185

Long Duration Analysis of the J2-Model Equations of Relative Motion For Satellite Clusters
A.J. Swank, Stanford University, C.A. McLaughlin and C. Sabol, Air Force Research Laboratory and R.D. Burns, NASA GSFC

The relative motion of satellites in a cluster is analyzed for various formations. Specifically, the long duration accuracy for the equations of relative motion which include Earth oblateness effects are presented. In addition, long-duration errors encountered by applying the original J2-Model equations to non-circular orbits are quantified. The long-duration deviations in the relative motion and the errors encountered in the application of the J2-Model equations are established using a realistic force model, the Draper Semianalytical Satellite Theory, for formations of various sizes and inclinations. The J2-Model equations are then further developed to include eccentric orbit effects and are again compared to the realistic force model.

0850 AAS 02 -186

The State Transition Matrix For Relative Motion of Formation Flying Satellites

D.W. Gim amd K.T. Alfriend, Texas A&M University

Under the necessities of the precise analytic solution of the relative motion for the perturbed non-circular reference orbit, the state transition matrices for the mean elements and the osculating elements were derived using the non-singular variables. However, these variables still have the singularity in inclination. The purpose of this paper is to remove the singularities in the state transition matrices using the equinoctial variables and obtain the precise solution to analyze any kind of relative motion under the existence of J2 effect.

0915 AAS 02 -187

A Study of the Steering Law of Satellite Formation Flight Using Solar Radiation Pressure

Z. Wang and and T. Williams, Unversity of Cincinnati

Satellite formation flight mission takes a long time, so long-term perturbation effects (such as the J2 effect) should be countered to maintain the formation. A small reflective surface fixed on a satellite (called "solar wing") receives solar radiation pressure, which can be harnessed in maintaining formation flight. In this paper a dynamic model for out-of-plane motion of formation flight was formulated. Considering the control of out-of-plane motion as a regulator problem first, a simple solar wing steering law was derived. Based on discussion of the simulation results, a refined steering logic was designed for formation keeping. Simulation results look good.

Break 0940 – 1000

1000 AAS 02 -188

Application of Several Control Techniques for the Ionospheric Observation Nanosatellite Formation

B. J. Naasz, C. D. Karlgaard, and C. D. Hall, Va. Tech

This paper presents the results of several generic control strategies applied to the problem of maintaining and maneuvering a formation of Earth observing satellites. These standard techniques include both linear and nonlinear control methodologies. The effects of several constraints are considered, including fixed thrust magnitude and non-radial thrusting. In-plane and in-track formation types are studied in both cooperative and master-slave command and control architectures.

1025 AAS 02 -189

The Dynamics of Formation Flight About a Stable Trajectory
F.Y. Hsiao and D.J. Scheeres, University of Michigan

This paper investigates the dynamics of a formation of spacecraft traveling in the center manifold about a stabilized halo periodic orbit. The description of motion in this system over relatively short time spans is investigated using the theory of linear dynamical systems. To describe the motion we approximate the time-varying linear dynamics with a "local" time-invariant system. The "orbital elements" of these linear solutions are defined and used to describe the possible motions for a formation of spacecraft. The error introduced by this approximation is evaluated and shown to be relatively small.

1050 AAS 02 -190

Formulas for the Drag Constant and Time of Flight in the Two-Body Problem With Quadratic Drag
T. Carter, Eastern Connecticut State University and M. Humi, Worcester Polytechnic Institute

In a previous paper we presented certain closed-form solutions of the orbit equation for the two-body problem with drag that is quadratic in the magnitude of the velocity and inversely proportional to the distance from the center of attraction. An exact solution was presented for initially circular orbits and an approximate solution was presented for elliptical orbits of moderately low eccentricity. The present paper presents simple formulas for calculation of the drag constant and flight time in terms of the loss in altitude in the first case. In the second case approximate formulas for flight time are presented in terms of the orbit angle.

Session 14: Orbit Determination I

Chair: Mr. James Campbell
JPL

0800 AAS 02 -191

Using Fractional Gaussian Noise Models in Orbit Determination

W.C. Chow and P.W. Schumacher, Jr., Naval Space Command, Dahlgren, Virginia

It is known that estimation methods based on standard least-squares regression theory only account for measurement noise but not model noise, and methods based on either least-squares or Kalman filtering cannot be used if any of the noise processes are time autocorrelated. This paper presents a Bayesian estimator, which can handle not only both type of noises but also can be used with autocorrelated model and measurements noises. Techniques are presented to model autocorrelated measurement and model noise based upon Gaussian fractional noise. Some inherent difficult difficulties are described that may be encountered in working with real data sets. The estimator's error covariance is also explicitly described.

0825 AAS 02 -192

Optimal Orbit Determination

J. Wright, Analytical Graphics, Inc.

Orbit determination refers to the estimation of orbits of spacecraft (or natural satellites or binary stars) relative to primary celestial bodies, given applicable measurements. All useful orbit determination methods produce orbit estimates, and all orbit estimates have errors. But what is optimal orbit determination? Textbook definitions for optimal estimation leave important questions unanswered. The proposed paper will present my answers to these questions, and will present my definition for optimal orbit determination.

0850 AAS 02 -193

Application of Genetic Algorithms To Orbit Determination Of Tethered Satellite Systems

T.A. Lovell, and J.E. Cochran, Auburn University

In this paper the class of intelligent systems tools known as genetic algorithms will be used for orbit determination, specifically the estimation of the orbital dynamics of a tethered satellite system. The problem of finding a minimumvariance estimate based on a particular batch of observational data is considered. For several cases of tethered satellite motion, the performance of a genetic algorithm-based computational scheme is compared with that of a conventionally employed least-squares filtering technique. Measures of comparison include orbit determination accuracy, long-term orbit prediction accuracy, computational speed, robustness in the face of sparse or noisy observation data, and overall ease of use.

0915 AAS 02 -194

Comparison of the Russian and US Algorithms for Catalog Maintenance for Geosynchronous Satellites
K.T. Alfriend and S. Paik, Texas A&M University

For catalog maintenance of geosynchronous satellites the US uses an analytic theory (SDP4) based on Brouwer's theory and Russia uses a semi-analytic theory that contains more terms of the geopotential. In this paper the performance of the two algorithms for predicting the motion after fit spans of 30, 60, 120 and 365 days is compared for five satellites.

Break 0940 – 1000

1000 AAS 02 -195

Validation Tool for the High Accuracy Satellite Drag Model
M. Storz, Air Force Space Command

An independent method for estimating dynamically varying thermospheric neutral density is used to validate the AF Space Battlelab's High Accuracy Satellite Drag Model (HASDM). This validation tool is designed to estimate neutral density near real-time using orbital energy dissipation rates (EDRs) from 60 calibration satellite trajectories. EDRs are computed via a separate orbit determination algorithm that uses "segmented" estimates for the ballistic coefficient. The tool estimates density in terms of time-varying spherical harmonic expansions of the exospheric temperature and inflection point temperature, the key parameters characterizing the local density profile in the Jacchia models.

1025 AAS 02 -196

More Results of Naval Space Surveillance System Calibration Using Satellite Laser Ranging

J.H. Seago and M.A. Davis, Honeywell, J.W. Middour and M. Soyka, NRL and E.D. Lydick, Naval Space Command

The Naval Space Command's Naval Space Surveillance System is an uncued satellite detection system which has undergone calibration using accurate orbits determined from satellite laser ranging. Previous long term analyses have shown that some error features are static, with seasonally periodic error remaining after removing the static error features. Here, models are presented to remove these features. An improvement in orbit quality is demonstrated for specific test cases when the estimate is based on the corrected Fence observations. A revised concept of operations is described for implementing these error models at Naval Space Command.

1050 AAS 02 -197

Validation Results of an Algorithm for Real-Time Atmospheric Density Correction and Prediction

S. Bergstrom, MIT, P. Cefola, MIT Lincoln Laboratory, R.J. Proulx, C.S. Draper Laboratory, A.I. Nazarenko, Center for Program Studies and V.S. Yurasov, Space Research Center

Atmospheric drag model inaccuracies can result in large errors in the determination and prediction of satellite orbits in low earth orbit (LEO). Improvements to any atmospheric density model can be made by incorporating observation data in near-real time. An algorithm has been created which uses estimated ballistic factors from observational data to create time-localized linear corrections to the model. Most functions of the algorithm have previously been validated with simulated data under idealized conditions for short time spans. This paper presents the results of comprehensive validation tests with simulated data. A brief mathematical description of the algorithm is also included.

Session 15: Tether Satellite Systems

Chair: Dr. Arun K. Misra
McGill University

0800 AAS 02 -198

Dynamics of Tethered Satellite Formations
T. Williams, University of Cincinnati and K. Moore, SDL

This paper will examine the feasibility of multi-tether systems (MTS), i.e. satellite formations linked by a system of tethers, held taut by rotation of the entire system. This approach greatly simplifies the satellite relative navigation problem, and avoids having to use propulsion to maintain the formation; on the other hand, it increases the complexity involved in deploying the satellite cluster, and introduces the possibility of snags and/or slack tether. The purpose of this paper is to investigate whether the potential benefits of tethered satellite configurations outweigh the increased complexity, specifically for the case of Earth-facing formations.

0825 AAS 02 -199

Centralized Dynamics and Control of Novel Orbiting Formations of Tethered Spacecraft
M.B. Quadrelli and F. Y. Hadegh, Jet Propulsion Laboratory

In this paper we present both an analytical model, as well as a numerical model, to investigate the multiscale interaction between an orbiting deformable tethered system and a single separated spacecraft acting as leader of the tethered formation. Some of the features of this interaction are: macro-modes of deformation of the virtual truss, micro-modes of deformation of the distributed structure, architecture of the formation sensor, and sources of dynamical perturbation that need to be mitigated for precision operation in space (an example being space interferometry).

0850 AAS 02 -200

Dynamics Stability Of a Bare Tether As a Deorbiting Device
J. Pelaez, O. Lopez-Rebollal, and E. Ahedo, Universidad Politécnica de Madrid and M. Lara, Real Observatorio de la Armada

The paper focuses on the analysis on a bare tether used as deorbiting device. The long-tether regime will be considered in order to describe the electrodynamic torque acting on the tether. It depends on the tether attitude in the orbital frame, i.e., on the in-plane and the out-of-plane angles for a rigid tether. The goal is to analyze how this new dependence affects the stability properties of the electrodynamic tether which is operated in a circular inclined orbit. Simple models will be assumed for the environment where the tether works.

0915 AAS 02 -201

Orbital Maneuvering with Electrodynamic Tethers

S.G. Tragesser and H. San, Air Force Institute of Technology

Electrodynamic tethers can be used as a fuel efficient means to propel spacecraft. Current induced in a conductive tether will interact with the Earth's magnetic field to produce a force that can change the spacecraft's orbit. For practical currents, however, the thrust is low and maneuvers can take many weeks to realize. Unlike most low thrust concepts, however, the acceleration vector cannot be controlled toward an arbitrary direction. Instead, the current in the tether is modulated in order to effect a desired change in the orbital elements. This paper uses the general perturbation equations to develop guidance laws for general orbital maneuvers.

Break 0940 – 1000

1000 AAS 02 -202

JTether: A Java-Based Finite Element Approach to Tether Modeling

K. Sorensen, NASA Marshall, J. Westerhoff, University of Illinois, S. Canfield and D. Johnson, Tennessee Technological University

Momentum-exchange/electrodynamic reboost (MXER) tether systems may enable high-energy missions to the Moon, Mars and beyond by serving as an "upper stage in space". In order to succeed, the state vector of the tether must be propagated with extreme accuracy and speed. A finite-element approach to tether modeling can yield a much more stable solution to the tether propagation than previous explicit approaches. An object-oriented computer code, written in Java, has been developed at MSFC and is called JTether. This paper will discuss the formulations used to model and propagate the tether, as well as the results of test cases compared to an older explicit tether code.

1025 AAS 02 -203

Dynamic Response and Error Analysis in Tether Momentum Exchange

S. Canfield and T. Johnson, Tennessee Technological University, K. Sorensen and K. Welsyn, NASA Marshall Space Flight Center

Momentum-exchange/electrodynamic reboost (MXER) tether systems may enable high-energy transfer to boost spacecraft from low Earth orbit to a higher energy orbit quickly, and potentially without using any propellant. One of the significant challenges in developing a momentum-exchange/electrodynamic reboost tether systems is in the analysis and design of the capture mechanism and its effects on the overall dynamics of the system. This paper will present a model for tether momentum exchange that will evaluate the dynamic effects of errors in the momentum exchange process and in the future, create guidelines for selecting the dynamic properties of a capture device.

1050 AAS 02 -204

Overview of the TAG (Tethered Artificial Gravity) Satellite Program

A. P. Mazzoleni, Texas Christian University and J.H. Hoffman, University of Texas at Dallas

This paper gives an overview of the Tethered Artificial Gravity (TAG) satellite program. Prolonged exposure in humans to a microgravity environment leads to significant loss of bone and muscle mass; a possible solution to this problem is to produce artificial gravity by tethering the crew capsule to the spent final rocket stage and spin-up the system. TAG is a 2-part program toward the development of such a system: Phase I will culminate in a test flight of a tether-deployer and various subsystems in a non-ejected GAS-Canister on the Space Shuttle; Phase II will involve the flight of a small (65 kg) tethered satellite system which will be boosted into LEO, deployed and then “spun-up” to produce artificial gravity.

Session 16: Optimization & Control

Chair: Dr. Srinivas R. Vadali
Texas A&M University

1330 AAS 02 -205

Direct Multiphase Optimisation of Multiobjective Trajectory Design Problems

M. Vasili and F. Zazzera, Politecnico di Milano

Some trajectory design problems require the optimisation of more than one objective functions. The quantities that are to be optimised can be competing or in accordance. It can even happen that the same quantity must be minimised by a player and maximised by another player. All these problems can be classified as multiobjective optimisation problems. In this paper a fully direct approach is proposed which transcribes the original optimal control problem (or differential game problem) using a multiphase DFET transcription and then solves the resulting nonlinear multiobjective programming problem. The approach has been tested on different test cases of different nature, finding efficiently a solution without resorting to adjoint variables and equations.

1355 AAS 02 -206

Stability Issues Using FIR Filtering In Repetitive and Learning Control

K. Chen and R.W. Longman, Columbia University

Spacecraft often have one predominant source of vibration from internal moving parts, such as a cryo pump or a momentum wheel. Repetitive control creates control laws that learn to eliminate the effects of a periodic disturbance, and can be used to isolate fine pointing instruments from the vibration source. To obtain good learning transients, one normally needs to design some kind of compensation that keeps the phase small for the product of the repetitive control law with the system. Various natural design approaches suggest the use of finite impulse response (FIR) filtering, either as a low pass filter or as a window cutting off convolution sum designs when the gains get small. This paper suggests that FIR filtering designs will very often have phase difficulties that produce instability. Methods are developed to improve this situation by eliminating any discontinuity at the end of the window.

1420 AAS 02 -207

Prediction Of Final Error Level In Repetitive and Learning Control

P. Le Voci and R.W. Longman, Columbia University

Repetitive control is a field that creates controllers to eliminate the effects of periodic disturbances on a feedback control system. The methods have applications in spacecraft problems, to isolate fine pointing equipment from periodic vibration disturbances such as slight imbalances in momentum wheels or cryo pumps. Experiments done on a robot at NASA Langley Research Center showed that the final error levels produced by different candidate repetitive controllers can be very different, even when each controller is analytically proven to converge to zero error in the deterministic case. The difference in final error level can be a major criterion for deciding which controller one wants to implement in practice. It is the purpose of this paper to develop an understanding of what determines the final error level, and to develop methods of predicting this level. Contributing factors include measurement noise and how it disturbs the learning process, finite word length considerations that can stop the accumulation of the needed corrective signal for frequencies with small learning gain, and the effects of amplification of errors at non targeted frequencies due to the waterbed effect.

1445 AAS 02 -208

Application of the SDC Optimal Control Algorithm To Low-Thrust Escape and Capture Trajectory Optimization

G. Whiffen and J.A. Sims, Jet Propulsion Laboratory

An application of the new optimization algorithm called State Dynamic Control (SDC) to design low-thrust escape and capture trajectories is presented. SDC is a general optimization method that is distinct from both parameter optimization and the calculus of variations. Trajectories are integrated with a multi-body force model and feature solar electric propulsion with a specific impulse that is a function of the engine throttle. The test problems include interplanetary trajectories with capture or escape at each of the inner planets. Optimizing capture and escape trajectories with a multi-body force model results in a significant improvement in the mass delivered compared to existing two-body formulations. SDC is robust for this application and does not require a good initial guess.

Break 1510 – 1530

1530 AAS 02 -209

Accurate Gradients for Direct Trajectory Optimization

D. Garza, University of Texas at Austin

Gradients for trajectory optimization are normally calculated using either finite differences, which are simple and general but have limited accuracy, or analytic expressions, which are accurate but must be derived for each new constraint and objective. Automatic differentiation provides gradients as accurate as the underlying functions without requiring derivation of many of complex, problem-specific analytic expressions. This work investigates the use of automatic differentiation with a direct transcription approach on two problems: the lunar launch problem and a launch vehicle ascent from the surface of the Earth. Run time, convergence behavior, and solution accuracy are compared.

1555 AAS 02 -210

On The Use Of Root Locus Departure Angle Information To Design Compensators In Repetitive Control

C.P. Lo and R.W. Longman, Columbia University

Repetitive control is a method to eliminating the effects of a periodic disturbance of known period, with application to vibration isolation of fine pointing equipment on spacecraft. Typical classical control design techniques like Routh, Jury, Nyquist and root locus have difficulty handling the repetitive control problem because of the size of the characteristic equation involved -- which can have thousands of roots, most of which are on the stability boundary when the gain is zero. This paper addresses methods of using the departure angle information for root locus in order to assist the design of repetitive controllers.

1620 AAS 02 -211

The Conceptual Design of the Guidance, Navigation and Control System for a Visual Inspection Spacecraft

R.R. Fullmer, Utah State and P. Patterson, Space Dynamics Laboratory

Large constellations of satellites may require a set of small, inexpensive satellites for inspection and repair. These maintenance spacecraft will have the ability to visually inspect satellites within the constellation and potentially replace consumable resources. These inspection spacecraft need to be able to operate in extended close proximity about a damaged and potentially nonoperational spacecraft. This paper describes the conceptual development of the guidance, navigation and control (GNC) system of an autonomous spacecraft that can perform an on-orbit rendezvous and extended proximity operations required by an inspection mission.

Session 17: Orbit Determination II

Chair: Dr. Paul Schumacher
Naval Space Command

1330 AAS 02 -212

Precise Orbit Determination for Champ Using Accelerometer Data
Z. Kang, B.D. Tapley, S.V. Bettadpur, H.J. Rim and P. Nagel, University of Texas at Austin

The CHAMP satellite was launched in July 2000 with altitude of 450 km. For precise dynamical orbit determination and global gravity field recovery, CHAMP carries an accelerometer directly to measure non-gravitational accelerations which are not precisely computed by using current models for low-Earth satellite. This paper will present the investigation of contribution of accelerometer data to CHAMP Precise Orbit Determination. It includes the accelerometer data preprocessing, and CHAMP orbit determination using GPS, accelerometer and attitude data. The orbit accuracy is assessed a number of tests. These include external orbital comparison and analysis of orbital fits, SLR residuals and orbit overlap. The preliminary results show an accuracy of about 11 cm in the radial direction and about 20 cm in 3D position can be obtained.

1355 AAS 02 -213

Effect of GPS Orbit Accuracy on CHAMP Precision Orbit Determination
H. Rim, S.P. Yoon, and B.E. Schutz, University of Texas at Austin

This paper examines the effect of GPS orbit accuracy on CHAMP POD. Similar study was carried out on Topex/Poseidon Precision Orbit Determination (POD), however, the accuracy of GPS orbits has been improved significantly due to the on-going efforts of IGS over the years. This paper evaluates three different IGS GPS orbit products, Predicted, Rapid, and Final, on the resulting CHAMP orbit when these orbits are fixed during POD process. Also, empirical parameters, called the orbit element correction parameters, are evaluated in their effectiveness of reducing the effect of GPS orbit errors on CHAMP orbit.

1420 AAS 02 -214

Effects of Ground Station and On-Board GPS Antenna Phase Center Variations on CHAMP Precision Orbit Determination
S. Yoon, H.J. Rim and B.E. Schutz, University of Texas at Austin

The phase center of the GPS antenna is the point where GPS signals transmitted from GPS satellites terminate. The phase center can be related to the antenna reference point through two parameters, phase center offset and phase center variation. Typical magnitudes of phase center offsets are as much as a few decimeters, while the magnitudes of the phase center variations are usually a few millimeters but can be as much as a few centimeters. The effects of the phase center variations of the ground station and on-board antennas on the quality of CHAMP precision orbit determination will be evaluated in this paper. The quality of the orbit solutions will be compared by analyzing the measurement residuals, orbit overlap statistics and SLR residuals.

1445 AAS 02 -215

State Estimation For Drag-Free Control of the STEP Satellite
H. She, S. Theil and A. Schleider, University of Bremen

The Satellite Test of the Equivalence Principle (STEP) is a space-based fundamental physics experiment to test the Equivalence Principle with greatly increased precision. To realize the drag free fall of the test mass, a Drag-Free Control (DFC) System has to be applied. This paper describes a nonlinear state estimator (Extended Kalman Filter) for the DFC. The Kalman Filter has been designed to estimate the states of the test masses on all three-axis as well as the aerodynamic drag acting on the satellite. To implement the Kalman filter in the on-board computer, a simplified model for the dynamics of the test massed and the aerodynamic drag is developed. The simulation results show that the simplified model is accurate enough for the estimation of the states of the test masses and the aerodynamic drag.

Break 1510 – 1530

1530 AAS 02 -216

GSAT-1 Precise Orbit Determination (T.O Phase)
N.V.Vighnesam, B. Subramanian and A. Sonney, ISRO Satellite Centre

Orbit determination results are obtained for GSAT-1 spacecraft, which is the first of the geo-stationary satellite series launched by ISRO's first of its indigenously developed Geo-synchronous Satellite Launch Vehicle GSLV-D1. This paper describes the performance of GSAT-1 Transfer Orbit (T.O) phase orbit determination. A brief description of the achieved GSAT-1 Transfer Orbit estimated from GSAT-1 operational orbit determination (ODP) software and comparison of orbit with injection parameters provided by Inertial Navigation System (INS), immediately after launch, is presented. The performance of the tracking systems employed by the tracking stations involved in the initial phase of this mission, namely, Lake Cowichan (Canada), Fucino (Italy), Hassan (India) and Perth (Australia) has also been evaluated.

1555 AAS 02 -217

Effect of GPS Orbit Errors on a Low-Low Satellite-to-Satellite Tracking Mission

J. Kim and B. D. Tapley, University of Texas at Austin

The Gravity Recovery and Climate Experiment (GRACE) mission is a low-low satellite-to-satellite tracking (SST) mission to map the Earth gravity field, measuring the inter-satellite range between two identical co-orbiting low satellites. In order to alleviate the singularity problem when estimating individual satellite's position by using the relative ranges only, it is necessary to combine them with GPS measurements. This study analyzed the effect of the GPS orbit errors on the low satellite orbit and gravity estimation through a series of numerical simulations. Possible GPS orbit handling approaches are compared, and its effect on the low-low range and range-rate are discussed.

1620 AAS 02 -218

Antenna Phase Center Determination of Inter-Communicating Satellites

F.Wang, B.D. Tapley and S.V. Bettadpur, University of Texas at Austin

The phase measurement between co-located communicating satellites is an important observation variable. Since the phase measurement reflects the range between the phase centers of the communicating antennas, it is required that the phase centers of the satellite antennas be known during the in flight phase. In this paper, the maneuvers and corresponding algorithm for determining the phase center of co-located satellites' antennas will be presented. A simulation for the LEO satellites shows that the phase centers can be determined with high accuracy and the boresight direction can be better than 0.5 mrad.

Session 18: Current and Future Use of NASA's Deep Space Network

Chair: Dr. David Morris
JPL

1330 AAS 02 -219

The JPL RAPSO Process

G. Burke and D. G. Morris, Jet Propulsion Laboratory

The Jet Propulsion Laboratory Resource Allocation, Planning and Scheduling Office is chartered to divide the limited amount of tracking hours amongst the various missions in as equitable allotment as can be achieved. To best deal with this division of assets and time, an iterative process has evolved that promotes discussion with all of the custmers that use the Deep Space Network (DSN). Aided by a suite of tools, the task of division of asset time is then performed in three stages of granularity. Using this approach, DSN loads are either forecasted or scheduled throughout a moving 10-year window. This approach allows the current pointing and tracking of the antennas to be performed, with a steady stream of increasingly better products as the future is looked toward.

1355 AAS 02 -220

The JPL RAPSO Baseline Mission Planning Set

J. Valencia, R. Bartoo and D. G. Morris, Jet Propulsion Laboratory

The RAPSO is chartered to divide the limited amount of tracking hours amongst the various missions in as equitable allotment as can be achieved. This paper addresses the mix of missions which are used to determine what the loading factor will be on any one antenna, subnet of antennas, or complex itself. The Baseline Mission Planning Set represents the tracking coverage that should be provided by the DSN, with emphasis on the 70m, 34m, and 26m antennas. Using this Baseline Mission Planning Set, the JPL-RAP Team conducts special studies in which new “proposal” Missions are added on top of the current/approved antenna load to determine the degree to which the tracking requirements of this new “proposal” Mission can be accommodated, or not supported

1420 AAS 02 -221

The DSN View Periods For a Mission
J. M. Kehrbaum and K. Kim, Jet Propulsion Laboratory

The JPL RAPSO is chartered to divide the limited amount of tracking hours amongst the various missions in as equitable allotment as can be achieved. The communication windows that can be used for communication between the ground and the Project/Spacecraft are called "viewperiods." The concept of the viewperiods for (any) mission is presented in this paper, along with the levels of refinement (Forecasting/Project/Mid-Range/NSS) associated with those viewperiods.

1445 AAS 02 -222

JPL RAPSO Mid-Range Planning and DSN Scheduling
K. Martinez, E. Hampton, Y.F. Wang and J. M. Kehrbaum, Jet Propulsion Laboratory

The JPL RAPSO is chartered to divide the limited amount of tracking hours amongst the various missions in as equitable allotment as can be achieved. This paper introduces the concept of the initial placement of the tracking passes during the communication windows for the supported missions, and then follows the process through the generation of the DSN 7-day schedule and the DSN Scheduling Process.

Break 1510 – 1530

1530 AAS 02 -223

JPL RAPSO Long Range Forecasting
N. Lacey and D.G. Morris, Jet Propulsion Laboratory

The JPL RAPSO is chartered to divide the limited amount of tracking hours amongst the various missions in as equitable allotment as can be achieved. This paper introduces the concept of the long range forecasting function which is performed by the group. This is then used to identify periods of peak over-subscription of resources years before they actually happen, so that proper corrective actions (construction of additional antennas, reduction in support commitment to the impacted projects) can be implemented.

1555 AAS 02 -224

The "Mars Overload" of the DSN Resources in 2003-4
S. Lineaweaver and E. Hampton, Jet Propulsion Laboratory

The JPL RAPSO is chartered to divide the limited amount of tracking hours amongst the various missions in as equitable allotment as can be achieved. This paper introduces the concept saturation of the DSN assets as a growing number of missions are continually added. This is compounded by the fact that many of the additional missions are going to the same location/part of the sky, and are therefore directly competing head to head for the same tracking passes at a time when each mission is conducting important activities.

1620 AAS 02 -225

Using Available DSN Tracking Coverage As a Design Parameter In Mission Proposals
J. Kehrbaum and R. Bartoo, Jet Propulsion Laboratory

Design of a Proposed Deep Space Mission should be linked to additional design parameters/constraints such as the availability of the Deep Space Network to support communications. This paper explores this methodology by examining the launch opportunities of a simulated mission to Jupiter during a decade long timeframe. Alternate launch dates during this window were examined from a perspective of the ability of the DSN to provide the tracking coverage needed during the mission critical events. The results of this multi-dimensional analysis are presented at the end of this paper, with a ranking of which launch windows are preferable relative to the other possible launch windows.

AUTHOR INDEX

RECORD OF MEETING EXPENSES

12th AAS/AIAA Space Flight Mechanics Meeting

Adams Mark Hotel
San Antonio, TX
27-30 January 2002

Name:________________________________ **Organization:** ______________________
Last **First**

Registration Fee: **AAS or AIAA Member @ $210** ______________________
Non-Member @ $295 ______________________
Student @ $20 ______________________

Conference Proceedings @ ______________________

Technical Paper Sales @ $1/paper ______________________

TOTAL: ______________________

Technical Paper Purchases:	**# of Papers**	**Cost**	**Date**
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