American Astronautical Society

AIAA

AAS/AIAA Space Flight Mechanics Meeting

Radisson Hotel Santa Barbara
Santa Barbara, California

February 11 – 15, 2001

PROGRAM

	General Chairs	Technical Chairs
AAS	Daniel J. Scheeres The University of Michigan	Louis A. D'Amario Jet Propulsion Laboratory
AIAA	Bobby G. Williams Jet Propulsion Laboratory	Lester L. Sackett Charles Stark Draper Laboratory

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MEETING INFORMATION

REGISTRATION

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

AAS or AIAA Members	$190
Non-members	$235
Students	$40

The registration desk will be open at the following times:

Sunday Evening	4:00 - 7:00 PM	(Adjacent to La Cantina)
Monday	7:00 AM - 4:00 PM	(Adjacent to Vista Mar Monte)
Tuesday and Wednesday	8:00 AM - 4:00 PM	(Adjacent to Vista Mar Monte)
Thursday	8:00 AM – 11:30 PM	(Adjacent to Vista Mar Monte)

The registration desk will be clearly marked. **Please note that credit cards cannot be accepted for payment of any conference fees.** The preferred form of payment for the registration fee is a check payable to the "American Astronautical Society"

CONFERENCE PROCEEDINGS

Conference attendees will be able to order the proceedings at the registration table at a pre-publication cost of $140. After the conference the proceedings will double in cost.

SOCIAL EVENTS

Sunday : An early bird reception will be held in La Cantina from 6:00 - 7:30 PM.

Monday : 11:45 AM "Live" Coverage of NEAR Landing at Eros (La Cantina)

4:30 PM Plenary Lecture (La Cantina)
"In Quest of Better Attitudes"
Malcolm D. Shuster, Orbital Sciences Corporation
AAS Dirk Brouwer Awardee 2000

6:00 PM General Reception (El Cabrillo)
General announcements and awards will be presented at this reception.

Tuesday: 4:30 PM Invited Talks and Panel Discussion (La Cantina)
"2001: Space Flight in the New Millennium - Then and Now"
Dr. Bruce Murray (California Institute of Technology)
Dr. Chris Chyba (Stanford University, SETI Institute)
Mr. Brent Sherwood (Boeing Company, Human Space Flight & Exploration)
Mr. Gerald David Nordley (Science Fiction Author)

6:00 PM Reception (El Cabrillo)

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

AAS General Chair
Dr. Daniel J. Scheeres
Department of Aerospace Engineering
The University of Michigan
Ann Arbor, MI 48109-2140
734-615-3282 (voice)
734-763-0578 (fax)
E-Mail: scheeres@umich.edu

AIAA General Chair
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Jet Propulsion Laboratory
MS 301-125J
4800 Oak Grove Drive
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E-Mail: bobby.williams@jpl.nasa.gov

TECHNICAL PROGRAM

TECHNICAL SESSIONS

There are 24 technical sessions scheduled over a 4 day period with a total of 144 papers on the agenda. The technical sessions will run in parallel with 3 morning sessions and 3 afternoon sessions each day. All regular technical sessions will be held in the Vista Mar Monte rooms I, II, and III. Morning and afternoon coffee breaks will be held mid-way through each technical session on the porch off of Monte Mar Vista I.

SPEAKERS' BRIEFINGS

Authors who are presenting papers and session chairs will meet for a short briefing each morning at 8:00 AM in the La Cantina room. Please attend only on the day of your presentation. A light breakfast will be served starting at 7:30.

PRESENTATIONS

Morning technical sessions will start at 8:30 AM, and afternoon technical sessions will start at 1:30 PM each day. All presentations are scheduled for 25 minutes: 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. There will be a 20 minute break midway through each session. Please note that the **NO PAPER/NO PODIUM** rule will be strictly enforced - i.e., speakers will not be allowed to present their work if they have not provided 50 copies of their completed paper. Also, papers will be automatically withdrawn from the meeting and will not be eligible for inclusion in the proceedings if one of the stated authors is not in attendance to present the paper.

PAPER SALES

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

COMMITTEE MEETINGS

All committee meetings will be held in the Gazebo room according to the following schedule:

AIAA Astrodynamics Technical Committee	Tuesday	11:45 AM - 1:15 PM
AAS Space Flight Mechanics Technical Committee	Wednesday	11:45 AM - 1:15 PM
AIAA Astrodynamics Standards Committee	Thursday	11:00 AM - 2:00 PM

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

AAS Technical Chair
Dr. Louis A. D'Amario
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4800 Oak Grove Drive
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AIAA Technical Chair
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617-258-2555 (fax)
E-Mail: lsackett@draper.com

SANTA BARBARA INFORMATION

CONFERENCE LOCATION

Radisson Hotel Santa Barbara
1111 Cabrillo Blvd.
Santa Barbara, CA 93103
805-963-0744
800-643-1994 or 800-333-3333
805-962-0985 (Fax)
www.radisson.com/santabarbaraca

The Radisson Santa Barbara is a Mediterranean style hotel offering 173 guest rooms, most with panoramic views of the Pacific or the majestic Santa Ynez Mountains. Each room is equipped with a color television (in-room movies), Nintendo games, mini-bar, telephone with voice mail and modem jack, climate control, coffee makers, hair dryers, irons and ironing boards. The hotel has a heated outdoor pool with a view of the Pacific Ocean. Next to the pool area is a gift shop, open 7 days a week. There is a fitness center, and Swedish massage is available by appointment. The Bistro Eleven restaurant is located adjacent to the hotel and serves breakfast, lunch, and dinner with a beachfront view. There is a lounge located in the Bistro, with live entertainment on the weekends. The Salon Blais is also located on the hotel grounds, offering complete hair and nail services.

The hotel is ideally situated across from the Pacific Ocean and East Beach. This historic hotel originally opened its doors on June 11, 1931 as the Hotel Vista Mar Monte. Over the years the hotel has played host to celebrities and royalty who chose to escape the hustle and bustle of Los Angeles. The hotel has undergone extensive renovations since that era, and offers a comfortable and modern environment for relaxation. The hotel has a convenient location, adjacent to one of Santa Barbara's finest beaches, a short walk from the Child's Estate Zoo, Waterfront Park, and Stearn's Wharf. An extensive beachway is right outside the hotel with a wide variety of beach sports. Public tennis courts and several golf courses are a short drive away. An electric shuttle service runs from the hotel to State street (the central Santa Barbara shopping area) and Stearn's Wharf. The hotel is 15 minutes from the Santa Barbara airport and 90 miles north of Los Angeles.

SANTA BARBARA

The city of Santa Barbara is renowned for its classic architecture, its Mediterranean climate, and its wide variety of shops, coffeehouses, and galleries. To find out more about the city, events, recreation, and other information please refer to the following web-sites (note that we do not endorse any material or information found on these sites): santabarbaralive.com, www.santabarbaratoday.com, TotalSantaBarbara.com, or check out the YAHOO! local Santa Barbara guide found by visiting the web-site: www.yahoo.com and searching under "Santa Barbara".

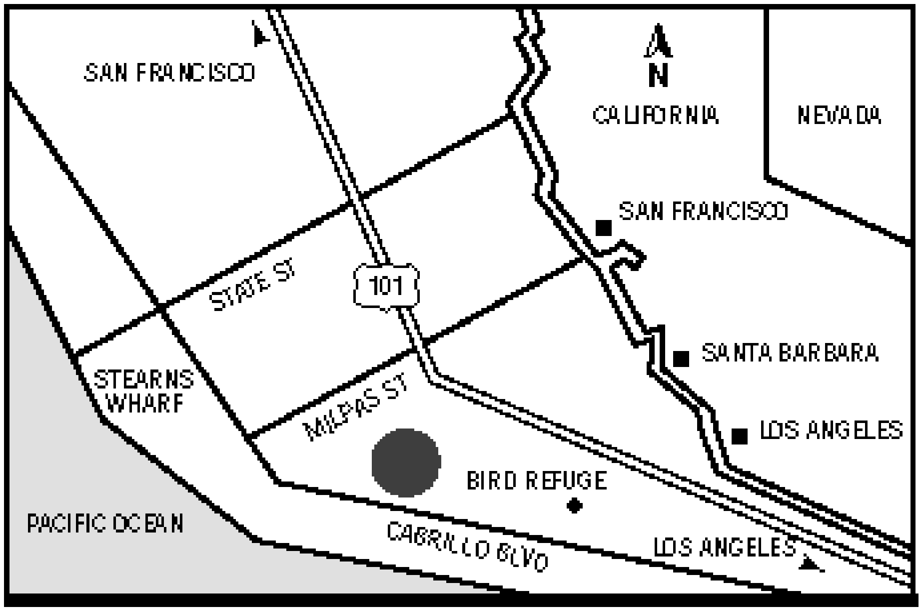
TRANSPORTATION

Just ninety minutes from Los Angeles and one mile from US 101, the Radisson Hotel is easy to find.

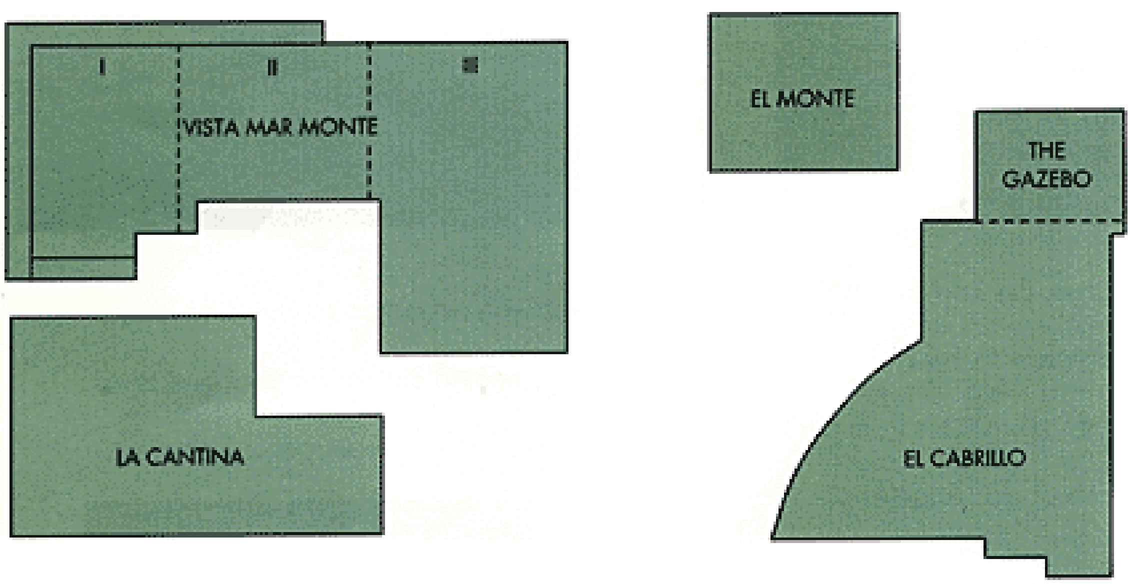
When arriving from the South on US 101, take the Cabrillo Boulevard exit (left lane), make a left at the stop sign, proceed along the Bird Refuge, and the hotel will appear on your right. When arriving from the North on US 101, take the Hot Springs/Coast Village/Cabrillo exit (left lane). Turn right. Proceed along Cabrillo past the Bird Refuge and watch for the hotel on your right.

Santa Barbara is accessible by many major airlines. If you are arriving at the Santa Barbara Municipal Airport, ten miles north of the hotel, airport personnel will gladly direct you to the hotel or recommend a limo service. If you choose to fly in to LAX, a reasonably priced and convenient transportation service is available, with a pick-up and drop-off point at the Radisson Hotel (check with hotel staff for more information). Santa Barbara is also served by an Amtrak line, running along the California coast. Taxi service from the railroad station is available.

LOCAL AREA MAP



RADISSON HOTEL FLOORPLAN



PROGRAM SUMMARY

Date/Time	Event	Location
Sunday, February 11		
4:00 - 7:00 PM	Conference Registration	Adjacent to La Cantina
6:00 - 7:30 PM	Early-Bird Reception	La Cantina
Monday, February 12		
7:00 AM - 4:00 PM	Conference Registration	Adjacent to Vista Mar Monte
8:00 AM - 5:00 PM	Paper Sales	Adjacent to Registration Desk
7:30 - 8:30 AM	Speakers' Breakfast and Briefing	La Cantina
8:30 - 11:45 AM	Technical Sessions 1, 2, 3	Vista Mar Monte I, II, III
11:45 AM - 1:30 PM	"Live" Coverage of NEAR Landing at Eros	La Cantina
11:45 AM - 1:30 PM	Lunch	
1:30 - 4:00 PM	Technical Sessions 4, 5, 6	Vista Mar Monte I, II, III
4:30 – 6:00 PM	Plenary Lecture: "In Quest of Better Attitudes"	La Cantina
6:00 – 8:00 PM	General Reception	El Cabrillo
Tuesday, February 13		
8:00 AM - 4:00 PM	Conference Registration	Adjacent to Vista Mar Monte
8:00 AM - 5:00 PM	Paper Sales	Adjacent to Registration Desk
7:30 - 8:30 AM	Speakers' Breakfast and Briefing	La Cantina
8:30 - 11:45 AM	Technical Sessions 7, 8, 9	Vista Mar Monte I, II, III
11:45 AM - 1:15 PM	AIAA Technical Committee Meeting	Gazebo
11:45 AM - 1:30 PM	Lunch	
1:30 - 4:00 PM	Technical Sessions 10, 11, 12	Vista Mar Monte I, II, III
4:30 - 6:00 PM	Invited Panel: "2001: Space Flight in the New Millennium - Then and Now"	La Cantina
6:00 - 7:30 PM	Reception	El Cabrillo
Wednesday, February 14		
8:00 AM – 4:00 PM	Conference Registration	Adjacent to Vista Mar Monte
8:00 AM – 5:00 PM	Paper Sales	Adjacent to Registration Desk
7:30 - 8:30 AM	Speakers' Breakfast and Briefing	La Cantina
8:30 - 11:45 AM	Technical Sessions 13, 14, 15	Vista Mar Monte I, II, III
11:45 AM - 1:15 PM	AAS Technical Committee Meeting	Gazebo
11:45 AM - 1:30 PM	Lunch	
1:30 - 4:45 PM	Technical Sessions 16, 17, 18	Vista Mar Monte I, II, III
Thursday, February 15		
8:00 – 11:30 AM	Conference Registration	Adjacent to Vista Mar Monte
8:00 AM – 5:00 PM	Paper Sales	Adjacent to Registration Desk
7:30 - 8:30 AM	Speakers' Breakfast and Briefing	La Cantina
8:30 - 11:45 AM	Technical Sessions 19, 20, 21	Vista Mar Monte I, II, III
11:00 AM - 2:00 PM	AIAA Standards Committee Meeting	Gazebo
11:45 AM - 1:30 PM	Lunch	
1:30 - 4:45 PM	Technical Sessions 22, 23, 24	Vista Mar Monte I, II, III

Session 1 Mars Missions 1

8:30 AM Monday, February 12 Vista Mar Monte 3

Chair: Joseph Guinn
Jet Propulsion Laboratory

8:30 AM
AAS 01-100

Mars Global Surveyor Mapping Orbit Determination

S. Demcak, E. Graat, P. B. Esposito, D. T. Baird - Jet Propulsion Laboratory

Throughout the Mars Global Surveyor mapping phase (3/9/99-2/1/01) the navigation team has been responsible for providing the engineering and science teams with predicted and reconstructed spacecraft ephemeris information. The major challenges of the orbit determination have been the modeling of the Mars gravity field and the autonomous spacecraft angular momentum desaturations (AMDs). The Mars gravity field has been significantly improved. The AMDs have been frequent (three per day) and difficult to model. This paper will elaborate on the improvement of both of these models and the resulting accuracy of orbital parameters for both knowledge and prediction.

8:55 AM
AAS 01-101

Optimal Orbits For Sparse Constellations Of Mars Navigation Satellites

T. A. Ely - Jet Propulsion Laboratory

Recent scientific discoveries at Mars have heralded an unprecedented commitment and focus by NASA and its international partners towards further exploration of Mars. As part of this effort NASA has an on-going project, called the Mars Network, to examine communication and navigation infrastructure requirements needed to support Mars exploration. This potentially could consist of a small constellation of satellites to provide in-situ communication relay and navigation services for other missions at Mars. Current, constellation ideas range any where from placing telecom/navigation payloads on orbiters that have a primary mission to gather scientific data, to satellite(s) that are dedicated to a telecom/navigation mission. A common denominator to all the ideas being advanced is that the constellations are small in number and provide only discontinuous coverage to Mars surface assets. This contrasts sharply with navigation systems at Earth, such as GPS, that provide continuous, multiple satellite coverage at all Earth surface locations. This study examines orbit selection for small constellations (4 or fewer satellites) at Mars that minimize time to achieve surface position accuracies at specified levels. A genetic algorithm coupled with a computationally efficient navigation metric tool are utilized to conduct the search through the constellation orbit space. The preliminary results indicate that retrograde, mid-altitude (2000 ~ 5000 km) orbits are most efficient.

9:20 AM
AAS 01-102

Mars Surface Asset Positioning Using In-situ Radio Tracking

J. Guinn, T. Ely, B. Portock - Jet Propulsion Laboratory

Positioning of Mars surface assets was accomplished in the past by collecting Direct-To-Earth (DTE) radio metric observations and using ground-based navigation software to produce location estimates. Accuracy improvements required many weeks of observations and ultimately an accuracy floor was reached due to limited geometry and uncertainties in the observations. Accuracy improvements and reduction of the number observations can be achieved by using radio metric measurements from an in-situ orbiter. This paper compares positioning performance resulting from DTE only and in-situ orbiter tracking.

9:45 AM **BREAK**

10:05 AM **Orbit Determination for Nozomi**

AAS 01-103

T. Ohnishi, S. Ishibashi - Fujitsu Limited; M. Yoshikawa, T. Kato, T. Ichikawa, H. Yamakawa, J. Kawaguchi - Institute of Space and Astronautical Science (ISAS), Japan

Nozomi is the first Japanese spacecraft to explore the planet Mars. It was launched in July, 1998, and placed into interplanetary trajectory by twice lunar swing-by and a powered Earth swing-by. This paper describes the analysis and efforts to orbit determination in each phase of Nozomi trajectory. A nonconservative force which is caused by solar radiation pressure and unexpected small maneuvers at reorientations has a significant influence on orbit determination for Nozomi. We improved the nonconservative force modeling, and the typical determination accuracy is 500 meters for position and 5 mm/s for velocity in cis-lunar phase.

10:30 AM **An Energy Controller Aerocapture Guidance Algorithm For The Mars Sample Return Orbiter**

AAS 01-104

S. Rousseau - Centre National d'Etudes Spatiales (CNES), France

The planetary low coast insertion is an important challenge of the current and future interplanetary missions. The aerocapture is a good alternative. It supposes onboard autonomous functions as navigation, guidance, and control. Among the several possible guidance algorithms, the CNES investigates a principle based on the energy control. First a presentation of the guidance principle is given. Then, in order to demonstrate the interest of this concept some simulations have been performed. The nominal trajectory and Monte Carlo results are presented. This paper concludes that the energy controller is a good candidate for the aerocapture.

10:55 AM **Orbit Selection of a Complementary Data Relay Mission for the CNES Aerocapture Demonstrator**

AAS 01-105

F. Dufour, J. Dubois, J. Benoist - Centre National d'Etudes Spatiales (CNES), France

Our objective is to find the best orbit for a secondary telecom mission taking into account the orbital constraints that were dictated by the primary aerocapture mission and the constraints that limit communications with the netlanders. In the latter case, the main constraint is related to the Sun illumination because the netlanders need daylight to send their data. Consequently, we will identify the orbits that provide not only a good contact with the netlanders (this is a classical performance index based on a simple geometric visibility), but also very good illumination on ground at the time of these contacts. Moreover, we will weight this illumination index with the effective data rate to take into account the link range between an orbiter and a netlander.

Session 2 Attitude Control

8:30 AM Monday, February 12 Vista Mar Monte 1

Chair: Alfred Treder

Dynacs Corp.

8:30 AM

AAS 01-106

A Local Optimization Technique For Attitude Motion Tracking Using Control Moment Gyroscopes

G. Avanzini - Polytechnic of Turin; G. deMatteis - University of Rome "La Sapienza", Italy

A control technique is proposed for satellite attitude slew maneuvers, where the required trajectory is a function of time. A feedforward control law is generated by local optimization, where, using integration methods, an inverse simulation problem is solved. Control torques are provided by four single-gimbal control moment gyroscopes in pyramid mounting configuration. Of many steering lawdesigns, the integration method is particularly suitable for solvingthe redundancy problem when local optimization is used. In particular, states and controls can be bounded for hardware constraints such as rate and position saturation of gimbals. Polynomial functions define the reference trajectory to obtain smooth variations of control inputs, and thus avoid the excitation of elastic modes. Furthermore, arbitrary initial and final boundary conditions are immediately enforced. The paper discusses real-time implementation of the algorithm and its effectiveness relative to redundancy management and singularity-robustness of the resulting steering laws.

8:55 AM

AAS 01-107

Minimizing The Effects Of Transverse Torques During Thrusting For Spin Stabilized Spacecraft

J. A. Oldenburg, S. G. Tragesser - Air Force Institute of Technology

During an orbital maneuver of a spin stabilized spacecraft, thruster misalignment causes the thrust vector to precess about a direction that is offset from the nominal. This oscillation of the thrust axis causes a pointing error and decreases the final delta-V magnitude. Previous work has shown that inserting a short coast phase timing into the maneuver can eliminate the pointing error. This paper reexamines the maneuver to find solutions for the coast phase that retain the property of eliminating the secular pointing error, and also minimize the average oscillation of the spin axis in order to maximize the delta-V.

9:20 AM

AAS 01-108

Optimal Design Of A Generalized Three-Dimensional Active Coning Attenuator For A Spinning Spacecraft Under Thrust

J. D. Kimball - Oral Roberts University

In this paper, I investigate the design of an optimal controller for attenuation of the coning motion of a spinning spacecraft under thrust. I use an actively controlled mass-inertial configuration which can operate in three dimensions. Several special cases of the problem are considered, while constraint equations for the stability and optimality of the general case (e.g., a non-symmetric spacecraft) are derived. These equations are then combined with neural network simulation and control techniques to determine usable control parameters for the system. Performance measures are determined for the resultant controllers.

9:45 AM BREAK

10:05 AM

AAS 01-109

Constrained Optimization Of Passive Coning Attenuators For Spinning Spacecraft Under Thrust

D. M. Halsmer, A. Lang - Oral Roberts University

The problem of optimal attenuation of coning about the thrust axis of a symmetric spinning spacecraft via passive internal mass motion is addressed. The degree of stability is expressed in terms of general system parameters. Constrained optimization is accomplished by maximizing the degree of stability while maintaining realizable values for design parameters. An approach to designing an optimal passive coning attenuator while simultaneously satisfying constraints imposed by spacecraft characteristics is presented.

10:30 AM

AAS 98-110

Simultaneous Precession Maneuver And Active Nutation Control

S. Tanygin - Analytical Graphics, Inc.

The approach proposed in this paper couples precesion maneuvers and active nutation control to achieve both simultaneously using the same pulsed thrusters. It is based on incorporating small changes in the timing of each pulse, which minimizes post-maneuver nutation while achieving desired precession arc. The approach is evaluated for various pulse durations and in the presence of timing and mass property imperfections.

10:55 AM

AAS 01-111

Large Angle Acquisition and Tracking Control of Attitude State Using GPS Output Feedback

G. Q. Xing, S. A. Parvez - Space Products and Applications, Inc.

This paper addresses the problems associated with implementing large angle acquisition and tracking control of the attitude state, using GPS measurement output feedback. This implementation is based on relative attitude kinematics and dynamics equations of spacecraft expressed in relative modified Rodrigues parameters. The advantage of using relative equations of motion is that it enables the transfer of the tracking problem into a regulator problem, thereby simplifying the design of the attitude acquisition and tracking control system. Use of modified Rodriguez parameters also minimizes the dimension of the attitude control system and avoids singular points.

11:20 AM

AAS 01-112

Spacecraft Large Angle Maneuver Under External Disturbance And Actuator Saturation Limit

H. Bang - Chungnam National University, Korea; H. D. Choi - Korea Aerospace Research Institute, Korea

The principal idea of control laws for spacecraft large angle maneuver is to use body-fixed actuators and body angular rates for stability. Quaternion feedback can be represented in a common PID(Proportional plus Integral plus Derivative) controller form. One potential problem that might arise in the implementation of the PID control law is actuator saturation due to the integral error. That is the integral error and associated control term cause accumulation of actuator signals or actuator saturation. In this paper we try to improve the performance of a generic PID controller for the large angle maneuver of spacecraft. The conventional feedback control law is augmented by AWC for performance improvement. The AWC is tested by assuming constant disturbances.

Session 3 Orbital Debris

8:30 AM Monday, February 12 Vista Mar Monte 2

Chair: David Spencer
Pennsylvania State University

8:30 AM
AAS 01-113

Covariance Generation For Space Objects Using Public Data

G. E. Peterson, R. G. Gist, D. L. Oltrogge - The Aerospace Corporation

SGP4 elsets are commonly used to generate state vectors for orbiting objects. The USAF as a public service makes the SGP4 elsets available through the RSO catalog, but error information is not typically released to the public. The current research describes a method (program COVGEN) for constructing simulated covariances based solely upon time series of SGP4elsets. As a sample study, COVGEN covariances were used to determine the overall risk to operating satellites at geosynchronous orbit. Results from this study show an average overall risk at GEO of approximately 3.5e-5 per satellite per year.

8:55 AM
AAS 01-114

A New Analytical Method For The Determination Of The Average Density Of A Debris Cloud

D. R. Izzo, C. Valente - Universita degli Studi di Roma "La Sapienza", Italy

In the present work the break-up event of an orbiting object is described as a probabilistic event and an analytical expression for the spatial density function is found in the case of a two-dimensional cloud. Under the hypothesis of a small ratio between the fragments and the orbital velocities, an approximate expression is derived and compared to Heard's one revealing a greater accuracy. The importance of such a betterment is particularly significant as the two dimensional case is a pre-requisite to the study of the more complex three-dimensional one.

9:20 AM
AAS 01-115

Analysis of the Collision Risk Associated with GPS Disposal Orbit Instability

A. B. Jenkin, R. A. Gick - The Aerospace Corporation

Recent studies show that disposal orbits used by the Global Positioning System (GPS) can be unstable, resulting in penetration of the operational constellation by the disposal orbit perigees. The purpose of this study was to obtain a preliminary understanding of the associated collision risk between disposed and operating vehicles. Collision risk was determined via direct statistical simulation, which involves determination of conjunction miss-distance distributions. Study results include time histories of constellation penetration by disposal orbit perigees and the variation of collision risk over initial disposal-orbit perigee altitude.

9:45 AM **BREAK**

10:05 AM

AAS 01-116

A Method For Calculating Collision Probability Between A Satellite And A Space Tether

R. P. Patera - The Aerospace Corporation

A method is presented for calculating the collision probability between a space tether and an orbiting object given the respective state vectors and error covariance matrices. The tether is modeled as a very long ultra-thin object and the colliding space object is assumed spherical in shape. Analytical techniques are use to reduce the problem to that of evaluating a one-dimensional path integral along the perimeter of a region representing the collision cross-section of the tether and space object. Test case results indicate collision probabilities significantly greater than satellite-satellite collision probabilities.

10:30 AM

AAS 01-117

Estimation And Prediction Of Orbital Debris Reentry Trajectories

J. M. Tardy, C. A. Kluever - University of Missouri-Columbia

Algorithms for tracking and predicting the trajectories of orbital debris during reentry are discussed. A ground-based method of trajectory estimation using an Extended Kalman Filter is presented, along with a Monte Carlo scheme to predict impact location. Simulation results suggest a high degree of accuracy in both the estimation and prediction stages.

10:55 AM

AAS 01-118

Energetic Cost And Viability Of The Proposed Space Debris Mitigation Measures

A. Rossi - CNUCE/CNR, Italy

The effectivenes of the different debris mitigation strategies are studied by means of the software package SDM 2.0, simulating the long term evolution of the space debris population. In particular, the passivation of satellites and upper stages, to prevent explosions, and the de-orbiting or re-orbiting of spacecraft at the end of their operational lifetime have been applied. Then, the ÇV needed to accomplish a given mitigation measure (such as de-orbiting in the disposal orbit or re-orbiting in the graveyard zone) is calculated for all the spacecraft, considering the minimum energy transfer. While some of the proposed measures produce similar long term effects on the debris environment, the study of their energetic requirements clearly points out which measure is most suited to be adopted from a practical point of view.

11:20 AM

AAS 01-119

Analytical Expressions For Computing Spacecraft Collision Probabilities

K. Chan - The Aerospace Corporation

This paper is primarily concerned with the determination of the optimal thrusting to increase the expected distance of closest approach between two space orbiting objects in a situation of high imminent collision probability. It is assumed that the orbital elements and covariance matrices of the two objects are known. When thrusting is in any direction, closed form solutions have been obtained for expressing the collision probability in terms of the thrusting. The converse relation has also been obtained for the case of intrack thrusting. These analytical results may be applied to the formulation of efficient algorithms which circumvent time-consuming Monte Carlo simulations of potential collisions.

Session 4 Mars Missions 2

1:30 PM Monday, February 12 Vista Mar Monte 3

Chair: Aron Wolf
Jet Propulsion Laboratory

1:30 PM
AAS 01-120

Lidar-based Hazard Avoidance For Safe Landing On Mars

A. Johnson, A. Klumpp, J. Collier, A. Wolf - Jet Propulsion Laboratory

One approach to safe landing on Mars is the hazard avoidance paradigm. During hazard avoidance the lander uses onboard sensors to detect hazards in the landing zone, autonomously selects an alternate landing site, and then maneuvers to the new site. Design of a system for hazard avoidance is facilitated by simulation where trades involving sensor and mission requirements can be explored. This paper describes the algorithms and models that comprise a scanning lidar-based hazard avoidance simulation including a terrain generator, a lidar model, hazard avoidance algorithms and powered landing guidance algorithms.

1:55 PM
AAS 01-121

Optimal Use Of Electric Propulsion For Mars Sample Return Orbiter Mission

S. Geffroy, R. Cledassou, N. Pillet, J. R. Meyer - Centre National d'Etudes Spatiales (CNES), France

The combined aerocapture / Solar Electric Propulsion (SEP) option seems really attractive for 2007-2009 Mars Sample Return Orbiter (MSRO) mission, for mass saving and planetary protection purpose. The main problem is the long transfer duration, because of the very low thrust level, and the limited available power due to the aerocapture shield accommodation. The duration, but also the consumption, should hence be minimized within a global system optimization, including the trajectory, the propulsion and the power. The aim of this paper is to propose the best MSRO mission design, in order to take the most advantage of SEP technology.

2:20 PM
AAS 01-122

Earth-Mars Trajectory Simulations

R. Sagdeev, K. Karavasilis - University of Maryland; S. Moskalov - Yuzhnoye State Design Office, Ukraine; D. Jorjoliani - National Institute Learning Center, Georgia; F. Chang-Diaz - NASA Johnson Space Center

We develop software simulating spacecraft trajectories in geocentric and heliocentric space. The geocentric program calculates and displays the trajectory of the spacecraft in Earth’s gravity field, until escape velocity is reached (determined by equality of kinetic and potential energy of the spacecraft.) With the simplification that the thrust acts in the tangential direction to the spacecraft’s trajectory, we have the equations of motion in polar coordinates. For integration we use fourth order Runge-Kutta method. The heliocentric program demonstrates the benefits of using variable specific impulse when short trip times are desirable. When we consider trip times to Mars as short as ninety days we demonstrate that variable specific impulse can triple the payload mass compared to constant specific impulse.

2:45 PM **BREAK**

3:05 PM **Aim Point Biasing Methods In Case Of Planetary Protection Requirement**

AAS 01-123 L. Francillout, P. Legendre - Centre National d'Etudes Spatiales (CNES); P.Y. Dussauze - SYSECA, France

The purpose of this paper is to present the work that is underway at CNES concerning interplanetary trajectory biasing and planetary protection. Part of this work consisted in finding an algorithm that allows to determine the successive aim points on quarantine contours in order to meet the impact probability requirements. To ensure that such trajectories really satisfy these requirements, a method based on Monte Carlo simulations using both linear and numerical propagation has been studied.

3:30 PM **Mars Direct Sample Return - Mission Design**

AAS 01-124 G. L. Condon, E. M. Braden - NASA Johnson Space Center

The authors address mission design aspects for a proposed Mars sample return mission employing both a direct entry-to-landing and low-thrust constant Isp return to earth. The mission scenario includes a ballistic outbound trajectory to a direct Mars landing with a low-thrust earth return following a 30 day surface stay. The authors discuss both the outbound and arrival mission design parameters and the low-thrust earth return trajectory design for selected opportunities. This mission provides a unique combination of technologies that will return a significant Mars surface sample, enhance planetary protection, and contribute to technologies useful for future human missions.

Session 5 Attitude Dynamics

1:30 PM Monday, February 12 Vista Mar Monte 1

Chair: Jeff Beck

Space and Missile Systems Center, USAF

1:30 PM **Man, Like These Attitudes Are Totally Random!**

AAS 01-125 M. D. Shuster - Orbital Sciences Corporation

The probability distribution for the attitude is studied for the case where there is no attitude information whatsoever. Such a distribution is needed, for example, for simulating "lost in space" scenarios. General results are obtained for the properties of this attitude distribution, and explicit functions are generated for all of the representations of the attitude currently in use. In particular, the common wisdom for the form of this "uniform" attitude distribution is shown to be incorrect. Particular attention is paid to the case of the Euler-Rodrigues symmetric parameters, which are defined on the three sphere S3 in four-dimensional space. Practical algorithms for simulating samples from this "uniform" distribution for different representations.

1:55 PM **The Wahba Problem From A Bayesian Point Of View**

AAS 01-126 M. D. Shuster - Orbital Sciences Corporation

Bayesian estimation techniques are studied with application to the problem of attitude estimation. For the minimum-variance estimation problem corresponding to the Wahba problem, the complete probability distribution function of the attitude given the measurements is obtained. Effects that are due to the finiteness of the probability space are displayed. Comparisons are made with the corresponding maximum-likelihood solution, as typified by the QUEST algorithm and its homologues.

2:20 PM **Energy Transfer Between Rotation And Revolution Via The Gravity Gradient**

AAS 01-127 Y. Watanabe - National Space Development Agency of Japan; Y. Nakamura - University of Toyko

By the gravity gradient effects, satellites experience orbital perturbation as well as attitude disturbance, and there are conjunctions between the phenomena, e.g. energy transfer. If a satellite is regarded as an ellipsoid of inertia, it has the potential energy generated by the gravity gradient which plays the roll as a passage of energy transfer between the rotational and orbital energies. With this principle, it is possible to augment the orbital energy by only providing the rotational energy. In this study, the optimal satellite attitude for the energy transfer is derived and numerically examined.

2:45 PM **BREAK**

3:05 PM **Spin Release Mechanism For Small Space Probe Separation**

AAS 01-128

N. Ishii, K. Higuchi, N. Okuizumi - The Institute of Space and Astronautical Science (ISAS); K. Abe, S. Tatsuta - Japan Aircraft MFG. Co., Ltd. (Nippi), Japan

In this paper, a simple spin-release mechanism is proposed for separation of small space probes, in which GFRP-made helical springs give rotational motion and translational speed simultaneously to a small body separated. Dynamics and energy relation of the spring were described, then spin-release motion of the space body was numerically simulated. These analysis and results were compared with the experiments conducted using a micro-gravity free fall tower.

3:30 PM **Dynamics Analysis Of ADEOS With Flexible Solar Array Paddle**

AAS 01-129

Y. Kojima, Y. Nakamura, T. Kurosaki, Y. Ohkami - National Space Development Agency (NASDA), Japan

ADEOS(Advanced Earth Observing Satellite) which had a single flexible solar array paddle was launched on August 17. After 10 months, ADEOS lost power due to an accident that damaged the blanket on the solar array paddle. On June 30, 1997, ADEOS operation was stopped. As a result of analysis using telemetry data and experiments, major cause of the accident was excessive tension load and tensile force concentration on the blankets during the second deceleration orbital maneuver on August 28, 1996. This paper will cover problem and dynamics simulations during the second deceleration orbital maneuver on August 28, 1996.

Session 6 Atmospheric Flight and Modeling

1:30 PM Monday, February 12 Vista Mar Monte 2

Chair: Cheryl Hilton-Walker
TRW, Inc.

1:30 PM

AAS 01-130

Modified Thermospheric Model To Estimate High Resolution Density Corrections For Satellite Drag

M. F. Storz - Space Warfare Center, Schriever AFB

This paper describes an atmospheric modeling tool designed to estimate dynamically varying features of the thermospheric density field. It uses orbital energy dissipation rates from many satellite trajectories. The thermospheric density is estimated through time-varying spherical harmonic expansions of exospheric temperature and Jacchia inflection point temperature. The resulting temperature profiles are linked to density through the diffusion equation. The model is tested to demonstrate that density can be accurately recovered from energy dissipation rates, including density simulated by MSISE-90. If implemented for orbit determination, the estimated density should significantly improve the accuracy of predicted trajectories for low perigee satellites.

1:55 PM

AAS 01-131

Comparison Of Ultraviolet Airglow Derived Density To Satellite Drag Derived Density

C. A. Hilton-Walker - ITT Industries; A. Nicholas, K. Dymond, S. Thonnard, S. Budzien - Naval Research Laboratory

The current atmospheric density models used to estimate the density for orbit determination estimate the density with an average error that ranges from 10% to 15%. This study will examine and compare two techniques, in the advanced stages of development, for improving the density estimation of the atmosphere. Total in-track densities were derived for fives satellites in the NORAD Space catalog using Space Surveillance Network (SSN) observations. These densities are compared with the output of the Low-Resolution Airglow and Auroral Spectrograph (LORAAS) abroad the Advanced Research and Global Observation Satellite (ARGOS).

2:20 PM

AAS 01-132

Atmospheric Density Variations At 1500-4000 Km Height Determined From Long Term Orbit Perturbation Analysis

B. R. Bowman - Space Warfare Center, Schriever AFB

Atmospheric density values have been determined from analysis of the orbit perturbations of 25 high A/M satellites in the height range of 1500 km to 4000 km. Over 30 years of NORAD semi-major axis values were used for most of these satellites. Almost 500 density values (averaged over 1 to 2 years) were obtained covering a span of three 11-year solar cycles. The density values were computed in terms of factors to be multiplied with the CIRA72 (Jacchia 1971) model densities, and were fit as a function of height and the index. The density factors are also compared to the MSIS90 model densities.

Session 7 Missions to Small Bodies 1

8:30 AM Tuesday, February 13 Vista Mar Monte 3

Chair: Jun'ichiro Kawaguchi - ISAS, Japan
Daniel Scheeres - University of Michigan

8:30 AM **Autonomous Descent And Touch-down Via Optical Sensors**

AAS 01-134 T. Hashimoto, T. Kubota, J. Kawaguchi - The Institute of Space and Astronautical Science (ISAS); M. Uo, K. Baba - NEC Aerospace Ltd.; T. Yamashita - NEC, Japan

This paper presents an autonomous descent and touch-down scheme of the asteroid sample and return spacecraft, MUSES-C. The spacecraft has some optical sensors, such as navigation cameras and a laser altimeter, and an artificial landmark which is released at about 100m altitude. Navigation system contains utilization of different kinds of sensors, image processing, and Kalman filtering. To realize "time of arrival" guidance, the descending plan is uploaded to the spacecraft, considering the asteroid motion. Six degree-of-freedom control is performed by RCS and reaction wheels. To verify the performance of the proposed scheme, computer simulations including Graphical Asteroid Simulator are performed.

8:55 AM **MUSES-C Touch-down Simulation on the Ground**

AAS 01-135 K. Yoshida - Tohoku University; T. Kubota, S. Sawai, A. Fujiwara - The Institute of Space and Astronautical Science (ISAS); M. Uo - NEC Aerospace System Ltd., Japan

The MUSES-C mission is the world's first sample and return attempt from the near Earth asteroid. In case of sampling, the contact with the surface of the asteroid is one of the most critical events. Therefore it is important to simulate the dynamic behavior with use of knowledge on the free-flying and contact dynamics. This paper presents the dynamics simulation of the touch-down sequence. The spacecraft dynamics and the contact dynamics are described. This paper also presents hardware simulation to verify the effectiveness of the modeling by using 3D robotic simulator and the sampler system.

9:20 AM **Robotic Lander MINERVA, Its Mobility And Surface Exploration**

AAS 01-136 T. Yoshimitsu, T. Kubota, I. Nakatani, J. Kawaguchi - The Institute of Space and Astronautical Science (ISAS), Japan

The authors have developed a small robotic lander named "MINERVA" (MIcro/Nano Experimental Robot Vehicle for Asteroid) and proposed it as an optional payload of ISAS's MUSES-C spacecraft which will conduct the sample return mission from newly discovered new-Earth asteroid 1998SF36. This paper describes the mobility system of the developed robot as well as the surface exploration strategy how to explore and navigate along the asteroid surface. Also the scientific observation functions onboard the robot are detailed.

9:45 AM **BREAK**

10:05 AM **A Test Of Autonomous Navigation Using NEAR Laser Rangefinder Data**

AAS 01-137 C. J. Weeks - Loyola Marymount University

While ground-based navigation of spacecraft missions has proved to be extremely effective, it involves intensive manpower and inherent downlink-uplink time delays. It would be beneficial to have autonomous navigation to determine the flight path in real time, compute maneuvers, and control science instrument pointing during the orbiting phase of a mission. Laser altimetry is an accurate data type that requires neither the two-way communication of Doppler nor the human identification of landmarks that optical data currently requires. The NEAR mission has offered the first real opportunity to compare navigation by real laser altimetry to navigation using the standard data types. The test would be whether laser altimetry provides sufficient information to perform orbit determination within mission requirements. To assess the effectiveness of laser altimetry-based navigation, questions of what constitutes an effective estimation strategy, the accuracy of spacecraft position and velocity estimates, the required accuracy of pre-determined shape and gravity models, the speed of recovery from maneuver errors, and the accuracy with which position may be mapped (predicted), are examined.

10:30 AM **Design And Analysis Of Landing And Low-Altitude Asteroid Flyovers**

AAS 01-138 D. J. Scheeres - The University of Michigan

A comprehensive discussion of the dynamics, analysis, and design of low-altitude flyovers and landing trajectories at asteroids is given. Although the specific application of these results is to the NEAR end of mission phase, the theory presented in the paper will be applicable to asteroid missions in general. The paper is divided into three main topic areas: the dynamics, analysis, and design of these trajectories.

Session 8 Attitude Control and Determination 1

8:30 AM Tuesday, February 13 Vista Mar Monte 1

Chair: Christopher Hall

Virginia Tech

8:30 AM

AAS 01-139

A Fail-safe Controller For An Underactuated Rigid Spacecraft

R. Eshaghi, P. K. C. Wang - University of California, Los Angeles; F. Hadaegh - Jet Propulsion Laboratory

It is well known that the angular velocity of an axi-symmetric rigid spacecraft modeled by Euler's equations can be stabilized to the zero equilibrium state using control torques supplied by two pairs of thrusters along its principal axes. In this work, the authors present a novel approach to the stabilization of the angular velocity equations under arbitrary single-actuation failures. A fail-safe smooth control law is proposed to accommodate any single-axis failure without the need for switching between controllers. The nonlinear control law is collective in the sense that it does not require advance knowledge of the failed-axis thrusters or a mechanism to identify the time of failure. The control scheme is developed based on Center Manifold theory and yields local stability results.

8:55 AM

AAS 01-140

Feedback Control Of Rigid Body Attitude With Inclinometer And Low-Cost Gyro Measurements

M. Akella, J. Halbert - The University of Texas at Austin

In this paper, we formulate the rigid body attitude control problem assuming measurements from inclinometers and low cost rate gyros. We consider fusion of measurements from these two types of sensors to achieve inexpensive and reliable feedback control solutions that can find numerous practical applications. Literature covers the rigid body attitude control problem extensively due to its relevance to spacecraft attitude maneuvers, underwater vehicles and several other applications in robot manipulation. Output feedback with the rigid body attitude measured indirectly in terms of inclinometers is a different problem that is addressed very recently in the literature. Solutions to the estimation problem for a rigid body endowed with low-pass sensors and cheap rate gyros are local in nature with motion restricted to the roll-pitch plane. There are further restrictions on the angular rates and other state variables. We consider the analogous control problem for global regulation of arbitrary 3D~motions with kinematics written in terms of the Modified Rodrigues Parameter~(MRP) vector. The main contribution of this paper is that we provide a stability proof that it is theoretically possible to control rigid body attitude tracking errors with inclinometers and rate gyros. In addition to a rigorous stability analysis, we provide numerical simulations of closed loop motion for a rigid body equipped with inclinometers and rate gyros as sensors.

9:20 AM

AAS 01-141

Equilibria Of A Satellite Subjected To A Constant Torque: Analysis Of Stability

V. A. Sarychev, A. Guerman - Universidade da Beira Interior, Portugal; P. Paglione - Instituto Tecnologico de Aeronautica, Brazil

We study stability of equilibria of a satellite acted upon by the gravity-gradient torque and some constant torque. For each orientation of the satellite, there exists a torque that makes it an equilibrium. We show that equilibria obtained by rotation through a single orientation angle can be stable for appropriate values of inertial parameters. Equilibria obtained by rotations through any two orientation angles are unstable (we prove that the necessary conditions of stability are incompatible). In the general case, the study of stability is performed numerically.

9:45 AM **BREAK**

10:05 AM

AAS 01-142

Kalman Filtering Using The Quaternion Extracted From Vector Measurements

I. Kim - INHA University, Korea; J. Kim - Swales Aerospace; S. Lim - INHA University, Korea

The attitude determination techniques are mainly divided into two parts, namely, the Kalman filter (KF) technique and the vector observation (VOBS) technique. KF estimates the optimal attitude for the previous attitude information accumulated in the covariance matrix. VOBS determines the optimal attitude for the current attitude information expressed as a vector or angle measurements form. In this paper, we propose the algorithm improving the performance and the convergence characteristics. In this algorithm, if the current measurements are inaccurate, KF works mainly, and otherwise, VOBS improves the convergence characteristics. Also, we apply this algorithm to KOMPSAT-II with two star trackers.

10:30 AM

AAS 01-143

Multiple Error LMS Disturbance Rejection Without a Disturbance Correlated Measurement

H. Chen - Columbia University; B. N. Agrawal - Naval Postgraduate School; R. W. Longman - Columbia University; M. Q. Phan - Dartmouth College; S. G. Edwards - USAF

Typical spacecraft have periodic excitation sources, such as solar array drives, cryo pumps, momentum wheels, reaction wheels, gyros, control moment gyros, etc. For highly precise pointing equipment, even slight imbalances in such rotating machinery parts can create serious problems. A popular approach to canceling vibrations is the Filtered-x or Filtered error LMS Algorithm. This could be used on an active vibration isolation platform for such space applications. A sometimes serious disadvantage is the need to have a disturbance correlated signal, requiring that one knows the source of the disturbance and has instrumented that source with some kind of sensor. This paper makes use of disturbance identification methods to develop a disturbance correlated signal without requiring the additional sensor. Experiments are performed on a Stewart Platform (of a kind soon to be flown on an experimental satellite) to investigate the effectiveness of the approach.

10:55 AM

AAS 01-144

Magnetic Attitude Determination And Control Of Inertial Pointing Small Momentum Bias Spacecraft

F. Santoni, P. Tortora - Universita di Roma "La Sapienza", Italy

An attitude determination and control system for small momentum bias spacecraft based only on three-axis magnetometer and magnetic coils is proposed. Pointing error components are estimated using an Extended Kalman Filter, based on magnetometer data only. This algorithm is suitable to achieve any desired momentum direction during the mission. It can be used for inertial stabilized spacecraft as well as for orbit normal pointing spacecraft. Moreover the same control law provides for nutation damping. The pointing accuracy obtained by this system is on the order of one degree, which is often suitable for small missions.

11:20 AM

AAS 01-145

Segmented Modelling Of The Geomagnetic Field For Use As A High Accuracy Reference Vector

G. Michalareas, S. B. Gabriel, E. Rogers - University of Southhampton, UK

This paper is concerned with the construction of a system that combines separate models for areas of the geomagnetic field with distinct characteristics. This method is used to eliminate the errors caused by the averaging process, inherent in the fitting algorithms which construct the model for the whole field. The results of this new method show that the accuracy can be drastically improved and consequently the geomagnetic field can be used as a high accuracy reference vector for attitude determination and control.

Session 9 Navigation

8:30 AM Tuesday, February 13 Vista Mar Monte 2

Chair: Craig McLaughlin

Air Force Research Lab, Kirtland Air Force Base

8:30 AM **Simulation Of High Accuracy Inter-Satellite Ranging Measurements**

AAS 01-146

J. Kim, K. W. Key, B. D. Tapley - The University of Teaxs at Austin

The Gravity Recovery and Climate Experiment (GRACE) is a dedicated spaceborne mission whose objective is to map the gravity field with unprecedented accuracy. Primary measurement is the range change between two co-orbiting satellites using a dual one-way microwave ranging system, which minimizes the oscillator drift effect by combination of two one-way phase measurements. In this study, the phase measurements were simulated with comprehensive error models. The simulation results demonstrate that a high level of accuracy can be achieved by use of the dual one-way ranging system.

8:55 AM **The Orbit and Maneuver Estimation of Interplanetary Mission Mased on Delta VLBI and Radiometric Measurements**

AAS 01-147

T. Ichikawa - Institute of Space and Astronautical Science (ISAS), Japan

In the future interplanetary mission, the orbit control will be executed by using impulse and the continuous low thrusts. From the viewpoint of the navigation, the highest accuracy of the orbit and maneuvers estimation is required in the missions at the critical and cruising orbit phases. Interplanetary spacecraft have been successfully navigated using conventional radiometric Doppler and range measurements acquired by the deep space tracking station. And also, we investigate Delta VLBI data to more precise accuracy for the orbit estimation. In this paper, we describe the orbit and maneuver estimations for the spacecraft where it is always being orbit controlled during the cruise.

9:20 AM **Accurate Navigation For Lunar Lander / Orbiter Based On Crater Identification**

AAS 01-148

T. Hashimoto, Y. Imamura, T. Kubota, K. Ninomiya - The Institute of Space and Astronautical Science (ISAS), Japan

This paper presents accurate navigation system for Lunar landers or orbiters, based on the crater identification. The navigation system consists of three stages. At first, craters are extracted from the surface images taken onboard, and the list of positions and radii of detected craters is obtained. The second step is identification between detected craters and known terrain maps obtained by other missions in advance. The final stage is the calculation of relative attitude and position towards Moon-fixed coordinates. To verify the effectiveness and performance of the proposed navigation system, computer simulations including image processing are performed.

9:45 AM **BREAK**

10:05 AM
AAS 01-149

Recursive Mode Star Identification Algorithms

M. A. Samaan - Teas A&M University; D. Mortari - Universtita degli Studi "La Sapienza" di Roma, Italy; J. L. Junkins - Texas A&M University

The star identification problem can be solved by many algorithms for identifying stars in the field of view of a star tracker. However efficiency and reliability remain key issues and the availability of new active pixel cameras require new approaches. Two novel algorithms of recursive mode star identification are presented in this paper. The first method is based on the Spherical Polygon Approach (SPA) that is used to access all possible cataloged stars in the area between the four corners of a square field of view (FOV) star tracker and to recursively augment/delete from this set during camera slewing motions. Star identification is carried out by a pattern matching technique to identify the stars in the field of view as specific stars in the star catalog. The second method uses a star neighborhood cone and constructs a cataloged neighborhood pointer matrix from all stars present in the star catalog. During the recursive mode star identification process, only the stars in the neighborhoods of previously identified stars are considered for star identification in the succeeding frames.

10:30 AM
AAS 01-151

A Factorization And Least-Squares Method For Multi-Pass Sensor Alignment Calibration

M. E. Pittelkau - Johns Hopkins University, Applied Physics Laboratory

A method is presented in this paper to statistically combine calibration parameter sets from individual maneuver scenarios to produce a composite calibration set that is more accurate than any of the individual parameter sets. This is useful in systems where calibration maneuvers are highly constrained. A Kalman filter used to produce the estimates was implemented such that only the UD factorization of the covariance matrix is immediately available. The algorithm used to produce the composite estimate is designed to utilize the UD factors directly in a recursive, computationally efficient, and numerically reliable manner. The algorithm is derived from Kalman filter theory and makes use of an established factorization method used for Kalman filter implementation. Simulation results show the effectiveness of combining calibration parameter estimates that result from various maneuver scenarios.

10:55 AM
AAS 01-152

Spacecraft Rendezvous Using GPS Relative Navigation

T. Ebinuma, R. H. Bishop, G. E. Lightsey - The University of Texas of Austin

A study of real-time GPS-based relative navigation in low Earth orbit using a GPS signal simulator has been performed. The tests are conducted using a user-programmable Mitel GPS Architect receiver, which we modified for space application, connected to a Global Simulation Systems STR4760 GPS signal simulator. The results of real-time open-loop navigation using an extended Kalman filter processing double-differenced carrier phase and pseudorange are presented. A close-loop software simulation for automatic rendezvous and capture has also been performed.

Session 10 Missions to Small Bodies 2

1:30 PM Tuesday, February 13 Vista Mar Monte 3

Chair: Felix Hoots
GRC International

1:30 PM **On Multiple Asteroids Sample Return Missions And Their Feasibility**

AAS 01-153 J. Kawaguchi - The Institute of Space and Astronautical Science (ISAS), Japan

The sample and return from small objects is usually confined to some special cases. One big determinant is the delta-V capability associated with the trajectories and contemporary missions analysis assumes the use of electric propulsion such as ion thrusters. There will be a number of near Earth asteroids about which even the multiple sample and return scenarios are built. The paper presents a few practical examples of this kind and shows multi near Earth asteroid sample and return scenarios for illustration. Some of those are feasible even with existing propulsion elements.

1:55 PM **Approaching Small Bodies**

AAS 01-154 A. H. Taylor, J. J. Bordi - Jet Propulsion Laboratory

This paper presents analysis of when and how well, on the approach to previously unvisited small bodies, the trajectory-design relevant physical parameters are determined. Quick acquisition of the knowledge of these parameters is required so that the orbital phase of a mission can be designed. We give covariance analysis results using radiometric and optical navigation data for a variety of conditions on the approach to four classes of small bodies ranging in diameter from 1 to 500 km. Time histories of the knowledge of mass, rotation characteristics, and comet outgassing are given for a variety of approach trajectories.

2:20 PM **On The Dynamics Of Spacecraft Orbiting Elongated Celestial Bodies**

AAS 01-155 A. Elipe - Universidad de Zaragoza, Spain; M. Lara - Real Instituto y Observatorio de la Armada, Spain

To understand the dynamics around elongated celestial bodies, we use an one-dimensional theoretical model consisting of a thin bar in uniform rotation around an axis perpendicular to the bar. The gravitational potential is then expressed in closed form. In a synodic frame we characterize the phase space by computing the zero-velocity curves, the equilibria and periodic orbits. The stability of the trajectories is obtained for each case. We found that three-dimensional periodic orbits appear as consequence of resonances between the rotation rate of the bar and the mean motion of the orbiter in an inertial frame.

2:45 PM **BREAK**

3:05 PM **Maneuver Strategy for Station Keeping and Global Mapping Around an Asteroid**

AAS 01-156

T. Kubota, T. Hashimoto - The Institute of Space and Astronautical Science (ISAS); M. Uo, M. Maruya, K. Baba - NEC Aerospace System Ltd., Japan

Global mapping of asteroid from the sun side and the terminator side are scheduled in MUSES-C mission. The spacecraft keeps the home position around the asteroid during global mapping. This paper proposes a method for a spacecraft to keep the home position autonomously. The spacecraft is navigated based on the image obtained by ONC and the range information obtained by LIDAR. This paper also proposes a global mapping method to estimate the shape of the asteroid based on motion stereo techniques.

3:30 PM **Hovering And Translational Motions Over Small Bodies**

AAS 01-157

S. Sawai, D. J. Scheeres - The University of Michigan

Previous investigations have shown that a spacecraft hovering close to the surface of a small body can be stabilized in most instances by using a simple feedback control law that only uses altimetry measurements (Sawai and Scheeres, AIAA Paper 2000-4421). This result simplifies the implementation of hovering for extended periods over a rotating body as this control loop can run with minimal processing and data reduction requirements, enabling the translational motion to be controlled with a more sophisticated suite of sensors. The current paper applies this result to issues of practical interest for a spacecraft hovering close to the surface of an asteroid. Specifically, this paper will investigate the implementation and stability of guidance laws for translational motion over the surface of the asteroid.

Session 11 Interplanetary Missions

1:30 PM Tuesday, February 13 Vista Mar Monte 1

Chair: Brian T. Barden
Jet Propulsion Laboratory

1:30 PM **New Trajectory Options For Ballistic Mercury Orbiter Mission**

AAS 01-158 C. L. Yen - Jet Propulsion Laboratory

This paper reports on recent advances made in obtaining low ΔV trajectories to conduct Mercury Orbiter missions. Most ballistic Mercury mission designs to date have been based on the methodology and the data provided by the author in 1985. The design of MESSENGER (a recent winner of NASA Discovery Program) mission followed the similar path. Hoping to enhance the performance potential of the mission, re-evaluation of the past trajectory optimization was made. In the paper of 1985, only one Venus gravity assist mode (V-V with 1:1 synchronicity) was considered. This study lead to ten new ways of conducting Multiple Venus Gravity Assists which gave lower ΔV and/or ways to utilize more naturally the attendant Earth-Venus phasing. Two additional Multiple Mercury Gravity Assists types derived from the concept contained in the 1999 paper by Y.Langevin were investigated and shown to permit further reductions in the mission ΔV's with small additional mission times. All useful VNMK trajectory types and the phasing requirements for each of these options are detailed and example launch opportunities are shown in the paper.

1:55 PM **Sun-Mars Lagrange Points And Mars Missions Simulations**

AAS 01-159 P. E. Damphousse, J. M. Kutrieb, J. D. Strizzi - Naval Postgraduate School; J. P. Carrico - Analytical Graphics, Inc.

Existing research has identified potential missions and data for Sun-Mars libration points, particularly for satellites orbiting L1 or L2. Regarding these halo missions, we address questions of "Why go there?", "How to get there?", and "How to stay there?". We use STK Astrogator, in part, for simulation and analysis of Earth-Mars transfers, halo insertions, and station-keeping. The data discussed will provide confirmation and insight for existing research and proposals, as well as new information on halo characteristics, insertion Dv, amplitude, potential missions, and station-keeping strategies. These data should prove useful to mission planners and concept developers for future Mars investigations.

2:20 PM **Paper Withdrawn**

2:45 PM **BREAK**

3:05 PM

AAS 01-161

Trajectory Design And Mission Analysis Of Fast, Outer Solar System Travel

C. H. Williams - NASA Glenn Research Center

An analytic approximation was derived to calculate performance data for propulsion systems of very high specific impulse and specific power for various human outer-planetary space missions. Closed form, 1D solutions for rendezvous and round trip missions, both deterministic and optimized, are provided. Example data includes trip times, mass fractions, thrust to weights, and delta velocities. Spacecraft trajectories assume field-free space, constant thrust/specific impulse/specific power, nearly straight-line, radial thrust, at very high (~milli-g) continuously variable acceleration, characteristic of very advanced propulsion concepts certainly available only in the distant future as depicted in the motion picture epic, "2001: A Space Odyssey".

3:30 PM

AAS 01-162

Optimal Out-of-the-Ecliptic Trajectories For Space-Borne Observatories

P. Gurfil, N. J. Kasdin - Princeton University

In this paper novel trajectories that are particularly suitable for space-borne observation missions are introduced. Based on the framework of the spatial circular restricted three body problem with the Sun and the Earth as the primaries and a special selection of a coordinate system, a family of trajectories with considerable displacements above the ecliptic plane is found. Stability analysis of these trajectories is carried out using practical stability theory. The normal component of motion results in significantly reduced noise from the interplanetary (zodiacal) dust and a concomitant reduction in the necessary size of the optical collecting area. The reduced size of the mirrors allows a considerable reduction in payload mass and manufacturing costs. The quest for optimal trajectories is performed using genetic algorithms. First, types of trajectories are characterized using a genetic search. Utilizing the results and insight obtained from the characterization process, optimal trajectories are designed. The first optimal trajectory requires low launch energy and yields a maximum decrease of 67% in the zodiacal cloud brightness. The second optimal trajectory requires higher launch energy, but it renders a dramatic 97% maximum noise decrease.

Session 12 Satellite Clusters and Formation Flying

1:30 PM Tuesday, February 13 Vista Mar Monte 2

Chair: Rich Burns

Air Force Research Laboratory, Kirkland AFB

1:30 PM

AAS 01-163

The Dynamics Of Relative Satellite Motion

W. E. Wiesel - Air Force Institute of Technology

We report on a new solution for relative satellite dynamics, where a precessing periodic orbit replaces the circular orbit of the Clohessy-Wiltshire solution, and a Floquet solution supplies the local motion. All zonal gravitational harmonics are included in this reference solution. Sectoral, tesseral, air drag, and second order terms can be included as perturbations to the first order solution. Using this solution, stationkeeping maneuver costs are below (perhaps much below) a centimeter per second per day at 600 km altitude.

1:55 PM

AAS 01-164

Non-Propulsive Stability Of Picosatellite Formations Using Solar Radiation Pressure

T. Williams, Z. Wang - University of Cincinnati

One way in which satellite formation flight differs from traditional proximity operations is the extended mission lengths that are required. Long-term perturbation effects, in particular the nodal regression that results from the oblateness of the Earth, must therefore be corrected for in some way if it is not to slowly pull the satellite formation apart. This compensation could be carried out using on-board propulsion systems; however, providing these in the available volume becomes a technical challenge for nanosatellites and picosatellites. Consequently, non-propulsive station-keeping techniques appear worth investigating. This paper will examine the use of solar radiation pressure for this problem.

2:20 PM

AAS 01-165

Ground Tracking And Control Of GEO Cluster Satelllites Using The Raven Telescope

C. C. Chao, J. Cox - The Aerospace Corporation; R. Burns - Air Force Research Laboratory

This paper discusses the concept and feasibility of simultaneous tracking and orbit determination of a cluster of several geosynchronous satellites using the ground based, optical Raven telescope. The instantiation of the Raven considered here has a field of view of 30x20 arc minutes, which is considerably larger than the 0.2 by 0.2 deg (12x12 arc min.) control box for a cluster of GEO satellites. Covariance and Monte Carlo simulations show that the common bias and other errors are largely removed and the relative position between a sub-satellite and a master satellite can be accurately determined. Collocation control strategies using combined ranging and optical Raven tracking are discussed.

2:45 PM **BREAK**

3:05 PM

AAS 01-167

The Role Of Short-Periodic Motion In Optimal Formation Flying Of Satellites With Large Area To Mass Ratio

R. Proulx, P. Cefola, K. Luu - Charles Stark Draper Laboratory

This paper considers the role of short-periodic motion in the design and maintenance of satellite formation flying. When the members of the formation experience large area-to-mass variations, differential drag and solar radiation pressure induces secular, long periodic, and short periodic dispersion of the formation. The effects of this dispersion are examined using the Draper Semi-analytical Satellite Theory (DSST), which analytically separates secular and long-periodic motion from short-periodic motion. The primary application will be to the differential motion between a large flat plate, and an infinitesimally small cannon ball (each with the same Mass.). Designing formation flying algorithms and fuel-budgets requires that these differential effects are properly sized and understood. Low altitude formations will be primarily effected by differential drag, while high altitude formations will be primarily effected by differential solar radiation pressure. At any dispersion tolerance, secular, (and likely long periodic) dispersion effects must be controlled; however control of short-periodic motion is highly dependent on the relationship of differential the short period motion to the magnitude of the dispersion tolerance. A low-altitude formation may experience only a few meters of short-periodic dispersion, while a GEO altitude formation may experience several kilometers of short-periodic dispersion. In this paper, we will examine near-optimal formation flying control algorithms for constrained formation dispersions.

3:30 PM

AAS 01-222

The State Transition Matrix Of Relative Motion For The Perturbed Non-Circular Reference Orbit

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

In this paper a state transition matrix for the relative motion of neighboring satellites is developed for an elliptic reference orbit under the influence of the $J2$ gravitational perturbation. The state transition matrix is developed for both osculating and mean elements. The relative displacements for the position and velocity are first expressed as a function of the differences in the orbital elements. Then, using Brouwer's theory modified for non-singular variables, the state transition matrix for the orbital element differences is developed. Matrix multiplication of these various matrices provides the state transition matrix.

Session 13 Earth and Lunar Missions

8:30 AM Wednesday, February 14 Vista Mar Monte 3

Chair: Bob Melton

Pennsylvania State University

8:30 AM

AAS 01-168

High Power Rocket Demonstrator Of A Reusable Glideback Booster

D. J. DeTurris, T. J. Foster - California Polytechnic State University

A series of high power rockets have been constructed which explore the concept of remotely controlled, fixed wing, flyable booster rockets. The goal is to reduce costs for getting payloads into orbit by using a completely reusable first stage booster with very short turn around times. The subsonic rocket demonstrators have a conventional vertical launch, with an R/C controlled horizontal glide and landing. The canard and delta wing configurations flown grew progressively in size to almost 10-ft tall. A 5-ft tall model under R/C control successfully glided for over 30 seconds.

8:55 AM

AAS 01-169

A Semi-analytical Evaluation Of Launcher Performances

E. DiSotto - GMV, Spain; P. Teofilatto - Universita de Roma "La Sapienza", Italy

In the preliminary design phase of launchers many options can be investigated; some parts of the launcher project can be changed, integrating new engine projects with already existing stages. At that phase of the design it is important to have some fast tool for launcher performances evaluations: this tool has to be sufficiently accurate to drive the design choices, while avoiding lengthly computations needed to find out optimal trajectories any time design changes on the launcher project are performed. In this paper a method of launch performances evaluation is proposed, based on a fast and sufficiently accurate estimate of the launcher trajectory.

9:20 AM

AAS 01-171

Experiences and Lesson Learned from NASDAs ETS-VII Robot Satellite - Anomalies in Satellites Operation and Recovery From Those

M. Oda - National Space Development Agency (NASDA), Japan

ETS-VII (7th Engineering Test Satellite) was launched on November 27th, 1997 to conduct rendezvous docking and space robot technology experiments. ETS-VII satisfactory conducted automated rendezvous docking three times during its 2 years mission operation period. A 2m long robot arm on ETS-VII were used various robot experiments. However these results were derived by overcoming various troubles such as loss of satellite attitude stability on the 3rd day in orbit, malfunction of gas jet thrusters that were essential in the rendezvous, and others. Troubles, recovery from those and results are presented.

9:45 AM **BREAK**

10:05 AM **Geostationary Positioning Phase From Super-Synchronous Transfer Orbit: Hispasat 1C Mission**

AAS 01-172

M. Rossi - Centre National d'Etudes Spatiales (CNES); J. Sarda - Cs Si Z.I. du Palays, France

The geostationary satellite Hispasat1C was injected in early 2000 on a super-synchronous transfer orbit, with apogee rising about 10.000 km above the geostationary radius. We describe the studies and adaptations performed at the CNES Flight Dynamics Center. Firstly, we present the transfer worked out for mission analysis, its mathematical modeling and its implementation in Object Oriented language. Secondly, we discuss the final drift strategy preparation. Finally, we illustrate the maneuver longitude rendez-vous issues by the actual positioning phase operations.

10:30 AM **WIND Lunar Backflip and Distant Prograde Orbit Implementation**

AAS 01-173

H. Franz - Computer Sciences Corporation

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, allowing WIND to fly an orbital profile that would have been impossible with reliance on propulsive delta-V maneuvers alone. In the past two years, WIND has utilized lunar flybys to become the first spacecraft ever to implement the lunar backflip and Distant Prograde Orbit concepts, achieving each trajectory with minimal use of spacecraft fuel.

10:55 AM **SIRTF Trajectory Design and Optimization**

AAS 01-174

M. Garcia - Jet Propulsion Laboratory

The Space Infrared Telescope Facility (SIRTF) had - since June 1995 - planned to launch on December 1, 2001 aboard a Delta 7920H launch vehicle into an Earth-trailing solar orbit. Unfortunately, recent events have forced the project to delay launch by 7.5 months until July 15, 2002. Because of this launch date change, the baseline launch/injection strategy known as "direct ascent" no longer leads to viable solar orbits for SIRTF. This paper examines why direct ascent is not an option for the summer launch, presents the new launch/injection strategy, and discusses the solar orbit optimization criteria used to find viable solar orbits.

Session 14 Attitude Control and Determination 2

8:30 AM Wednesday, February 14 Vista Mar Monte 2

Chair: David Rubenstein
Charles Stark Draper Laboratory

8:30 AM

AAS 01-175

Attitude Control Of A 3-axis Stabilized Spacecraft With Electric Propulsion During Orbital Maneuvers

K. Y. Pimenov, R. Z. Sagdeev, K. Karavasilis - University of Maryland

An orbit transfer of a solar electric propulsion spacecraft could impose significant demands on the vehicle attitude control system. Simultaneously steering the thrust vector and pointing the solar cells exactly at the sun require high-speed attitude maneuvers when a direction of the thrust is close to the sun vector. The problem has been studied for planar and general case orbit transfers. Asymptotic formulae have been obtained to estimate the maximum angular rates and accelerations. The proposed attitude control algorithm based on the imperfect solar array pointing in the vicinity of kinematical singularities reduces the maximum required vehicle angular rate to the rate of steering the thrust vector.

8:55 AM

AAS 01-176

Web-Based Tools For Spacecraft Attitude Dynamics And Control Simulation

D. Quock, J. Puig-Suari - California Polytechnic State University

The web-based application presented in this paper provides attitude dynamics and control simulation tools utilizing the advantages of the World Wide Web. A user can access the program from the office, classroom, home, or local Internet cafe without the hassle of single-machine licenses. The program features an easy-to-use interface, allowing the user to quickly alter spacecraft characteristics, orbit parameters, and initial conditions. Different levels of complexity, ranging from rigid-body torque-free motion to active control of a flexible spacecraft are available to the user. A number of output options are also available to the user, ranging from simple graphs to three-dimensional movies.

9:20 AM

AAS 01-177

Robust Star Identification Technique For Use in Laser Pointing Determination of the ICESAT

S. Bae, B. E. Schutz - The University of Texas at Austin

The paper presents both pattern match and direct match algorithms developed for the star identification of star tracker observations in the ICESAT precision attitude determination. Two methods are compared and the optimal use of them is discussed. The Laser Reference Sensor (LRS) in the Stellar Reference System, which is developed for the precise laser pointing determination of the ICESAT, occasionally observes a star in its field-of-view. The unique problem of the LRS star identification is addressed. The direct match algorithm is modified for the identification of the stars measured by the LRS.

9:45 AM **BREAK**

10:05 AM **CHAMP Attitude Dynamics - Early Operations Results**

AAS 01-178

U. Feucht, M. Schneller - German Space Operations Center

CHAMP (CHAllenging Minisatellite Payload) is a German small satellite mission for geoscientific and atmospheric research and applications.The spacecraft was launched on July 15 2000 from the Plesetsk cosmodrome. The mission is of special importance as a precursor mission for the NASA-DLR GRACE project where 2 spacecrafts similar to CHAMP will fly in formation. The paper described in this abstract will deal with the attitude dynamics of the CHAMP spacecraft. Basing on a description of the missions operations system's attitude part the attitude activities during LEOP are presented. The main chapter is about the encountered problems and anomalies and its operational solutions. The conclusion concentrates on the relevance of these results for both CHAMP future operations and GRACE mission preparations.

10:30 AM **In-Flight Estimation Of The Cassini Spacecraft's Inertia Tensor**

AAS 01-179

J. Wertz, A. Y. Lee - Jet Propulsion Laboratory

A new methodology for estimating the spacecraft 3-by-3 inertia tensor is proposed in this study. This methodology exploits the fact that the total angular momentum vector of a spacecraft, as expressed in an inertial coordinate system, is conserved when it is being slewed about any of its axes by three reaction wheels. Inputs needed for this methodology are telemetry data of the reaction wheel spin rates, spacecraft per-axis angular velocities over the time duration of the slews, and ground-measured inertia properties of the reaction wheels. By collecting these data over one or more per-axis spacecraft slews, one can make least-square estimates of both the moments and products of inertia of the spacecraft. On March 15, 2000, the Cassini spacecraft used its three reaction wheels to perform slews about its three axes. The proposed methodology has been applied on the telemetry data collected on that day. The inertia matrix estimated using the proposed methodology agrees well with that predicted pre-launch. The uncertainties associated with this estimated inertia matrix have also been computed.

Session 15 Orbit Determination

8:30 AM Wednesday, February 14 Vista Mar Monte 1

Chair: Yoaz Bar-Sever

Jet Propulsion Laboratory

8:30 AM **Orbit Determination Accuracy Requirements for Collision Avoidance**

AAS 01-181 R. G. Gottlieb - The Boeing Co., Houston; S. J. Sponaugle - The Boeing Co., Chandler; D. E. Gaylor - The University of Texas

A simulation has been developed to examine how orbit determination accuracy, size of avoidance maneuvers, encounter geometry and warning time affect the probability of collision. The simulation shows that reasonably sized collision avoidance maneuvers are effective in reducing the probability of collision only if accurate orbit determination data is available for both the active satellite and the threat. Also, a method to determine the maneuvers required to reduce the probability of collision to a desired value is presented.

8:55 AM **MITA Satellite Orbit Determination From Malindi Ground Station**

AAS 01-182 F. Curti, F. Longo - University of Rome "La Sapienza", Italy

The paper presents the results of the orbit determination problem without ranging measurements. Since the satellite has a polar low orbit (altitude 450 km, inclination 87 deg), there are a few contacts with the Malindi Station, and, some of these have short arc of visibility. As a consequence, the observations could not be sufficient to compute the antenna pointing elements and more information is needed to evaluate the orbital parameter. The algorithm, devised in this study, uses the magnetic field measurements, recorded on-board along the orbit, and the angles measured in the arcs of visibility. The estimation process is carried out by means of the Extended Kalman Filter.

9:20 AM **Estimation Of Periodic Accelerations To Improve Orbit Ephemeris Accuracy**

AAS 01-184 M. T. Soyka - Naval Research Laboratory; M. A. Davis - Honeywell Technical Solutions, Inc.

Limitations in the modeling of solar pressure, drag, and thermal radiation using the satellite attitude, surface properties and space environment will always result in some unmodeled acceleration, which tends to be periodic. The use of periodic accelerations, with a period near once per revolution of the satellite orbit, have been used by precision orbit determination programs to improve the accuracy of the derived ephemeris. The utility of being able to estimate and apply accelerations coincident to the potential source has the ability to improve the accuracy of the resultant ephemeris, and access the accuracy of the conservative force models, when the suitable observablity of a dataset is available. The frames for each of these natural sources are described. General guidelines for using these accelerations as tools will be described.

9:45 AM **BREAK**

10:05 AM **Earth Radiation Pressure Effects On GPS Orbit Determination**

AAS 01-185

H. Rim, C. E. Webb, B. E. Schutz - The University of Texas at Austin

The radiation pressure efftects on the GPS orbit due to solar flux reflected and re-emitted from the earth were investigated. Since the effect of the direct solar radiation pressure dominates on the GPS orbit at its 20,000 km altitude, the earth radiation pressure effects were ignored for most GPS orbit determinations. As the accuracy of GPS orbit determination improves, however, it becomes necessary to include smaller perturbations, such as earth radiation pressure, to improve the orbit determination accuracy further. This paper examines the earth radiation pressure effects on GPS orbit using a diffuse earth radiation pressure model implemented in UTOPIA/MSODP1. There were a few cm effects on the GPS orbit, especially in the radial component. To access the resulting GPS orbit accuracy, the quality of the estimated geodetic parameters, such as the station coordinates, earth orientation parameters, were evaluated. Also, the Satellite Laser Ranging (SLR) data fit was used as an independent check for the GPS orbit accuracy.

10:30 AM **Satellite Selection Strategy For LEO Orbit Determination From the GPS & GLONASS Constellations Using Double Differemces**

AAS 01-186

S. Casotto, A. Zin - Universita di Padova, Italy

Some of the currently orbiting LEO missions are using the Global Positioning System (GPS) for the precise determination of their orbits. It is foreseen that the majority of future LEO missions will adopt Global Navigations Satellite Systems (GNSS) as the primary means to carry out this fundamental task. Operational GNSS constellations usable for LEO applications currently include GPS and GLONASS, the Russian counterpart to the American GPS system. In fact LAGRANGE, the first orbiting receiver capable of tracking both GPS and GLONASS signals, was launched as an experimental package last November onboard the Argentinian satellite SAC-C. The extended capability of this new class of GNSS receivers will heavily increase the number of actual data collected (in the case of an ideal 24-satellite GLONASS constellation, this would theoretically double). Consequently some new strategy is required for an optimal handling of the enormous amount of data. This paper reviews satellite selection strategies in the case of an orbit determination system based on the use of double difference carrier phase data. In particular it introduces a class of algorithms that make the best use of the strength of the observational data by selecting satellites on the basis of the sky-distribution of the GNSS passages as seen by the LEO receiver.

10:55 AM **New Approach Of Orbit Determination To Improve The Stardust Dynamic Models**

AAS 01-187

T. You, J. Ellis, T. McErath - Jet Propulsion Laboratory

Since the launch of Stardust in February 1999, the navigation team has encountered considerable difficulty in determining and predicting a consistent estimate of the Stardust orbit. The primary factors contributing to the estimation errors are the mismodelling of nongravitational accelerations due to both the solar radiation pressure and the small forces that arise owing to the attitude control system. This paper describes the estimation strategy to model the small forces. The detailed spacecraft dynamic models and the evaluation of the dynamic error sources are discussed. A unique filter method has been developed to create a simple and efficient orbit determination strategy.

Session 16 Tether Systems 1

1:30 PM Wednesday, February 14 Vista Mar Monte 2

Chair: Arun Misra

McGill University

1:30 PM **Periodic Solution In Rigid Electrodynamic Tethers On Inclined Orbits**

AAS 01-188

J. Pelaez - Universidad Polit ecnica de Madrid; M. Lara - Real Instituto y Observatorio de la Armada, Spain

Recently a new kind of dynamic instability has been addressed for electrodynamic tethers operating at inclined orbits. The inclination i and e---giving the order of magnitude of the electrodynamic forces---are free parameters. We introduce an algorithm based on the Poincaré method of continuation of periodic orbits. We extend previous analysis made with asymptotic techniques when e approaches 0, to values of order unity. We determine additional periodic solutions not detected with asymptotic techniques. Finally, we analyze the stability properties of the system when the variation of the tether current along the orbit (induced by the changes of the ionospheric plasma density) produce resonant force components.

1:55 PM **Damping In Rigid Electrodynamic Tethers On Inclined Orbits**

AAS 01-190

J. Pelaez, O. Lopez-Rebollal, M. Ruiz - Universidad Politecnica de Madrid, Spain; E. C. Lorenzini - Harvard-Smithsonian Center for Astrophysics

We study a rigid electrodynamic tether with a longitudinal "damper kit". Three new nondimensional parameters f, d and s appear in the system governing equations, associated with the damper system. The total number of free parameters is five. The coupling between the oscillation of the damper mass and the tether motion takes place via the parameter s. We study the stability domain of the system using a numeric algorithm.

2:20 PM **Modeling and Dynamics of Tethered Formations for Space Interferometry**

AAS 01-231

M. Quadrellli - Jet Propulsion Laboratory

The paper considers planar motion of a three-body tethered system whose center of mass moves in a circular orbit around the Earth. The equilibrium configurations of the system and their stability are examined. It is observed that there are four classes of equilibrium: in two of them the bodies are collinear, while in the other two, the bodies lie in a triangular configuration. Analysis of the stability of these equilibrium configurations shows that the triangular configurations are unstable, while one of the collinear configurations (the one along the local vertical) is stable. An integral of motion is obtained, which turns out to be the Hamiltonian of the system. The zero-velocity curves based on this Hamiltonian are presented.

2:45 PM **BREAK**

3:05 PM

AAS 01-192

Active Control Of Tether Satellites Via Boom Rotation: A Proof Of Concept Experiment

F. Bernelli-Zazzera - Politecnico di Milano, Italy

The goal of the present research is the study and experimental verification of an active control system for the bobbing oscillations of tethered systems. The control is provided by moving the attachment point between the tether and the space platform. The relative motion is provided by rotating the boom connecting the tether to the platform. The boom is activated in a straightforward way by an electric motor, and can control the in plane pendulum oscillations and also the tether bobbing, which is the focus of the experiments performed. A small laboratory experiment has been set up. A frame structure, over 4 meters high, supports the DC motor and the rotating boom, to which an elastic tether carrying a sub satellite is connected. The tether is 1.75 meters long in the equilibrium configuration, and the maximum elastic deformations are in the order of ±20 per cent. The sensors used are one potentiometer to measure the boom rotation and one accelerometer to measure the acceleration of the sub satellite in the direction of the tether. In this way the system states for what concerns the longitudinal motion can be recovered. The active control law is based on velocity feedback, studied on the linearized model of the system in order to maximize the damping of the bobbing oscillations, and modified to take into account the physical limitations on the boom rotation. The damping of the oscillations has been doubled with the active control.

3:30 PM

AAS 01-193

Attitude Dynamics Of The ASTOR Tethered Satellite System

A. P. Mazzoleni - Texas Christian University

This paper concerns analysis of the attitude dynamics of the ASTOR (Advanced Safety Tether Operation and Reliability). The main purpose of the ASTOR Satellite is to demonstrate the performance of the Emergency Tether Deployment (ETD) system which is designed to overcome the safety hazard caused by snags during tether deployment. Should a snag occur on a tethered satellite mission being deployed from the Space Shuttle, the main worry is the possible rebound and contact of the payload with the Shuttle in the first few seconds after deployment. Thus, validation of the ETD system by the ASTOR project is critical to future Shuttle/tether missions.

Session 17 Control Systems

1:30 PM Wednesday, February 14 Vista Mar Monte 1

Chair: Don Mackison
University of Colorado

1:30 PM

AAS 01-194

Trade-offs Between Feedback, Feedforward, And Repetitive Control For Systems Subject To Periodic Distrubances

R. W. Longman, R. Akogyeram - Columbia University; A. Hutton - Thomas Jefferson National Accelerator Facility; J. Juang - NASA Langley Research Center

Typical spacecraft have internal moving parts, such as solar array drives, cryo pumps, momentum wheels, reaction wheels, gyros, control moment gyros, etc. For highly precise pointing equipment, even slight imbalances in such rotating machinery parts can create serious problems. They produce periodic disturbances with a period associated with each revolution, including a fundamental and harmonics. One can make an isolation platform with some form of active control system in order to nullify the effects of such disturbance sources. Then in designing the control approach one has many choices, including simple use of feedback, use of feedback with a comb filter, iterative real time repetitive control, periodic update repetitive control, and feedforward control. This paper discusses the trade-offs of using each of these methods. With sufficient broad band sensor noise, feedback or feedback with comb filtering can actually be counter productive due to the waterbed effect. Methods are given to analyze when feedback is advantageous to the RMS error level. Batch updates can reduce the adverse influence of the waterbed effect, as can pure feedforward, but the latter is done at the expense of reduced performance.

1:55 PM

AAS 01-195

Repetitive Control Methods When The Disturbance Period Is Not An Integer Multiple Of The Sample Time

H. Wen. R. W. Longman - Columbia University

Repetitive control creates methods of canceling the effects of periodic disturbances on the output of feedback control systems. Fine pointing instruments on spacecraft are often subject to periodic disturbances from rotating wheels within the spacecraft, and repetitive control offers one option for improving the performance of active isolation systems for such equipment. Typical repetitive control assumes that the period of the disturbance can be represented as an integer multiple of the sample time of the digital control system. In practice, it will not in general be an integer multiple. It is shown here how this can seriously degrade performance. Interpolation schemes are studied to address the situation. Methods are developed to ensure stability of the learning process over a range of speeds when interpolation is used. It is seen that the process of stabilization is often done at the expense of the final error level reached. However, examples are given in which the interpolation process stabilizes an otherwise unstable repetitive control law.

2:20 PM **On The Relationship Between The Waterbed Effect And Repetitive Learning Control**

AAS 01-196

T. Songchon - King Mongkut's University of Technology Thonburi, Thailand; R. W. Longman - Columbia University

Learning control can eliminate tracking errors for repeated commands to a control system, such as eliminating the effects of vibrations in a repeated satellite maneuver. The maneuver must be performed several times for learning. Repetitive control has a similar formulation for learning. It is a prime candidate for eliminating vibrations at some point on a spacecraft, for example due to imbalance in a rotating momentum wheel. The waterbed effect is a fundamental limitation to feedback control. It states that the transfer function from command to the resulting error, and the transfer function from output disturbance to resulting error, will have the property that attenuation in some frequency range must be paid for by amplification in some other frequency range. In a previous paper, it was shown how learning control is able to bypass the waterbed effect. This paper studies what is required for repetitive control to similarly bypass the waterbed effect. The use of non causal zero phase filtering in a batch update mode can be an important element in bypassing the effect to get improved performance.

2:45 PM **BREAK**

3:05 PM **Simulation Of A Closed Loop Test For The SELENE Model-Following System Using The Flying Test Bed**

AAS 01-197

Y. Hamada, T. Ninomiya, I. Yamaguchi, S. Sasa - National Aerospace Laboratory (NAL); H. Itagaki - National Space Development Agency; H. Soga - Toshiba Corporation; K. Kamo - Fuji Heavy Industries LTD., Japan

The SELenological and ENgineering Explorer (SELENE) project is aimed at acquiring scientific data and developing the lunar exploration technology. As part of the SELENE development program, a preliminary terrestrial landing experiment using a jet engine-powered flying test bed (FTB) was started to evaluate soft-landing algorithms and hardware. For that purpose it is desirable for the FTB to emulate the SELENE lander. In this paper we propose the SELENE model-following system. It is composed of the FTB, the SELENE mathematical model and a simple PID controller. It is shown that the FTB can emulate the SELENE lander well using the system.

3:30 PM **Joint Dynamics Modeling And Parameter Identification For Space Robot Applications**

AAS 01-198

A. R. da Silva, B. Schafer - Deutsches Zentrum fur Luft- und Raumfahrt e.V (DLR), Germany; L. C. Gadelha de Souza, R. A. Fonseca - Instituto Nacional de Pesquisas Espaciais (INPE), Brazil

Space robotics dynamics performance is severely depending upon the adequate modeling of the strongly non-linear joint dynamics under micro-gravity and outer space environment such as large temperature differences. In order to identify all the required parameters that accurately describe the robot dynamics, an integrated identification strategy is derived. The approach is applied to the Intelli-gent Robot Joint experiment that is being developed at DLR for early utilization opportunity on the International Space Station. The results using real and simulated measurements have shown that the developed algorithm and strategy have remarkable features in identifying all the parameters with good accuracy.

3:55 PM **Dynamics Of A Gyroscopic Hopping Rover**

AAS 01-199 M. A. Peck - University of California, Los Angeles

This paper outlines the design of a hopping rover that incorporates internal angular momentum both to stabilize the open-loop dynamics and to provide a means to translate the rover during hopping. On the ground the rover experiences top-like precession, which is used to point the rover in the direction of the hop. After the rover's foot leaves the ground, free precession (or nutation) of the system swings the leg around to an attitude that minimizes landing torques. The wheel momentum is chosen to provide a nutation rate equal to about half the duration of a jump. Taking advantage of the system dynamics in this way helps reduce control effort.

4:20 PM **An Object Oriented Architecture For Flight Dynamics Mission Support**

AAS 01-200 P. R. Prasad, H. K. Kuga - Instituto nacional de pesquisas espaciais (INPE), Brazil

The China-Brazil Earth Resources Satellite (CBERS) mission necessitated an integrated approach for the design of Flight Dynamics Software System. Workstation based software was developed for flight dynamics analysis and satellite mission support. The primary requirements for mission are performing orbit determination, maneuver analysis, attitude determination, satellite ephemeris generation and orbit information. In the past these activities were performed through groups of tasks and analysts acting in parallel on several types of computer platforms, which led to many operational difficulties. In this scenario an integrated approach along with visual interfaces to provide quick and near real time decision oriented flight dynamics software is needed. Towards this goal, an integrated software design is being done. This paper describes the product and process assurance methodologies applied to each phase of flight dynamics mission support lifecycle. The Object Oriented Design (OOD) approach for flight dynamics system is of a class structure with existing flight dynamics models to produce a very complete, yet re-configurable prototyping tool. The C++ OOD code addresses the development of OOD classes for inertial reference systems for navigation, sun sensors for orientation and attitude determination and maneuver planning and execution. The conceptualization of object oriented methodology for flight dynamics is described along with the software design methodologies.

Session 18 Multi-Body Dynamics and Libration Points

1:30 PM Wednesday, February 14 Vista Mar Monte 3

Chair: David Folta

NASA Goddard Space Flight Center

1:30 PM

AAS 01-201

Resonance Induced Coupled Planar N-Body Point Solutions

T. A. Bauer - Twelve Enterprizes

Resonance coupling can be induced directly into the n-body equation resulting in a redefined n-body resonance problem. This resonance problem contains a subset of the original n-body trajectories. These resonance constrained trajectory subsets are regional and structured relative to a given mass configuration. Actual solutions are collinear point period ratios and resonance state vectors. Collinear point period ratio solutions reveal a comprehensive multi-body resonance structure such as Euler points, points and possible null orbit regions. The regional resonance structure can be analyzed by systematically numerically integrating the corresponding resonance state vectors.

1:55 PM

AAS 01-202

Effect Of Perturbations In Coriolis And Centrifugal Forces On The Location And Stability Of The Equilibrium Point In The Robe's Circular Restricted Three Body Problem

P. P. Hallan, N. Rana - University of Delhi, India

The location and stability of the equilibrium point in the Robe's (1977) circular restricted three-body problem with the density of the fluid filling one of the primaries, a rigid spherical shell and the density of the infinitesimal body being equal, have been studied when small perturbations e and e' are given to the coriolis and centrifugal forces respectively. It is proved that there is only one equilibrium point which lies on the right or left of the center of the shell on the line joining the center of the shell and the second primary according as e' is positive or negative and the change e in the coriolis force does not affect the location of the equilibrium point. Further it is seen that the range of stability increases or decreases depending upon whether the point (e,e') lies in one or the other of the two regions in which the (e,e') plane is divided by a line.

2:20 PM

AAS 01-203

The Nonlinear Stability Of L4 In The Restricted Three Body Problem When The Bigger Primary Is A Triaxial Rigid Body

P. P. Hallan, S. Jain - University of Delhi; K. B. Bhatnagar - Centre for Fundamental Research in Space Dynamics and Celestial Mechanics, India

The non-linear stability of L4 in the restricted three-body problem has been studied when the bigger primary is a triaxial rigid body with its equatorial plane coincident with the plane of motion. It is found that L4 is stable in the range of linear stability except for three mass ratios which depend upon the lengths of the semi axes of the triaxial rigid body.

2:45 PM **BREAK**

3:05 PM

AAS 01-204

Long Duration Lissajous Orbit Control For The ACE Sun-Earth L1 Libration Point Mission

C. Roberts - Computer Sciences Corporation

The Advanced Composition Explorer (ACE) mission is NASA's first to fly a libration point Lissajous orbit. Orbiting the Sun-Earth L1 collinear point approximately 1.5 (106) kilometers Sun-ward since December 1997, ACE's location is ideal for its Sun-weather and solar wind observation program. Long-term control of the Lissajous orbit such that it avoid a circular solar RFI zone of 4.75 degrees about the Sun is required. The so-called 'Z-axis control' technique, which freezes the Lissajous phase such that virtually the same avoidance pattern is repeated continually, as implemented via delta-V maneuvers is described. Options for an extended L1 mission are considered.

3:30 PM

AAS 01-205

Trajectory Design Strategies For the NGST And NEXUS L2 Libration Missions

D. Folta, S. Cooley - NASA Goddard Space Flight Center

The Origins' Next Generation Space Telescope (NGST) mission is addressed in light of improved trajectory design methods for attaining constrained libration orbit parameters and their control at the exterior collinear libration point, L2. The use of dynamical systems approach, state-space equations for initial libration orbit control, and optimization to achieve constrained orbit parameters are emphasized. The trajectory design encompasses a direct transfer and orbit maintenance under a constant acceleration. A dynamical approach can be used to provide a biased orbit and maintenance method that incorporates the constraint of a single axis correction scheme.

3:55 PM

AAS 01-206

Simulation Of Formation Flight Near Lagrange Points For the TPF Mission

A. Barr - California Institute of Technology; G. Gomez - Universitat de Barcelona, Spain; M. Lo - Jet Propulsion Laboratory; J. Masdemont - Universitat Politecnica de Catalunya, Spain; K. Museth - California Institute of Technology

The TPF Mission (Terrestrial Planet Finder) is one of the center pieces of the NASA Origins Program. The goal of TPF is to identify terrestrial planets around stars nearby the Solar System. For this purpose, a space-based infrared interferometer with a baseline of approximately 100 m is required. To achieve such a large baseline, a distributed system of five spacecraft flying in formation is an efficient approach. The current concept has four 3.5 m diameter telescopes, each with its own spacecraft, and a central spacecraft that collects and combines the beams. Since the TPF instruments needs a cold and stable environment, near Earth orbits are unsuitable. Satellites in Earth orbit are exposed to the radiation of the Earth and the Moon. Furthermore, the thermal cycling from the frequent coming in and out of Earth's shadow creates a thermally unstable environment which is unsuitable for infrared missions. Two potential orbits have been identified: a SIRTF-like heliocentric orbit; a libration orbit near the L2 Lagrange point. In this paper, we focus on the second case: an orbit near the L2 Lagrange point. Simulations indicate that formation flight near L2 is acheivable for the TPF mission dynamically. Prefliminary results indicate that propulsion requirements are not prohibitive.

4:20 PM

AAS 01-207

Trajectory Arcs With Lunar Encounters For Transfers To Small Amplitude Lissajous Orbits

K. C. Howell, J. J. Guzman, J. P. Anderson - Purdue University

In support of current and future libration point missions, analysis concerning trajectories that use a lunar encounter to reach a libration point orbit is ongoing. The design process to compute transfer trajectories, via a lunar encounter, to small amplitude Lissajous orbits in the vicinity of the L1 and L2 libration points, may involve a time-consuming shooting procedure. Additional insight and an improved understanding of the solution space will eventually translate into a more efficient and flexible design process. This paper summarizes a recent preliminary investigation into the design of such transfer trajectories, specifically to the vicinity of L2. The phase at insertion into the Lissajous is pre-specified to be consistent with an "opening pattern," that is, a phase when the orbit is expanding. The addition of phasing loops is also briefly considered.

Session 19 Low Thrust Missions

8:30 AM Thursday, February 15 Vista Mar Monte 3

Chair: Craig Kluever
University of Missouri-Columbia

8:30 AM
AAS 01-208

Anatomy Of The Constant Radial Thrust Problem

R. A. Brouke, M. R. Akella - University of Texas at Austin

The paper describes the general types of solutions of the low-thrust problem with constant outward radial thrust. We do not use the known closed-form analytical solution in terms of the elliptic integrals because of the lack of physical insight obtained from these mathematical functions. Instead we use numerical integrations and concepts that are commonly used for non integrable dynamical systems, such as the theory of periodic orbits and Poincare's characteristic exponents.

8:55 AM
AAS 01-209

Application Of A Novel Optimal Control Algorithm To Low-Thrust Trajectory Optimization

G. J. Whiffen - Optimal Dynamics Corporation; J. A. Sims - Jet Propulsion Laboratory

An application of the new optimization algorithm called Static/Dynamic Control (SDC) to the design of low-thrust interplanetary trajectories is presented. SDC is a general, gradient based optimization method that is distinct from both parameter optimization and the Calculus of Variations. Interplanetary trajectories are integrated with a multi-body force model and may include gravity assists. Engine operation is modeled as finite burns. A novel feature of the SDC approach is its ability to locate favorable intermediate flybys. SDC does not require a good initial trajectory guess to begin the optimization. SDC's ability to begin with poor guesses and locate favorable intermediate flybys results in the identification of non-obvious, and highly efficient trajectories. Results produced by SDC are compared to results produced by a program based on the Calculus of Variations and a program based on parameter optimization.

9:20 AM
AAS 01-211

Direct Approach For Low-thrust Positioning Computation Under Satellite Constraints

S. Herbiniere, V. Martino - Alcatel Space Industries, France

This article deals with low-thrust propulsion positioning in the frame of nearly circular LEO to LEO transfers. The purpose is here to demonstrate that a direct approach taking into account the satellite and operational constraints from the beginning of the study can be as efficient as "classical" optimization methods to solve a practical problem. This approach is illustrated on a case study inspired from a broad-band constellation project. The positioning strategy is fully described including simulation results (positioning duration, mass diminution).

9:45 AM **BREAK**

10:05 AM

AAS 01-212

Optimal Low Thrust Trajectories Combined with an Aeroassist Maneuver About Mars

A. J. Trask, V. L. Coverstone - University of Illinois at Urbana-Champaign

This paper presents the results of optimal powered aeroassisted orbit transfers using solar electric propulsion. These trajectories use a combination of solar electric propulsion and controlled atmospheric perturbations. Single revolution coplanar and plane change trajectories are considered about the planet Mars. The objective of the coplanar trajectory is to circularize the orbit and the objective of the plane change trajectory is to minimize the absolute value of the inclination. Optimal trajectories are presented for both mission objectives.

10:30 AM

AAS 01-213

Solar Electric Propulsion Leverage: Electric Delta-VEGA (EDVEGA) Scheme and its Application

J. Kawaguchi - The Institute of Space and Astronautical Science (ISAS), Japan

In high-energy interplanetary missions, the Delta-V Earth Gravity Assist (Delta-VEGA) scheme is sometimes utilized. While the chemical delta-V is applied impulsively, having the low thrust delta-V near aphelion is not practical for the Delta-VEGA, owing to the solar power austerity and the large steering loss. This paper presents an idea about the orbital energy leverage with the Earth gravity assist and the electric propulsion. The scheme here is designated as Electric Delta-VEGA (EDVEGA). The one year and one-and-a-half year resonant trajectory are chosen as this energy garnering orbit. The paper also gives some application examples of this scheme.

10:55 AM

AAS 01-214

Comparing Solar Sail and Solar Electric Propulsions for Propulsive Effectiveness in Deep Space Missions

C. L. Yen - Jet Propulsion Laboratory

A promise of new sail technology is generating renewed interest in solar sailing. Ultra light-weight carbon films with built-in stiffness for example is predicted to result in a sail with very low area density (~2 g/m**2) with high temperature tolerance. There are many solar sail mission studies in the past suggesting the usefulness of solar sails for a gamut of planetary and space physics missions. However, the question of "how does the sail compare with the SEP?" was often raised by some NASA program evaluators but never addressed in a consistent manner. The results of a brief study to answer the question is presented. This paper considered a broad set of NASA missions of interest. The goal of the study was to compare in a logical and uniform manner the effectiveness of each propulsive device (Sail or SEP) in performing the given set of missions. The study selected the use of a Delta II/7925 launch vehicle and set the same payload goal (net mass) of 500 kg for each to deliver. Then the flight time required by each device becomes the single performance discriminator.

Session 20 Satellite Constellations

8:30 AM Thursday, February 15 Vista Mar Monte 1

Chair: Karen Richon

NASA Goddard Space Flight Center

8:30 AM **Molniya Orbit Constellation Considerations for Commerical Applications**

AAS 01-215 A. E. Turner - Space Systems/Loral

This paper discusses a constellation of spacecraft in 12-hour period, critically-inclined orbits to provide continuous broadband or other high data rate commercial service to fixed user terminals with high-gain antennas having narrow fields of view. For many northern hemisphere ground sites the elevation of the active units within the constellation would actually be higher than for any geosynchronous spacecraft at the same longitude relative to a ground observer. A Molniya orbit spacecraft can simultaneously view both Tokyo and New York City, which are too far apart in longitude for a geosynchronous equatorial spacecraft to link in a single hop.

8:55 AM **Probability of Overlap for Footprints of Satellites Flying in Formation**

AAS 01-217 M. A. Vincent - Jet Propulsion Laboratory

The general problem of determining footprint overlap for instruments on different platforms was analyzed by determining the formation flying and pointing requirements needed to satisfy the science requirements of the Cloudat and Picasso-CENA missions. A control value of +/-1 km was found to satisfy the requirement of keeping the footprints within 2 km of each other. If the pointing errors are considered as pure random variables this control results in a 71% probability of footprint overlap. However, if the pointing errors a considered to be fixed biases, the difference between the crosstrack bias values must be less than the sum of the footprint half-widths in order to reach the goal of the footprints overlapping 50% of the time. Satisfying this limit has an 81% probability of occurrence. Combining both a bias and various noise levels indicated that the 50% overlap criterion is independent of the noise. For lower bias values the noise decreases the likelihood of overlap but the noise has the opposite effect for higher bias values. The effect of having a tighter control band on the overlap probability was also studied.

9:20 AM **A New Concept for Constellation Control of Formation Flying Satellites**

AAS 01-218 S. R. Vadali, K. T. Alfriend, S. Vaddi - Texas A&M University

This paper demonstrates the use of Hill's equations and mean elements to design and control relative motion orbits of satellites in a constellation. Hill's equations describe the linearized dynamics of a satellite (Deputy) with respect to another satellite (Chief) or a fictitious point, which is assumed to move in a circular orbit. Given the initial conditions of the Chief, it is easy to determine initial conditions of a Deputy, for periodic relative motion. In general, this ideal motion degenerates in the presence of perturbations. The control acceleration or the fuel required to cancel the perturbation varies for each satellite in a constellation, depending upon its orbital inclination with respect to that of the Chief. A novel control methodology is presented for minimizing the total fuel consumption of all the satellites and maintain equal, average fuel consumption of each satellite, over a desired period of time. Analytical results, which have been verified by numerical simulations, indicate that intelligent cancellation of the disturbance for constellation control can be achieved with at least 33% less fuel than that required by the "brute force" approach.

9:45 AM **BREAK**

10:05 AM **An Improved Strategy for Maintaining Constant Distance Between Satellites in an Elliptically Orbiting Constellation**

AAS 01-219

Z. Tan, P. M. Bainum - Howard University

The Auroral Cluster Observation System is proposed by NASA for scientific data collection. It requires the constellation with a constant separation between adjacent satellites in an elliptical orbit. A novel idea for maintaining constant separation between satellites is developed. The daughter satellite orbit is changed in two steps: 1. A small angle rotation of the major axis (can reduce the separation distance error from 25% to 2.4%; this strategy was discussed previously); 2. A slew around the major axis (can further reduce the separation error to 0.45%). Simulations are conducted by MATLAB and the BG14 orbital propagator; the latter treats non-Keplerian type perturbations.

10:30 AM **The Acceleromeer Proof Mass Offset Calibration of GRACE Satellite**

AAS 01-220

F. Wang, B. D. Tapley, S. V. Bettadpur, Y. Liu - CSR, University of Texas

The accelerometer, one of key instruments on board Gravity Recovery And Climate Experiment (GRACE), serves to measure all non-gravitational accelerations. The Proof-Mass Center (PMC) of the accelerometer needs to be positioned precisely at the Center of Gravity (CG) of the GRACE satellites in order to avoid measurement disturbances. In this paper, the maneuver is designed and estimation algorithm is put forward. The optimal timing for CG offset calibration has been found. The simulation shows that the accuracy of CG offset could be determined better than 0.1mm.

10:55 AM **Antenna Phase Center Determination of Inter-communicating GRACE Satellites**

AAS 01-221

F. Wang, B. D. Tapley, S. V. Bettadpur, Y. Liu - CSR, University of Texas

The Gravity Recovery And Climate Experiment (GRACE) satellites are interconnected by a microwave RF link to measure the exact separation distance. The phase centers of the satellite antennas have to be determined accurately during the in flight phase. In this paper, the satellite phase center determination maneuver is designed and estimation algorithm is put forward. The simulation shows that the boresight direction, the phase center position vector of antenna in the satellite's body fixed system, can be determined better than 0.5 millirad.

Session 21 Special Topics in Astrodynamics

8:30 AM Thursday, February 15 Vista Mar Monte 2

Chair: Kim Luu

Air Force Research Laboratory, Kirkland AFB

8:30 AM

AAS 01-223

Mitigation of the Effects of Eclipse Boundary Crossings on the Numerical Integration of Orbit Trajectories Using an Encke-Type Correction Algorithm

J. Woodburn - Analytical Graphics, Inc.

The proper application of a shadow model during the integration of orbit trajectories requires that the solar radiation pressure be sampled adequately during transitions between lighting conditions. An integration scheme is presented in which the lighting condition is held constant across steps of a primary integrator. If the lighting condition changes during that step, then an Encke-like integration is performed to correct the state at the end of the primary integration step. Results will be presented for several classes of orbits utilizing various combinations of the equations of motion and integration methods.

8:55 AM

AAS 01-224

Resonant Stability and Its Criterion for the Orbits Around the Sphere of Influence

M. Utashima - National Space Development Agency (NASDA); J. Kawaguchi - The Institute of Space and Astronautical Science (ISAS), Japan

This paper discusses the stability of the pseudo orbit, which flies outside of the sphere of influence of the secondary body in the Circular Restricted Three-Body Problem and has the same semi-major axis as the secondary body and a small eccentricity. The whole aspect of the stability of the inclined pseudo orbit is resolved for the first time by both examination using virtual energy and reduction to Mathieu's equation.

9:20 AM

AAS 01-225

Canonical Elements Derived from a Redundant Set of Burdet-Ferrandiz Focal-Type Variables

L. Floria - Universidad de Valladolid, Spain

Concerning some canonical extensions of the point transformation to linearizing focal variables, and their application to perturbed Keplerian systems, to establish a canonical perturbation theory of two-body motion we introduce canonical elements attached to focal variables. We construct a canonical transformation, from a set of Burdet-Ferrandiz (BF) variables to canonical elements of the motion, by means of a generating function which is a solution to the Hamilton-Jacobi equation linked to the Kepler problem in the BF-variables. We solve this equation by separation of variables, and the components of the generating function are determined by quadrature. Once the transformation equations are developed, the Keplerian Hamiltonian is simplified and readily integrated.

9:45 AM **BREAK**

10:05 AM

AAS 01-226

Numerical Experiments on the Convergence of Spherical and Spheroidal Harmonic Representations of the External Potential Inside the Brillouin Sphere

S. Casotto - Universita di Padova, Italy

It is well known that the convergence of the Spherical Harmonic representation of the potential is not guaranteed inside the Brillouin sphere associated with a massive body. The solution indicated by several authors and adopted in this paper consists in the minimization of the region of divergence by adopting spheroidal coordinates so that one of the orthogonal coordinate surfaces more closely fits the physical surface of the body. Methods are presented for the computation of the coefficients of the potential expansion in oblate and prolate spheroidal coordinates.

10:30 AM

AAS 01-227

Variational Calculus and Approximate Solutions of Algebraic Equations

D. G. Hull - The University of Texas at Austin

The equations for the various-order solutions of the algebraic perturbation problem are derived using the expansion process and the variational process. The two processes are equivalent, but variational calculus, which is developed here, makes it possible to construct a Taylor series on a term by term basis using a differential process. Applied to the general problem, the variational process requires about the same amount of effort as the expansion process. However, applied to a particular problem, the variational process is superior to the expansion process. Only differentiation is needed, and the next-order equations can be obtained from the previous-order equations. These points are illustrated by deriving the equations for solving Kepler's equation for small eccentricity.

10:55 AM

AAS 01-228

Variational Calculus and the Solutions of Differential Equations

D. G. Hull - The University of Texas at Austin

Variational calculus is a differential process whereby Taylor series expansions can be developed on a term by term basis. Therefore, it can be used to obtain the equations which must be solved for the various-order terms arising from the application of regular perturbation theory to problems involving a small parameter. Variational calculus is developed for ordinary differential equations and applied to the approximate analytical solution of the regular perturbation problem. Its use for deriving the equations for the various-order solutions is demonstrated for the initial value problem with fixed final time, the initial value problem with free but constrained final time, and the boundary value problem. As an example, theproblem of satellite motion in the eqatorial plane of an oblate spheroid earth with small eccentricity is discussed.

Session 22 Tether Systems 2

1:30 PM Thursday, February 15 Vista Mar Monte 2

Chair: Peter Bainum

Howard University

1:30 PM

AAS 01-229

A Novel Control Design Methodology for Maintaining Position and Attitude of a Power Sail

J. L. Junkins, K. Subbarao - Texas A&M University

This paper deals with control of the motion of a Power Sail relative to a chief satellite. This motion is critical for the mission as the relative motion drives the length of the umbilical tether attachment and control requirements. The desired configuration is for the tether to remain tension free. However the fact that this will not occur exactly and extreme cases where the tether may become taut is considered. This is more so because then the dynamics of the system changes abruptly, both the satellite and the power sail experience translational and rotational impulses. A potential design wherein the umbilical is attached with a softly coiled tether is investigated. Another possible design wherein some sort of a near-zero spring reeling mechanism, which unwinds when the tether length becomes greater than some "design value" and winds up when the tether becomes slack, is also investigated. The position control is established whenever this "nominal slack condition" is violated, via winding/unwinding the reel. Furthermore tension measurements are explicitly used in the feedback law. The feedback control on the Power Sail is designed to minimize tether tension variations, take up unwanted slack in the tether and accommodate a failsafe emergency brake to arrest relative separation velocity smoothly to zero (in the unlikely event that large along orbit separation occurs for any un-anticipated reason). The attitude control law is designed so that the powersail body axes tracks a desired target frame constructed using the relative position vector and the sun-pointing axis. The control strategies are evaluated against initial condition errors and disturbances due to drag and solar radiation.

1:55 PM

AAS 01-230

Dynamics and Control of the Power Sail

K. T. Alfriend, S. R. Vadali, K. Subbarao, M. P. Wilkins - Texas A&M University

In this paper the dynamics and control of the USAF Power Sail concept are investigated. In contrast to most formation flying problems the primary disturbing forces are the solar radiation and aerodynamic forces. First an analysis is performed using Hill's equations and it is shown by comparison with numerical simulation using Free Flyer that Hill's equations, or their equivalent for elliptic orbits, are a good mathematical model for this problem. A control strategy for the Power Sail to maintain a fixed position with respect to the host is presented and fuel budgets developed.

2:20 PM

AAS 01-191

Equilibrium Configurations of Tethered Three-Body Systems and Their Stability

A. K. Misra - McGill University

In this paper, we describe a rather general model used to predict the dynamics and control performance of formations of spacecraft connected by tethers both in heliocentric and in low Earth orbit. These models consist of: dynamics, environment, formation guidance, commander, and controller. Preliminary numerical results obtained with our simulation capability refer to analyses done for Synthetic Aperture Radar and Space Interferometry applications.

2:45 PM **BREAK**

3:05 PM **Quick-Look Identification and Orbit Determination of a Tethered Satellite**

AAS 01-232 D. A. Cicci, J. E. Cochran, Jr., C. Qualls, T. A. Lovell - Auburn University

This paper presents a three-stage methodology which has been developed to address the quick-look identification, accurate orbit determination, and long-term orbit prediction of a of a tethered satellite system. The first stage uses preliminary orbit determination methods which use only a short-arc of data. The second stage utilizes ridge-type estimation methods, which improves the solution accuracy in these types of ill-conditioned problems. The third-stage analysis utilizes an enhanced tether satellite dynamical model suited for long-term orbit determination and motion prediction. The effectiveness of this proposed three-stage method is demonstrated using both simulated tether satellite data and actual data.

3:30 PM **On the Validity of Recent Predictions for Tethers on Elliptical Orbits**

AAS 01-233 S. W. Ziegler, M. P. Cartmell - University of Glasgow, Scotland

The simulations presented in this paper based on numerically integrating the tetherís rigid body equation of motion suggest that the maximum velocity increment for a prograde librating and spinning tether at perigee after completing a full orbit is several factors less in magnitude than that predicted by recent mission analyses employing the principle of conservation of momentum and classical Hohmann transfer analysis. New insights are gained into the magnitudes of deltaV that are achievable on elliptical orbits and the ability of spinning tethers to deliver the payload above the facility directly in line with the gravity vector.

3:55 PM **Analysis of Tether Aerobraking Maneuvers Using a Lifting Probe with Parametric Uncertainties**

AAS 01-234 B. Biswell - Raytheon Systems Company; J. Puig-Suari - California Polytechnic University

A lifting probe with moveable attachment point is applied to the traditional tether aerobraking maneuver. The control is designed to regulate tether tension, which is directly related to orbiter braking, without breaking the tether. Tether cutting strategies are examined to achieve the minimum orbiter eccentricity without mission failure. The effects of trajectory perturbations and parametric uncertainties, which can have a significant effect on the success of the maneuver, are examined.

4:20 PM **Aerocapture Trajectories for Spacecraft with Large, Towed Ballutes**

AAS 01-235

J. L. Hall, A. K. Le - Jet Propulsion Laboratory

Large, towed inflatable structures (ballutes) are a potential technology for enabling aerocapture maneuvers of spacecraft at other planets. The ballute provides most of the drag force and energy dissipation during the maneuver and is detached once the desired velocity change has been achieved. A key premise of this concept is that the timing of ballute detachment provides sufficient trajectory modulation capability to enable aerocapture despite atmospheric uncertainties and navigation errors at the target planet. Numerical simulations performed for four candidate missions have confirmed this premise and quantified the entry corridor in terms of a flight path angle range at each planet. The results show a general trend of entry corridor width scaling with the density scale height of the planetary atmosphere.

Session 23 Guidance and Control

1:30 PM Thursday, February 15 Vista Mar Monte 1

Chair: Dennis Byrnes
Jet Propulsion Laboratory

1:30 PM
AAS 01-236

Fuel-Optimal Rendezvous in a Central Force Field with Linear and Quadratic Drag

M. Humi - Worcester Polytechnic Institute; T. E. Carter - Eastern Connecticut State University

In this paper we consider the fuel-optimal rendezvous between a satellite and a spacecraft in a central force field with a drag force that is linear or quadratic in the velocity. In this general setting we linearize the equations of motion of the spacecraft and show that they can be reduced effectively, in the case of a linear drag, to one second order linear differential equation. In the case where the drag accelerations of the spacecraft and the satellite are essentially the same, these equations simplify and can be solved in terms of integrals. This leads to a state-transition matrix that includes the effects of drag. This work can then be placed in the context of various control models that have been developed in previous work.

1:55 PM
AAS 01-237

Linear Optimal Periodic Position Control for Elliptical Orbits

A. Schubert - ESG Elektroniksystem- und Logistik GmbH, Germany

Position control for spacecraft is of industrial and scientific interest in numerous applications. Contrary to the case of circular orbits, neither linearized descriptions of motion nor an appropriate control law exist for elliptical orbits. Linearization of Newton's second law of motion relative to a desired orbit yields continuous periodic system and control matrices which are transformed into a discrete time periodic system. The controller design procedure is performed via the time-invariant reformulation. A linear-quadratic optimal control law is obtained by solving the well-known Riccati equation. It is proven in simulation runs that the closed loop system is reliably stabilized.

2:20 PM
AAS 01-238

Applications of Autonomous On-Board Orbit Control

J. R. Wertz, G. Gurevich - Microcosm, Inc.

Fully autonomous, on-board orbit control was flight demonstrated on UoSAT-12. This technology was developed to reduce operations cost. It does this (using less propellant than traditional orbit maintenance), but also opens a new array of potential mission applications. Because the position of the spacecraft is controlled and, therefore, known at all future times, users can plan applications without updating the spacecraft ephemeris; simple ground equipment can know the position of all system satellites at any time; and the ground track of the spacecraft can be made to follow a pre-defined path. Other applications are also described.

2:45 PM BREAK

3:05 PM

AAS 01-239

Aerodynamic Maneuvering for Stability and Control of Low-Perigee Satellites

M. J. Lewis, S. Bowman - University of Maryland; D. Manzer - NASA Goddard Space Flight Center

This paper explores the advantages and disadvantages of using aerodynamic forces for orbital plane change and maneuvering are revisited, with the specific application to low-perigee satellites. The concept involves using aerodynamic lifting force during an atmosphere passage. The velocity increment required to change orbital plane, including transfer to an orbit that enters the atmosphere, and drag losses through the maneuver, are calculated. It is shown that the velocity losses scale inversely with the ratio of lift to drag, with a requirement that lift be approximately equal to drag for the maneuver to represent a reasonable drag savings. Likely lift and drag performance is calculated for satellites which are designed for aeromaneuvering, or for which maneuvering is added onto an existing mission. It is further demonstrated that the concept is impractical for geosynchronous orbiting satellites. Estimates of achievable plane change and practical lift-to-drag ratios are presented.

3:30 PM

AAS 01-240

Design of a Controller for Hypersonic Flight Vehicle Using Sliding Mode Control Method

H. Xu - University of Southern California; P. Leung, M. Mirmirani - California State University; P. A. Ioannou - University of Southern California

The dynamics of hypersonic air vehicles is high dimensional and highly nonlinear and, in general, hard to model or measure. Design of robust nonlinear controllers has been the main target of research for hypersonic flight. In this paper, a MIMO sliding mode controller coupled with feedback linearization is used to effectively deal with model nonlinearity and uncertainty associated with the flight of a longitudinal model of a generic hypersonic air vehicle. A set of sliding observers is designed to estimate the unmeasurable states. The closed loop system is robust for both unmodeled uncertainty and sensor noise.

3:55 PM

AAS 01-241

Re-Entry Trajectories Design by Ineractive Multiobjective Optimization with Parallel Programming

M. Tava, S. Suzuki - University of Toyko, Japan

Optimal re-entry trajectories are calculated using a multiobjective interactive method which permits trade-off between many performance criteria while reducing the number of constraints, in favor of both increased robustness and reduced computing time. Since multiple solutions are calculated in parallel, the decision maker can compare the results in real time. This permits mid-course corrections on the partial results as undesired solutions are discarded and the released processes are re-utilized to search in the vicinity of preferred points. Up to four objectives are simultaneously considered in the optimization, namely crossrange, heating rate peak, total heat load and control cost.

4:20 PM **Feedback Control of Kinetic Energy Projectile Trajectories**

AAS 01-242

M. Akella, M. Erengil, J. McGregor - University of Texas at Austin

New classes of launch systems, such as electromagnetic (EM) guns, propose to fire the projectiles at hypervelocity (over 2.0 Km/s), thus allowing targets to be engaged at increasingly greater ranges. To ensure a high probability-of-hit at long ranges, however, the KE projectiles have to be controlled. This is because all gun-launched projectiles are affected by small disturbances, which result in deviation away from the intended flight trajectory. In this paper, we formulate the closed-loop control problem for trajectory control of kinetic energy (KE) projectile systems. In the case of rapidly rolling projectiles practical considerations suggest that trajectory control implementation with deflecting fins would be undesirable. In fact, non-moving parts are preferred. Therefore, in our formulation, we consider discrete-event control utilizing thrusters which can impart to the projectile a small lateral impulse causing a change in the angle of attach (AoA). Again, the deflection in the flight trajectory is primarily caused by aerodynamic lift due to changing AoA. A novel hybrid controller is formulated which attempts to control the KE projectile - a nonlinear dynamical system using as few discrete control events as possible. Both trajectory deflection and AoA damping issues are considered within this framework.

Session 24 Orbit Dynamics and Design

1:30 PM Thursday, February 15 Vista Mar Monte 3

Chair: David Vallado
HQ USSPACECOM, Peterson AFB

1:30 PM
AAS 01-243

Orbital Analysis of Space Passenger Operations Depicted in "2001: A Space Odyssey"

T. Williams - University of Cincinnati; P. Collins - Azabu University, Japan

The film "2001: A Space Odyssey" envisaged that passenger flights (described as taking less than one hour to accomplish) would now be available to low Earth orbit, serving an orbiting space station hotel. This is shorter than the fastest rendezvous ever demonstrated, the first-orbit rendezvous of Gemini 11, and considerably shorter than the 1-2 days typically required for phasing correction during docking missions. The paper will examine whether the orbital parameters of a space station can be set up so as to allow regular short-duration flights to it from Earth, ideally from a set of several geographically separated locations.

1:55 PM
AAS 01-244

GPS Disposal Orbit Stability and Sensitivity Study

R. A. Gick, C. C. Chao - The Aerospace Corporation

This paper provides the results of a Global Positioning System (GPS)/Evolved Expendable Launch Vehicle (EELV) disposal orbit stability and sensitivity study. Long-term perturbations and stability of MEO disposal orbits are understood through analytical and numerical investigations. Two-hundred-year semi-analytic integration reveals interesting facts about the orbit stability. Initially near circular, these GPS disposal orbits may evolve into orbits with large eccentricity (as much as 0.5 over 140 years). These results directly impact the disposal of future GPS satellites and EELV upper stages. Proper selection of the argument of perigee and RAAN combination can greatly enhance the stability of the disposal orbit.

2:20 PM
AAS 01-245

A Class of Orbits with 24 Hour Sun Exposure

M. J. Gabor, R. D. Burns, C. A. McLaughlin - Air Force Research Laboratory

Continuous spacecraft exposure to the sun, particularly in the early phases of a mission, is often a desirable characteristic for mission planners because it provides a type of natural safe mode for charging batteries during boom/panel deployment and attitude acquisition. This paper elucidates the conditions necessary for continuous sun exposure, which vary based on the season and the plane of the orbit. The analysis presented here enables mission planners to adjust the mission timeline or orbital plane to exploit continuous sun exposure in the early phases of the mission.

2:45 PM **BREAK**

3:05 PM

AAS 01-246

Sunset - Synchronous Orbits and Other Astrodynamics Support for the Optical Calibration Sphere

C. Sabol - Air Force Research Laboratory; S. Deakin - Air Force Space and Missile Center

The Optical Calibration Sphere (OCS) was an experimental satellite launched for the Air Force Research Laboratory to support research at the Starfire Optical Range. In order to maximize the number of terminator viewing opportunities and therefore usefulness of the satellite, a class of sunset-synchronous orbits was designed. This paper addresses the utility of the sunset-synchronous orbits and discusses other astrodynamics support required to successfully implement the mission design. The additional considerations included node selection, launch time calculation, launch window estimates, satellite lifetime predictions, and a close approach calculation.

3:30 PM

AAS 01-247

The Effect of Tidal Forces on Orbit Transfers

B. Villac, D. J. Scheeres - University of Michigan; L. A. D'Amario, M. D. Guman - Jet Propulsion Laboratory

This article presents a systematic approach to the dynamics of a particle in a strongly perturbed tidal gravitational field. The results obtained are applied to the design of orbit maneuvers. Specific applications are made to the Europa Orbiter mission, which initially motivated this study. The results may be applied, however, to a wider range of planetary-satellite systems or even sun-planet systems. Numerical simulations made for the Europa Orbiter Mission show that spacecraft orbits in a strong tidal perturbation field can experience very large changes in orbital energy and angular momentum over a single orbit. These changes can lead to an escape of the spacecraft from Europa, an impact upon its surface, or a large shift in its inclination, among other changes. The work presented in this paper provides an approximate model of how these effects depend on the geometry of the transfer orbit and gives guidelines on how these forces can be used to reduce the cost of orbit transfers.

3:55 PM

AAS 01-248

Mission Design of an In-Orbit Satellite Inspection

M. Oda - National Space Development Agency (NASDA), Japan

In-orbit inspection of satellite, in-orbit re-fuelling to satellite, capturing and de-orbiting useless satellite by an unmanned satellite is considered to be one of useful mission in near future. NASDA's ETS-VII satellite conducted visual inspection, rendezvous docking automatic satellite capture, simulated refueling tasks within its mission. Based on these results, it became clear that a fly-around a target while monitoring the target is also feasible. These technologies will be used by un-manned in-orbit-satellite-servicing-vehicle in future.

4:20 PM

AAS 01-249

Effects of Orbital Perturbations on Trajectory of the Low-Earth-Orbiting Satellites and its Application to Z-SAT

K. Danesjou, S. Rezaei - Advanced Electronics Research Center, Iran

A satellite, moving in its orbit, is under the influence of perturbing forces, such as atmospheric drag, solar radiation pressure, earth oblateness, and gravity of the celestial masses (other than earth). In this paper, effectiveness of these forces on trajectory of different types of low-earth-orbits and a sample satellite (Z-SAT) is determined. The orbits are based on different Keplerian parameters. A few analyses are done on these orbits and the relevant results are conformed as substantial logic of perturbation influence on Keplerian parameters of the orbits. The variation of parameters method is used for analyses.

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AAS/AIAA 11th Space Flight Mechanics Meeting

Radisson Hotel Santa Barbara
Santa Barbara, California
February 11–15, 2001

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